Fabrication, Testing, and Optimization of MWCNT Epoxy Polymer Nanocomposites Through Taguchi, TOPSIS, and Response Surface Techniques

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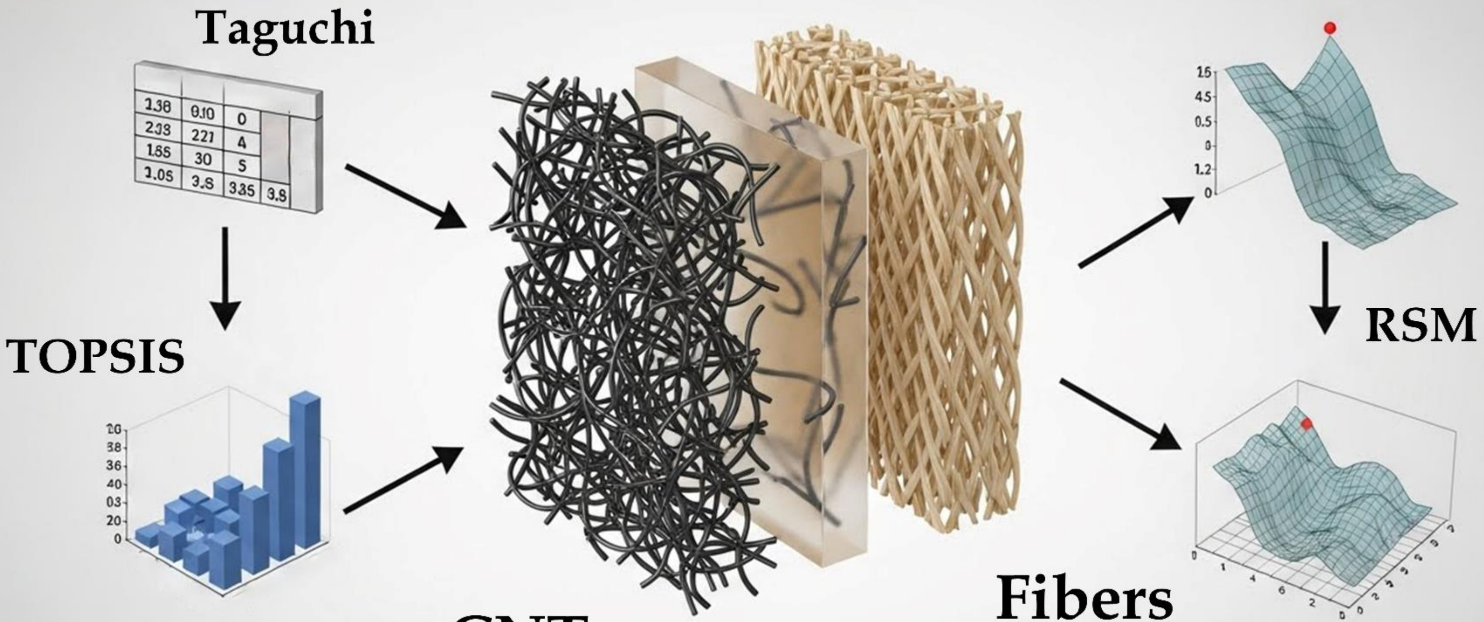
Editor's note: The optimization of nanocomposites with different volume fractions of nanofillers is a classic multi-criteria decision-making challenge. Nyonyi et al. introduced a hybrid decision-making approach that combines Taguchi methods, TOPSIS, and Response Surface Methodology (RSM) to identify the most effective nanocomposite. This innovative approach successfully improved the mechanical properties of epoxy-E-fiberglass nanocomposites reinforced with multi-walled carbon nanotubes (MWCNTs). The optimization results confirmed that the content ratios of MWCNTs and other components in the system significantly affect both tensile and flexural strength.

doi: 10.22034/jams.2025.210155

How to cite: D. Nyonyi et al. *Journal of Applied Material Science*, **2025**, *1*, 210155.



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Journal of Applied Material Science **2025**, *1*, 210155
How to cite: D. Nyonyi et al., *Journal of Applied Material Science*, **2025**, *1*, 210155.
Journal homepage: **jams.hsu.ac.ir**

Original Research

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Abstract

The mechanical optimization of nanocomposites, which involves different nanofillers and varying nanofiller volume fractions, represents a classic, multi-criteria decision challenge. In practical scenarios, the values of attributes and their corresponding weights frequently exhibit uncertainty, leading to certain constraints. This study presents a novel hybrid decision-making approach that integrates Taguchi, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and Response Surface Methodology (RSM) to identify the nanocomposite with optimal mechanical properties. This study explores the enhanced mechanical properties of nanocomposites reinforced with multi-walled carbon nanotubes (MWCNTs) and epoxy-E-fiberglass. The parameters assessed consist of tensile strength, tensile modulus, tensile strain at break, flexural strength, flexural modulus, and flexural strain at break. The input variables used to improve the mechanical properties of the nanocomposite samples include MWCNT (vol%) nanofiller, e-glass fiber, and epoxy polymer. The Taguchi method was applied to design an experiment that studied the interaction of the process on the response variables of the samples. The TOPSIS technique and response surface methodology (RSM) analyses were employed for the simultaneous optimization and ranking of multiple responses. After determining the optimal settings for the control factors, confirmation experiments were conducted to validate the results. The TOPSIS analysis ranked the experiments, with experiment code A22 identified as having the most significant effect, followed by A88, A11, and A55, in that order. Taguchi and RSM indicated that experiment code A44 achieved optimal mechanical properties. Therefore, the results demonstrate that the mechanical properties of MWCNT nanocomposites have been optimized.

Keywords: Optimization; Taguchi; Surface Response; Mechanical Strength; Nanocomposites.

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Received 3 December 2025
Revised 16 December 2025
Accepted 19 December 2025
Available online 20 December 2025

https://doi.org/10.22034/jams.2025.210155

1. Introduction

The use of nanocomposite materials has come about because of improvements in transportation and infrastructure. To make nanocomposites, you have to mix nanotubes or nanoparticles into a composite matrix. This combines the ideas of composites with the nanometer-scale range, which is from 1 nm to 100 nm [1]. The goal is to change the composite structure at the atomic, molecular, and supramolecular levels to make it more stable, better at conducting electricity, and better at holding together, while keeping the interface stable so that materials can be made [2]. The small size of the nanofillers and the chemical interactions that happen at the interface of nanoparticle/nanotube-matrix provide nanocomposites with unique and better properties [3].

Carbon nanotubes (CNTs) are viewed as promising for enhancing polymer matrices because of their exceptional strength, stiffness, lightweight nature, high flexibility, diameter-dependent specific surface area, high aspect ratio, excellent thermal conductivity, and electrical properties, including moderate electrostatic discharge capabilities [1, 4, 5]. Their outstanding mechanical and thermal attributes make CNTs highly appealing nanofiller materials, making them suitable for manufacturing multifunctional polymer nanocomposites. Besides the type and surface functionalization of CNTs, the properties of the polymer matrix, stabilization additives, and production processes significantly influence the maximum CNT load and the resulting composite properties [2, 6].

The literature examines diverse methodologies for the design and fabrication of nanocomposites, leading to varying degrees of interfacial contact and mechanical strength characteristics. The investigation carried out by Miraidin et al used dispersion and surface modification methods to make MWCNT/epoxy composites work better mechanically by aligning the MWCNTs in the polymer resin [7]. This made it easier for the MWCNTs to stick to the epoxy polymer matrix. It is essential to improve mechanical strength and deal with the problems that come up during synthesis and the clumps that intermolecular Van der Waals forces cause. The suggested solutions are meant to stop agglomerations and voids from forming in the composite. This will make the MWCNTs spread out better in the polymer matrix and make the nanocomposite's mechanical qualities better [8]. Some researchers, however, consider the formation of agglomeration in the nanocomposite this be an essential issue that hasn't been answered, in addition to the problems with the surface functionalization of MWCNTs nanomaterials [7].

