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Effect of Fibre Parameters on the Physical and Mechanical Properties of Epoxy-Based Reinforced Deleb Palm Fibre Composite; Using Taguchi Grey Relational Optimization

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Abstract

This study considered the consequence of the length and weight composition percentage of Deleb palm fruit fiber on the physio-mechanical characteristics of an epoxy-based composite through the Taguchi grey relational optimization technique. Considering fiber reinforcement of 30-40 wt% and fiber reinforcement length of 1-5mm, the physical and mechanical properties were determined based on standards. The findings demonstrated that the Deleb palm fruit fiber's characteristics tend to differ from those of other types of fiber reinforcement in that they significantly impact the physio-mechanical characteristics of the resulting epoxy-based reinforced Deleb palm fruit fiber composite. The ANOVA result showed that, at a confidence interval of 5%, the effects of the fiber characteristics on the physio-mechanical properties of the composites were particularly notable for tensile strength and a decrease in water absorption.

Keywords: "Composites"; "Deleb palm fibre"; "Physio-mechanical properties"; "Taguchi"; "optimization"

1 | Introduction

There is a constant rise in concern for environmental sustainability, with rising worldwide environmental consciousness, as a result of the unavoidable expanding global waste problem, whose existing management strategy poses a threat to the ecosystem through pollution of the water, air, food, and life according to Lohman [1] and Mortaz Hejri et al. [2]. Numerous research has been done on this subject because of the rise in the manufacturing and usage of plastic, the price of resin, and growing environmental safety concerns [3]. Although as a result of the global quest for an eco-friendly environment devoid of pollution and harmful gases, man has acceded to better waste management techniques, such as turning waste into money by combining agricultural and polymer wastes into

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valuable products. Due to this, it has gained prominence in global research [4]. The desire for new materials has increased due to man's ongoing pursuit of technological advancement. Composite materials, for example, surpass monolithic materials, which previously dominated the market for technological materials. Agro waste can be used for a variety of things, such as animal feed, fuel, and filler materials. This is especially true if processed into particles or fibers that are valuable raw materials for complex composites [5]. There is great potential for natural fiber-reinforced composite [6].

Even though natural fibers have a better stiffness and strength-to-weight ratio than traditional reinforcing materials, they have received much attention in the last 20 years as a replacement for synthetic fiber reinforcements like glass and carbon [7]. Recycled natural fiber materials have been demonstrated to offer superior composite properties in some cases, making them useful in various industries [7-9]. Depending on the sources and methods of extraction used, their quality can vary [11]. Natural fibers are advantageous because they are readily available, inexpensive, low-density, and environmentally benign. However, employing them has a disadvantage. Natural fibers tend to soak up a lot of moisture, influencing how well they adhere to the matrix. Fortunately, chemical processing can make the fiber's surface characteristics better.

Tropical Africa is the natural habitat of the sturdy, single-stemmed deleb palm tree. The unbranched stem can reach a height of 20 to 30 meters and a thickness of 40 to 50 centimeters. Usually, the base of the palm is wider than the stem and has a thickness of 85 cm. The middle of the tree enlarges as it ages, eventually growing to a diameter of 80 cm. It has enormous, 3 to 4 meter long, and 3 to 4 meter wide, fan-shaped leaves with spines on the tips. A helpful tree, the deleb palm, is used for food, medicine, and other things [12]. This study reinforces a polymer-based composite with the fiber husk of its fruit by utilizing the multiple economic, technological, and environmental advantages of natural fibers.

One of the most adaptable types of thermoset, epoxy resins, finds use in various industries, including composites, wind energy, building, electrical, and paint & coating [13]. The monomer of the resins contains two or more epoxy groups that resemble rings. A class of reactive polymers and prepolymers with an epoxide in them includes epoxy resin [13-15]. Epoxies are amorphous resins that can be adjusted to attain glass transition temperatures in the range of 60 ^{o}C up to 250 ^{o}C, depending on the choice of ingredients, using various prepolymers. The qualities may be hard and powerful or tough and resilient. The compressive strength of thermosets is twice as strong as the tensile strength, which can be among the highest values possible and occasionally surpass 80 MPa. With elongation-to-break values typically in the range of 5-10 percent, high strength can be paired with a practical level of ductility [13]. In order to help the composite solidify, epoxy resins are frequently employed in conjunction with a hardener, a viscous liquid. Epoxy resin transforms into a shelf-stable liquid when the curing agent is introduced.

