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DEVELOPMENT OF SUSTAINABLE EPOXY-BANANA FIBRE COMPOSITES AND THEIR MECHANICAL AND TRIBOLOGICAL CHARACTERIZATION

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The present investigation aims to develop epoxy-based composites reinforced with banana fibre (*5 mm* length) and evaluate their various properties. Different sets of composites were fabricated via a simple hand lay-up method with fibre loadings of *0*, *2.5*, *5*, *7.5* and *10* wt. *%* to investigate their performance. Findings indicate that increasing fibre content reduces the composite's density, while water absorption increases with higher fibre percentages. Banana fibre composites with *7.5%* exhibited the maximum tensile, flexural, and impact strengths, with values of *33.1 MPa*, *55.6 MPa*, and *31.7 kJ/m²*, respectively. On the other hand, composite specimens with *10* wt.*%* fibre loading resulted in maximum tensile modulus (*3124 MPa*), flexural modulus (*3583 MPa*) and Barcol Hardness Number (*33*). The addition of natural fibre improves the wear resistance of the material. The minimum specific wear rates reported are 2.37×10^{-4} mm^3/Nm for minimum normal load when measured at varied normal load and 1.93×10^{-4} mm^3/Nm for maximum sliding velocity when measured at varied sliding velocity. Scanning electron microscopy morphological analysis of abraded samples showed micro-cracks, micro-plugging, and fibre debonding on the surface. The AHP-TOPSIS multi-criteria decision-making technique determined that composites with *7.5* wt.*%* fibre loading offer the optimal balance of mechanical strength and wear resistance, making them highly suitable for structural and tribological applications.

Key words: polymer composites, short banana fibre, mechanical properties, wear, AHP-TOPSIS.

1. Introduction

Polymer composites are widely recognized as the best class of products that surpass other materials in meeting the needs of many people. The demand for polymer composites has increased, leading to a growing interest in such materials from the materials industry. The widespread use of these materials in many human activities is mainly due to their ease of fabrication, lightweight, reasonably good mechanical properties and high dimensional stability. Polymer composites with fibre as reinforcement exhibit an impressive strength-to-weight ratio and showcase outstanding attributes like stiffness, toughness, and durability, along with resistance to wear and corrosion [1]. These versatile features have propelled the widespread adoption of such materials in varied industries such as mechanical, construction, biomedical, automobile, aerospace, marine, and more. The performance of these composites relies heavily on the constituent elements and manufacturing techniques [2, 3].

The inherent environmentally friendly qualities of natural fibres have garnered significant interest among both industrial professionals and researchers. Their "green" attributes make a substantial contribution to sustainable practices. Many industries are now embracing sustainable technologies to enhance the

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equilibrium between environmental conservation and addressing social and economic considerations [4]. When compared to traditional synthetic composites, natural fibre-reinforced polymer composites offer numerous advantages and surpass traditional counterparts from various perspectives. They exhibit superior stiffness and strength, enhanced recyclability, increased corrosion resistance, superior impact absorption capacity, higher fatigue strength, lower toxicity levels, and lower life-cycle costs [5-8]. Certain issues, such as moisture absorption, poor wettability and insufficient adhesion, are associated with natural fibre composites, but these may be eliminated with various surface modification processes of natural [9]. Natural fibres derived from plants, including banana, sisal, coir, kenaf, jute, and others, have undergone extensive research for their industrial viability. Banana fibre, in particular, has garnered significant attention due to the widespread consumption of bananas globally, reaching *115.7* million tonnes of annual production across *130* countries. This ubiquity ensures the local availability of waste generated from them. Different parts of the banana plant. High-quality fibres are generally extracted from the pseudo-stem of the banana plant, which may be used to manufacture textiles, sanitary pads, pulp and paper. It may also be used for the development of composites [10, 11].

The composites prepared with short fibre reinforcement possess numerous industrial applications due to their exceptional specific properties. Ease of manufacturing and cost-effectiveness of these composites make them suitable for the preparation of components of automotive, aerospace, and biomedical industries. The parameters that influence the characteristics of the short fibre reinforced composites are the shape of the fibre, the orientation of fibres, and the packing arrangement of fibres. Generally, it has been observed that the short fibres randomly distribute themselves inside the matrix body. There are models available which can be useful in predicting the elastic properties of the composites [12]. Apart from the mechanical behaviour of the composites, such composites also have tribological properties that are of importance. These materials are commonly used in the manufacturing of automotive and aerospace components [13]. The composites with fibre reinforced tribological properties were primarily governed by different parameters like operating conditions, properties of the two phases, the process of manufacturing, interfacial interaction, and the physical properties of the continuous and discontinuous phases [14].

An ample quantity of work is available on the polymeric composites reinforced with natural fibres. Akhyar *et al.* [15] worked on the effect of the coconut fibre length on the flexural behaviour of epoxy-based composites. The value of flexural strength thus obtained was compared with the values of neat epoxy resin and continuous fibre composites. The investigation revealed that the composite prepared with the smallest length of fibres delivers the minimum flexural strength value, whereas, with an increase in the length of fibres, the flexural strength increases and reaches a maximum when the longest fibres are used. The SEM analysis of the damaged surface shows that the primary cause of failure is the voids present inside the composite body. The variation in flexural strength with fibre length is explained as shorter fibre length has an issue of fibre pullout. Mathu Kumar *et al.* [16] worked on the combination of epoxy with date palm stem fibres. They varied the fibre content from *10* wt. *%* to *25* wt. *%* and investigated the different properties of the composite body. Jagadish *et al.* [17] used short pineapple fibre for the preparation of epoxy-based composites. They fabricated two sets of the composites with different fibre content and fibre length. From the experimental investigation, they reported that better properties are obtained for the composites prepared with low fibre loading, whereas longer fibres are better compared to shorter fibres. Raj *et al.* [18] used short Sansevieria Trifasciata fibres reinforced with polyester resin and prepared the samples with reinforcement varied from *5* wt. *%* to *50* wt. *%*. They investigated the influence of fibre length, where the length of the fibre varied from *5-50 mm*. From their investigation, they found that the length of the fibre influences the properties, as with an increase in fibre length, the mechanical properties increase. They also found that the increment in mechanical properties is limited to a fibre length of *40 mm*. Similarly, the optimum properties are obtained for a fibre content of *40* wt. *%*.