The research conducted by Sharma. S et al. underscores the persistent obstacles related to morphological structures that could affect the structural stability and lead to fracture formation; these issues were substantially alleviated with the implementation of bulk polymerization and sonication during the MWCNT dispersion process [9]. However, the improvement of mechanical qualities has not yet been accomplished. Some writers say that ball milling or chemical treatment can change the surface of MWCNTs. [8]. Chemical functionalization methods, including amino functionalization, oxidation, fluorination, and surface modification, can make the dispersion process faster, improve processing efficiency, and make MWCNTs work better with polymers. This procedure cannot improve the strength and modulus of the polymer nanocomposites [10]. The current literature suggests a need for more research into the enhancement of MWCNT nanocomposite optimization techniques.

There are various types of optimization techniques used to fine-tune parameters in nanocomposite manufacturing with multiple quality features, which often depend on the researcher's judgment and experience [11]. Since different quality characteristics may require unique optimal parameter sets, these must be combined to determine the final parameter combination for product design or system and process optimization [12]. The nanocomposite fabrication study, conducted using the Taguchi method, aimed to optimize a single quality by varying process parameters, including carbon nanotube powder and resin adhesive. These results were then combined with Response Surface Methods and TOPSIS for multi-quality optimization to identify the best parameter set for the fabric [13-15]. The approach also included response analysis to evaluate how each factor influenced different quality characteristics.

This research examines three additional techniques to augment the mechanical strength of nanocomposites, which encompass the interaction of three elements: a certain volume fraction of MWCNTs, e-fiberglass, and an epoxy polymer matrix (comprising resin and hardener). The study employs several Taguchi methodologies for experimental design, response surface methodology (RSM) utilizing Minitab software, and TOPSIS analysis to optimize and evaluate the performance of the nanocomposite.

2. Experimental

2.1. Materials

The polymer matrix consisted of a 600 g E-glass fiberglass woven roving mat (density 2.5 g/cm^3) and epoxy resin (LY556), along with a hardener (HY951). Multi-walled carbon nanotubes (MWCNT) had a purity exceeding 98% (information taken from the supplier's data sheet). The vacuum bagging kit system and the vacuum pump system were all sourced from local Indian suppliers.

2.2. Taguchi Experimental Design (TED) Set-Up

Three experiments were conducted employing the Taguchi design of experiments (DOE) methodology, one for each factorial experiment listed in Table 1. The experiment was structured to incorporate three input variables: the MWNT (vol%) nanofiller, epoxy polymer (resin (LY551) and hardener (HY956)), and E-glass fiber [5]. These methods employ analysis of variance (ANOVA) and the signal-to-noise ratio (S/N) to examine the results and the interactions among various parameters. These methods effectively distinguish the critical factors influencing the reaction from the less significant ones, ensuring the optimal settings are identified to get superior results. Minitab was employed to design the experiments and analyze the outcomes.

Table 1. Input parameter and variation level

Parameter input Factors	Level		
	1	2	3
MWCNT content (Vol%)	1.0	1.5	2
Epoxy polymer matrix (Vol)	56	64	72
E-glass Fiber(gm)	60	70	80

2.3. Sample Preparation and Fabrication

The different laminate specimens were manufactured using vacuum bagging techniques (VBT). The fabrication sequence was based on an orthogonal array of designed experiments, as shown in Table 2. The protocol for the fabrication process was kept constant for all fabricated samples. After MWCNT surface modification and proper dispersion mixing, the epoxy polymer with MWCNT was stirred using a magnetic stirrer for 10 minutes, followed by probe sonication for 5 minutes under control of the exothermal temperature. The hand layup technique was used to apply an MWCNT-epoxy polymer matrix (a mix of resin and hardener) to each layer of the E-glass fiber mat, thereby forming a laminate. This laminate instant was transferred to a vacuum bagging-enclosed system and cured under an atmospheric pressure of 700 bar and room temperature for 24 hours [16, 17].

The manufacturing of E-glass fiber polymer nanocomposites involves adding a small volume fraction of multi-walled carbon nanotubes (MWCNTs) to various amounts of the polymer matrices, as shown in Table 2. The main goal is to evenly distribute the MWCNTs and achieve uniform dispersion within the bonding mechanisms of the polymer matrices—novel approaches for creating high-strength MWCNT E-glass fiber nanocomposite materials.

Table 2. Taguchi design experiments array

Exp. run	Exp. Code	E-Glass Fiber (gm)	Epoxy matrix (Resin Hardener)	MWCNT (Vol%)
1	A11	56	60	1.0
2	A22	56	70	1.5
3	A33	56	80	2.0
4	A44	64	60	1.5
5	A55	64	70	2.0
6	A66	64	80	1.0
7	A77	72	60	2.0
8	A88	72	70	1.0
9	A99	72	80	1.5

2.4. Response Surface Methodology

The response surface method (RMS) focuses on assessing the relationship between essential factors and the recorded response output. The principal benefit of employing RSM is that it enables the selective reduction of factors in a design of experiment, thereby effectively illustrating all potential influences on a system's response and optimizing it [18]. The mechanical testing results represent the proper response of a processing method, which is contingent upon critical factors related to the mechanical properties of the nanocomposite. The Minitab software tool will be employed to finalize the optimizations.

2.5. TOPSIS

The technique for order preference by similarity to ideal solution (TOPSIS) is a fundamental theory in ranking methods, determining the optimal choice as the one closest to the ideal solution and furthest from the least desirable option [19]. The assessment and ranking of the mechanical properties of the MWCNTs are performed using a detailed index that quantifies their deviation from the ideal solutions [14, 19]. The evaluation and categorization of the mechanical properties of the MWCNT results are conducted through a detailed index that considers their variances from the ideal solutions. The process involves several stages and numerical evaluations of TOPSIS, beginning with the ranking phase.

2.6. Measurements

The mechanical properties of the samples were tested under tensile, compression, bending, and impact loads. Tensile tests followed the ASTM D3039 standard at a crosshead speed of 1 mm/min using a Universal Testing Machine (UTM). The specimens were cut from a single laminate, measuring 20 mm in width, 2.5 mm in thickness, and 240 mm in length [20]. The gauge length was 100 mm, with a clamping length of 50 mm. Three specimens from each sample were tested. Flexural tests under three-point bending were also conducted on the UTM following ASTM D790 standards to determine flexural strength and modulus [20]. The crosshead moved at a steady speed of 2.0 mm/min, with a span-to-depth ratio of 16:1. Flexural strength was measured as the maximum stress at failure on the tensile side, averaged over three specimens. To achieve the objectives of optimization and prioritization, Taguchi, RSM, and TOPSIS were used to analyze the results of the extensive testing conducted [14, 15, 19].

The composite's crystal structures were analyzed using an X-ray diffractometer (XRD) with Cu-Kα radiation. A Shimadzu FTIR spectrometer was used for Fourier transform infrared spectroscopy to examine the interfacial interaction between the MWCNT and epoxy matrix in the specimen [21]. The morphological analysis of the MWCNT composites was conducted with an SEM (Tescan model MAIA3 XMH), and the results were gathered and analyzed to discover research insights.

