Mechanical Properties of Epoxy Composites Reinforced with *Areca catechu* Fibers Containing Silicon Carbide

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The physical and chemical attributes of *Areca catechu* fiber (ACF) were explored. ACF is attractive because of its high cellulose content at 63.2 wt%. The mechanical properties were evaluated for *Areca catechu* fiber-reinforced epoxy composites, in which silicon carbide (SiC) was used as filler. The studied properties included water absorption, flexural strength, impact strength, tensile strength, and hardness properties. The tensile and flexural properties improved when the filler content increased from 40 to 50 wt%, but further increment in the filler content reduced the strength values. The addition of SiC adversely affected the bending and flexural properties of the composites at 40 and 50 wt% filler content, but it positively affected the properties at 60 wt% filler content. The hardness of the composites increased with the addition of 10% silicon carbide. From the results of this study, it is recommended that the ratio of silicon carbide in the composite should not exceed 10 wt% due to agglomeration. The composites containing 10 wt% SiC can be used for outdoor applications such as decking, railing, garden fencing, cladding, and siding applications.

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INTRODUCTION

Natural fibers have been used by humans for centuries because of their abundance, versatility, and environmental friendliness. Derived from plants, animals, and minerals, these fibers have inherent properties that make them suitable for various applications (Alhijazi *et al.* 2022). Natural fibers are known for their biodegradability, renewability, low density, and excellent mechanical properties. Natural fiber composites (NFCs) are composite materials consisting of a matrix material and natural fibers embedded in it (George *et al.* 2001; Alwani *et al.* 2015; Jawaid and Abdul Khalil 2011). The matrix material, often a polymer or biopolymer, acts as a binder and provides cohesion and strength to the composite. The natural fibers reinforce the matrix and contribute to the overall mechanical performance of the composite. NFCs offer several advantages over traditional synthetic fiber composites (Kamarudin *et al*. 2022). They have lower energy consumption during production, lower carbon emissions, and less dependence on non-renewable resources. In addition, natural fibers have high specific strength and stiffness, making NFCs suitable for various applications, including automotive components, construction materials, packaging, and consumer goods (Cheung *et al.* 2009; Binoj *et al.* 2016).

The mechanical properties of epoxy composites reinforced with novel luffa fibers, both before and after chemical treatment, were determined by Chakrabarti *et al.* (2020). The luffa fibers were treated with benzoyl chloride and NaOH. Tensile and flexural tests were performed on the composites to evaluate the effects of the chemical treatment (Kumar *et al*. 2019). The results showed notable improvements in tensile strength, tensile modulus, flexural strength, and flexural modulus of the fibers, with increases of 27.21%, 49.37%, 41.84% and 6.44%, respectively. Sreenivasan *et al.* (2012) presented the procedure for the manual preparation of the *Sansevieria cylindrica* fiber reinforced polyester composite. In addition, the properties of the unsaturated polyester were described. The results showed that the mechanical behaviour of the treated fibers exceeded that of the untreated fibers, and the wettability of the treated fibers was favourable. The efficient treatment of the fibers with $NaOH/Na_2SO_3$ resulted in the separation of the fibers and the reduction of the lignin content in the fibers (Sreenivasan *et al.* 2012). The mechanical and tribological properties of rubber/epoxy composites reinforced with jute/sisal/glass fabrics was investigated by Athith *et al*. (2018). Different proportions of tungsten carbide powder were added to the composites. Notable improvements in thr flexural strength, tensile strength, impact strength, and abrasion and wear resistance were achieved in the composites containing the tungsten carbide powder. Sathish *et al*. (2017) fabricated hybrid epoxy composites using the compression moulding method. The effect of varying the percentage of flax and bamboo fibers on the water absorption behaviour and mechanical properties was investigated. Raju *et al.* (2021) used nanoclay, SiC, and glass-*Caryota* intraply fibers to fabricate a novel hybrid composite of high toughness epoxy resin. The study investigated how the load bearing and abrasion properties were affected by the inclusion of nanoclay and the introduction of *Caryota urens* natural biomass fiber in conjunction with synthetic glass fiber. The incorporation of silicon carbide resulted in remarkable changes in the material properties. This robust intra-ply composite reinforced with glass-*Caryota urens* fibers, silicon carbide, and nanoclay holds promise for various applications in industries such as automotive, sports equipment, household appliances and structural components (Raju *et al.* 2021).

