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Research Article

Optimisation of Graphene Nanofiller Addition on the Mechanical and Adsorption Properties of Woven Banana/Polyester Hybrid Nanocomposites by Grey-Taguchi Method

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Throughout history, techniques have shifted from mainstream metals and minerals to nanocomposites to generate smaller, more practical elements for particular purposes. Natural fibres have greater advantages than glass fibres, such as being cheaper, recyclable, and nonflammable. The main objective of the current experiment is to determine how the accumulation of graphene to hybrid polyester composites reinforced with woven banana fibre affects their mechanical properties. Composites were constructed utilising the hand lay-up process with the following limitations: (i) graphene filler weightiness, (ii) woven banana fibre thickness in gsm, and (iii) number of woven banana layers, all at three different levels. Using the L_9 (3^3) orthogonal design, nine composite samples are generated and tested according to the ASTM standard. According to the grey research, hybrid composites having 5% graphene powder and 350 grammes per square metre of woven banana fibre in three layers have high mechanical strength. Adding fibre content to immaculate polyester increased its mechanical properties in general. As the fibre and filler concentrations grew, more energy was required to break the fibre bundles between the matrix and its resin. The confirmation test by the optimal process value utilising the grey relation analysis is considerably better than the actual test data. Tension strength has improved by 17.14%, bending strength has improved by 96.75%, and impact energy has increased by 16.17%.

1. Introduction

Natural fabrics are plentiful and recyclable and offer no health concern to humans or animals. Moreover, natural fibre-reinforced fibres are thought to have a good prospect as a replacement for hydrocarbon and fossil-based fibres. Natural materials are generated from different portions of plants and then categorised [1, 2]. For example, natural fabrics like cotton, rice husk, pineapple, and jute are abundant in underdeveloped countries like Thailand, Malaysia, and China [3, 4]. Development environments using polymeric materials reinforced with natural fibres have developed rapidly in recent years, owing to the benefits of both favourable composite qualities and fibre and environmental strength.

Environmental contamination and finite hydrocarbon supplies have been increasingly important to scholars in recent history [5–7]. Natural-source fibres are increasingly being used in research projects. Plant fibres are employed on a variety of polymer substrates. Nguyen and Nguyen [8] investigated the use of banana fibres in the epoxy matrix at percentages of 0, 5, 10, 15, and 20% by weight. The findings show that mechanical characteristics rise if banana fibre content is 16 wt.%; whenever it reaches 16 wt.%, material strength begins to fall. Venkateshwaran et al. [9] looked at banana fibre volume fraction at various percentages, like 10, 15, and 20%. Numerous studies employ banana filler material for other polymers, mainly polyamide with varied components: 12%, 18%, and % by weight. Sumesh and Kanthavel [10] used a liquefied approach followed by blow moulding banana fibre to apply alkaline and various silanes to investigate and construct banana fibre biodegradable polymer acid. Several studies [11–13] have attempted to hybridise banana fibre-reinforced composites with other nanoadditives such as nanosilica and nanoaluminium oxide to optimise their mechanical properties. The outcomes demonstrated that combining banana fibre with nanoadditives enhanced the material's mechanical stability by establishing nanoparticle hydrogen atoms at the fibre-matrix contacts [14]. Plant fibres of biological origin are plentiful, but several studies have been conducted on them. The objective is to develop a biocompatible material of high value. In addition to bamboo fibre, coco fibre, jute fibres, lime peels, viscose and cotton, and other additives produced from the outer skin of vegetables, tomatoes, and turnips were investigated [15–17]. Vinod and Sudev [18] created a 25% banana fibre and 25% phenolic adhesive bonding product that can withstand higher loads than previous mixtures and could replace traditional fibre-reinforced polymeric materials. The kinematic characteristics of banana-hemp-glass-reinforced composite samples, cannabis, and glass fibre-reinforced banana fibres were studied by Aji et al. [19]. This marijuana plant fibre hybrid epoxy composite could be employed as a replacement for synthetic fibre-reinforced materials, according to the investigation.