3. Results and discussion

3.1. X-Ray Diffraction Analysis

XRD graphs of the MWCNT phase peak were obtained, confirming the presence of its components. The phase angle purity of MWCNT was analyzed using an XRD equipment through Cu Ka radiation constant (k = 1.542 Å). The MWCNT specimens, along with their composites (MWCNT/epoxy), were compacted into suitable glass molds equipped with pits for XRD analysis techniques [7]. The XRD diffraction phase

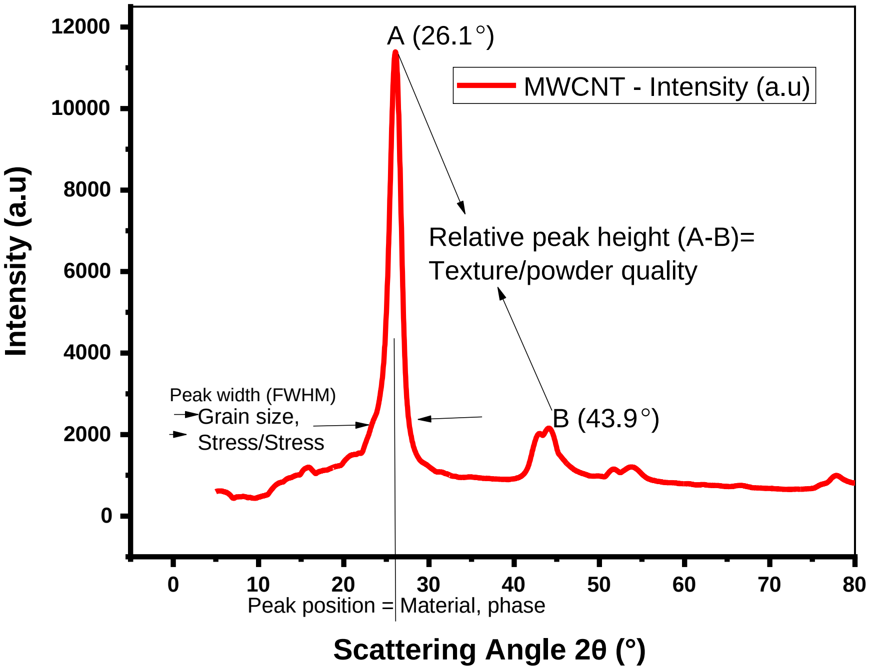

Figure 1. XRD Surface phase plot analysis.

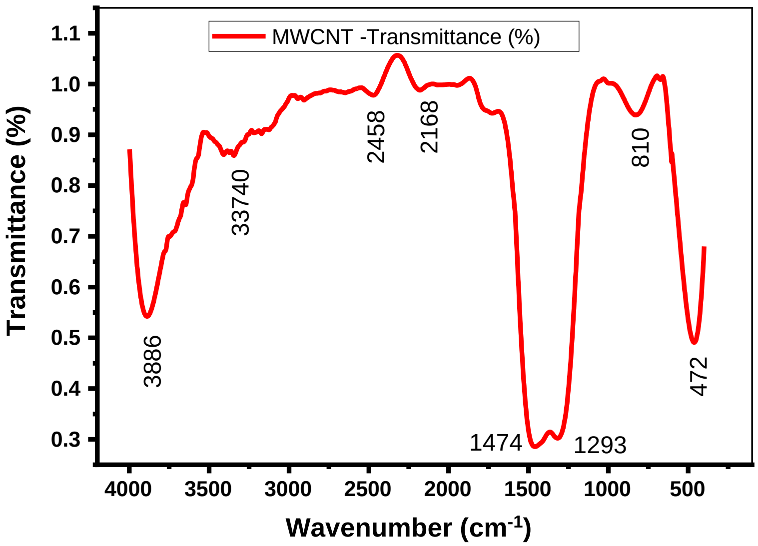

Figure 2. FTIR Sample Bond Plot.

sample plot (Figure 1) displays clear, high-pitched peaks that correspond to the crystal lattice parameters of (002) and (100) at a diffraction angle 2θ of 26.1° and 43.9 °. The size (d-spacing) of MWCNT was determined using the mathematical Debye-Scherrer formula (Equation 1):

$$d = k\frac{\lambda}{\beta \cos \phi} \quad (1)$$

where **d** is the average diameter of the crystallite, λ is the radioactivity wavelength (1.542 Å), β is the full width at half maxima, $\emptyset$ and β is Bragg's angle of corresponding peaks, shape constant k=0.9. The Crystallinity and crystal size of MWCNT were calculated to be 95.9% and 2.4 Å.

3.2. FTIR analysis

Figure 2 displays the FTIR spectrum, which provides information about the chemical composition, structure, and bonding of the MWCNT samples. The study is conducted at a resolution of 4 cm^{-1}, with an incident angle of 30°, and the wavenumber range from 200 to 800 cm^{-1} [21]. The presence of the unique band at 3374 cm^{-1}, which corresponds to the O–H stretch of terminal carboxyl groups, suggests the incorporation of polar functional groups, like (OH), on the surface of MWNT. The wavenumber maxima at 2458 cm^{-1} and 2168 cm^{-1} show the –C≡C– stretch, while the value at 1474 cm^{-1} shows the C-H bond. The fingerprint region, ranging from 1400 to 400 cm^{-1}, features peaks at 1293 cm^{-1}, 810 cm^{-1}, and 472 cm^{-1}, which signify the C-C stretching of the ring bond. The presence of these functional groups has been shown to improve the interfacial contact between MWNT and epoxy polymer.

3.3. Scanning Electron Microscopy (SEM) Analysis

The TESCAN model MAIA3 XMH, utilizing scanning electron microscopy, was used to examine the morphology and structure of MWCNT nanocomposites, yielding high-resolution images and comprehensive details regarding their surface structure [8]. The SEM analysis uncovers characteristics of the MWCNT nanocomposite, such as particle size, shape, lamination behavior, and arrangement, subsequent to mechanical testing. The examined surface characteristics included cracks, pores, and agglomeration [7, 8, 21]. Figure 3a displays SEM images that depict the failure of the specimen attributed to tensile stress, which arises from cracks within the MWCNT/epoxy matrix. Figure 3b illustrates the delineation between the MWCNT epoxy matrix and the E-glass fiber, in addition to instances of fiber fracture.

The micrographs of the MWCNT nanocomposite display significant clusters of resin, suggesting robust adhesion between the MWCNT/epoxy matrix and the fibers. Following the fracture, only slight debonding is observed between the glass fibers and the epoxy matrix, indicating a strong bond at the fiber-matrix interface. This feature is linked to the inclusion of MWCNT in the nanocomposite. Furthermore, the incorporation of

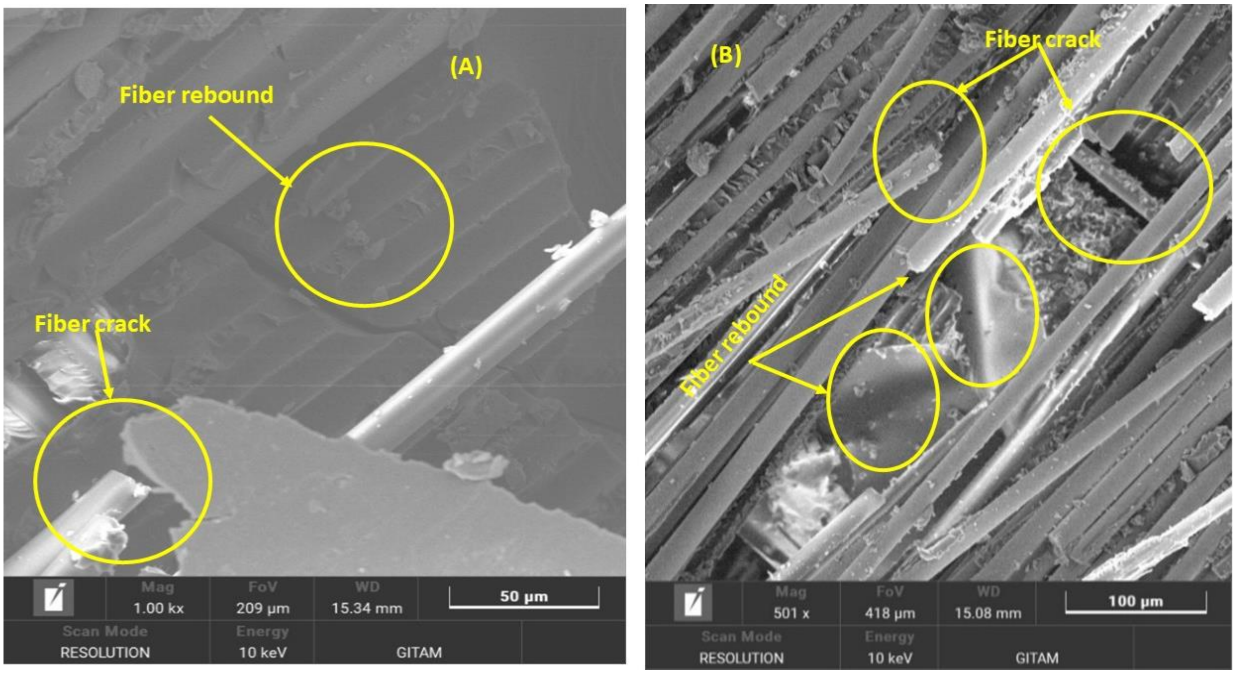

Figure 3. SEM images of the fracture surface of the MWCNT nanocomposite.