The use of natural fiber-reinforced polymer composites is rapidly increasing in technical applications. The exploration of new plants for their fibers can accelerate the replacement of synthetic fibers with natural fibers. As a result, *Areca catechu* fiber is being considered for the first time as a reinforcing material. *A. catechu* is a species of palm belonging to the Arecaceae/Palmae family, which grows naturally in humid tropical climates, particularly in South Asian countries. Its fibers are commercially used as reinforcements in polymer composites. In a previous study, *A. catechu* fibers were found to have a tensile strength of 232 MPa, a density of 0.78 g/cm^3 and a cellulose content of 57.4%. Its cellulose content was found to be higher than that of hardwood and softwood species. In general, cellulose is mainly responsible for the strength of the lignocellulosic fibers due to its high degree of polymerization and linear orientation (Winandy and Rowell 2005).

The greater the ratio between the length and diameter of the fiber (aspect ratio), the more suitable it is as a fiber reinforcing filler. The diameter of the areca fiber is approximately 0.435 mm (Binoj *et al.* 2020). Previous studies reported that the *A. catechu* fiber could be successfully used in thermoplastic or thermoset composites (Binoj *et al.*

2016; Ashok *et al.* 2018; Nurfajriani *et al.* 2022). *A. catechu* fiber reinforced polymer composites have found applications in structural and non-structural applications such as automotive interiors, exterior decking and siding, partitions, and interior applications. In some tribological applications, treated betel nut fiber reinforced polymer composites have been found to be superior to chopped strand mat glass fiber reinforced polyester (Nirman *et al.* 2012). Betel-nut polyester composites have similar mechanical properties to glass polyester composites. Therefore, *A. catechu* fibers have a high potential to replace glass fibers (Yousif and Nirmal 2010) and for low load applications (Ha *et al.* 2013).

Silicon carbide (SiC) is a remarkable abrasive material with outstanding mechanical properties characterised by low density, high strength and exceptional hardness. SiC exhibits high thermal shock resistance and retains its strength even at elevated temperatures. However, as the concentration of ceramic particles increases, the particles tend to agglomerate, resulting in a decrease in properties and a less homogeneous structure.

The research gap addressed in this study is the lack of investigation into higher fiber weight ratios (40 to 60 wt%) in *A. catechu* fiber reinforced epoxy composites. The previous studies mentioned above predominantly focused on lower ratios (0 to 20 wt%), leaving uncharted territory regarding the mechanical characterization and performance of these composites at elevated fiber concentrations. This research aims to fill this gap by providing a comprehensive understanding of the mechanical behaviour of *A. catechu* fiber composites, particularly in the context of higher fiber weight ratios, providing valuable insights for potential applications in various industries.

The objective of this study was to evaluate the mechanical properties of *A. catechu* fiber epoxy composites by incorporating silicon carbide into the composites. The aim was to assess the impact of silicon carbide addition on the mechanical performance of the composites, including properties, such as tensile strength, flexural strength, impact strength, and hardness. The results will contribute to the understanding of the potential of silicon carbide as a reinforcing filler in *A. catechu* fiber epoxy composites and provide valuable insights for future applications in various industries.

EXPERIMENTAL

Natural Fiber and Its Modification

The natural fibers were collected in the Theni district of Tamil Nadu, India. The average length and dimater of the fibers were determined as 46 mm and 0.74 mm (aspect ratio: 62.2), respectively. The stem of *A. catechu* was then soaked to permit microbial water degradation for 18 days to ease the extraction of the fibers, which were then separated by hand. Tha water was changed weekly. The fiber was then washed in running water. Finally, the fiber was allowed to air dry for seven days to remove moisture, and the fibers were carefully extracted. This retting process facilitates fiber extraction and removes dirt, as shown in Fig. 1. The fiber was soaked in a 5% NaOH solution for 2 h before being rinsed with tap water to remove all traces of NaOH. The fiber was then treated with a 10% $KMnO_4$ solution for 1 h before being rinsed thoroughly with water. The fibers were then dried in an air oven at 75 °C for 24 h.