Natural fiber reinforced polymer composites have emerged as a potentially eco-friendly, economical, and practical material [16-19]. According to Onyekwere et al. [19], [20], by utilizing characteristics like low density, great specific strengths and moduli, and affordable costs of natural fibers over synthetic fibers, natural fiber composites (NFC) can find a wide range of uses in the creation of valuable materials. Even so, a significant concern that needs to be addressed is the challenge of its poor matrix compatibility, high natural fiber water absorption rate, and low recycling rate [21]. For instance, a considerable amount of milled fiber (50–70 wt percent) was used to create epoxy-peach palm tree fiber composites [22]. It was shown that this reinforcement significantly increased the composite's modulus in the rubbery area. Synthetic fiber-reinforced epoxy composites (with synthetic fibers such as carbon, glass, aramid, and Kevlar) are typically employed in automotive and construction applications because of their lightweight, strong strength, and good modulus; however, natural fibers are seen to be a better choice because it is uncertain whether the synthetic fibers from composites can be recycled after usage. Yet a number of elements—including filler characteristics, filler shape, matrix characteristics, filler orientation in the matrix, filler-matrix interactions, and filler volume fraction—are linked to the performance of the composite [21].

No standard parameter setting for processing natural fiber composites applies to all-natural fibers since different types of natural fibers have distinct processing properties. As a result, Deleb palm fruit fiber processing parameters must be optimized. This is because choosing the best natural fiber matrix combinations and processing techniques will require determining the best parameter values for high-performance composites. [19], [23]. This study aims to ascertain the impact of fiber characteristics on the physio-mechanical characteristics of an epoxy-based composite reinforced with Deleb palm fruit fiber. Additionally, optimizing the fiber characteristics of Deleb palm fruit fiber using Taguchi Grey Relational Optimization is studied for the first time in producing Epoxy resin composite materials to enhance the following physical and mechanical qualities.

2| Materials and Methods

2.1 | Materials

The under-listed materials were used for this research work.

i. Deleb palm fruit consists of natural fiber from the deleb palm fruit (Borassus Aethiopum) acquired at Zaria, Nigeria.
ii. Epoxy resin: The Nigerian Institute of Leather and Science Technology Samaru in Zaria, Nigeria, is where the epoxy resin was purchased. The details included a light yellow appearance, the equivalent epoxy weight of 187 g/eq, and room temperature viscosity of 12600 cP
iii. Hardener: In this study, Hexamethylenediamine was used, a popular hardener.

2.2 | Experimental Design

Based on recommendations from previous studies [23-24], this study used Taguchi's Orthogonal Array (OA) to design the experiments. Two processing factors, each with three levels of design, were adopted for this study. Table 1 shows the factors and classes used to develop the reinforcement and matrix composites. In contrast, Table 2 shows the orthogonal array of L9 generated in the Minitab statistical software.

Table 1. Factors used in the development of the composites.

Factors	Levels		
	1	**2**	**3**
RW - Reinforcement weight percentage of fiber (%wt)	30	35	40
RL - Reinforcement length (mm)	1	3	5

Table 2. Experimental layout.

Experimental Number	RW (%wt)	RL (mm)
RWL1	30	1
RWL2	30	3
RWL3	30	5
RWL4	35	1
RWL5	35	3
RWL6	35	5
RWL7	40	1
RWL8	40	3
RWL9	40	5

2.3 | Composite Formulation

The fiber was taken from the mesocarp, the fruit's outermost layer of the deleb palm. Retting was employed in the extraction procedure to separate the fibers from the woody core. The fibers were extracted from the deleb palm shells by pulling them out, and they were then washed to remove the embedded dirt between the fibers and allowed to air dry for 48 hours. In order to lessen the effects of variance, the fibers were carefully mixed throughout the extraction process. Fiber treatment, one way of increasing the compatibility of natural fiber with the hydrophobic polymer matrix [19], was employed. Before the alkali treatment, the Coir fibers were chopped into the appropriate diameters. *Eq.* (1) was used to prepare the solution [20], [26], [27]:

$$NaOH = \frac{percentage\ needed}{100} \times Total\ volume\ of\ distilled\ water \tag{1}$$

After submerging in an alkaline solution with a 6 percent concentration for 3–4 hours, the fibers were repeatedly rinsed with water to remove any remaining sodium hydroxide. According to the recommendations of Yan et al. [28], the fibers were then oven-dried for 8 hours at 70 °C.

