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Optimum Selection of Sisal and Flax Fiber Reinforced Composites for Experimental Investigation Utilizing VICOR Method

Sara M. Younes[a], Ahmed Bahei El-Deen Mahrous[b*], Seham A. Elsaid[c]

[a]*Chemical Engineering Department, Borg El Arab Higher Institute Engineering and Technology, Alexandria, Egypt*
[b] *Production Engineering & Mechanical Design Dept., Faculty of Engineering, Menoufia Univeristy , Shebin El-Kom, Menoufia, Egypt.*
[c]*Basic science deparment, higher Institute of Engineering and Technology, menoufia.*

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A B S T R A C T

In recent years, the industrial demand for composite materials has grown considerably. However, the majority of composite materials are made from synthetic fibers and resins. As a result, the contemporary manufacture of composite materials continues to have several issues, the most concerning of which is the environment and human health. As a result of these obstacles, natural fiber composites are progressively emerging as a global research and development trend. The selection of material for a specific engineering component, which plays an important role in its design and proper functioning, is frequently regarded as a multi-criteria decision-making (MCDM) problem in which the best acceptable material is chosen based on a specified set of competing criteria. In this paper, six laminated composite materials selection problem is handled using VIKOR which means multi-criteria optimization and compromise solution in Serbian, based on assessing the different criteria using the CRITIC method. To choose the best laminated composites, five conflicting criteria are measured: density, water absorption content, damping, flexural strength, and interlaminar shear strength (ILSS). specimens are made from varied weight percentages of sisal fibers (SFs) and flax fibers (FFs) with varying stacking sequences and fiber orientations. These laminated composites are made utilizing the hand layup method to choose the best material with the lowest density and water absorption content while having the highest damping, flexural strength, and ILSS. The results revealed that material No. 3 is the best material, whereas material No. 5 is the worst.

1. Introduction

Composite materials are becoming more popular for their environmental impact as well as other properties such as light weight and high strength for specific applications, prompting an increase in the number of new scholars working on developing new natural composite materials to replace traditional manufacturing materials. In particular composites made of natural fiber materials are gaining appeal as a replacement for synthetic fiber-based composites, particularly for automotive structural and semi-structural applications. Material selection for a specific engineering component, which is critical to its design and proper operation, is sometimes viewed as a MCDM problem in which the most appropriate material is chosen based on a given set of conflicting criteria. The success of any component is determined by its superior performance and low cost of materials used. Designers are frequently unsure of the optimal number of criteria required to arrive at the best decisive action while solving these MCDM

*Corresponding author. Tel.: +2 01060267167
E-mail address: ahmed.basyouni@sh-eng.menofia.edu.eg