Fig. 1. Photographic views of: (a) Areca fruit, (b) Dry areca fruit shell, (c) Untreated *Areca catechu* fiber, and (d) Treated *Areca catechu* fiber

Polymer Matrix

An important component of a fiber composite is the matrix. It protects the surface of the fibers from mechanical losses and transfers loads to the fibers. Currently, synthetic polymer matrices dominate the field of natural fiber composites due to their light weight and suitability for low temperature processing. Both thermoplastic and thermoset polymers have been used as matrices for natural fibers (Holbery and Houston 2006).

Moto Polymers and Chemicals, Tamil Nadu, India, supplied the epoxy resin LY556 and hardener HY951 for use as a matrix in the manufacture of composites. LY556 resin and HY951 hardener were selected for their compatibility with common processing techniques such as vacuum infusion, hand lay-up, and resin transfer moulding. These resin systems offer excellent viscosity control and suitable cure profiles, facilitating ease of processing and efficient reinforcement impregnation.

Silicon Carbide

The SiC was obtained from United Nanotech Innovations Pvt. Ltd. (Bangalore, Karnata, India). The SiC had a purity of 99% and a grain diameter of 150 µm. Its density was in the range of 3.21 to 3.25 g/cm³.

Fabrication of Composites

Epoxy resin formulations exhibited remarkable viscosity levels, resulting in improved adhesion and performance characteristics. However, the increased viscosity of the epoxy resins presented a challenge in achieving proper dispersion of the silicon carbide, potentially resulting in suboptimal composite performance.

Fig. 2. Die used for fabrication of composites

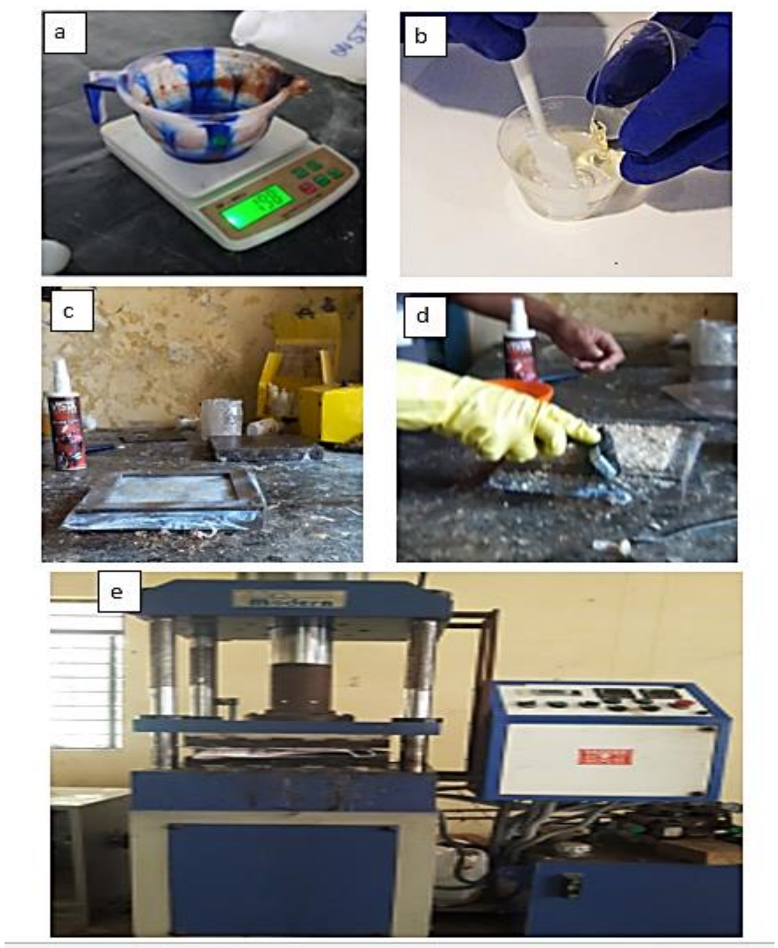

Fig. 3. Fabrication process of composites: (a) matrix measurement, (b) mixing matrix with hardener, (c) die set, (d) mixing the fiber with matrix by rolling, and (e) curing process of composite