After the fibers were prepared, they were put within an 80 by 30 by 5 mm^3 mold covered in a release spray. According to the hand lay-up method, the resin and hardener mixture was gradually poured over the fiber as further layers of fiber were added to one another to reach the desired thickness. Following production, the samples underwent a 5-minute curing process at 150 ^oC and 2.5 MPa of mold pressure. Figure 1 displays the created samples for this study.

Fig. 1. Developed Samples.

2.4 | Characterization

2.4.1 | Tensile Properties

According to ASTM D-638, the tensile test was performed using a Hounsfield Monsanto Tensometer (model 9875). Tensile parameters for each sample, including tensile strength, strain, and modulus, were determined after a tensile force was applied to dumbbell-shaped samples using *Eq.* (2) – *Eq.* (4).

$$Tensile\ Strength = \frac{F}{bd} \tag{2}$$

$$Strain = \frac{\Delta L}{L} \tag{3}$$

$$Modulus = \frac{Stress}{Strain} \quad (4)$$

b is the sample thickness, d is the sample breadth, L is the change in length, L is the gauge length, and F is the maximum tensile force.

2.4.2 | Flexural Strength

The load in the middle of the two endpoints determines how the material responds, referred to as the material's flexural properties. The sample was built in a rectangular shape with a 5.0 mm thickness using the Motorized Automatic Recording Tensometer for the flexural strength test (based on standard test method ASTM D7028-07-2015). The autographic recording drum was then taken out of the machine and coated with graph paper designed especially for the drum. The sample was fixed to the Tensometer using the flexural fixture and pins. The autographic recording drum was turned to the proper starting position, and the perspex indicator and the pricker of the graph sheet were both set to zero. As the load was applied to the sample, the amount of elongation or deflection was continually transmitted via a rotating spindle until failure. Using a sliding arm to follow the column and a button to mark the graph sheet at certain intervals, the load was then drawn on the deflection diagram. After the test, the machine's autographic recording drum and the graph sheet paper were removed. On graph paper, the force and deflections were measured for analysis. The flexural strength was evaluated according to *Eq.* (5) [29]

$$\sigma = \frac{3FL}{2bd^2} \quad (5)$$

L is the length of the support span, F is the force at the fracture point, and b and d are the breadth and thickness, respectively.

2.4.3 | Impact Energy

The materials were tested for impact energy using a Ceast Lot - Resil Impactor with Ceast NotchVIS Unit at the Nigerian Institute of Leather and Science Technology Samaru, Zaria, Nigeria. The sample was created per the DENT-specific ISO 8256 (2004) standard. These measurements: 64 mm x 12.7 mm x 5 mm, were used to conduct the impact study. Up to an early crack length of 2 mm, which implies 1 mm on each side, the sample's thin sidewalls were nicked with metal blades using a pneumatic notching tool. The test was conducted following ISO 291 (2008) standards, with an ambient temperature of 23 °C and relative air humidity of 50%, as detailed in the study of Salakhov et al. [30].

The sample was secured in a clamp parallel to an immovable clamp, and the pendulum hammer's crosshead impacted the sample at the lowest point of the circular motion. With the notches in the middle, the gauge length l0 mm was initially 30 mm. The hammer speed corresponding to this was 3.7 m/s. Following that, the hammer speed was set to 1.5 m/s, or a 60° falling angle. According to the pendulum device's service manual, the recorded load values were analyzed using extension diagrams.

2.4.4 | Water Absorption Characteristics

Since the natural fibers used in the composite's development are bio-based and have a propensity to absorb water, monitoring their water absorption characteristics over time is essential for the best effectiveness. In fiber-reinforced polymer composites, water absorption can lead to matrix cracking, dimensional instability, and poor mechanical properties [31]. In accordance with ASTM standard D 570-98, the water absorption test involved measuring the samples' differences before and after exposure to water at regular intervals. *Eq.* (6) provides the formula needed to determine the values:

$$Moisture\ Content = \frac{M_2 - M_1}{M_1} * 100 \quad (6)$$

M_1 is the composite's initial weight, and M_2 is the composite's final weight after immersion.

2.5 | Numerical Analysis

The quantitative analysis employed in this study was grey relational analysis. The grey relational analysis begins with the development of grey relations. At this point, the gathered responses were standardized between zero and one. The desired and actual responses were connected using the grey relational coefficients derived from the normalized data [32]. Next, the average of the grey relational coefficients for each performance criterion was used to determine the grey relational grade. The grey relational grade was utilized to evaluate the overall effectiveness of the numerous performance metrics. As a result, the optimization of a complex set of various performance indicators was changed into the optimization of a single grey relational grade [33-35]. The ideal level for a process parameter was the one with the highest grey relational grade. Additionally, an analysis of variance (ANOVA) was utilized to establish the statistical significance of the process components.