Polyoxymethylene thermoplastic matrix is used with banana fibre [19]. The composites are fabricated with three different contents of banana fibre, i.e. *3* wt. *%*, *6* wt. *%* and *9* wt. *%*. The banana fibres were surface modified with alkali treatment. The findings revealed that post-treatment of the fibre, the properties of the composites increase. Apart from the short natural fibre, a recent work on bi-directional banana fibre-reinforced composites is investigated [20, 21]. A noteworthy improvement of *18 %* in the flexural strength, *25 %* in tensile strength and *20 %* in the impact strength is registered. Raj *et al.* [21] worked on a hybrid composite with banana fibre and compact disc powder as a reinforcement material in epoxy resin. In the analysis, they found that with *10* wt. *%* of *%* compact disc powder, the best output in the mechanical behaviour is obtained. In their study of the tribological behaviour of fly ash and banana fibre hybrid polymer composites, Kannan *et al.* [22] highlighted the materials' potential for environmentally friendly uses. According to experimental data, optimal fibre reinforcement reduces wear rate by *20%* when compared to the unreinforced matrix. After fibre chemical treatment, interfacial adhesion was improved, and wear resistance increased by *15%* under a *30 N* load, while the coefficient of friction fell by *10%*.

Choudhary *et al.* [23] used a combination of epoxy and short areca-catechu fibres to make polymer composites using the usual hand lay-up technique. They investigated the porosity, density, and tensile strength of the prepared samples. Shankar *et al.* [24] applied a hybrid AHP-TOPSIS method to optimize the properties of banana and coir fibres reinforced composites. The study identified that the optimal mechanical performance was achieved with a green composite containing *5* wt.*%* banana fibre and *10* wt.*%* coir fibre. The inclusion of natural fibres, even in small amounts, improved the composite's mechanical performance. Rajput *et al.* [25] applied integrated AHP-TOPSIS to rank epoxy/Kota stone dust composites. They reported that the epoxy/*20* wt. *%* Kota stone dust composite showed the best combination. Gupta *et al.* [26] studied the phenomenon of wettability for epoxy composites reinforced with Bhimal fibre. This study is conducted to validate that AHP-TOPSIS is a robust multi-criteria decision-making tool for assessing bio-composite surface interactions.

From the past research, it is experienced that the scientific community are working in the area of replacing synthetic fibres with environmentally friendly synthetic fibres. Among the various natural fibres, it is observed that the banana fibre is a suitable natural fibre for reinforcement in polymeric resin. Based on that, the present investigation focuses on the development of banana fibre/epoxy composites at varied loading of the reinforcement. The fabricated samples are tested for their physical (density, void content and water absorption), mechanical (tensile strength, tensile modulus, flexural strength, flexural modulus, impact strength and hardness) and tribological properties (abrasive wear). A well-established optimization technique, like AHP and TOPSIS, is used to find the best possible combination of matrix and reinforcement. To optimize the performance of the composites, the study employs an integrated AHP-TOPSIS approach, which is particularly effective in complex decision-making scenarios is performed for the first time for such a combination of matrix and fibre and for such a large number of properties, which includes physical, mechanical and abrasion.

2. Materials and methods

In the present work, epoxy is utilized as a base matrix material. The measured density of the epoxy resin used is $1.19\ g/cm^3$. It is obtained in the form of a liquid. To initiate the curing process, triethylenetetramine (TETA), identified as Ciba Geigy's HY 951, was employed. The curing process occurred at ambient temperature, ensuring the proper setting and hardening of the resin. This combination of resin and hardener is known for its strong adhesive properties, making it suitable for various industrial and research applications where durability and stability are required. In this study, banana fibres are used as a reinforcing phase. The pseudo-stem leaves of the plant are cut off for the extraction procedure. Banana fibres were collected from nearby suppliers.

The fabrication of composites for physical, mechanical and wear test samples is done through the hand lay-up technique. The epoxy resin and corresponding hardener are mixed as per the proportion suggested by the supplier. The short banana fibres are also mixed in varying proportions (*0*, *2.5*, *5*, *7.5* and *10* wt.*%*) to obtain samples for various characterizations. The combination is poured into their moulds and allowed to cure for approximately *24* hours, after which they are taken out of the respective moulds.

3. Characterization

The density of the prepared samples is obtained by the water immersion technique (ASTM D792-91 standard). The rule of the mixture model is used to calculate the theoretical density. The percentage variation between the two values gives the void content. The water absorption behaviour is determined according to the ASTM D570 standard. The mechanical properties under investigation are tensile strength (ASTM

D638), flexural strength (ASTM D2344-84), impact strength (ASTM D7136) and hardness (ASTM-2240). Barcol hardness test is performed as per ASTM D2583-95 test standards to determine the hardness, whereas other tensile and flexural properties are experimented with using the Instron 3382 Universal testing machine. Impact testing was performed using a Ceast Resil impactor Charpy test. The tests are conducted in normal environmental conditions.