difficulties. As a result, designers face a significant task in selecting the best material from a wide range of accessible materials to solve complicated design difficulties. Nowadays, the MCDM method is employed as a useful tool for material selection in complicated design challenges [1]. The MCDM method entails developing alternatives, establishing the necessary criteria, and evaluating the alternative materials using a set of criterion weightings. These steps result in a ranked list of possible options [2]. According to Ashok et al. [3], connected interactions between reinforced natural fibers inside various matrix materials influence dynamic variables such as storage modulus, loss modulus, and damping factor. The vibration damping parameters for structural applications are given a high priority in order to improve the performance of the building restrictions. In their review, the employability of various natural fibers, as well as the impact of fiber length, chemical treatment, and compositions on dynamic mechanical properties, were thoroughly investigated. Kumar et al. [4] planned to create a new natural fiber composite using banana stem and pineapple fibers. Resins and hardeners were selected based on the mechanical characteristics of the fibers, and manufacturing was completed appropriately. It was discovered that examples with more pineapple fiber layers had better mechanical characteristics. The tensile properties of these laminates were evaluated utilizing the universal tensile testing machine. Finally, conclusions were reached following mechanical testing of the composites. Asim et al. [5] conducted a rigorous analysis of chemical, physical, and mechanical qualities to determine the logical and justifiable use of pineapple leave fiber (PALF) for diverse applications. From an economic point of view, PALF could be a viable replacement for the costly and nonrenewable synthetic fiber. However, only a few investigations on PALF had been conducted, demonstrating interaction between fibers and fiber reinforcement integration. In their review, the fundamental understanding of PALF was covered, and the chemical, physical, and mechanical features had been outlined in comparison to other natural fibers. Peng et al. [6] proposed an integrating approach of extended Data Envelopment Analysis (DEA) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to explain material selection in green design. The integrated DEA/TOPSIS model offered a more reasonable and empirical foundation for material selection in green design. The results revealed that the hybrid DEA/TOPSIS model could evaluate and reject materials with poor performance when selecting wood for furniture manufacturing. Veeresh et al. [7] selected polymer composites because of their low weight, high damping, and high stress concentration factor. In their research, bamboo fiber weaved into cloth was employed to create a polymer composite using hand layup. The mechanical attributes of the natural fiber-epoxy composite were then tested, including Brinell's hardness, flexural, tensile, and compression tests. The composite demonstrated significant potential as a superior natural fiber composite, with strengths comparable to other natural fiber composites. Islahuddin [8] investigated pineapple leaf fiber composites that were manually formed into hollow cylinders with varying fiber orientations. This pipe composite was examined using Experimental Modal Analysis (EMA) to determine the crack position. The mechanical parameters acquired from the tensile test were utilized as input to calculate natural frequencies and mode shapes. The results demonstrated that pipe composites had low natural frequencies in crack conditions, and that modifying the mode shape curve might be used to identify crack position. Van et al. [9] conducted their research to learn about natural fibers and matrices for natural fiber composites. The mechanical properties of the coir fiber sheet were determined through testing studies on epoxy resin composites reinforced with the coir fiber sheet. The experimental results showed that the non-split coir fiber sheet had attributes equal to those of single coir fiber and had a greater mechanical performance than the split coir fiber sheet. Doddi et al. [10] evaluated the influence of fiber orientation on the dynamical mechanical features of PALF hybridized with basalt-reinforced epoxy composite at various vibration frequencies. The composites were manufactured using the hand layup process. In addition to the storage modulus and damping factor, tensile and flexural moduli for various PALF fiber angles were calculated. The results showed that not only the storage modulus and loss factor, but also the glass transition temperature, increased with frequency. Rao et al. [11] conducted a comprehensive analysis of banana fiber reinforced composites from a physical, mechanical, and wear standpoint, with possible applications in automotive, construction, and machinery. The appropriate use of banana fiber derived from trash provided an economic benefit for industries. Several factors influencing the behavior of banana fiber reinforced polymer composites, including fiber length, orientation and configuration, water content, temperature, and fiber surface treatments were discussed. In their review study, Khalid et al. [12] emphasized some of the significant advancements related with natural fiber reinforced polymer composite (NFRPC) materials in terms of long-term viability environmentally friendly, and economic value. The review also covered the hybridization of NFs with synthetic fibers, which is an extremely efficient way of increasing the mechanical attributes of NFRPCs, as well as some chemical modifications. It also underlined the importance of adopting mathematical algorithms for NFRPCs. Guerfala et al. [13] studied the possible application of a new hybrid bio-composite material blending flax and basalt fibers with PA11 polymer, with the goal of minimizing the water sensitivity, fluctuations, and uncertainty of vegetable fibers by incorporating basalt fibers. The experimental results demonstrated the benefits of hybridization. Given the promising features of the hybrid composite, the potential of constructing a sports car's front hood from that material was examined. Suriani et al. [14] conducted a review on the production, characteristics, applications, and cost of natural fiber reinforced hybrid composites. It was reported that great effort was put into improving the mechanical properties of natural fiber composites through the hybridization process. Furthermore, their review article aimed to provide an overview of the factors that contribute to the mechanical and structural failure of natural fiber reinforced polymer composites. Elizabeth et al. [15] conducted a literature review that suggested the use of vegetable fibers and vegetable-based matrices using natural rubber as a binder method. According to the review, vegetable fibers employed as reinforcements in natural rubber composites have a high potential for engineering applications due to their physical-mechanical qualities and environmental impact, which could lower their carbon footprint when compared to synthetic fibers. Abubakar et al. [16] attempted to create a low-cost, user-friendly natural fiber tensile test device. The tensile test findings were compared to tensile test data from the existing literature, and the experimental test values were found to be similar. The study's findings were expected to aid researchers, academia, and business by promoting the growth of Indonesia's natural fiber industry and increasing its competitiveness internationally. Prashanth and Basava [17] used modal testing to study the vibrations of natural hybrid composites. The test specimens were constructed utilizing the hand layup procedure with untreated banana and sisal fibers as reinforcement materials. The experimental study of vibration characteristics of hybrid composite specimens yielded curious findings such as damping ratio, natural frequency, and mode shape based on various purposes. Sonali et al. [18] conducted a comprehensive assessment of the most successful and widely utilized natural fiber-reinforced polymer composites (NFPC). A multitude of disadvantages, including greater absorption of water and smaller mechanical characteristics, limited the use of NFPCs. The use of NFPCs in the aerospace, automotive, and sports industries was also examined. Jute fiber-reinforced composites provided benefits due to its low cost, low density, stiffness, accessibility, and low production capacity. Yashas et al. [19] examined the various sources of natural fibers, their qualities, key applications modification, the influence of treatments, and their effectiveness as reinforcement for polymer composite materials. According to their review, it is advisable that natural fibers is used as reinforcement in polymers to make the materials more biodegradable. Shahana et al. [20] conducted a review to address the mechanical characteristics obtained by the composite after natural fiber reinforcing, as well as the many factors influencing the mechanical attributes of natural fiber composites (NFCs). The review also focused on the usability of natural fibers as a substitute for synthetic fibers in a vast range of applications. Ricciardi et al. [21] investigated the effect of stacking sequence on the impact damage mechanisms and matrix-fiber dependent characteristics of epoxy hybrid basalt/flax composites, including flexural and ILSS. The flexural modulus was unaffected by fiber sequencing, however the flexural and interlaminar shear strengths changed with resin content. Following impact testing, indentation measurements were taken to gain insight into the damage process, and the characteristics that produced were influenced by the hybridization type and impact strength. Asokan et al. [22] investigated the fabrication of hybrid fiber reinforced biodegradable composites with sisal and hemp fiber and polylactic acid utilizing melt processing and injection moulding methods. The combination of sisal and hemp fibers with polylactide significantly boosted the impact strength of composites. The hybrid composites performed well, indicating a high potential for usage as an environmentally friendly alternative material in the automobile industry. From the previous literature review, it has been noted that natural fibers reinforced composites have greater variety in characteristics, necessitating further investigation as Natural fibers are playing an essential role in atypical reinforcement materials for technologically advanced products. As a result, the current study is an experimental examination of material selection for specimens created using the hand layup procedure. The manufactured specimens are made from various percentages of weight of SFs and FFs, with different stacking sequences and fiber arrangement, in order to select the best material with the lowest density and water absorption content and the highest damping, flexural strength, and ILSS. To determine the optimum laminated composite material, five competing characteristics are considered: density, moisture content, damping, flexural strength, and ILSS. The material section problem is solved using VICOR, which measures the weights of numerous criteria using the CRITIC approach.