Eq. (7) was used to calculate the greater-is-better criterion for the linear data preprocessing method used in this study for the physical and mechanical features of the generated composite. *Eq.* (9) calculated the average of each response variable of the produced composites, and *Eq.* (8) was used to calculate the grey relational coefficient (GRC).

$$x_i(k) = \frac{y_i(k) - \min y_i(k)}{max\, y_i(k) - \min y_i(k)} \tag{7}$$

x_i (k) is the preprocessed data, min y_i (k) is the smallest y_i (k) estimation for the response, k^{th} and max y_i (k) is the largest y_i (k) estimation for the response, k^{th}.

$$\xi_i(k) = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{oi}(k) + \zeta\Delta_{max}} \tag{8}$$

ζ is the differentiating coefficient (0~1), customarily assigned an equal weight of 0.5 to each parameter; and $\Delta_{oi}(k) = \|x_o(k) - x_i(k)\|$, in which x_o^*(k) and x_i^*(k) denote the reference and similarity arrangements, respectively. Every reaction variable's base and mainly deviations are called Δ_{min} and Δ_{max}.

$$\gamma_i = \frac{1}{n}\sum_{i=1}^{n} \xi_i(k) \tag{9}$$

γ_i is the value of GRG determined for the ith experiment, and n is the total number of performance characteristics.

3 | Results and Discussion

3.1 | Tensile Properties

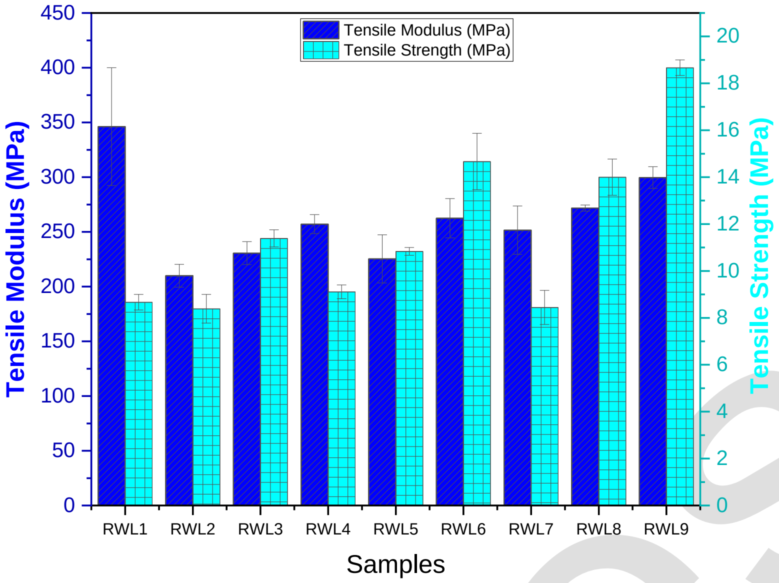

Fig. 2. Tensile Modulus and Strength of the Developed Composites.

Figure 2 shows the tensile modulus of the developed samples. In comparing the tensile moduli of samples, it was observed that with an increase in the reinforcement length from 1mm to 5mm, there seems to be a reduction in the tensile modulus. This is a result of an increase in the strain of the samples as a result of the presence of reinforcement. One would have expected that the tensile modulus of the composite samples would increase as the fiber length increases, as obtained in other studies like that of Mohammed et al. [36]. However, this result trend can be associated with the elastic property of the Deleb palm fruit fiber, as given by Ngargueudedjim et al. [37].

Additionally, Figure 2 displays the generated samples' strength and tensile modulus. In comparing the tensile strengths of the samples, it was found that the tensile strength of the composite increased as the reinforcement's fiber length went from 1 mm to 5 mm. Furthermore, with an increase in the weight percentage of the reinforcement from 30 wt% to 40 wt% in the same sample length, there was an increase in the tensile strength except for sample RWL7, which had a drop in tensile strength in comparison with sample RWL4. This drop can be due to the poor homogeneity of the reinforcement with the epoxy matrix. However, the presence of fiber reinforcement in the polymeric matrix is more noticeable at sample RWL3 (5mm, 40 wt%) with an increase in length and weight percentage, leading to improved tensile strength. The obtained result is in line with the findings of Oladele et al. [38], who reinforced epoxy composites with palm kernel shell fiber and particulate cassava peel.