The pin-on-disc experimental apparatus, established according to ASTM G99 standards, is intended to assess the abrasive wear resistance of polymer composite samples. The setup comprises a rotating disk, usually composed of hardened steel, and a stationary pin, which is the test specimen made of a polymer composite. The wear is quantified by measuring the pin's mass loss, which is then converted into the specific wear rate. The JEOL JSM-6480LV scanning electron microscope is used to visualize the interaction between the matrix and the reinforcement phase, along with the composite deteriorated surface post-wear test. The Analytic Hierarchy Process (AHP), created by Thomas L. Saaty in the 1970s, is an innovative and adaptable technique that facilitates decision-making through the comparative prioritization and assessment of criteria. It operates by structuring a problem into a hierarchy, enabling pairwise comparisons among criteria and alternatives to determine their relative importance through consistent judgment matrices. To enhance the precision of decision-making, AHP is often integrated with the TOPSIS, which ranks alternatives based on their distance from an ideal solution. This combination effectively manages intricate decision-making, which makes it appropriate for a range of applications in engineering, design, and production systems, as well as material selection [27].

4. Results and discussion

4.1. Physical characterization

The measured and theoretical density, along with the void content, evaluated in the present investigation for epoxy/banana fibre composites, is shown in Fig.1. As observed from the figure, the density of the composite decreases with banana fibre content. An unfilled epoxy possesses a density of $1.19\ g/cm^3$. Incorporating banana fibre in epoxy marginally decreases the density. With the addition of a maximum fibre loading of *10* wt. *%*, the density decreases to $1.085\ g/cm^3$. Similarly, theoretical density gives a value of $1.134\ g/cm^3$ for the same fibre loading of *10* wt. *%*.

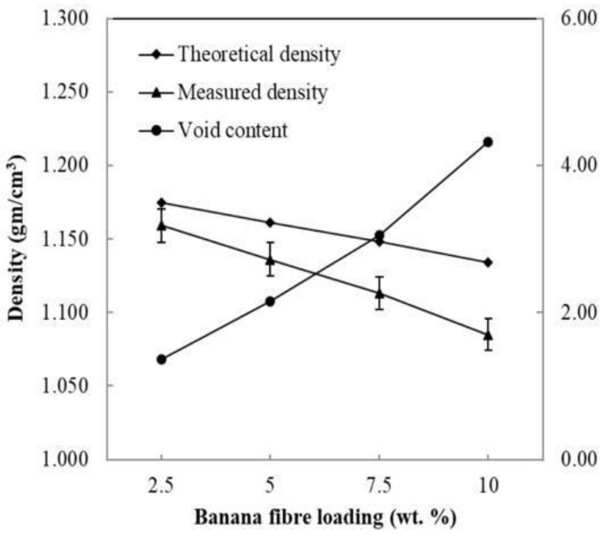

Fig.1. Density and void content variation of the prepared composite samples.

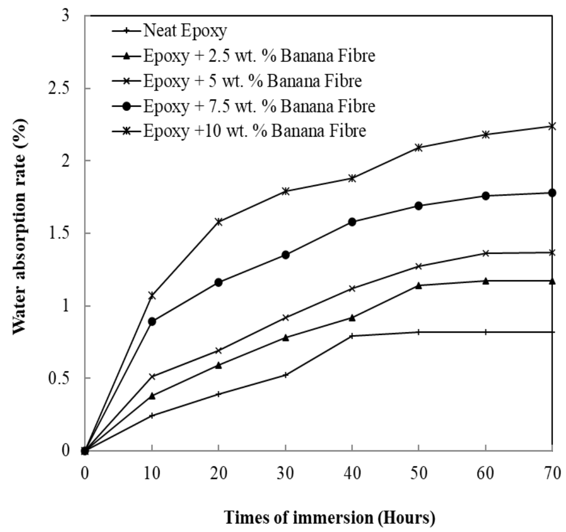

Fig.2. Effect of fibre content and immersion time on water absorption rate.

The decrease in the density value with fibre loading is mainly attributed to the fact that the banana fibre density value is less than epoxy resin. The difference in the density value obtained by the two different methods for the same fibre loading is due to the voids generated in the actual material, as voids have a lower density value than the other two phases. The maximum void content is *4.32 %* for maximum fibre loading, and the same can be seen in Fig.1. A similar observation regarding the density and void content was made in the past by Sahu *et al.* [28] while investigating the sisal fibre reinforced polyester composites.

The water absorption percentage of the fabricated composites is shown in Fig.2. It is clear that, as the banana fibre loading in the epoxy resin increases, along with immersion time, the water uptake in the composite body increases. Nayak *et al.* [29] also reported a similar behaviour of rattan fibre-reinforced polymer composites. This is primarily due to the hydrophilic nature of the natural fibre. The cellulose and hemicellulose parts of the natural fibre assist the absorption of water in the natural fibres. Cellulose contains hydroxyl (–OH) groups that form hydrogen bonds with water molecules. This makes cellulose highly hydrophilic. On the other hand, hemicellulose increases the moisture regain capacity of the fibre [30].

As the fibre loading increases, the number of water absorption sites increases, thus increasing the water uptake rate. The other reason is the presence of voids. As per the experimentation, the maximum absorption of water is observed when the banana fibre content is *10* wt. *%* and the immersion time is *70* hours. The value of water uptake is *2.24 %* against *0.82 %* obtained for neat epoxy. The issue related to moisture and water absorption can be addressed with fibre surface treatment processes.