2 Methodology

2.1. Weight measurement using the CRITIC method

The objective weights of the relative importance of responses in MCDM circumstances will be determined by implementing the Criteria Importance by Inter-criteria Correlation (CRITIC) approach. Weights are determined by considering both contrast intensity and conflict, both of which are included in the structure of the choice issue. A multi-attribute decision-making (MADM) problem is solved by comparing each alternative to a specified set of n attributes, resulting in a decision matrix represented by Eq. (1).

$$[\mathrm{U}]_{\mathrm{mxn}} = (\mathrm{u}_{\mathrm{ij}})_{\mathrm{mxn}} = \begin{bmatrix} \mathrm{u}_{11} & \mathrm{u}_{12} & \cdots & \mathrm{u}_{1\mathrm{n}} \\ \mathrm{u}_{21} & \mathrm{u}_{22} & \cdots & \mathrm{u}_{2\mathrm{n}} \\ \vdots & \vdots & \vdots & \vdots \\ \mathrm{u}_{\mathrm{m}1} & \mathrm{u}_{\mathrm{m}2} & \cdots & \mathrm{u}_{\mathrm{mn}} \end{bmatrix} \quad (1)$$

Eqs. (2, 3, 4, and 5) are utilized for determining response weights using the CRITIC approach described in Ref. [23]. By employing Eqs. (2 and 3), the defined decision matrix u_{ij} is first normalized to produce all replies ranging from 0 to 1.

$$\rho_{ij} = \frac{u_{ij}-u_j^{worst}}{u_j^{best}-u_j^{worst}} \quad i = 1,2,.,m;\ j = 1,2,\ldots,n \text{ for beneficial attributes} \quad (2)$$

$$\rho_{ij} = \frac{u_j^{best}-u_{ij}}{u_j^{best}-u_j^{worst}} \quad i = 1,2,.,m; j = 1,2,\ldots,n \text{ for non beneficial attributes} \quad (3)$$

Eq. (4) shows how C_{jk} (the correlation between replies) is used to create the symmetric matrix (m×m). The weights of the criterion are then calculated using Eq. (5).

$$C_{jk} = \frac{\sum_{i=1}^{m}(\rho_{ij}-\overline{\rho_j})(\rho_{ik}-\overline{\rho_k})}{\sqrt{\sum_{i=1}^{m}(\rho_{ij}-\overline{\rho_j})^2\sum_{i=1}^{m}(\rho_{ik}-\overline{\rho_k})^2}} \quad j,k = 1,2,.,n) \quad (4)$$

$$w_j = \frac{\beta_j}{\sum_{k=1}^{n}\beta_k} \quad (5)$$

Where,

$$\beta_j = \sigma_j\sum_{k=1}^{n}(1-C_{jk});j = 1,2,.,n$$

$$\text{and} \quad \sigma_j = \sqrt{\frac{\sum_{i=1}^{m}(\rho_{ij}-\overline{\rho_j})^2}{m}} \quad (6)$$

The standard deviation (σ_j) indicates the degree of contrast between responses.

2.2 VIKOR method

Using the ideal point technique, Opricovic developed the well-known MCDM system known as VIKOR. It is founded on the core assumption of first discovering the greatest solutions, both positive and negative [24]. This method can be used to make decisions in complex decision-making circumstances based on several factors. The VIKOR technique for finding a final solution is based on multi-criteria optimization and compromise. VIKOR intends to complete the decision-making process for current options by collecting and assessing sets of samples with conflicting criteria. The next stage in the ranking process is to compare the distance to the best solution. To calculate the VIKOR Index, follow the techniques outlined by Tong et al. [25].

Step 1. Normalize the decision matrix,

One way to define the normalized matrix is as $F = (F_{ij})_{mxn}$ Where

$$F = \frac{u_{ij}}{\sum_{i=1}^{m}(u_{ij})^2} \quad (7)$$

In this case, u_{ij} is the corresponding value of the j[th] attribute, and i=1, 2, 3,.. m; j=1, 2, 3,.. n.