3.2 | Flexural Strength

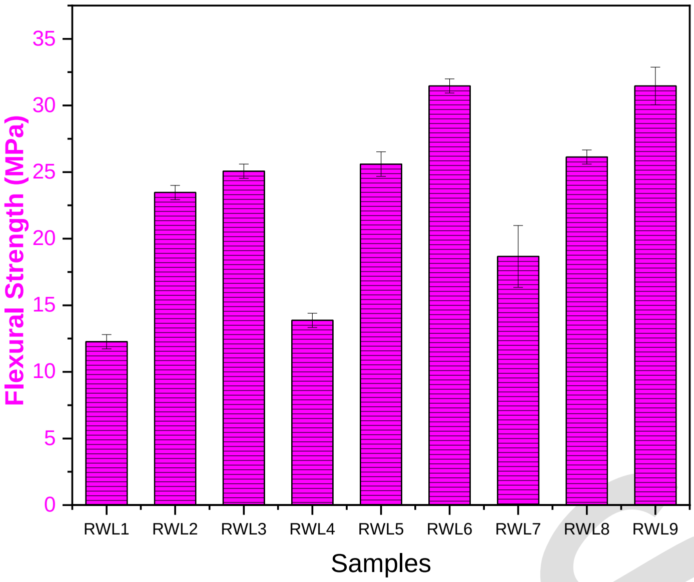

Fig. 3. Flexural Strength of the Developed Composites.

A three-point bending flexural test tested the fiber composite samples, and the result obtained is shown in Figure 3. When the flexural strengths of samples were compared, it was found that the flexural strength of the composite increased with an increase in the reinforcement's fiber length from 1mm to 5mm. Furthermore, with an increase in the weight percentage of the reinforcement from 30 wt% to 40 wt% with the same sample length, there was an increase in flexural strength. As to some studies like that of Oladele et al. [35], flexural strength usually increases to a particular level and then decreases. That was ascribed to poor flexural properties of the fibers; however, that was not observed in this case. A similar result was obtained by Davindrabrabu et al. [39], who reinforced polymer material with pineapple leaf fibers.

3.3 | Impact Energy

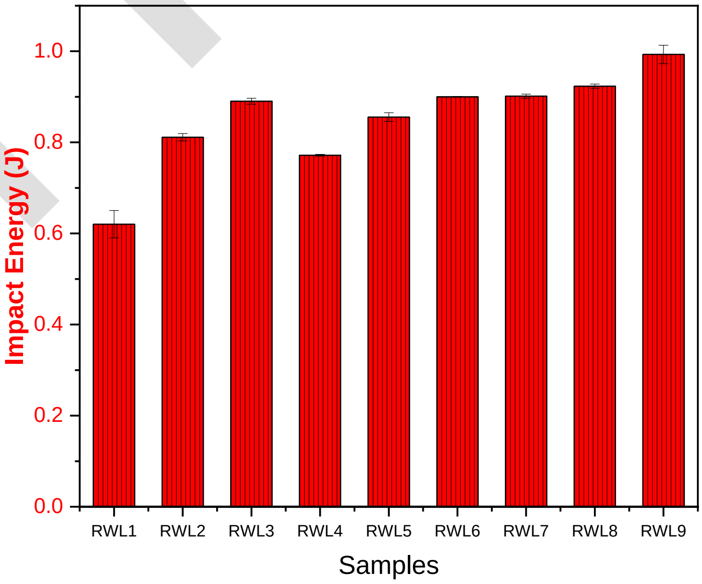

Fig. 4. Impact Energy of the Developed Composites.

The fiber composite samples were tested using the Charpy impact test machine, and the result obtained is presented in Figure 4. When the impact energy of samples was compared, it was found that the impact energy of the composite increased as the reinforcement's fiber length increased from 1mm to 5mm. Furthermore, with an increase in the weight percentage of the reinforcement from 30 wt% to 40 wt% with the same sample length, there was an increase in the impact energy. The high microfibrillar feature of Deleb Palm Fruit fiber as a reinforcing material can be credited for this. Studies have shown that reinforcing fibers with higher microfibrillar angles typically have higher impact strength [8]. The obtained result is in line with the findings of Costa et al. [40], who reinforced epoxy with mallow fibers and evaluated the Izod impact and bending properties.