Mixed materials are composed of numerous ferromagnetic layers in a homogeneous material. By resolving the shortcomings of individual combinations, hybridisation may enhance the properties of organic fibres and biodegradable polymers. Furthermore, the overall effect of mixing threads in resins on increasing elastic modulus has peaked. The nanomaterials are used to improve the link between composite systems, thereby improving the properties [20, 21]. As a consequence, the use of nanostructures in synthetic materials is becoming increasingly common. This research is aimed at figuring out how to use graphite dust to control the actions of biocomposites [22]. Because of their nanoscale level, nanomaterials offer distinctive properties that might have been utilised to generate innovative goods and services that improve the performance of current models. Much of the research focused on how novel nanomaterials could be used to address major environmental issues [23–25]. Graphite, a double strip of monosaccharides structured in a Hexa residue, has been the most recent substance to spark researchers' interest [26]. Graphene's extraordinary thermodynamic features have piqued curiosity, particularly its large interfacial region, electron and heat transport, and elastic modulus. Because of a few exceptional capabilities, major attempts have been made to integrate graphite into many different purposes, from electricity to biomedicine [27]. In climate change research, graphite and polymer composite compounds were employed to construct innovative potassium carbonate or photodetector apparatus enabling ecologically clean water metal surfaces and as photocatalytic for pollution monitoring or expelling. Different organic modifications will be used to enhance the adherence of polyester resin to hybrid composites [28, 29]. It was established that such a stress-strain curve of natural fibres is governed by the shape and position of fracture toughness after evaluating these under loaded circumstances and repeated packed attempts [30, 31]. The formation of cohesive interfacial interaction between fibre matrix and nanoparticles improves the effectiveness of a polyester composite nanoparticle. On the other hand, the surface morphology of nanostructured materials produces unforeseen consequences like physical deterioration, recurrence of severe swelling, or outside damage [32, 33]. Several multiresponse issues such as those in manufacturing methods have effectively improved through grey-based conventional techniques. The Taguchi experimental plan effectively enhances the production process and meets ambitious goals while raising costs. The S/N analysis is used to calculate the impact of additive noise on the intention of identifying, and also, an asymmetrical pattern of microarray (OA) is employed to examine a number of factors in minimal repetitions [34, 35]. Whenever it comes to a S/N proportion, there really are three primary types of performance metrics to consider: simple, bigger, and hypothetical. Depending on the feature getting studied, this S/N proportion consolidates the many datasets within an experiment.

The key purpose of the current investigation is to create, appraise, and enhance the material behaviour of hybridised biomaterials using the following conditions: graphene weight percent, woven banana fibre in gsm, and banana fibre layer count. The graphene filler-based composite materials were made through manual procedure. Natural fibres were alkali-treated to increase adherence and reduce moisture absorption, and their mechanical properties were examined and improved using Taguchi techniques based on grey analysis.

2. Experimental Works

2.1. Reinforcement Materials. GVR Fiber Industry in Madurai, Tamil Nadu, India, provided the woven banana fibre mates. Wetness in the banana fibre mates and resources were gently washed using sparkling aquatic and sundried for 48 hrs. The banana fibre was then submerged in a NaOH solution for four hours. The resource was then cleaned with water and located in a hot oven at 75 degrees Celsius. This research used graphene and polyester as a matrix. Global Industries in India supplied the matrix and graphene fillers (40 nm size). Figure 1 depicts the process of extracting banana fibre from banana plants, and Figure 2 shows the photographic images of nanofiller and matrix materials.

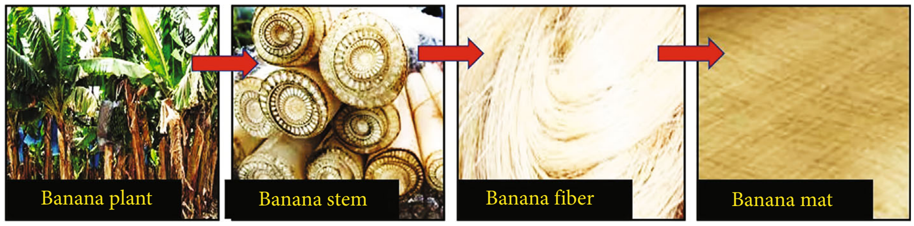

FIGURE 1: Banana fibre extraction from banana plant.