Step 2 Determination of positive-ideal and negative-ideal solutions. The following formulae (8 and 9) are used to obtain the positive ideal (best) solution, denoted by F^+, and the negative ideal (worst) solution, represented by F^-:

$$F^+ = \{(\max F_{ij}, \quad j \in J) \text{ OR } (\min F_{ij}, \quad j \in J')\} \tag{8}$$

$$F^- = \{(\min F_{ij}, \quad j \in J) \text{ OR } (\max F_{ij}, \quad j \in J')\} \tag{9}$$

In the case when the desired response is small, J={j=1,2,3………n}, and the desired response is large, J′={j=1,2,3………n}

Step 3 Calculation of utility measure (M_i) and regret measure (R_i)

For every outcome, Eqs. (10 and 11) yield the utility measure and the regret measure, respectively.

$$M_i = \sum_{j=1}^{n} \left\{ w_j \frac{(F^+ - F_{ij})}{(F_j^+ - F_j^-)} \right\} \tag{10}$$

$$R_i = max_j \left\{ w_j \frac{(F^+ - F_{ij})}{(F_j^+ - F_j^-)} \right\} \tag{11}$$

where w_j is the correct weight for the j[th] attribute determined using the CRITIC weight measurement method.

Step 4 VIKOR index calculation (Q_i)

The following relation is used to construct the VIKOR index:

$$Q_i = \upsilon \left\{ \frac{(M_i - M^+)}{(M^- - M^+)} \right\} + (1 - \upsilon) \left\{ \frac{(R_i - R^+)}{(R^- - R^+)} \right\} \tag{12}$$

where υ is the maximum group utility weight in general (υ=0.5) and Q_i is the VIKOR Index of the i[th] choice.

$$M^- = max(M_i),\ M^+ = min(M_i),\ R^- = max(R_i),\ R^+ = min(R_i)$$

Step 5 Sort the alternatives in a ranking.

To prioritize the options, the VIKOR index's lowest value (minimum Q) is regarded the highest rank order, while the highest value (maximum Q) is considered the lowest rank order. In other words, the best rank is chosen at the lowest Q value, while the worst rank is chosen at the highest Q value.

3. Experimental Work

3.1. Fabrication of composite materials

The simplest composite manufacturing approach is hand layup. The method has a minimal infrastructure need. Figure 1 depicts the wooden mold of dimensions 200 mm x 150 mm x 6 mm, natural fibers, and polyester resin utilized for composite manufacturing

Fig. 1: Open wooden mold, natural fibers and polyester resin mixed with hardener

In the current study, the hand layup process is employed to create composite laminates with dimensions of 200 x 150 x 6 mm, from which specimens of various sizes are used for further static, dynamic, and physical examinations. Each ply is weighed separately. The fabrication is done on the surface of the open wooden mold. Polishing wax is first put on to the flat surface to aid in the release of the laminate once it has cured. The liquid polyester resin LY 556 is properly mixed in the proper amounts with a prescribed hardener HY951 (curing agent) and then poured onto the top of the first layer of sisal or flax fibers already in the mold. A brush is used to spread the polyester evenly. The second layer is then applied, and a roller is pushed with light pressure across the mat-polymer layer to remove any trapped air and excess polymer. The process is repeated for each layer of polymer, sisal fiber (SF) plies, and flax fiber (FF) plies until the requisite layers are stacked to form the final laminated composite plate measuring 200 x 150 x 6 mms. The six laminated composite plates are made using four layers of SFs and FFs with varying stacking sequences and fiber orientations. After 24 hours of curing at room temperature, the produced composite part is removed from the mold and cut into various specimens of varying sizes for subsequent testing. Figure 2 illustrates the phases involved in the hand layup method, whereas Figure 3 depicts the six laminated composite plates after they have been taken out of the mold. Table 1 displays the various stacking sequences and weight percentages of the composite ingredients for the six manufactured laminated composite plates.

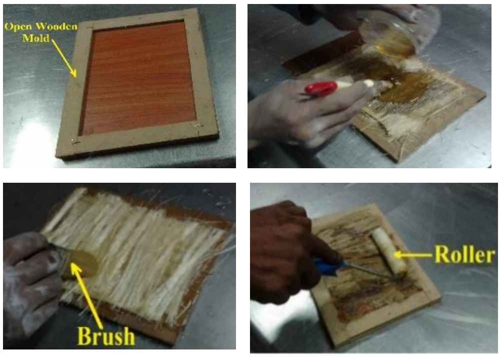

Fig. 2: Procedures of hand layup method

Fig. 3: Six laminated composite plates Manufactured by hand layup methodology

3.2. Static tests

3.2.1. Three-point flexural test

The flexural strength of a composite is the greatest tensile stress that it can withstand when bending before breaking. In the bending test, a specimen is loaded under uniaxial bending stress (tension and compression) to gather information about material bending behavior. A standardized specimen is attached on two supporting pins of a universal testing machine. As the load increases, a loading pin located in the center bends the specimen. The three-point flexural test, named after its three pressure points at the pins, determines the flexural strength ($\sigma_{bending}$) in MPa of all test specimens using Eq. (13) [26].

$$Flexural\ Strength(\sigma_{bending}) = \frac{3P_{max}L}{2bt^2} \quad (13)$$

Table 1. composite laminates with the specified stacking sequences

Alternatives (Materials)	Stacking Sequences	Weight Percentage (wt.%) of composite constituents		
		Sisal Fiber (SF) wt.% content	Flax Fiber (FF) wt.% content	Polyester wt.% content
M1	[$FF_0/FF_{90}/FF_0/FF_{90}$]	0	12	88
M2	[$SF_0/SF_{90}/SF_0/SF_{90}$]	14.815	0	85.185
M3	[$FF_0/SF_{90}/FF_0/SF_{90}$]	6.557	5.902	87.541
M4	[$SF_0/FF_{90}/FF_0/SF_{90}$]	7.547	6.792	85.660
M5	[$SF_0/FF_{90}/SF_0/FF_{90}$]	6.897	6.207	86.897
M6	[$FF_0/SF_{90}/SF_0/FF_{90}$]	7.273	6.545	86.182