3.4 | Water Absorption Characteristics

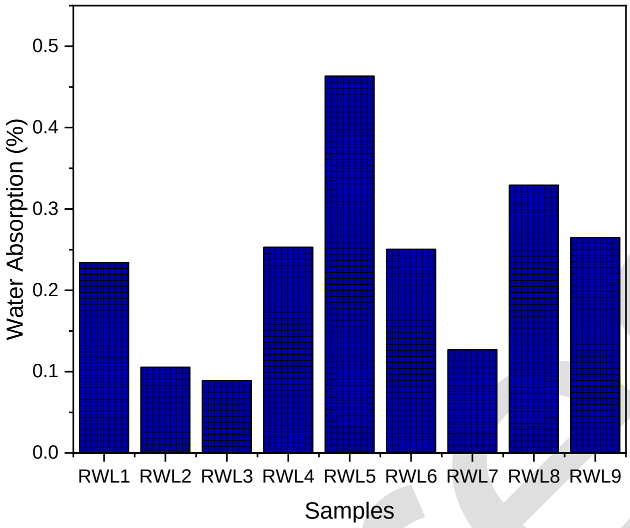

Fig. 5. Water Absorption of the Developed Composites.

In order to ascertain how much water the composite will absorb during a specified period (in this study, seven days), under specific circumstances, the water absorption test was performed. The results are shown in Figure 5. When comparing the water absorption of the samples, it was found that there was a rise in water absorption for each fiber length with a weight percentage increase of the reinforcement from 30 to 40%. At room temperature, it was discovered that the water absorption of the composites followed fiction diffusion. The hydrophilic properties of natural fibers, which are cellulose fibers, can be used to explain this occurrence. However, it was found that once the fiber length was increased over 3mm, the water absorption started to decrease.

Contrary to the majority of studies on fiber-epoxy composites, which hold that longer fibers can absorb water simultaneously with the fiber and at the fiber/matrix interface without interruption, for shorter fibers, the ability to absorb water is typically hampered by the matrix because the matrix absorbed less water than the fiber did [41]. Therefore, the property of the Deleb palm fruit fiber can be attributed to the decrease in the water absorption property of the composite with an increase in the fiber length [42], making Deleb palm fruit fiber a suitable reinforcing material with desired low water absorption properties that have previously limited epoxy-fiber reinforcement. This highlights some of the several applications for palm fibers.

According to Jeyapragash et al. [43], the mechanical properties of Epoxy-Deleb palm fiber composites developed in this work were compared to those of other natural fiber-epoxy composites, such as tensile strength, flexural strength, and impact energy (as presented in Figure 6). Because of characteristics like cellulose enrichment and increased adherence between natural fiber and epoxy matrix, natural fiber reinforcement alters mechanical properties. The higher impact energy in this study is due to the fiber's high microfibrillar characteristic from Deleb Palm Fruit [12]. High impact strength is typically achieved using reinforcing fibers with high microfibrillar angles [8].