MWCNT nanofillers contributes to the mitigation of cracks and redirects crack propagation within the glass fiber-epoxy-MWCNT reinforced nanocomposites.

3.4. Mechanical Properties and TOPSIS Analysis

The fabricated samples of MWCNT nanocomposites underwent mechanical testing to evaluate their tensile properties, modulus of elasticity, flexural strength, and strain at break, following ASTM code standards. The tensile and flexural tests were performed using an Instron servo-hydraulic Universal Testing Machine model 8801 [17, 22]. The tensile test specifications are detailed in ASTM D3039, while the flexural testing guidelines are specified in ASTM D790, which employs a 3-point loading condition. This analysis encompassed a thorough application of the TOPSIS method to determine the rankings of alternative experiments based on their optimal mechanical performance.

The UTM tests performed in accordance with ASTM Standards for the mechanical properties of the MWCNT nanocomposite samples produced the following parameters: tensile strength, flexural strength, modulus of elasticity, and strain at break [22, 23]. The matrix result was normalized following the specified equation. Figure 4 presents the normalized decision matrix, where a weight value of 1.0 is uniformly applied across all parameters to demonstrate the mechanical properties of the nanocomposite.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}}} \tag{2}$$

where r_{ij} is a normalized value, x_{ij} are the criterion values (i=1, 2, 3, …, n and j=1,2, 3, …, m).

$$D_i^{+} = \sqrt{\sum_{i=1}^{n} \left(y_{i_j}^{+} - y_{ij}\right)^2} \tag{3a}$$

$$D_i^{-} = \sqrt{\sum_{i=1}^{n} \left(y_{i_j}^{-} - y_{ij}\right)^2} \tag{3b}$$

where y_{ij}^{+} and y_{ij}^{-} are positive and negative ideal values selected from the normalized weighted matrix (V), D^{+} and D^{-} are the positive and Negative profit selection perspectives.

$$V_i = \frac{D_i^{-}}{D_i^{+} + D_i^{-}} \tag{4}$$

where V_i are the Euclidean distance values.

For both positive (+) and negative (-) ideal solutions, the Euclidean distance (D) was computed by applying the following equation (3). The results of this calculation are depicted in Figure 5. The rank, the preference value

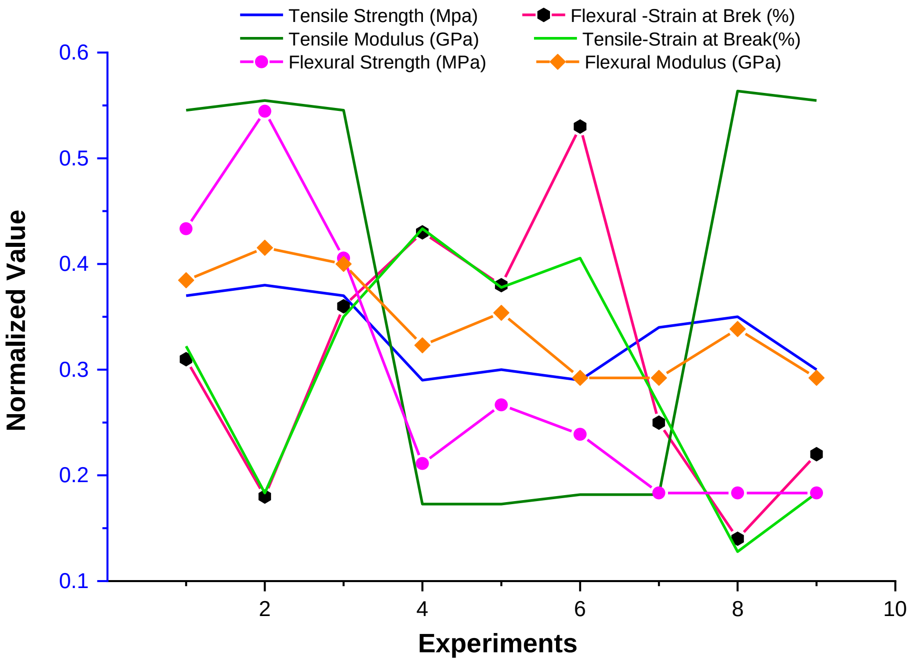

Figure 4. Normalized Decision Matrix.

(relative closeness), and the separation measure are all determined with the help of Equation 4, and the results are displayed in Figure 5. The ranking is determined by the preference value, with the highest possible closeness resulting in the highest possible rank [14, 19].

It was determined that experiment code A22, which was referred to in Table 2, was the most suitable alternative among the many MWCNT epoxy e-glass fiber-reinforced nanocomposite possibilities. This particular experiment had a constituent nanofiller concentration of 1.5 vol% MWCNT, 70 vol% epoxy polymer, and 72 g of E-glass fiber. In terms of mechanical performance, the experiment code A55 has been ranked the lowest, which indicates that it has the worst overall performance. For this experiment, the MWCNT concentration was set at 2 vol%, the epoxy polymer was set at 70 vol%, and the E-glass fiber was 64 g.

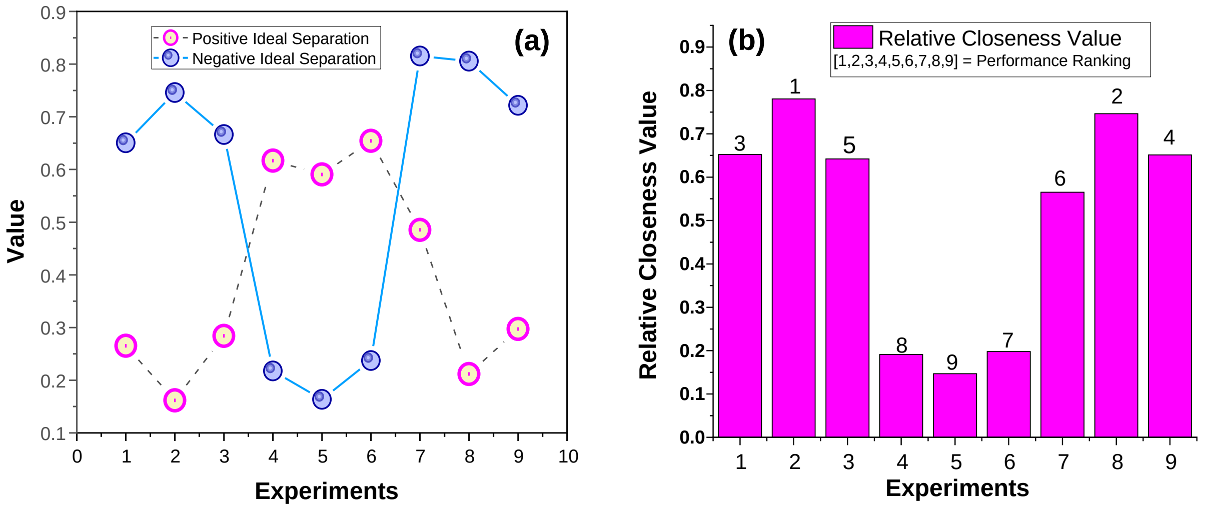

Figure 5. (a) Ideal Separation Distance. (b) Mechanical Performance Ranking.