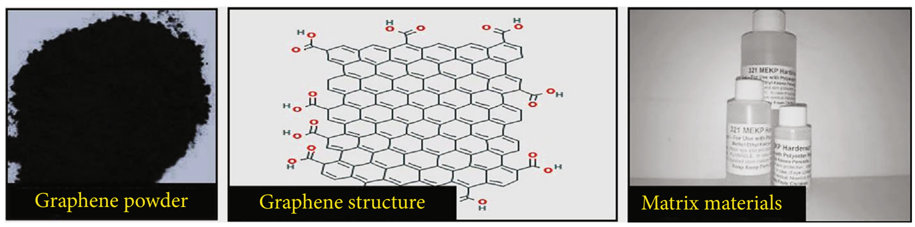

FIGURE 2: Photographic images of nanofiller and matrix materials.

TABLE 1: Parameters and their levels for hybrid composite.

Sl.no.	Process variables	Signs	Levels S1	S2	S3
1	Graphene powder (wt.%)	A	2.5	5	7.5
2	Woven banana mate (gsm)	B	200	250	300
3	No. of banana fibre layers (no.)	C	1	2	3

TABLE 2: L_9 orthogonal array of hybrid composites.

Trail no.	Graphene powder (wt.%) A	Woven banana mate (gsm) B	No. of banana layers (no.) C
1	2.5	200	1
2	2.5	250	2
3	2.5	300	3
4	5	200	2
5	5	250	3
6	5	300	1
7	7.5	200	3
8	7.5	250	1
9	7.5	300	2

2.2. Alkaline Treatment. Fresh banana fibres were manually washed in 1 to 2% washing solutions at 60 to 70°C for 1 hour to remove contaminants after being wetted by pure aquatic aeration in a hot gasping rotisserie at 55°C for 90 minutes, as directed. Untreated filaments were defined as "dry fibres." The fibres were first disembowelled by immersing them for 70 to 72 hours at 50°C in a 2 : 1 mixture of benzene and ethanol, after which they were thoroughly wetted with water and stored for 50 hours. Finally, the cleaned fibres are engrossed in a 5% alkali solvent for 4 hours at room temperature.

2.3. Creation of Nanocomposites. Sonication was employed to disperse graphite and bananas in synthetic materials. In

TABLE 3: Outcomes of current investigation.

Experiment no.	Tensile (MPa)	Flexural (MPa)	Impact (kg/m^2)
1	34.14	41.70	27.57
2	36.41	43.97	29.84
3	37.55	46.90	33.46
4	38.04	45.60	31.47
5	42.58	47.47	34.24
6	36.52	44.08	29.95
7	38.44	46.84	33.33
8	35.28	42.84	28.71
9	39.39	46.95	32.82