Where L is the specimen's span length (mm), P_{max} is the maximum load (N), b is the specimen's width (mm), and t is the specimen's thickness (mm). The test specimens measured 200 × 20 × 6 mm. The span length of 180 mm and cross-head speed of 10 mm/min remain constant. At Benha university, engineering faculty, all composite samples are subjected to a three-point bend test utilizing a computer-controlled electro-hydraulic servo universal testing equipment (Model WAW 600). Figure 4 illustrates the loading arrangement.

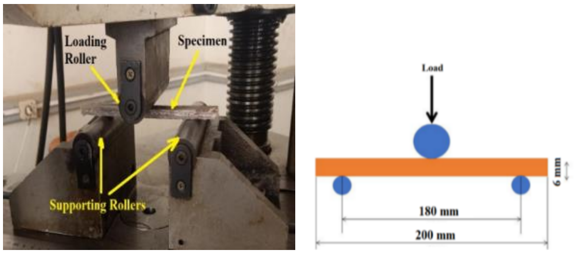

Fig. 4: Experimental setup of three-point bending test

The variations in flexural strengths of different composite materials are shown in Table 2. According to flexural strength results and with help of Eq. (13), it is noted that material No. 3 has the highest flexural strength (3168.75 MPa) while materials No.1 has the lowest flexural strengths (2793.75 MPa)

Table 2. Flexural strengths of laminated composite specimens

Material	P_{max}, Newton	Flexural Strength, ($\sigma_{bending}$) MPa
M1	7450	2793.75
M2	7850	2943.75
M3	8450	3168.75
M4	7800	2925
M5	7500	2812.5
M6	7750	2906.25

3.2.2. Interlaminar shear strength (ILSS) test

The ILSS of the laminated composites is calculated using the short-beam method. The ILSS for laminated composites is determined using Eq. (14), which is based on the beam theory [27].

$$ILSS(\tau_{max}) = \frac{3P_{max}}{4bt} \quad (14)$$

Where, τ_{max} = ILSS or Short beam shear strength (MPa), P_{max} = Maximum load measured during the test (N), b = specimen width (mm), and t = specimen thickness (mm). The test specimens measured 200 × 20 × 6 mm. The span length of 110 mm and cross-head speed of 10 mm/min remain constant. This test is performed on all composite samples at the college of engineering, Benha University, Egypt, using a computer-controlled electro-hydraulic servo universal testing equipment (Model WAW 600), as illustrated in Fig. 5. The ILSS, as an important parameter and main designation, characterizes the interlaminar quality of composite laminates. Because composite failures frequently occur at the interface, enhancing interface bonding strength is critical. Table 3 indicates the differences in interlaminar shear strengths between various composite materials. According to the ILSS data and Eq. (14), materials No. (1, 3 and 6) have the maximum interlaminar shear strength (46.875 MPa), whereas material No. 4 has the lowest interlaminar shear strength (46.25 MPa).

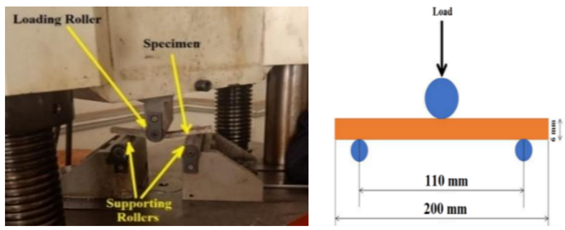

Fig. 5: Experimental setup of beam shear strength testing

Table 3. ILSS of composite materials

Material	P_{max}, Newton	ILSS(τ_{max}) Mpa
M1	7500	46.875
M2	7450	46.5625
M3	7500	46.875
M4	7400	46.25
M5	7450	46.5625
M6	7500	46.875

3.3. Experimental modal analysis (Dynamic Test)

The conventional hitting method is used to do experimental modal analysis on the composite specimens in order to retrieve modal characteristics. Figure 6 depicts the experimental setup, which includes a piezoelectric impact hammer, accelerometer and free-free boundary conditions. The specimen has dimensions of 200 mm×150 mm x 6 mm. Elastic strings secure the test specimen to the fixture. A piezoelectric impact hammer is used and data gathering system/software. For free-free to trigger the composite specimen at the center of geometry, and the reaction was monitored by an accelerometer positioned at the specimen's center of geometry and attached to the specimen using wax. The accelerometer is attached to a data gathering system. Data acquisition software processes the observed response into frequency, mode shapes, and damping values. The specimen is excited five times, and an average result is recorded to eliminate any error in the experiment. Modal analysis software is used to study the frequency response function (FRF). FRF measurements are used to determine modal parameters such as frequency, mode shapes, and percentage damping.