3.5. Determination of the Optimum Using the Taguchi Techniques.

The experiment's optimal design was evaluated through the analysis of a signal-to-noise (S/N) ratio to enhance mechanical strength properties. [24]. The objective evaluation of mechanical strength, including tensile, modulus, and flexural data, employed the "the larger is better" function. Conversely, the strain at break was assessed through the "nominal is better" function [25]. Figure 6 illustrates the impact of each parameter on tensile strength, flexural strength, modulus of elasticity, and strain. The ideal parameters for attaining maximum strength, as illustrated in Figure 6a, include an E-glass fiber content of 64 g, an epoxy polymer content of 60 vol%, and a MWCNT content of 1.5 vol%. This combination may yield the highest possible tensile strength, flexural strength, and Young's modulus [26].

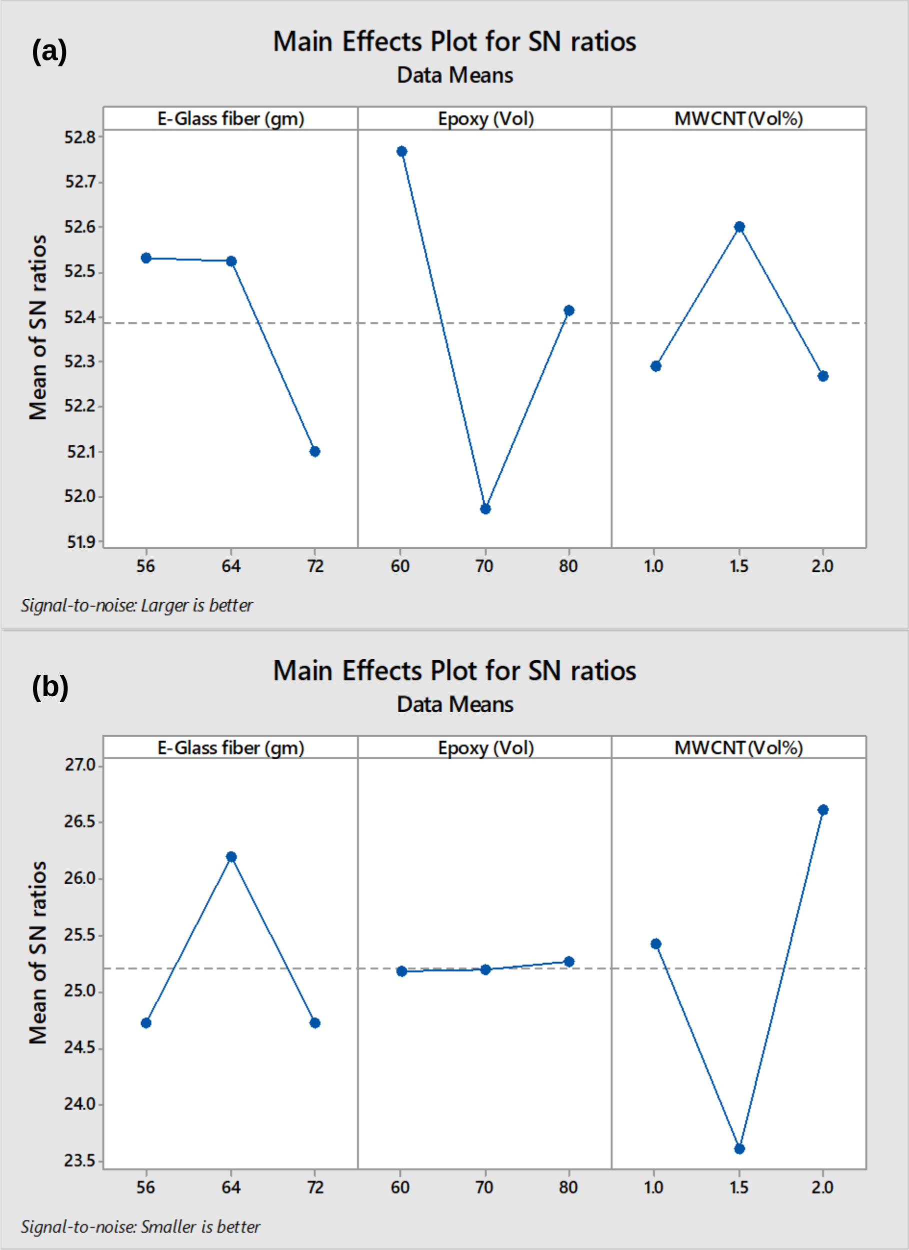

Figure 6. Taguchi Analysis: (a) Tensile-Strain, Flexural-Strain, and Modulus versus E-Glass fiber, Epoxy (Vol%), MWCNT(Vol%); (b) Tensile-Strain, Flexural-Strain at the break versus E-Glass fiber, Epoxy polymer (Vol%), and MWCNT(Vol%).

The combination of 56 g E-glass fiber, an epoxy polymer comprising 60 vol% content, and a MWCNT content of 1.5 vol% yields the optimal minimum strain in both tensile and flexural properties.

3.6. Response Surface Method (RSM) Analysis

This analysis phase aims to extract significant insights from the completed experiment and assess the observed quality or improvement level. At this stage, we subject the data from each experimental run to comprehensive analysis and evaluation [15]. This study seeks to identify combinatory factors, including the concepts of larger being preferable and smaller being advantageous, for improvement purposes [27]. Due to the multiple samples evaluated in each experimental run, various analytical techniques were employed. The RSM was employed to predict the relationships between specific