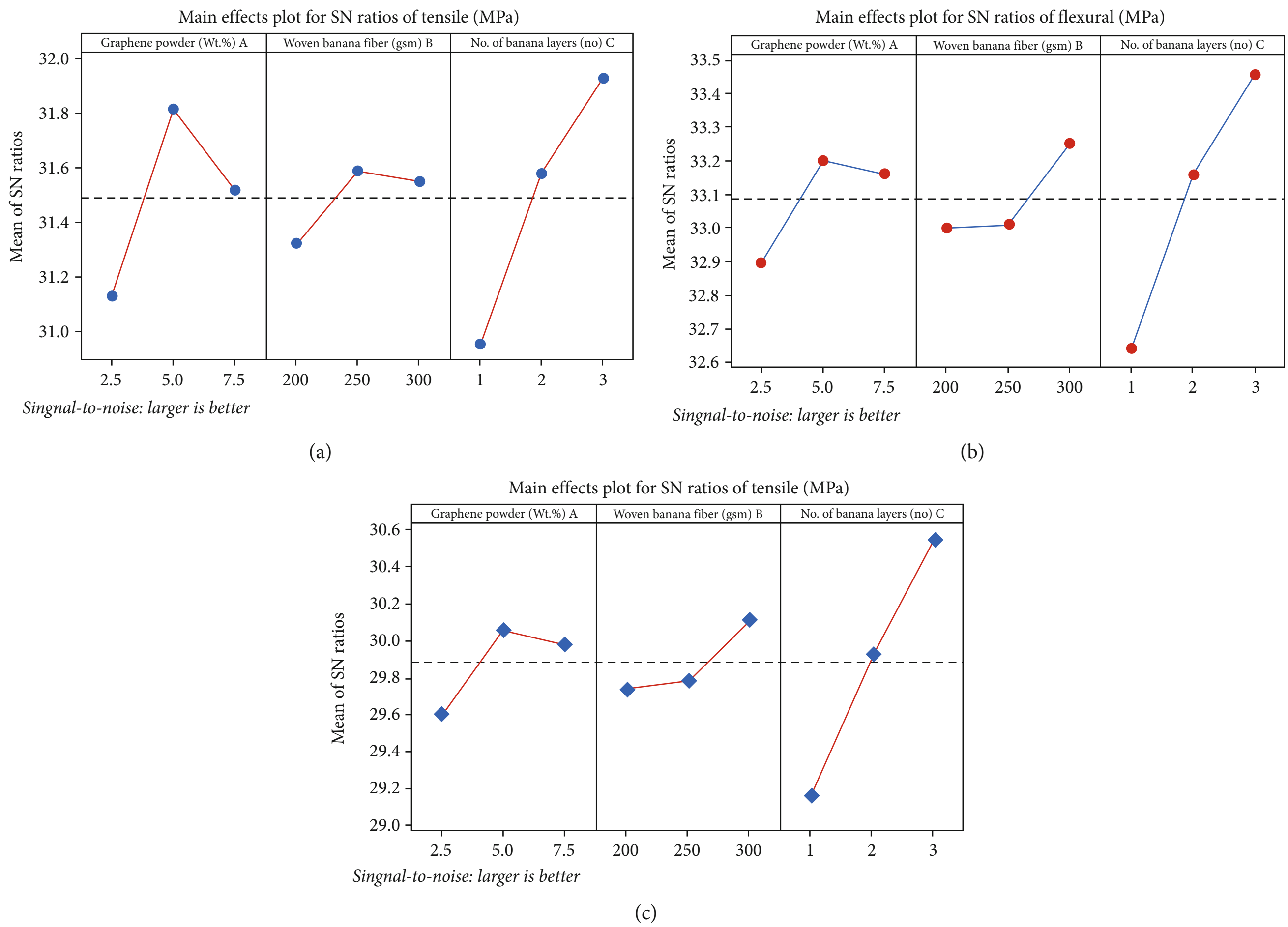

FIGURE 3: S/N values of mechanical properties: (a) tension; (b) bending, and (c) impact.

TABLE 4: S/N and standardized S/N ratio.

Exp. no.	S/N ratio Tensile strength (MPa)	S/N ratio Flexural strength (MPa)	S/N ratio Impact strength (kg/m^2)	Standardized S/N Tensile strength (MPa)	Standardized S/N Flexural strength (MPa)	Standardized S/N Impact strength (kg/m^2)
1	30.665	32.404	28.810	0.000	-0.098	0.000
2	31.224	32.864	29.497	0.291	0.352	0.382
3	31.492	33.423	30.491	0.431	0.898	0.934
4	31.604	33.180	29.959	0.489	0.660	0.638
5	32.584	33.528	30.691	1.000	1.000	1.045
6	31.250	32.886	29.529	0.305	0.373	0.400
7	31.696	33.412	30.457	0.537	0.887	0.915
8	30.950	32.638	29.162	0.149	0.131	0.196
9	31.907	33.433	30.324	0.647	0.908	0.841