4.2. Mechanical characterization

The tensile properties of the prepared samples are presented in Fig.3. The strength under tensile loading of the composite increases when the banana fibre content in epoxy resin increases, but the increment is limited only to *7.5* wt. *%*. More addition of banana fibre reduces the strength value under tensile loading. The neat epoxy shows a tensile strength of *15.5 MPa*, which reaches *33.1 MPa* with *7.5* wt. *%* fibre loading. When the fibre loading reaches *10* wt. *%*, the value decreases and drops sharply to *20.5 MPa*. The tensile modulus is another property evaluated under tensile loading. The tensile modulus increases with banana fibre content over the entire range. The tensile modulus of the neat polymer is *2380 MPa* and reaches *3124 MPa* for *10* wt. *%* banana fibre. The increment in modulus signifies that the combination is getting tougher and stiffer with the addition of banana fibres in the matrix material.

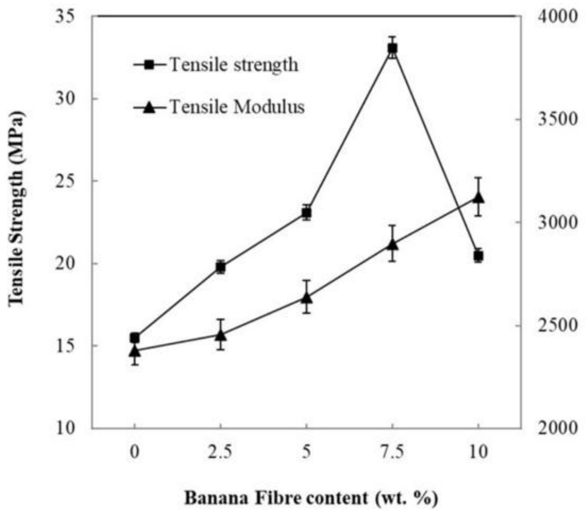

Fig.3. Variation in the tensile properties of the prepared composite samples.

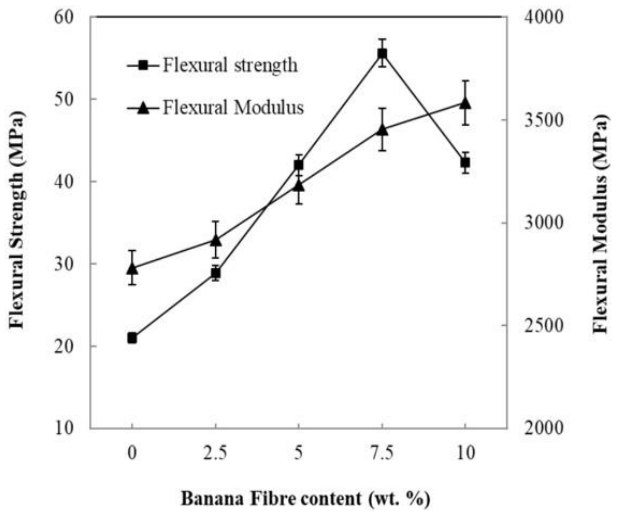

Fig.4. Variation in the flexural properties of the prepared composite samples.

The flexural properties of the composites also show a similar behaviour as presented in Fig.4. For unfilled epoxy, the value of flexural strength is *21 MPa*, which reaches *55.6 MPa* for *7.5* wt.*%* fibre and then reduces thereafter. For *10* wt.*%* banana fibre, the strength declines to *42.3 MPa*. Similar trends for tensile strength and flexural strength have been reported by Joe *et al.* [31] in the case of Ficus benjamina L. Aerial Root fibre/Polyester composite. Similarly, the flexural modulus of unfilled epoxy is *2782 MPa*, which reaches *3583 MPa* for a similar filler loading, showing a continuously increasing trend with fibre loading, as is the case for tensile modulus. While studying the impact strength, the trend remains unchanged. The results obtained during the impact strength test are presented in Fig.5. It is seen that the *7.5* wt. *%* of the banana fibre came out to be optimized for better mechanical properties. Initially, for a low fibre loading up to *7.5* wt. *%*, the adhesion between the two phases is good as epoxy covers the fibre completely, thus having high load-bearing capability. The complete covering of fibres with matrix results in good bonding between the two phases. Mohanty *et al.* [32] share similar findings of impact strength increment till the optimal level, and then a decrease. Neat epoxy resin shows an impact strength of $17.4\ kJ / m^2$. When *7.5* wt. *%* of the banana fibre is reinforced, the impact strength improves to $31.7\ kJ / m^2$ which again reduces to $28.4\ kJ / m^2$ when the fibre loading reaches *10* wt. *%*.

The reduction in strength at increased reinforcement loading is due to the increased porosity, which is caused of the agglomeration of reinforcement, mainly because of the excessive loading [33]. A similar behaviour is reported in earlier investigation in polymeric composites whether it is reinforced with particulate fillers (synthetic filler, waste material or natural filler) or with short fibres, though the weight percentage at which the reverse trend is observed depends upon the type of reinforcement [28, 33, 34]. The value of hardness obtained in the present investigation is presented in Fig.6. The neat epoxy has a Barcol hardness number (HBA) of *25*, which improves with fibre content and reaches *33* Barcol hardness for *10* wt. *%* of banana fibre. This is an improvement of *32 %* against the value of unfilled resin. The increment is mainly because of the hard and brittle nature of the banana fibres. Generally, inclusion of natural fibre in the polymer results in the marginal improvement in the hardness as a similar small improvement in hardness is observed by Mishra *et al.* [35] when they increased the content of short ficus benghalensis in the epoxy resin from *2* wt. *%* to *6* wt. *%*.