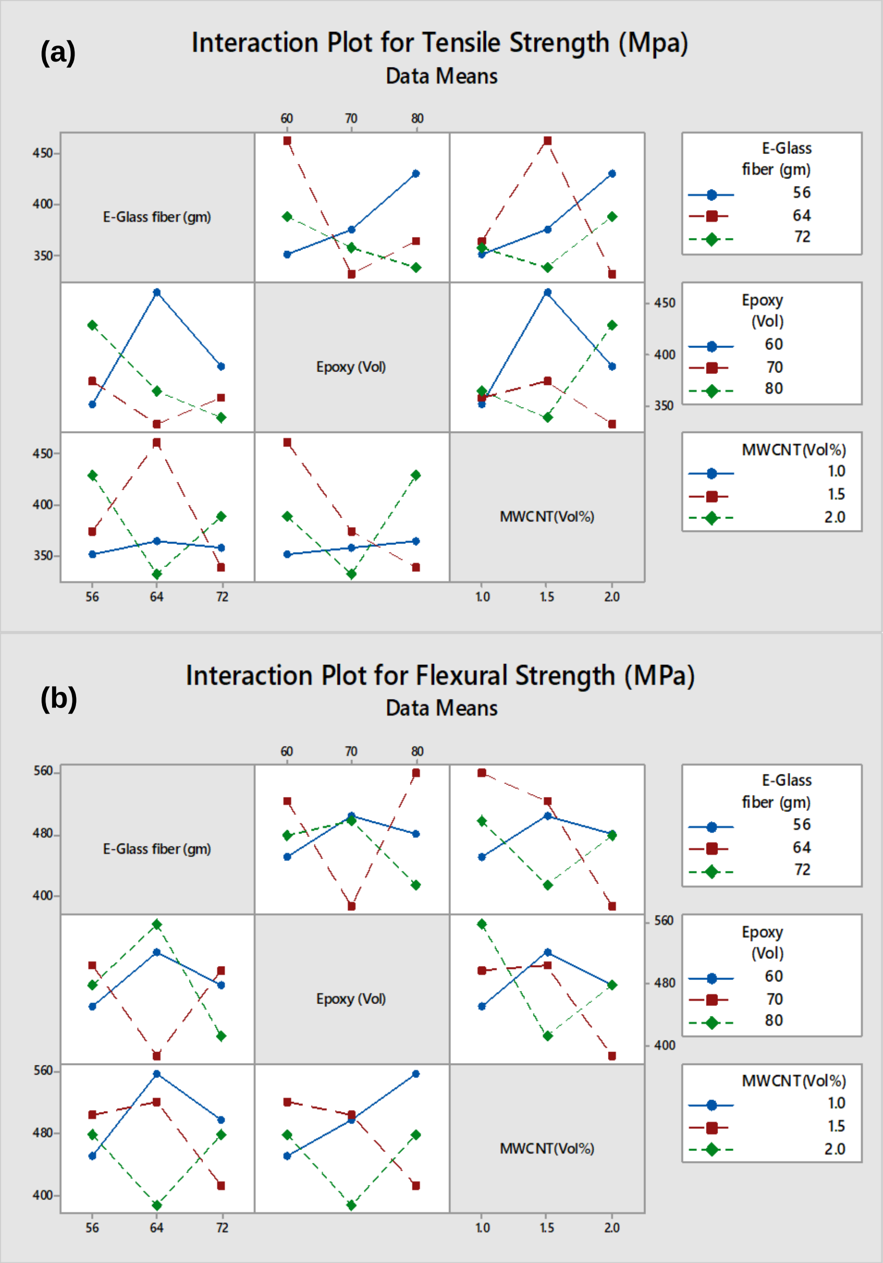

Figure 7. Interaction of E-Glass fiber, Epoxy, and MWCNT effects on (a) Tensile Strength, (b) Flexural Strength.

measurable response variables and various experimental conditions that may affect those responses, as shown in Figure 7.

3.7. Prediction Mathematical Modelling

Experiments are repeated several times to achieve better results, which costs a lot of money and takes a lot of time. We use Response Surface Methodology (RSM) to solve this problem[15]. This method uses math and statistics to determine the best values for different process parameters and verify how well they work [24]. This study utilizes the Minitab software suite for modeling and optimization purposes. This software application creates a mathematical model of the second order. Figure 6 shows how to choose a characteristic. It shows that "Larger" is better, but "Smaller" also has certain advantages. Better signal-to-noise ratios are linked to better mechanical performance and lower levels of vibration. A lower signal-to-noise ratio means that the quality or performance of the machine has gotten worse [18]. In this case, S stands for the continuous beneficial change, whereas N stands for the unpredictable small change. The study utilized the larger-the-better criterion for tensile strength, flexural strength, and modulus, as delineated in Equation (5), while the smaller-the-better criterion was applied for tensile strain and flexural strain, as described in Equation (6).

$$\frac{S}{N} = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{X_i^{2}}\right] \qquad (5)$$

$$\frac{S}{N} = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}X_i^{2}\right] \qquad (6)$$

Given n is the number of experiments run, and x_i is the response (tensile strength, flexural strength in the i^{th} experiment). For a Prediction model with three factors (x=MWCNT, y=epoxy polymer, and z=E-glass fiber), where t refers to tensile, f refers to flexural, generally, the equation is given as equations (7) – (12):

$$\sigma_t = -198x^2 - 0.701z * y + 564x + 43.7y + 47.6z - 2954 \qquad (7)$$

$$E_t = 0.4884y^2 - 10.5534z^2 - 6.6262y * z + 5287x + 300.4y + 1907.5z - 61933 \qquad (8)$$

$$\varepsilon_t = -0.04819x^2 - 0.00098z^2 - 0.000837x * z + 0.0003x * y + 0.1698x - 0.0007y + 0.3476 \qquad (9)$$

$$\sigma_f = -197.7x^2 - 1.118y * z + 450x + 71.5y + 77.3z - 4667 \qquad (10)$$

$$E_f = 0.04193y^2 + 0.03284z^2 - 0.1432x * z - 0.01301y * z + 9.12x - 4977y - 2914z + 285.2 \qquad (11)$$

$$\varepsilon_f = -0.09667x^2 + 0.00017z^2 + 0.001167x * y + 0.19867x - 0.00168y - 0.021198z + 0.618 \qquad (12)$$

3.8. Optimization of Mechanical Performance

The model that was created finds process parameters that try to get the best values for tensile strength, flexural strength, and modulus of elasticity while putting the least amount of strain on the material [24]. To get the best mechanical strength in a nanocomposite, you should use 1.5 vol% MWCNT nanofiller, 70 vol% epoxy polymer, and 72 g of E-glass fiber. The mathematical model predicts that the best nanocomposite sample will have a tensile strength of 99.468 MPa, a tensile modulus of 11.3 GPa, a flexural strength of 512 MPa, a flexural modulus of 37.8 GPa, and break strains for tensile and flexural tests of 0.003% and 0.005%, respectively. This ideal value was also recorded by [28], as shown in Figure 8.

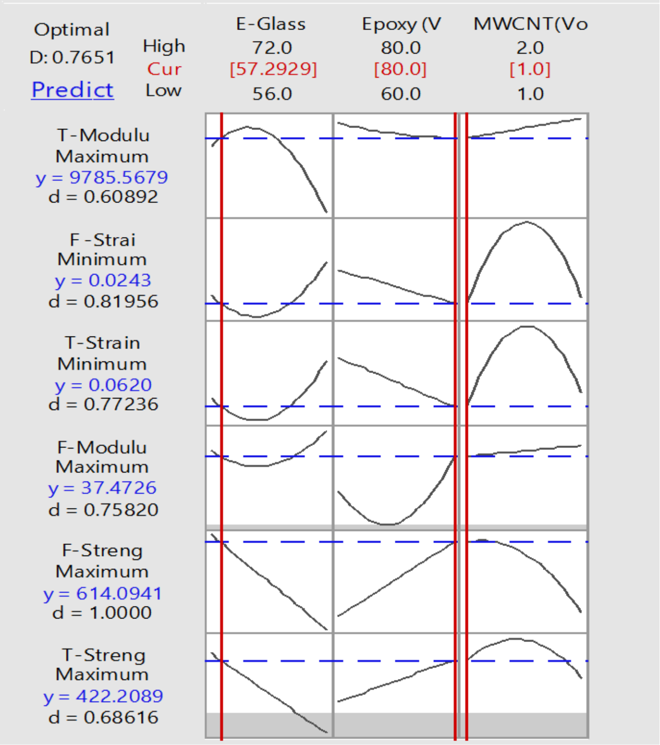

Figure 8. Optimization Plot.