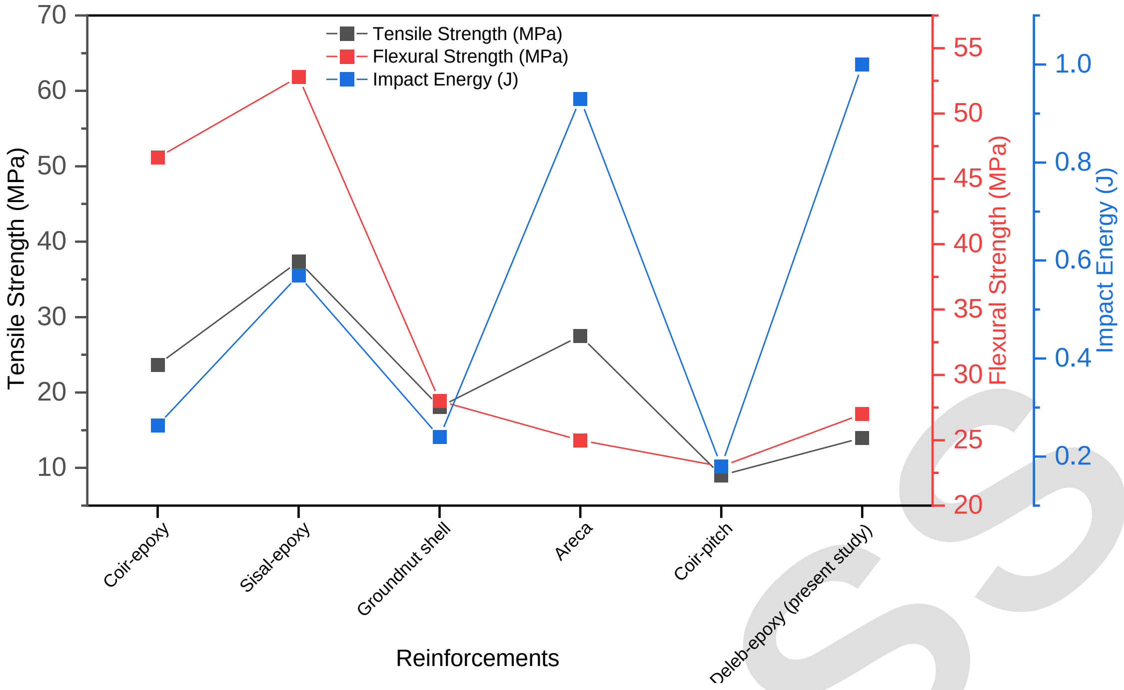

Fig. 6. Comparison of some of the mechanical characteristics of epoxy composites reinforced with natural fiber

3.5 | Grey Relational Analysis

The responses' data processing (normalization), which was done using the grey relational analysis and the maxim "the more, the better," is shown in Table 3. Additionally, Table 4 provides the gray relational coefficient of each developed sample based on their responses, and Table 5 provides the grey relational grade appropriate to identify the ideal fiber parameters that produced the best physical and mechanical properties of epoxy-based reinforced Deleb palm fiber composite.

Table 3. Normalized physio-mechanical properties of the developed composites.

Samples	Tensile Modulus	Tensile Strength	Flexural Strength	Impact Strength	Reduction in Water Absorption
RWL1	1	0.040728801	1.5975E-15	1	1
RWL2	0	0	1.5975E-15	0.614271935	0.898770986
RWL3	0.18753907	0.382243272	1.5975E-15	0.546491137	0.611596593
RWL4	0.40468511	0.10325501	6.94566E-16	0.207437561	0.612123717
RWL5	0.141690795	0.319717063	0.3731143	0.660684278	0.530642173
RWL6	0.446488028	0.698483855	1.5975E-15	0	0.50580553
RWL7	0.361439705	0.008252595	1	0.441400039	0.568713571
RWL8	0.516119544	0.640321573	0	0.452072814	0
RWL9	0.711088869	1	0.660876372	0.882419386	0.208956187

Table 4. Grey relational coefficient of the physio-mechanical properties of the developed composites.

Samples	Tensile Modulus	Tensile Strength	Flexural Strength	Impact Strength	Reduction in Water Absorption
RWL1	0.333333333	0.924677952	1	0.333333333	0.333333333
RWL2	1	1	1	0.448723498	0.357456657
RWL3	0.727231399	0.566737107	1	0.477787133	0.449803466
RWL4	0.55267849	0.82883688	1	0.706776156	0.449590268
RWL5	0.77919148	0.609966563	0.572662709	0.430780368	0.485134427
RWL6	0.5282687	0.417193772	1	1	0.49711399
RWL7	0.580423676	0.983762808	0.333333333	0.531123836	0.467852204
RWL8	0.516119544	0.640321573	0	0.452072814	0
RWL9	0.711088869	1	0.660876372	0.882419386	0.208956187

Table 5. Grey relational coefficient of the physio-mechanical properties of the developed composites.

Samples	Grey relational grade	Ranking
RWL1	0.584936	6
RWL2	0.761236	1
RWL3	0.644312	5
RWL4	0.707576	2
RWL5	0.575547	8
RWL6	0.688515	4
RWL7	0.579299	7
RWL8	0.691142	3
RWL9	0.448768	9

From the ranking of the grey relation grade, as shown in Table 5, it was observed that sample RWL2 denoting 30 wt% compositions of the Deleb palm fruit fiber reinforcement at 3mm fiber length gave the optimum physio-mechanical properties. This result is supported by the main effects plot for the SN ratio obtained from the Minitab Statistical software for Taguchi design of experiment analysis (Figure 7).