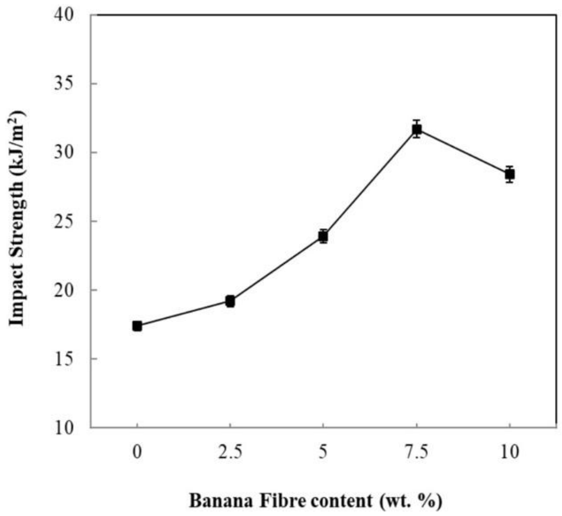

Fig.5. Variation in the impact strength of the prepared composite samples.

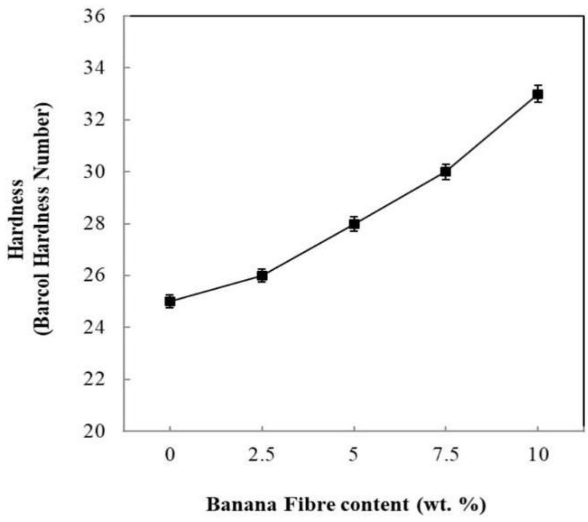

Fig.6. Variation in the hardness of the prepared composite samples.

4.3. Abrasive wear test

The result of the specific wear rate at different velocities of sliding for steady-state conditions (normal load of *30 kN* and sliding distance of *3000 m*) has been reported in Fig.7. The figure shows that the mass loss decreases as the velocity of sliding increases. This phenomenon can be described as follows: an increase in sliding speed substantially reduces the number of adhesive sites due to a reduction in contact time, resulting in decreased adhesive friction force and consequently a lower wear rate [36]. Also, the *10* wt.*%* loading composites give the lowest wear rate. This indicates that a higher content of banana fibre loading shows improved wear resistance.

The variation of specific wear rates for varied normal loads is reported in Fig.8. As the applied load on a short banana fibre-reinforced epoxy composite increases, it encounters a greater number of abrasive particles, resulting in an increased wear rate. The inclusion of short banana fibre in the polymer delivers improvement in the abrasive wear resistance. Composites with increased fibre content exhibit enhanced wear resistance because of the superior strength and hardness of the fibres. A similar work is reported by Patnaik *et al.* [37] while studying the abrasive wear properties of epoxy reinforced with natural fibre in mat form, where they reported that the inclusion of reinforcement in polymeric resin improves the wear resistance of the polymeric matrix.

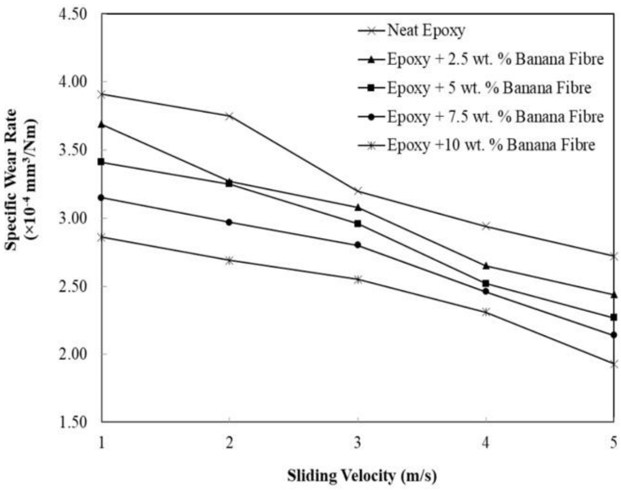

Fig.7. Variation of specific wear rate with sliding velocity.

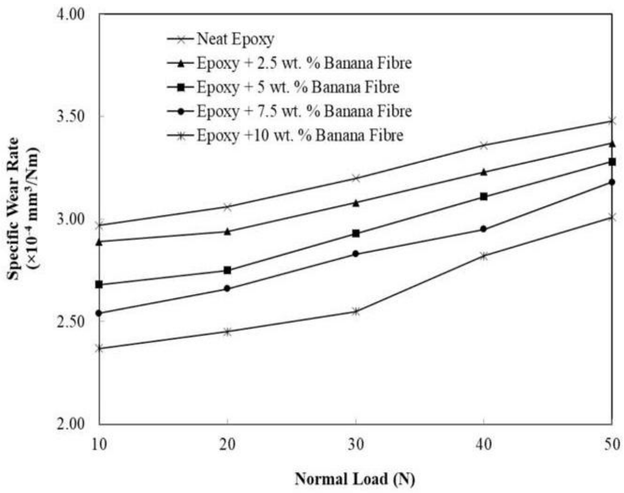

Fig.8. Variation of specific wear rate with normal load.

4.4. Scanning electron morphology

SEM images of the short banana reinforced epoxy composite are reported in Figs 9 and 10.