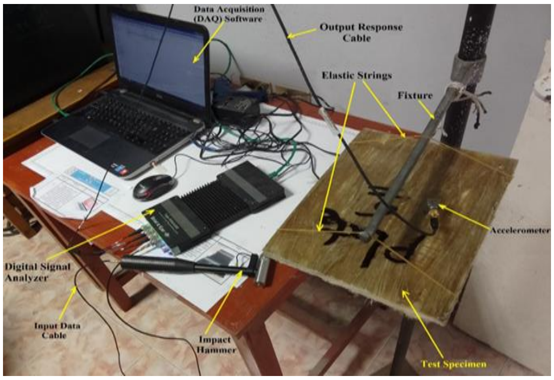

Fig. 6: Experimental setup for modal testing

The modes determined from modal analysis of the composite laminates for the free-free boundary condition are the structure's inherent characteristics. Modal parameters, such as natural frequency (ω_n), mode shape, and damping ratio (ξ), define each mode individually. In this study, the modal damping ratios and natural frequencies for the first four modes are calculated using the frequency response function of the modal testing findings, as shown in Figure 7. Figure 8 depicts the coherence function derived from dynamic testing for specimen No. 1, as an example. The coherence function reveals a high correlation between input and output signals as it approaches unity, implying trustworthy measurements of modal parameters. Table 4 depicts the differences in damping ratios for the first four modes of the six laminated composite specimens. In terms of the first mode, which represents the structure's dynamic behavior, it is worth noting that material No. 3 has the highest damping ratio (13.4%) and material No. 5 has the lowest damping ratio (5.5%).

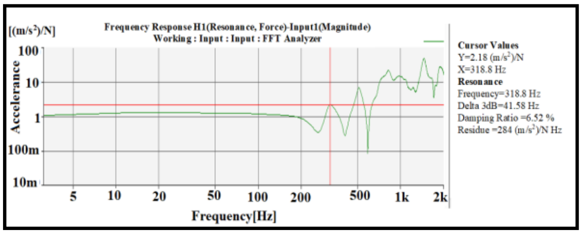

Fig. 7: Measured magnitude of FRF versus frequency

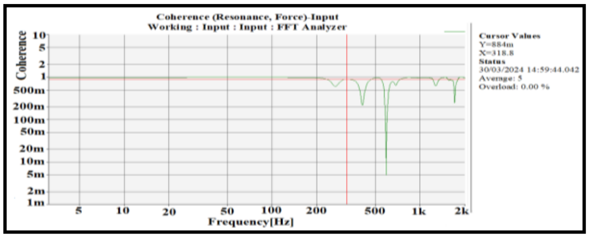

Fig. 8: Measured coherence function versus frequency

Table 4. Damping Ratios for first four modes of composite laminates

Material	Damping Ratios (%)			
	ξ_1	ξ_2	ξ_3	ξ_4
M1	6.52	3.35	4.68	2.5
M2	6.04	5.32	2.58	3.46
M3	13.4	7.77	4	2.98
M4	7.57	4.53	5.33	2.05
M5	5.5	3.68	8.28	1.6
M6	9.75	10.4	3.94	2.34

3.4 Physical Tests

3.4.1. Water Absorption Test

The water absorption test of the laminated composites is carried out by weighing the sample before immersing them in normal water. After 49 days, the specimens are weighed. The specimens are removed from the wet environment and all surface moisture is removed using a clean, dry cloth. After withdrawing the specimens from the damp environment, they are reweighed to the nearest 0.0001 gm on a digital balance. Moisture absorption testing is used to monitor the change in moisture content over time by measuring the total mass change of a specimen exposed to a moist environment, as shown in Fig. 9. The moisture content (%) in each test specimen is calculated using Eq. (15). [28]

$$Moisture\ Content\ (\%) = \left[\frac{m_2 - m_1}{m_1}\right] x100 \qquad (15)$$

Where m_1 and m_2 indicate the specimen's mass before and after immersion in water, respectively. Table 5 depicts the water absorption % of the six laminated composite specimens during a 49-day period. The results show that material No. 6 has the highest percentage of moisture content (6.54%), while material No. 1 has the lowest moisture percent content (5.12%).

Fig. 9: Moisture absorption test of laminated composite specimens after 49 days

Table 5. Results of water absorption test

Material	Mass before immersion (m_1), gm	Mass after immersion (m_2), gm	Moisture content (%)
M1	14.3372	15.0708	5.12
M2	13.9198	14.683	5.48
M3	15.8402	16.6648	5.21
M4	12.2109	12.8433	5.18
M5	14.0346	14.8012	5.46
M6	14.1012	15.0235	6.54

3.4.2. Density Measurement

The sample is weighed in the air and again while immersed in normal water at room temperature. Archimedes' principle of buoyancy states that the weight of the water displaced by the volume of the solid equals the difference in weights [29]. Eqs. (16 and 17) are used to compute specific gravity and density.

$$SG = \frac{m_a}{(m_a - m_w)} \qquad (16)$$

$$Density\ of\ Specimen(\rho) = \frac{SG}{\rho_L} \qquad (17)$$

Where m_a and m_w indicate the masses of specimens in air and water, respectively. SG is the specific gravity of the immersed liquid, while ρ_L is the density of the immersed liquid. In the chemical laboratory at Menoufia University's Faculty of Engineering, Shebin El-Kom, Egypt, a digital balance is used to measure the mass of specimens in air and water. Figure 10 depicts the mass of the specimen as measured with a digital balance. Table 6 lists the measured densities of the six laminated composite specimens. According to the densities of the six laminated composite specimens, material No.3 has the highest density (1.277 gm/cm^3), while material No. 6 has the lowest density (1.189gm/cm^3).