3.8.1. Surface Plots and Contour Plots

Figures 9 and 10 show the outcomes of changes in tensile strength, modulus, strain, and flexural strength that are caused by process parameters. Figure 9 shows contour plots, and Figure 10 shows surface plots [23]. These numbers show what the results were. You can utilize the shifts in hue to find differences and inconsistencies in the material's ultimate tensile and

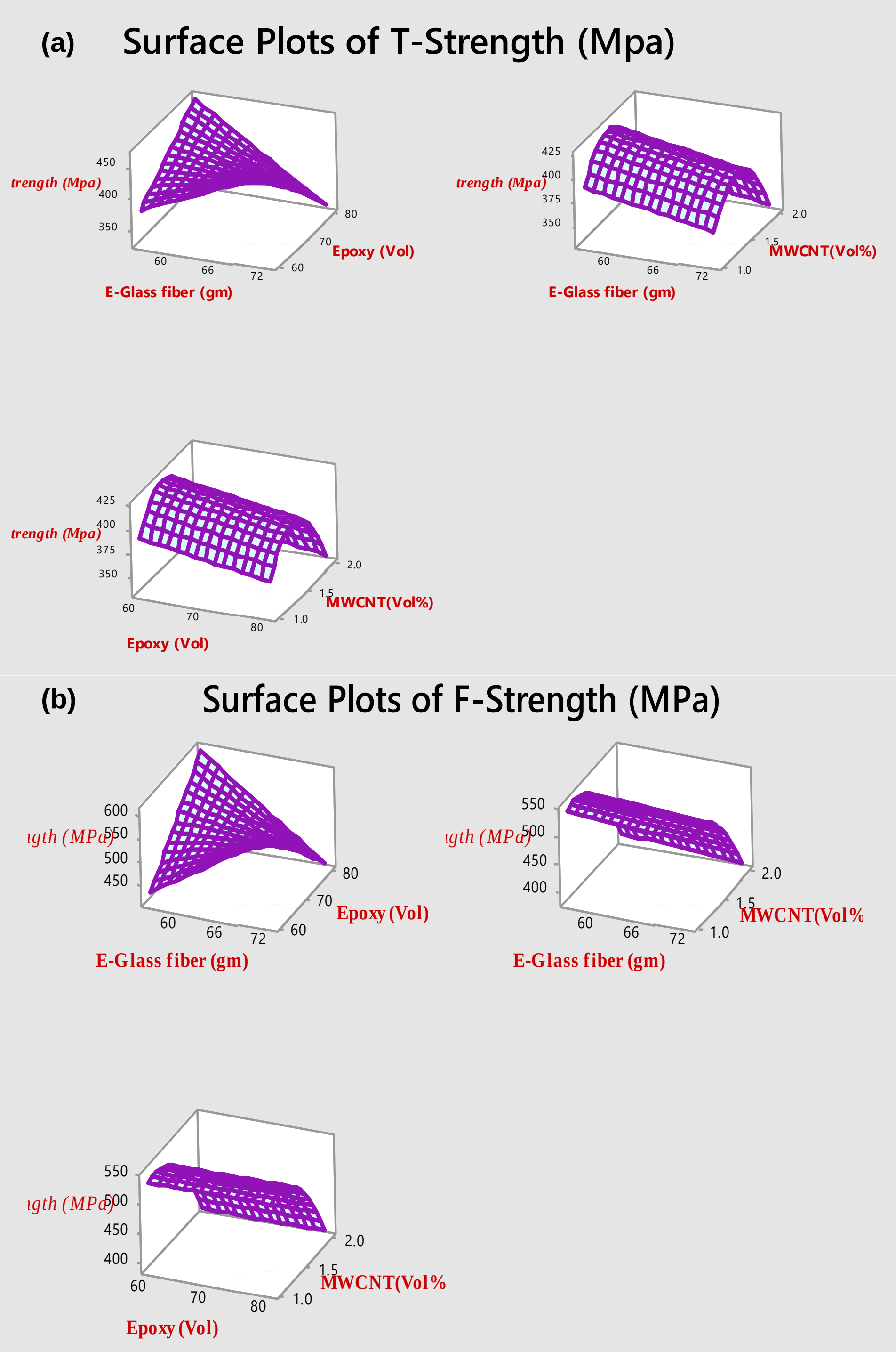

Figure 9. Surface plot (a) Tensile Strength, (b) Flexural Strength.

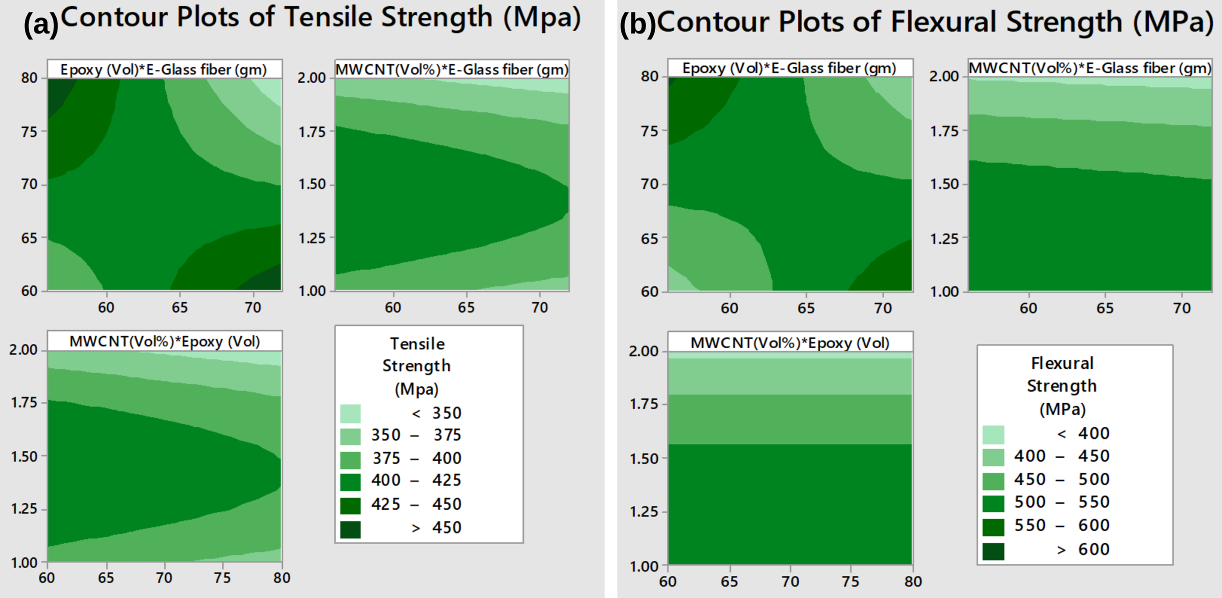

Figure 10. Contour Plot (a) Tensile Strength, (b) Flexural Strength.

flexural strength. The counterplot's color change from blue to light green and then back to green shows that the ultimate tensile and flexural strength values have gone up in a way that is proportional to the temperature change. Observing the graphs shows that when the number of passes goes up, the tensile strength and flexural strength of the material both go up in the same way.

3.8.2. Experimental Confirmation Analysis

The optimization process was finished, and then a confirmation analysis was performed using the optimal factor levels. This analysis was done after the optimization operation was finished. A total of seventy percent of epoxy polymer, seventy-two grams of E-glass fiber, and one volume percent of MWCNT were incorporated in these quantities [28]. In Table 3, the expected values and the experimental values are compared. Based on the data presented in Table 3, the experimental error between the predicted and experimental values aligns suitably with the anticipated value. The table's information leads to this conclusion.

4. Conclusions

This study investigates approaches to improve the strength of nanocomposites. We examined the grams of fiberglass, the volume percentage of multi-walled carbon nanotubes, and the volume percentage of epoxy polymers. The investigation employed various optimization techniques, including the Taguchi Method, Response Surface Methodology (RSM), and TOPSIS Analysis, to determine the optimal volume percentage of MWCNTs. The implementation of these steps enhanced the mechanical properties of the nanocomposite. Minitab software was utilized to formulate a hypothesis regarding potential outcomes. FTIR spectroscopy, scanning electron microscopy, and X-ray diffraction were employed to examine the morphology and

Table 3. Experimental and prediction verification

Response	Experiments	Predicted	Error (%)
Tensile Strength (MPa)	384.68	422.21	8.9
Tensile Modulus (GPa)	10.65	10.79	1.3
Flexural Strength (MPa)	559.18	614.1	8.94
Flexural Modulus (GPa)	36.7	37.47	2.06
Tensile-Strain at Break (%)	0.062	0.065	4.6
Flexural -Strain at Break (%)	0.08	0.085	5.9

structural characteristics of the MWCNT powder and nanocomposite. The findings indicated a strong proximity between the epoxy matrix and the MWCNTs.