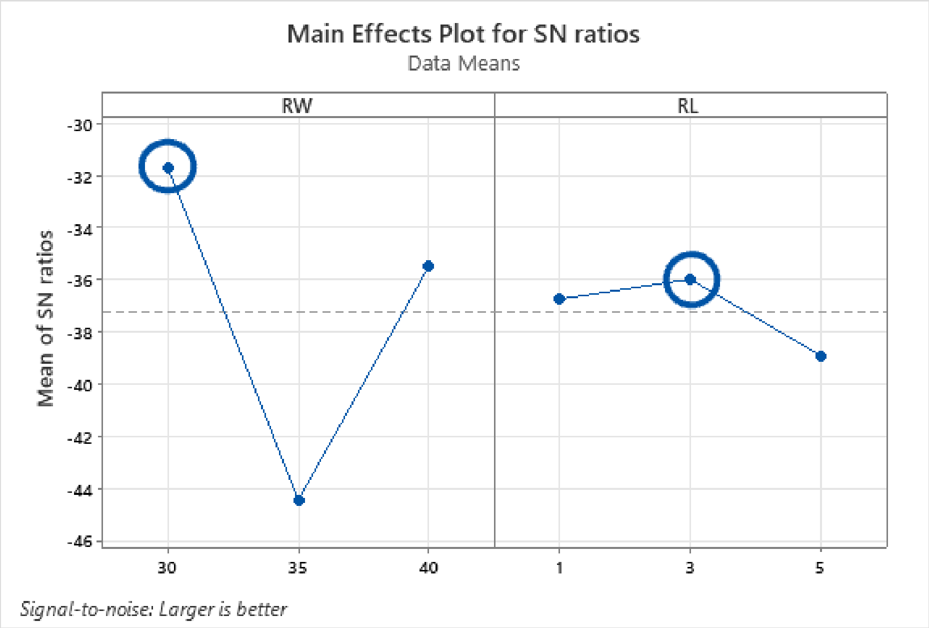

Fig. 7. Main effects plot for SN ratio denoting the optimal composite

3.6 | Analysis of Variance

To ascertain the relevance of the performance characteristics, a statistical study known as analysis of variance was also conducted. The F-test was performed to identify which factor combination substantially impacts the performance characteristic of each physio-mechanical property. This study provided information on the percentage contribution by each factor combination using the total sum of the squared deviations SST.

Table 6. Analysis of Variance of the fiber parameters' impact on the physio-mechanical characteristics of composites.

Source	DF	Sum of squares	Mean Square	F-Value	P-value	Remark
Response: Tensile Modulus						
RW	1	218.5	218.5	0.10	0.761	Insignificant
RL	1	642.8	642.8	0.30	0.604	Insignificant
Residual error	6	12909.6	2151.6			
Total	8	13770.9				
Response: Tensile Strength						
RW	1	26.74	26.741	9.43	0.022	Significant
RL	1	57.04	57.042	20.12	0.004	Significant
Error	6	17.01	2.836			
Total	8	100.80				
Response: Flexural Strength						
RW	1	1.1874	1.1874	4.04	0.091	Insignificant
RL	1	0.1391	0.1391	0.47	0.517	Insignificant
Error	6	1.7654	0.2942			
Total	8	3.0919				
Response: Impact Strength						
RW	1	0.000039	0.000039	0.35	0.577	Insignificant
RL	1	0.000014	0.000014	0.12	0.740	Insignificant
Error	6	0.000678	0.000113			
Total	8	0.000731				
Response: Reduction in Water Absorption						
RW	1	0.07009	0.070095	22.92	0.003	Significant
RL	1	0.01706	0.017056	5.58	0.056	Insignificant
Error	6	0.01835	0.003059			
Total	8	0.10550				

The tensile strength and water absorption were the two physio-mechanical features of the composites most significantly impacted by the fiber parameters, according to the ANOVA result obtained and presented in Table 6 with a 95% confidence interval.

4 | Conclusion

In this study, Taguchi grey relational optimization was used to examine the impact of fiber parameters on the physical and mechanical characteristics of an epoxy-based reinforced Deleb palm fiber composite. The results found that the Deleb palm fruit fiber's features tend to differ from those of other types of fiber reinforcement in terms of their impact on the physio-mechanical properties of the epoxy-based reinforced Deleb palm fruit fiber composite.

Additionally, the results demonstrated that sample RWL2, which contained a 30-weight percent composition of Deleb palm fiber reinforcement with a 3 mm fiber length, was the sample with the best physio-mechanical properties. These samples were identified by the ranking of the grey relation grade and the main effect plot of the SN ratio. The ANOVA result showed that, at a confidence interval of 5%, the composites' tensile strength and reduction in water absorption were the most significantly affected physio-mechanical properties by the fiber parameters.

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Conflicts of Interest

The authors report there are no competing interests to declare.

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