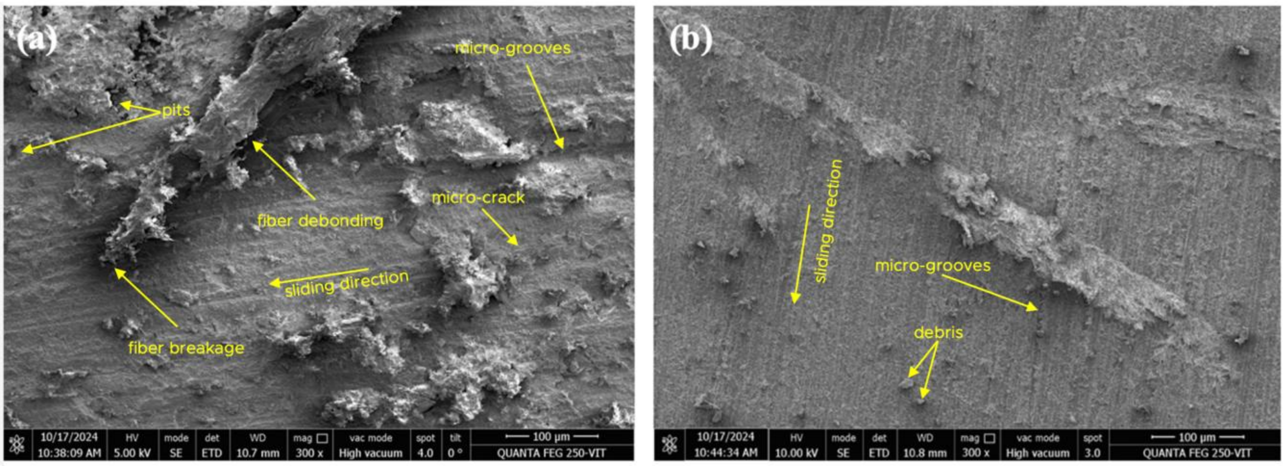

Fig.9. Epoxy/*10* wt. *%* banana fibre composites: (a) sliding velocity of *1 m/s*, b) sliding velocity of *5 m/s*.

Figure 9 (a) shows the SEM images of the worn surface of *10* wt.*%* fibre content composites subjected to conditions of low sliding velocity of *1 m/s* and having a normal load of *30 kN* and a sliding distance of *3000 m*. The wear tracks and micro-ploughing are clearly visible. The wear debris is also present over the deteriorated surface. At low velocity of sliding, fibre breakage and fibre debonding are also observed. Severe surface damage is observed at low velocity. At high velocity, the worn surface seems to be less damaged, Fig.9 (b). The possible wear mechanisms are micro-grooves, micro-pitting, micro-cracks and fibre-matrix debonding.

The worn surfaces of the composites with different fibre loading (*10* wt. *%* and *2.5* wt. *%*) at a normal load of *30 N* are shown in Fig.10. At higher fibre loading, the fibre damage is less, exhibiting good resistance to abrasive wear (Fig.10a). Micro-ploughing can be observed over the worn surface. High wear loss occurred due to less fibre reinforcement in *2.5* wt.*%* samples (Fig.10b). Due to the asperity present on the disc surface, the bond between the two phases is broken. The main wear mechanisms are fiber-matrix detachment and matrix pitting.

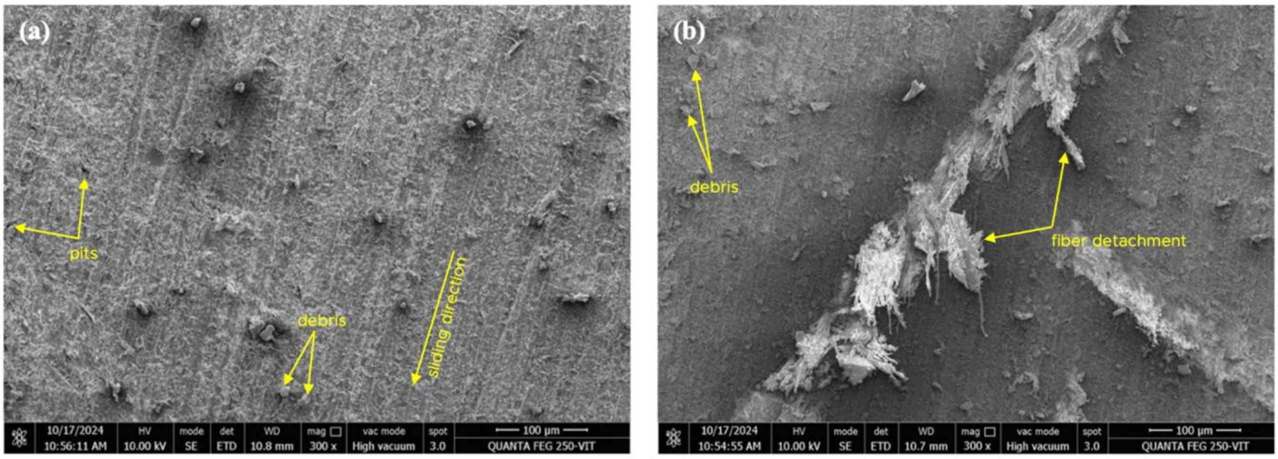

Fig.10. Sliding wear test performed under *30 N* load: (a) Epoxy/*10* wt. *%* Banana fibre, (b) Epoxy/*2.5* wt. *%* Banana fibre.

4.5. AHP-TOPSIS

As per the AHP method, the pair-wise comparison matrix is the basic element used to calculate the relative importance of various criteria. In Tab.1, each criterion is compared with another criterion. It uses a Saaty scale to show the importance of one criterion over another. Saaty scale is generally 1 (equal importance) to 9 (much more important). The matrix is symmetrical, that is, if criterion A is more important than criterion B, criterion B will be equally less important than criterion A. Such numbers help to obtain the weight of the criteria after normalization.