To ensure thorough integration, the silicon carbide was subjected to a 30-minute sonication process with acetone. The amalgam was then introduced into the epoxy resin and mixed at 70 °C for a further 30 min. This meticulous process was designed to achieve a uniform distribution of silicon carbide within the epoxy matrix, while removing any residual acetone from the epoxy mixture. For the manufacture of *A. catechu* fiber reinforced epoxy composites, the fibers were placed in the mould (Fig. 2), and the required epoxy resin was poured on top. Release agent was applied to the mould surfaces to prevent sticking (Karuppusamy *et al.* 2023). The weighed fiber was placed inside the mould and then the weighed epoxy resin was poured over and thoroughly mixed. The mould was then sealed and placed in a compression moulding machine, as shown in Fig. 3. The samples were then cured under pressure at 90 °C and 4.5 MPa for 30 min. After curing, the samples were allowed to cure gradually to room temperature. The composite laminates measured 300 x 300 x 3 mm^3. Similar hybrid composites containing silicon carbide were also produced. Five composite panels were produced for each type of the composite.

The experimental design of the study is given in Table 1.

Table 1. Experimental Design

Sample Code	*Areca catechu* fiber content (wt%)	Epoxy content (wt%)	Silicon carbide (SiC) content (wt%)
S_1	40	60	-
S_2	50	50	-
S_3	60	40	-
S_4	40	50	10
S_5	50	40	10
S_6	60	30	10

Physical and Chemical Analysis

The lignin and cellulose contents in *A. catechu* fiber were determined using the Klason and Kurschner/Hoffer methods, respectively (Almeshaal *et al.* 2022; Madhu *et al.* 2019; Palanisamy *et al.* 2022). The Conrad method with Soxhlet extraction was used to determine the wax content in the fiber (Conrad 1944). The density of *A. catechu* fibers was determined according to ASTM D 1577-07 (2018) standard using the Mettler Toledo balance technique (Hyness *et al.* 2018; Palanisamy *et al.* 2021).

Mechanical Characterization

Tensile test

An Instron 3369 universal testing machine (Instron Universal Testing Systems Company, Norwood, MA, USA) was used to perform the tensile test. According to ASTM 3039 (2008) (Pinnell *et al*. 2005), five measurements were taken for each composite and the mean was used to determine the tensile strength (Alhijazi *et al.* 2022; Goud and Rao 2011; Kurien *et al.* 2023; Palanisamy *et al.* 2023b). The specimen measured 250 mm x 25 mm x 3 mm and a 5 kN load cell was used. Testing was performed at a crosshead speed of 2 mm/min and a gauge length of 80 mm. Five test specimens were used in the tensile test for each type of the composite.

Flexural test

The flexure test was performed according to ASTM D790 (2017) (Ishak *et al.* 2010) using an Instron 3369 universal testing machine (Amir *et al.* 2017; Palanisamy *et al.* 2023a; Singh *et al.* 2014). The specimen dimensions were 127 x 12 x 3 mm^3, and the overall specimen had a span to depth ratio of 32:1. A 5 kN load cell and a crosshead speed of 3 mm/min were used for measurement. Five test specimens were used in the flexural test for each type of the composite.

Hardness test

The purpose of the Shore D hardness test was to evaluate the ability of the composite to withstand conical indentation. The evaluation followed the ASTM 2240-15 (2021) (Ganapathy *et al.* 2021) hardness standard, specifically using the Type D scale (Salama *et al.* 2022). A digital Shore D durometer with a measuring range of 0 to 100 HD and an accuracy of 0.5 HD was used to evaluate the composites. Five test specimens were used in the hardness test for each type of the composite.