addition, the mixture was constantly combined. This continuous mixing is done for a certain timeframe till the combination is homogeneous. During mechanical churning, vapours are maintained and should be removed to use the relevant field of study technique. The combination is dried for 2 hours at 600 degrees Celsius, then for 4 hours at 1000 degrees Celsius. A stainless steel mould measuring 150 × 150 × 3 mm was first refined. 1 wt% cobalt naphthenate and 1 wt% methyl ethyl ketone peroxide were blended well into the matrix material. The graphene powder and woven banana fibre composite were made using the hand lay-up method. Graphene powder of various weights % was dispersed in the manufactured polyester resin by hand stirring with a glass rod. This matrix mixture was sprinkled throughout the fibre layers of the mould.

Table 5: GRC and GRG of the composites.

Trail series	GRC			GRG
	Tensile (MPa)	Flexural (MPa)	Impact (kg/m^2)	
Trail 1	0.333	0.313	0.333	0.327
Trail 2	0.414	0.435	0.447	0.432
Trail 3	0.468	0.830	0.883	0.727
Trail 4	0.495	0.595	0.580	0.557
Trail 5	1.000	1.001	1.098	1.033
Trail 6	0.418	0.444	0.454	0.439
Trail 7	0.519	0.816	0.854	0.730
Trail 8	0.370	0.365	0.383	0.373
Trail 9	0.586	0.844	0.759	0.730

Table 6: Retort table for GRG.

Levels	Graphene powder (wt.%) A	Woven banana mate (gsm) B	No. of banana layers (no.) C
S1	0.495	0.538	0.379
S2	0.676	0.613	0.573
S3	0.611	0.632	0.83

After the fibre mats were thoroughly wet by matrix combinations, the mould was affixed and dehydrated in the open air for one day. The Taguchi design was used to choose the L_9 orthogonal array for three constraints, each with three steps, and nine samples were created for further analysis. Desiccators were utilised to prevent the hybrid composite samples from absorbing any more moisture. The parameters, their ranges, and Taguchi's orthogonal arrangement (OA) are presented in Tables 1 and 2.

3. Techniques and Testing

3.1. Testing of Composite Specimen. For tension tests, the produced nanocomposite specimens were cut and moulded to ASTM specifications of D 638-03, ASTM D-790, and ASTM D-256 for flexural and impact resistance, respectively.

3.2. Investigational Significances by GRG Method. The Taguchi procedural knowledge is a valuable technique enabling logical reason, study, and improvement of multiple control factors to obtain the intended impact. Using this method, the investigation report is turned into an S/N proportion to identify the key restrictions. The S/N proportion features are divided into the following stages based on the persuasive rationale for improving the principal functionality: (i) greater is better, (ii) substantially finest, and (iii) shortest is better. The present prosecution's empirical results are shown in Table 3.

3.2.1. Signal-to-Noise Ratio. The bigger a performance characteristic is, independently of a producing showcase family, the bigger its S/N proportion is. Consequently, the optimum value for the characteristic will be the one with the highest S/N proportion. Flexural, tension, and impacting characteristics are measured using the stronger concept throughout the nanocomposite tests. Figure 3 depicts the S/N coefficients of nanomaterials with mechanical and physical properties. As a consequence, significance S/N proportions (bigger-is-better) are specified as [3, 36]

$$\text{S/N Ratio} = -10 \log_{10} \frac{1}{e} \sum_{a=i}^{e} \frac{1}{X_{ab}^2}. \quad (1)$$

3.2.2. Normalized Signal-to-Noise Ratio. Standardization is a change made to that quantitative intake to distribute the data consistently and evaluate things into a proper assemblage for further inquiry. Zab is standardized to make the right consequence of assertions for numerous aspects and minimize discrepancies. One of the most significant components of this investigation was selected using the significantly larger bending, tension, and shock capabilities as a guideline. Both the S/N proportion and the standardized S/N proportion were very well suited for the following attributes. The S/N and mainstreamed S/N proportions of the results are shown in Table 4:

$$K_{ij} = \frac{z_{ab} - \min\left(z_{ab} a = 1, 2 \cdots \cdots e\right)}{\max\left(z_{ab} a = 1, 2 \cdots \cdots k\right) - \min\left(z_{ab} a = 1, 2 \cdots e\right)}. \quad (2)$$