Fig. 10: Samples prepared for measuring the density

Table 6. Measured densities of laminated composites using buoyancy principle of Archimedes

Material	Mass in air (m_a), gm	Mass in water (m_w), gm	Density (ρ), gm/cm^3
M1	4.1138	0.7194	1.212
M2	4.9813	0.8206	1.197
M3	6.1152	1.3248	1.277
M4	3.3559	0.6159	1.2248
M5	3.8498	0.7265	1.233
M6	3.8541	0.6122	1.189

4. Implementation of CRITIC Method and VICOR Method

4.1 Determination of Attributes' Weights by CRITIC Method

The following section indicates how to use the CRITIC method to evaluate six alternatives (six laminated composite specimens) based on five measured criteria: density, water absorption content, damping, flexural strength, and ILSS.

Step 1: Normalization of the initial decision matrix.

First, Table 7 displays and tabulates the initial decision matrix for all measurable criteria. Because damping, flexural strength, and ILSS criteria are maximized and considered as helpful attributes, Eq. (2) is applied for normalizing the elements of the initial decision matrix, whereas density and water absorption content criteria are minimized and termed as non-benefit attributes. Equation (3) is used to normalize elements of the initial choice matrix. Table 8 presents the overall normalized decision matrix.

Step 2: Calculation of standard deviation of the elements of the normalized decision matrix using Eq. (6). We arrived at standard deviation for criteria as σ_j = (0.3573, 0.3744, 0.3780, 0.3578, 0.4082)

Step 3: By using Eq. (4), one can create a matrix of linear correlation between the three analyzed answers, which is tabulated in Table 9. At last, Eq. (5) is used to calculate the individual weight of each criterion, which is shown in Table 10.

Table 7. Initial Decision Matrix

Alternatives (Materials)	Non-beneficial attributes		Beneficial attributes		
	Density(ρ), gm/cm^3	Water Absorption content	Damping Ratio (ξ)	Flexural Strength ($\sigma_{bending}$), MPa	ILSS, MPa
M1	1.212	0.0512	0.0652	2793.75	46.875
M2	1.197	0.0548	0.0604	2943.75	46.5625
M3	1.276	0.0521	0.134	3168.75	46.875
M4	1.225	0.0518	0.0757	2925	46.25
M5	1.233	0.0546	0.055	2812.5	46.5625
M6	1.189	0.0654	0.0975	2906.25	46.875

Table 8. Normalized Decision Matrix

Alternatives (Materials)	Normalized non-beneficial attributes		Normalized beneficial attributes		
	Density(ρ)	Water Absorption content	Damping Ratio (ξ)	Flexural Strength ($\sigma_{bending}$),	ILSS
M1	0.735	1.000	0.129	0.000	1.000
M2	0.904	0.743	0.068	0.400	0.500
M3	0.000	0.938	1.000	1.000	1.000
M4	0.588	0.956	0.262	0.350	0.000
M5	0.498	0.757	0.000	0.050	0.500
M6	1.000	0.000	0.538	0.300	1.000

Table 9. Linear correlation matrix between responses

	Density(ρ)	Water Absorption content	Damping Ratio (ξ)	Flexural Strength ($\sigma_{bending}$),	ILSS
Density(ρ)	1.000	-0.571	-0.579	-0.644	-0.065
Water Absorption content	-0.571	1.000	0.134	0.103	-0.316
Damping Ratio (ξ)	-0.579	0.134	1.000	0.860	0.479
Flexural Strength ($\sigma_{bending}$),	-0.644	0.103	0.860	1.000	0.171
ILSS	-0.065	-0.316	0.479	0.171	1.000

Table 10. Weights of attributes determined by CRITIC method

Attribute	Density(ρ)	Water Absorption content	Damping Ratio (ξ)	Flexural Strength ($\sigma_{bending}$),	ILSS
Weight	0.269	0.224	0.151	0.161	0.196

4.2 Implementation of VICOR Method

The VICOR method relies on ranking and selecting the best alternative by applying Eq. (7) to reduce the units of all criteria using the normalizing method outlined in Table 11. The normalized values of the multiple responses range from 0 to 1. The weight of each attribute is determined using the CRITIC technique, as previously indicated and shown in Table 10. By multiplying the weights of the criteria by the normalized matrix, we get the weighted normalized decision matrix shown in Table 12. Equations (8 and 9) are used to calculate the positive ideal (best) solution (f +) and the negative ideal (worst) solution (f -). Table 13 displays the utility measure (M_i) and regret measure (R_i) for each material, which were calculated using Eqs. (10 and 11). After computing M_i and R_i values, Eq. (12) is used to calculate the VIKOR index (Q_i) for the optimum parametric combination. Table 14 shows how preference ranking is used to identify the best alternative. The choice with the lowest Q_i value is closest to the perfect answer, while the alternative with the greatest Q_i value is farthest from it. As a result, it is noted that material No. 5, with the biggest VIKOR index (0.581), is the worst material, resulting in a compromising solution of the largest values for density and water absorption content and the least values for damping, flexural strength, and ILSS. Material No.3, on the other hand, has the lowest VIKOR index value (0.081), resulting in a compromise solution with the lowest density and water absorption content and the highest damping, flexural strength, and ILSS values.