In the AHP, the normalized matrix is obtained from the pairwise comparison matrix (Tab.2). It plays a vital role in determining the relative weight of the parameters. Each element of the matrix is divided by the sum of its columns to normalize the values. Finally, a priority vector is determined by averaging the normalized values in each row. This priority vector represents the importance or relative weight of each criterion. The normalized matrix is essential for converting raw pairwise comparisons into a consistent set of weights. This can be used to rank parameters based on their importance.

The decision matrix for the manufactured composites, which consists of the actual values discovered during mechanical and physical characterization, is shown in Tab.3. Here, the criteria are represented in each column, and an alternative is represented in each row. The normalized matrix may be found in Tab.4. The matrix should be normalized to make it dimensionless because the criteria might have different units of measurement. One frequent method of normalization is vector normalization.

Table 1. Pairwise comparison matrix among parameters.

Criteria	Density (g/cm^3)	Water absorption rate (%)	Tensile strength (MPa)	Tensile modulus (MPa)	Flexural strength (MPa)	Flexural modulus (MPa)	Impact strength (kJ/m^2)	Hardness (HBa)	Specific wear rate (mm^3/mN)
Density (g/cm^3)	1	2	1/5	3	1/5	4	1/5	1/3	1/2
Water absorption rate (%)	1/2	1	1/5	2	1/5	3	1/6	1/4	1/3
Tensile strength (MPa)	5	5	1	6	2	7	3	3	4
Tensile modulus (MPa)	1/3	1/2	1/6	1	1/6	2	1/7	1/5	1/4
Flexural strength (MPa)	5	5	6	6	1	7	2	3	4
Flexural modulus (MPa)	1/4	1/3	1/7	1/2	1/7	1	1/8	1/6	1/5
Impact strength (kJ/m^2)	5	6	1/3	7	1/2	8	1	2	4
Hardness (HBa)	3	4	1/3	5	1/3	6	1/2	1	2
Specific wear rate (mm^3/mN)	2	3	1/4	4	1/4	5	1/4	1/2	1

Table 2. Normalized matrix.

Criteria	Density (g/cm^3)	Water absorption rate (%)	Tensile strength (MPa)	Tensile modulus (MPa)	Flexural strength (MPa)	Flexural modulus (MPa)	Impact strength (kJ/m^2)	Hardness (HBa)	Specific wear rate (mm^3/mN)	Priorities (%)
Density (g/cm^3)	1	2	1/5	3	1/5	4	1/5	1/3	1/2	5.2
Water absorption rate (%)	1/2	1	1/5	2	1/5	3	1/6	1/4	1/3	3.7
Tensile strength (MPa)	5	5	1	6	2	7	3	3	4	27.6
Tensile modulus (MPa)	1/3	1/2	1/6	1	1/6	2	1/7	1/5	1/4	2.6

Table 2 cont. Normalized matrix.

Criteria	**Density** (g/cm^3)	**Water absorption rate** (%)	**Tensile strength** (MPa)	**Tensile modulus** (MPa)	**Flexural strength** (MPa)	**Flexural modulus** (MPa)	**Impact strength** (kJ/m^2)	**Hardness** (HBa)	**Specific Wear rate** (mm^3/mN)	**Priorities** (%)
Flexural strength (MPa)	*5*	*5*	*6*	*6*	*1*	*7*	*2*	*3*	*4*	*22*
Flexural modulus (MPa)	*1/4*	*1/3*	*1/7*	*1/2*	*1/7*	*1*	*1/8*	*1/6*	*1/5*	*1.9*
Impact strength (kJ/m^2)	*5*	*6*	*1/3*	*7*	*1/2*	*8*	*1*	*2*	*4*	*18.1*
Hardness (HBa)	*3*	*4*	*1/3*	*5*	*1/3*	*6*	*1/2*	*1*	*2*	*11.2*
Specific wear rate (mm^3/mN)	*2*	*3*	*1/4*	*4*	*1/4*	*5*	*1/4*	*1/2*	*1*	*7.5*

Table 3. Decision matrix of fabricated composites

Banana fibre content (%)	**Density** (g/cm^3)	**Water absorption rate** (%)	**Tensile strength** (MPa)	**Tensile modulus** (MPa)	**Flexural strength** (MPa)	**Flexural modulus** (MPa)	**Impact strength** (kJ/m^2)	**Hardness** (HBa)	**Specific wear rate** (mm^3/mN)
0	*1.19*	*0.82*	*15.5*	*2380*	*21*	*2782*	*17.4*	*25*	*0.00032*
2.5	*1.159*	*1.17*	*19.8*	*2457*	*28.9*	*2918*	*19.2*	*26*	*0.00031*
5	*1.136*	*1.37*	*23.1*	*2638*	*42.03*	*3186*	*23.9*	*28*	*0.00029*
7.5	*1.113*	*1.78*	*33.1*	*2898*	*55.6*	*3454*	*31.7*	*30*	*0.00028*
10	*1.085*	*2.24*	*20.5*	*3124*	*42.3*	*3583*	*28.4*	*33*	*0.00025*

Table 4. Normalized matrix.

Banana fibre content (%)	**Density** (g/cm^3)	**Water absorption rate** (%)	**Tensile strength** (*MPa*)	**Tensile modulus** (*MPa*)	**Flexural strength** (*MPa*)	**Flexural modulus** (*MPa*)	**Impact strength** (kJ/m^2)	**Hardness** (HBa)	**Specific wear rate** (mm^3/mN)
0	*0.467987*	*0.235693*	*0.29931*	*0.392235*	*0.23592*	*0.388899*	*0.314855*	*0.391678*	*0.491551*
2.5	*0.455795*	*0.336293*	*0.382345*	*0.404925*	*0.32467*	*0.407911*	*0.347426*	*0.407345*	*0.47619*
5	*0.44675*	*0.393779*	*0.446069*	*0.434755*	*0.472176*	*0.445375*	*0.432473*	*0.43868*	*0.445469*
7.5	*0.437705*	*0.511625*	*0.639172*	*0.477604*	*0.624625*	*0.482839*	*0.573615*	*0.470014*	*0.430108*
10	*0.426694*	*0.643843*	*0.395862*	*0.51485*	*0.47521*	*0.500872*	*0.513901*	*0.517015*	*0.384025*

Table 5. Weighted normalized matrix.