3.2.3. Grey Relational Grades (GRG). Formula (3) would be used to turn every GRC response into a grey relational grade.

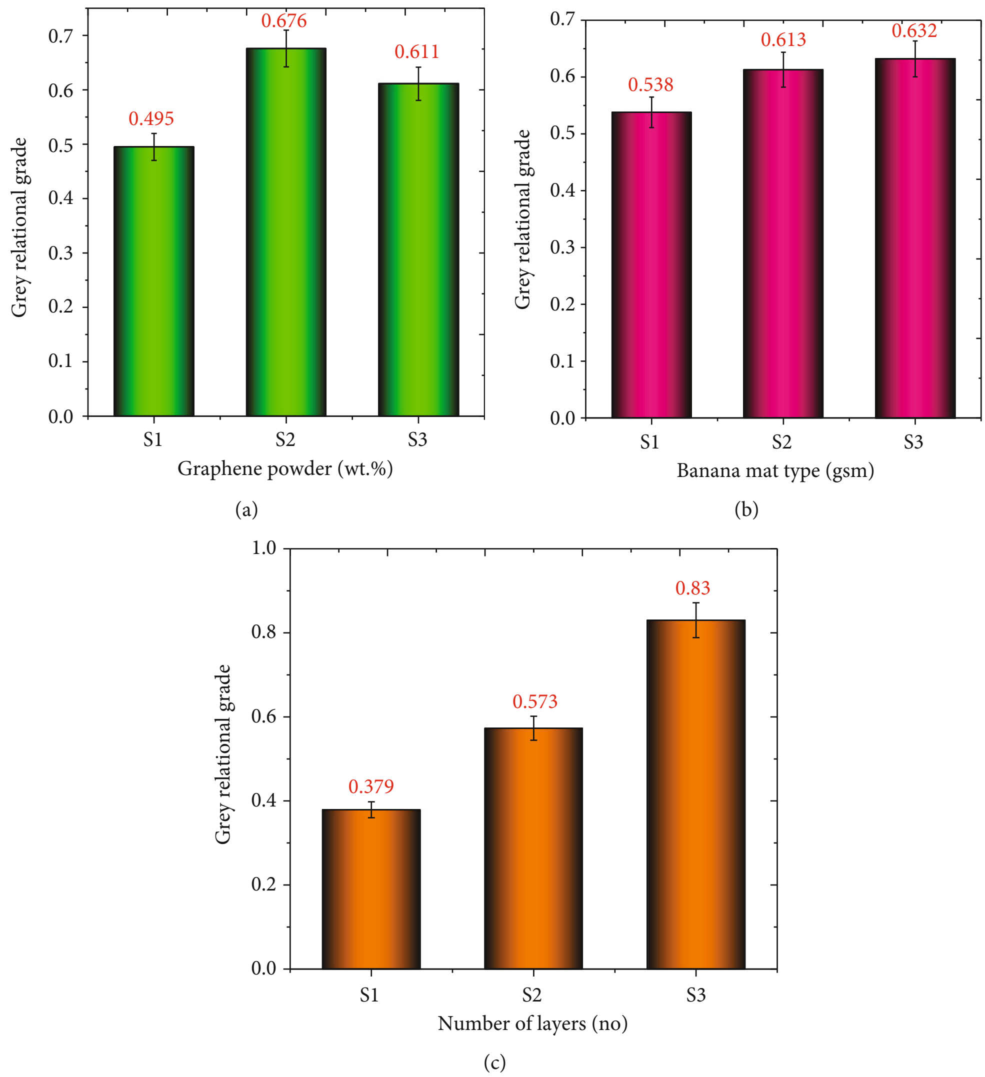

Figure 4: Grey relational grade values of nanocomposites: (a) graphene (wt.%); (b) woven banana (gsm), and (c) number of banana layers (no.).