It can be concluded that although the six laminated composites consist of the same constituents namely sisal fibers, flax fibers and polyester resin, they have different values of the measured criteria (density, water absorption content, damping, flexural strength and ILSS. This variation in measured criteria is referred to the variation in weight fraction and fiber arrangements for the six laminated composites. Based on VIKOR index, the VIKOR index's lowest value (minimum Q) is regarded the highest rank order, therefore material No. 3 is the best material. Additionally, the highest value (maximum Q) is considered the lowest rank order therefore material No. 5 is the worst material.

5 Application of natural fiber reinforced polymer composites

Composites reinforced with natural fibers such as flax and sisal fibers are utilized in a wide range of applications, including consumer goods, building construction, transportation, packaging, and many more. Natural fiber composites exceed synthetic fiber reinforced composites in the automotive sector because they are less expensive, lighter, and more environmentally friendly. Hybrid composites generally incorporate the properties of their constituent materials. The physical and mechanical properties of composites are considerably improved when sisal fibers are hybridized with other natural fibers such as flax fibers. Sisal composites are used to make a variety of major components, including door panels, roof panels, floor lamination, wall insulation and structural applications.

Table 11. Normalized matrix of responses

Alternatives (Materials)	Normalized non-beneficial attributes		Normalized beneficial attributes		
	Density(ρ)	Water Absorption content	Damping Ratio (ξ)	Flexural Strength ($\sigma_{bending}$),	ILSS
M1	0.405	0.378	0.310	0.390	0.410
M2	0.400	0.406	0.288	0.411	0.407
M3	0.426	0.385	0.638	0.442	0.410
M4	0.409	0.383	0.360	0.408	0.405
M5	0.412	0.404	0.262	0.392	0.407
M6	0.397	0.484	0.464	0.405	0.410

Table 12. Weighted normalized data matrix of output responses

Alternatives (Materials)	Weighted normalized non-beneficial attributes		Weighted normalized beneficial attributes		
	Density(ρ)	Water Absorption content	Damping Ratio (ξ)	Flexural Strength ($\sigma_{bending}$),	ILSS
M1	0.071	0.000	0.131	0.161	0.000
M2	0.026	0.057	0.140	0.097	0.098
M3	0.269	0.014	0.000	0.000	0.000
M4	0.111	0.010	0.111	0.105	0.196
M5	0.135	0.054	0.151	0.153	0.098
M6	0.000	0.224	0.070	0.113	0.000

Table 13. Utility Measure (M_j) and Regret Measure(R_j)

Alternatives (Materials)	Stacking Sequences	Utility Measure and Regret Measure	
		M_j	R_j
M1	[$FF_0/FF_{90}/FF_0/FF_{90}$]	0.364	0.161
M2	[$SF_0/SF_{90}/SF_0/SF_{90}$]	0.418	0.140
M3	[$FF_0/SF_{90}/FF_0/SF_{90}$]	0.283	0.269
M4	[$SF_0/FF_{90}/FF_0/SF_{90}$]	0.532	0.196
M5	[$SF_0/FF_{90}/SF_0/FF_{90}$]	0.591	0.153
M6	[$FF_0/SF_{90}/SF_0/FF_{90}$]	0.406	0.224

Table 14. VIKOR Index (Q_i) scores and Rank Order.

Alternatives (Materials)	Stacking Sequences	Weight Percentage (wt.%) of composite constituents			VIKOR Index (Q_i) scores and Rank Order.	
		Sisal Fiber (SF) wt.% content	Flax Fiber (FF) wt.% content	Polyester wt.% content	Q_i	Rank
M1	[$FF_0/FF_{90}/FF_0/FF_{90}$]	0	12	88	0.212	2
M2	[$SF_0/SF_{90}/SF_0/SF_{90}$]	14.815	0	85.185	0.301	4
M3	[$FF_0/SF_{90}/FF_0/SF_{90}$]	**6.557**	**5.902**	**87.541**	**0.081**	**1**
M4	[$SF_0/FF_{90}/FF_0/SF_{90}$]	7.547	6.792	85.660	0.485	5
M5	[$SF_0/FF_{90}/SF_0/FF_{90}$]	**6.897**	**6.207**	**86.897**	**0.581**	**6**
M6	[$FF_0/SF_{90}/SF_0/FF_{90}$]	7.273	6.545	86.182	0.281	3

6. Conclusion

An investigation has been carried out on specimens prepared from various wt. % of SFs, and FFs to select the optimum material with the lowest density and water absorption content and the highest damping, flexural strength and ILSS. Based on CRITIC weight based VICOR method as a MCDM method, the following conclusions are obtained:

1. Material No. 3 whose VIKOR index is of the smallest value (0.081) is the optimum material resulting in compromising solution of the least values for density and water

absorption content and the largest values for damping, flexural strength and ILSS.

2. On the other hand, and according to the largest value of VIKOR index (0.581), material No. 5 is the worst material resulting in compromising solution of the largest values for density and water absorption content and the least values for damping, flexural strength and ILSS.

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