Banana fibre content (%)	**Density** (g/cm^3)	**Water absorption rate** (%)	**Tensile strength** (*MPa*)	**Tensile modulus** (*MPa*)	**Flexural strength** (*MPa*)	**Flexural modulus** (*MPa*)	**Impact strength** (kJ/m^2)	**Hardness** (HBa)	**Specific wear rate** (mm^3/mN)
0	*0.024335*	*0.008721*	*0.080814*	*0.010198*	*0.051902*	*0.007389*	*0.056989*	*0.043868*	*0.036866*
2.5	*0.023701*	*0.012443*	*0.103233*	*0.010528*	*0.071427*	*0.00775*	*0.062884*	*0.045623*	*0.035714*
5	*0.023231*	*0.01457*	*0.120439*	*0.011304*	*0.103879*	*0.008462*	*0.078278*	*0.049132*	*0.03341*
7.5	*0.022761*	*0.01893*	*0.172576*	*0.012418*	*0.137418*	*0.009174*	*0.103824*	*0.052642*	*0.032258*
10	*0.022188*	*0.023822*	*0.106883*	*0.013386*	*0.104546*	*0.009517*	*0.093016*	*0.057906*	*0.036866*

Table 5 includes the weighted normalized matrix. In many decision-making problems, different criteria may have different levels of importance. The weight W_j to each criterion C_j need to be assigned, where the sum of the weights is typically 1. In constructing the Weighted Normalized Decision Matrix, we have to multiply the normalized values by their respective weights.

Table 6 shows the positive and negative ideal solutions for all calculated parameters, derived from Tab.5. The ideal solution is the set of values that gives the best performance for each criterion. The negative model solution is the set of values that provides the worst performance for each criterion. The next step is to determine the relative closeness to the ideal solution by utilizing the positive and negative ideal solutions, and the same is shown in Tab.7. The relative closeness measure quantifies the degree to which each alternative is close to both the solutions. Rankings of the alternatives are presented in Tab.8. This value ranges from *0* to *1*, with higher values indicating the alternative is closer to the ideal solution. At *7.5%* fibre content, the *Ci* value is *0.915278*, which is the highest and ranked 1st.

Table 6. The positive and negative ideal solution matrix.

IDEAL BEST	*0.022188*	*0.008721*	*0.172576*	*0.013386*	*0.137418*	*0.009517*	*0.103824*	*0.057906*	*0.036866*
IDEAL WORST	*0.024355*	*0.023822*	*0.080814*	*0.010198*	*0.051902*	*0.007389*	*0.056989*	*0.043868*	*0.032258*

Table 7. Separation of each alternative from the ideal solution and its relative closeness to the ideal solution.

Banana fibre content (wt.%)	**Si^+**	**Si^-**	**Si^++Si^-**	**Ci**
0	*0.134696*	*0.015788*	*0.150484*	*0.104915*
2.5	*0.104971*	*0.032615*	*0.137586*	*0.237052*
5	*0.06801*	*0.069593*	*0.137603*	*0.505752*
7.5	*0.012432*	*0.134307*	*0.146739*	*0.915278*
10	*0.075769*	*0.070616*	*0.146385*	*0.482399*

Table 8. Ranking of the composites.

Banana Fibre Content (wt. %)	**Ci**	**Rank**
0	*0.104915*	*5*
2.5	*0.237052*	*4*
5	*0.505752*	*2*
7.5	*0.915278*	*1*
10	*0.482399*	*3*

5. Conclusions

The present work is the experimental study on short banana fibre/epoxy composites. The composites are prepared for different fibre loading. The investigation presents that the short banana fibre-reinforced epoxy composites show very less voids. The maximum value reported is *4.32%*. The water absorption test showed that natural fibre composites are prone to water or moisture. Among the different sets, samples with *2.5* wt.*%* exhibited the lowest water absorption rate of *1.17 %* for maximum immersion time. The composites with *7.5* wt.*%* fibre loading exhibited maximum tensile strength (*33.1 MPa*), flexural strength (*55.6 MPa*) and impact strength $\left(31.7\ kJ/m^2\right)$. Against that, the other mechanical properties like tensile modulus, flexural modulus and hardness shows maximum value for *10* wt. *%* fibre loading i.e. *3124 MPa*, *3583 MPa* and *33* Barcol hardness number respectively. Also, specimens with *10* wt.*%* fibre loading exhibited maximum abrasive wear resistance in the case of varying normal loads as well as sliding velocities. The different wear mechanisms like micro-grooves, micro-pitting, micro-cracks, micro-plugging and fibre-matrix debonding are observed by micrographs. Multi-criteria decision model based on AHP-TOPSIS represented that composite with *7.5* wt.*%* short banana fibre reinforced composites as the highest ranked composites considering all the test results of the study collectively. By carefully selecting the appropriate fibre content, the overall properties of the composite can be improved. The developed composites show great potential for various practical uses, such as in automotive components (interior panels, dashboards, and door trims), building and construction materials (partition boards, ceiling panels, insulation sheets, and wall claddings), as well as in the manufacture of sports goods and packaging materials.

Nomenclature

wt.% – weight percent

S_i^+ – Separation from Positive Ideal Solution

S_i^- – Separation from Negative Ideal Solution

C_i – Closeness Coefficient

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