Table 7: ANOVA of GRG.

Features	Constraints	DOF	SOS	MSOS	% of contributions
A	Graphene powder (wt.%)	2	0.01678	0.0084	11.56
B	Woven banana fibre (gsm)	2	0.02607	0.0130	17.95
C	No. of banana layers (no.)	2	0.10236	0.0512	70.49
Error	—	0	—	—	—
Total	—	6	0.14521	—	100

The grey relational evaluation is utilised to identify the appropriate quantity for every adjustable element. The GRG findings are shown in Table 5:

$$\bar{\gamma}_J = \frac{1}{k}\sum_{i=1}^{m}\gamma_{ij}, \quad (3)$$

where k is the sum of technical specifications and the GRG of the jth trial; the GRC and GRG were eventually performed on all L_9 (33) tracks. The multiresponse optimisation issue was confined to a mere optimal configuration by integrating Taguchi methodologies and grey relational modelling. The entire GRG, which was derived by using the grey-based Taguchi technique, is the sole productivity characteristic [3, 14]. Searching for a variable setup could acquire the greatest overall grey association rating. Table 5 displays the GRC and GRG for nine experiments.

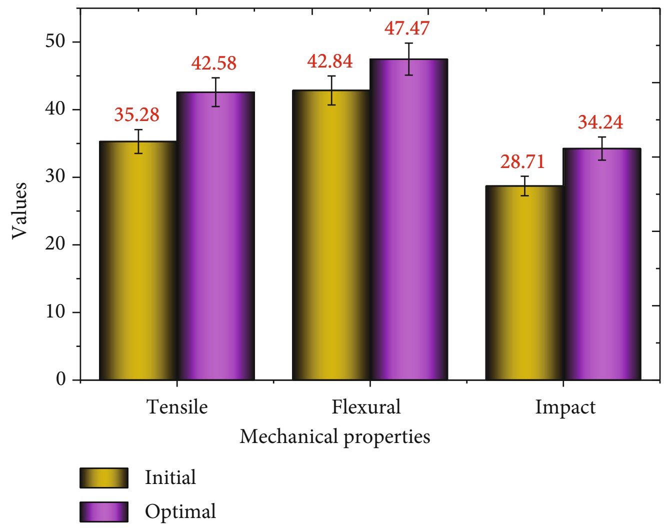

FIGURE 5: Comparison of initial and optimal parameters of mechanical properties.

4. Result and Discussion

4.1. Grey Relational Grades. The Taguchi technique with relative importance study was performed to determine the optimal variables for the mechanical behaviour of hybridised nanocomposites. The best restriction subgroups and most important features in biocomposites were lowered using grey-based analysis and analysis of variance [20, 21].

The average GRG for every restriction factor was calculated using the Taguchi product's reaction table. To calculate the relative importance rating for graphite dust, mean the relationship numbers of the grey relational variables of plain (grade) 1 in row A (i.e., experiments 1-3) and therefore the relationship readings of plain 2 in the same columns.

Experiments 4-6 mean this very same row A's flattened 3 relationship variables, while attempts 4-6 mean the same section A's flattened 3 relational morals (trials 7-9). Likewise, the precise thickness of banana fibre and the number of banana layers are designed. This is seen in Table 6. Figures 4(a)–4(c) depict the GRG reaction facts at various degrees of the composite's limitations. As per the information, the greatest relative importance degree results in excellent strategy restriction intensity [37, 38].