The morphological analysis of FE-SEM images indicates a significant enhancement in the COOH activity of MWCNTs incorporated into the epoxy polymer matrix. FTIR studies indicate that altering the chemical structure of MWCNTs containing carboxylic acid groups (COOH) is achievable. The interaction at the interface between the polymer and the acid-treated multi-walled carbon nanotubes (MWCNTs) appears to be more favorable due to the higher carbon content compared to oxygen. A servo-hydraulic machine was utilized to produce nanocomposite samples, which were subsequently analyzed to determine their strength and identify their most intricate features.

Table 3 summarizes that the verification test of the theoretical and experimental values shows that the error percentage stays about the same. The practical results indicated that the optimization model worked well for further processing and confirmed what was expected in theory. TOPSIS indicates that the MWNT concentration (1.5 vol%), the epoxy polymer (70 vol%), and the E-glass fiber-woven material (56 g) all have a major effect on the tensile and flexural modulus. The result means that both the tensile and flexural strength was optimized.

Acknowledgments

The author expresses gratitude to the Government of the United Republic of Tanzania, through the Rector of the National Institute of Transport in Dar es Salaam, and the Government of India, through the ICCR program, for their financial support during this study.

Conflict of Interest

The authors declare no conflict of interest.

References

1. A. Ali, et al. Carbon nanotube characteristics and enhancement effects on the mechanical features of polymer-based materials and structures – A review. *Journal of Materials Research and Technology*, **2023**, *24*, 6495.
2. A. Mostovoy, et al. Epoxy Nanocomposites Reinforced with Functionalized Carbon Nanotubes. *Polymers*, **2020**, *12*, 1816.
3. A. Kumar, K. Sharma, and A.R. Dixit. A review on the mechanical properties of polymer composites reinforced by carbon nanotubes and graphene. *Carbon Letters*, **2020**, *31*, 149.
4. A. Sharma and R. Kumar. Fabrication and characterization of carbon nanotubes-based Polymer nanocomposites. *INTEGRATED RESEARCH ADVANCES*, **2018**, *5*, 42.
5. D. Nyonyi, et al. Fabrication and Mechanical Analysis of Polymer Nanocomposites Reinforced With Multi-walled Carbon Nanotubes for Marine Applications. *Journal of Inorganic and Organometallic Polymers and Materials*, **2025**, *35*, 6709.
6. E.W. Fenta and B.A. Mebratie. Advancements in carbon nanotube-polymer composites: Enhancing properties and applications through advanced manufacturing techniques. *Heliyon*, **2024**, *10*, e36490.
7. M. Mirzapour, et al. Dispersion Characteristics, the Mechanical, Thermal Stability, and Durability Properties of Epoxy Nanocomposites Reinforced with Carbon Nanotubes, Graphene, or Graphene Oxide. *Polymers*, **2024**, *16*, 1836.
8. R. Islam Rubel, et al. Carbon nanotubes agglomeration in reinforced composites: A review. *AIMS Materials Science*, **2019**, *6*, 756.
9. S. Sharma, et al. Mechanical, morphological, and fracture-deformation behavior of MWCNTs-reinforced (Al–Cu–Mg–T351) alloy cast nanocomposites fabricated by optimized mechanical milling and powder metallurgy techniques. *Nanotechnology Reviews*, **2021**, *11*, 65.
10. U.U. Orji, et al. Development of polymer/carbon nanotubes incorporated sustainable materials for manufacturing of autobrake pad. *The International Journal of Advanced Manufacturing Technology*, **2024**, *132*, 3227.
11. R. Chipiri, et al. Experimental Investigation on Hybrid Laminated Composites Reinforced with Basalt-Pineapple-Bamboo Fibers. *Journal of Construction Engineering, Technology & Management*, **2023**, *13*, 9.
12. N. a and A. Faiyaz Ahmed. EVALUATION OF CARBON FIBRE REINFORCED POLYMERS USING FUZZY TOPSIS MCDM METHOD. *International Journal of Advanced Research*, **2023**, *11*, 1773.
13. U.A. Kumar, A. Kumar, and R. Nathawat. Taguchi design of experiments based optimization and experimental investigation of mechanical performance of hybrid epoxy nanocomposites. *Zastita Materijala*, **2023**, *64*, 433.
14. H. Sulistiani, et al. New TOPSIS: Modification of the TOPSIS Method for Objective Determination of Weighting. *International Journal of Intelligent Engineering and Systems*, **2024**, *17*, 991.

15. S. Lamidi, et al. Applications of Response Surface Methodology (RSM) in Product Design, Development, and Process Optimization. *Research Advances and Applications*, **2020**, *1*, 1.

16. D. Nyonyi, V.S.P. Ventala, and S. Peravali. Graphene oxide nanofiller-reinforced polymer nanocomposites for marine applications: fabrication and mechanical testing. *Iranian Polymer Journal*, **2025**, https://doi.org/10.1007/s13726-025-01573-0.

17. D. Nyonyi, V.V.S. Prasad, and P. Swapna. Mechanical Performance Analysis and Seawater Absorption of Graphene Oxide (GO)-Reinforced Epoxy Nanocomposite for Marine Applications. *Journal of Materials Engineering and Performance*, **2025**, https://doi.org/10.1007/s11665-025-12328-6.

18. L. Adamo, et al., *A Response Surface Methodology Approach to Develop a Multiphysics Simulation Model of a Tensile Friction Test*, in *The 28th Saxon Conference on Forming Technology SFU and the 7th International Conference on Accuracy in Forming Technology ICAFT*. **2022**, MDPI. p. 22.

19. S. Bhaskar, M. Kumar, and A. Patnaik. Application of Hybrid AHP-TOPSIS Technique in Analyzing Material Performance of Silicon Carbide Ceramic Particulate Reinforced AA2024 Alloy Composite. *Silicon*, **2020**, *12*, 1075.

20. K. S V H, L. K V, and G.N. Yogavardhan Swamy. Nanocomposite Materials: Enhancing Mechanical and Thermal Properties Using Carbon Nanotubes. *Library Progress International,*, **2024**, *44*, 19256.

21. P.P. Pandey. Preparation and Characterization of Polymer Nanocomposites. *Soft Nanoscience Letters*, **2020**, *10*, 1.

22. P. Hiremath, et al. Investigation on tensile properties and analysis of wear property of glass fiber-epoxy-nanoclay ternary nanocomposite using response surface methodology. *Cogent Engineering*, **2021**, *8*, 1.

23. R. Butola, et al. Experimental analysis and optimization of process parameters using response surface methodology of surface nanocomposites fabricated by friction stir processing. *Journal of Nanomaterials, Nanoengineering and Nanosystems*, **2024**, *238*, 119.

24. S. Kumar and S. Balachander. Studying the effect of reinforcement parameters on the mechanical properties of natural fibre-woven composites by Taguchi method. *Journal of Industrial Textile*, **2020**, *50*, 133.

25. Haniel, B. Bawono, and P.W. Anggoro. Optimization of Characteristics Polymer Composite Reinforced Kenaf and Jute Fiber Using Taguchi-Response Surface Methodology Approach. *Journal of Natural Fibers*, **2023**, *20*.

26. K. Manjula and B.K. Narendra. An Analysis Using the Taguchi Optimization Process to Statistically Investigate the Mechanical Properties of Composite Materials. *Journal of the Institute of Engineers India Series D* **2025**, *106*, 825.

27. Y.R. Almahamid, S.H. Hussein-Al-Ali, and M.K. Haddad. Application of Factorial Design and Response Surface Methodology in the Optimization of Clindamycin Nanocomposites. *Journal of Nanomaterials*, **2022**, *2022*, 1967606.

28. J. R, et al. OPTIMIZATION OF HYBRID COMPOSITE USING TAGUCHI METHOD. *International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)*, **2016**, *3*, 430.