Levels A2, B3, and C3 have the greatest grey relative grade value of the constraints such as graphene powder weight, woven banana mat, and the number of banana layers. The hybrid composites' optimal specifications were graphene powder of 5% and fabric banana type 300 gsm with three layers. The usage of weaved bananas will boost the strength of composites. It is owing to a heavier, higher-density fibre composition that mitigates the impacts of vacancies. Only 5% of the graphene weight ratio increased the strength of natural composites. Adding more filled graphene to the polymer matrix increased the conveyance and size of holes, influencing the decohesion bonding between the fibre and the matrix. The matrix and fibre connection get weaker as the graphene weight ratio rises. In the case of woven banana fibre, 300 gsm gives maximum strength. It demonstrates that a thicker woven banana would improve nanocomposite strength. It is because the presence of thicker, higher-density fibre materials reduces the impacts of voids, which is consistent with author Ganesan's findings [3, 37, 39]. The composites demonstrate a beneficial effect as parameter C is raised. The interaction between the fibre and matrix enhanced as the fibre quantity increased. As a result, breaking the interlaced fibre bundles' connection takes more energy. The composite's strength declined marginally, with a graphene filler loading of 5 wt%. It is well accepted that when filler loading is high, the polymer has a harder time penetrating the shrinking gaps between the fillers, resulting in poor wetting and, as a result, a loss in stress transfer efficiency at the filler resin interface. Epoxy resin offers great adherence to many substrates and can be reinforced further by adding fibres or particles. This drop is due to the filler's difficulties in maintaining loads transmitted from the polymer matrices and poor interfacial adhesion, which results in largely empty gaps between filler and matrix components, leading to a negative structure.

TABLE 8: Comparison of initial and optimal parameters.

Response	Initial parameter	Optimal parameter	% of improvement
Levels	A3, B3, C2	A2, B3, C3	%
Tensile	35.28	42.58	17.14%
Flexural	42.84	47.47	9.75%
Impact	28.71	34.24	16.17

4.2. ANOVA Analysis. The ANOVA results are utilised to determine which graphite and banana-based composite material process variables determine the influencing sources of variation. As in the analysis of variance, the standard gradient number can be utilised. To assess the influence of altering processing conditions on performance qualities, utilise a percentage distribution determined from the entire mean squared departures [40, 41].

The influence of each process parameter is seen in Table 7 with graphene powder, weaved banana, and the number of banana layers accounting for 11.56%, 17.95%, and 70.49%, respectively. It implies that the number of banana layers is the key factor.

4.3. Confirmation Test. A confirmation experiment is carried out to ensure that the overall performance of nanocomposites has improved [42]. Table 6 displays the outcome for initial values of control factors, such as 7.5% graphene powder weight, 300 gsm banana mat type, and 2 banana layers (A3, B3, and C2). The following are the process parameters via a confirmation test at the optimum level:

Figure 5 indicates the comparison of initial and optimal parameters of mechanical properties. Table 8 shows that the optimal parameters are preferable to the starting values in percentage growth [43]. The graphene powder weight percent is 5%, the banana mat type is 300 gsm, and the number of banana layers is 3. (A2, B3, and C3) [44]. Furthermore, for tensile strength, flexural strength, and impact strength, the findings produced from the confirmation test by the optimal process value utilising the grey relation analysis are considerably better than the actual test data [45]. Tensile strength has increased by 17.14%, flexural strength has increased by 96.75% [46], and impact energy has increased by 16.17%.

5. Conclusion

The Taguchi approach and GRA were used to optimise the process constraints in this work, which looked at the mechanical properties of graphene and woven banana-based polyester hybrid composites. The following conclusions were drawn:

(i) The proposed controlled process parameters for graphene and banana-based hybrid composites are 5% graphene powder and 300 gsm jute with 3 layers. The combination of several elements results in hybrid composites with improved mechanical properties

(ii) According to statistical analysis (ANOVA), the most important attribute was the number of jute layers, which contributed 70.49%, followed by braided banana fibre 17.95% and graphene powder 11.56%

(iii) The grey relation analysis confirms the excellent process value, which is significantly better than the actual test data. Tensile strength is up 17.14%, flexural strength is up 96.75%, and impact energy is up 16.17%

Data Availability

The data used to support the findings of this study are included within the article. Should further data or information be required, these are available from the corresponding author upon request.

Conflicts of Interest

According to the researchers, there have been no competing interests surrounding the publishing of this research.

Acknowledgments

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