Water absorption test

The water absorption test was performed according to the guidelines of ASTM D570 (2022) (Lazrak *et al.* 2023). The specimens measured 64 x 12.7 x 3 mm^3, as per the specimen dimensions for testing (Venkateshwaran *et al.* 2011; Karuppiah *et al.* 2020). Distilled water was used to evaluate the water absorption characteristics of the composites. Five test specimens were used in the water absorption test for each type of the composite.

The water absorption percentage of the composite was calculated using Eq. 1:

$$Water\ absorption\ (\%) = \left[\frac{(final\ weight - Initial\ weight)}{Initial\ weight}\right] x\ 100 \qquad (1)$$

Scanning Electron Microscopy (SEM) Analysis

To evaluate the quality of the composites, their surface characteristics and morphology were examined by SEM. The SEM analysis of the ACF epoxy composite was performed using an SU150-Hitachi SEM (Ibaraki, Japan) device. The co-precipitation technique (Rajpoot *et al.* 2022) was used to obtain the SEM image of the ACF. In order to assess the dimensions and the interaction between the ACF and the composite matrix, the image was obtained using electron beams accelerated to 10 kV in the secondary electron (SE) mode.

RESULTS AND DISCUSSION

The objective of the chemical analysis was to ascertain the cellulose, lignin, hemicellulose, and moisture content within the fiber, as well as the presence of waxes. Upon analyzing the chemical composition of cellulose derived from *A. catechu*, it became evident that cellulose is the primary component of *A. catechu* fiber. Additionally, it was observed that lignin, waxes, and fats were present on the outer longitudinal surface of the fiber (Ashok Kumar *et al.* 2019). Consequently, it is imperative to remove these substances to facilitate the utilization of *A. catechu* fiber in composite materials. The properties of natural fiber are primarily shaped by cellulose and lignin, which serve as the dominant components. In the authors' investigation, *A. catechu* fiber was selected as the subject, revealing exceptionally high cellulose content when compared to other natural fibers. This heightened cellulose content in *A. catechu* fiber plays a critical role in enhancing mechanical properties, including Young's modulus and tensile strength, among other natural fibers.

The estimated cellulose content for *A. catechu* fiber, *Althaea officinalis* L. fiber, straw, and banana was 63.24 wt%, 44.6 wt%, 40 wt%, and 32 wt%, respectively (Guimarães *et al.* 2009; Helbert *et al.* 1997; Sarikanat *et al.* 2014). The cellulose content in *A. catechu* fiber is notably higher than that in *Althaea officinalis* L. fiber, straw, and banana fibers, demonstrating its superiority in terms of cellulose composition. The high cellulose content suggests that *A. catechu* fiber possesses excellent potential for enhancing the mechanical properties of composite materials. Lignin serves as a preservative for retaining moisture within the fiber structure and acts as a protective agent against biological degradation. It plays a significant role in shaping the fiber's characteristics, properties, and morphology. The lignin content in *A. catechu* fiber was determined as 22.6%, surpassing that of banana (5% wt%) (Geethamma *et al.* 1998; Joseph *et al.* 2002), sisal (12%) (Bledzki and Gassan 1999; Geethamma *et al.* 1998; Santulli *et al.* 2022), and jute (11.8%) (Bledzki and Gassan 1999; Kurien *et al.* 2023). Enhanced bonding between the fiber and matrix is achieved when the fiber has a lower weight fraction of wax. The presence of wax content deliberately influences the interfacial bonding between the fiber and matrix in composites. The ACF distinguishes itself with an exceptionally low wax content, measured at 0.34 wt%, significantly lower than observed in other natural fibers such as *Prosopis juliflora* (0.61%) (Saravanakumar *et al.* 2013), *Acacia arabica* (0.49%) (Manimaran *et al.* 2016), *Acacia leucophloea* (0.57%) (Arthanarieswaran *et al.* 2015), and *Acacia planifrons* (0.57%) (Hyness *et al*. 2018). The density of the fiber was determined as 1.6 g/cc. The compression moulding procedure was used to make composites with varying volume fractions of modified *A. catechu* fiber-reinforced hybrid composites made from *A. catechu* fiber and silicon carbide particles. Figure 4 and Table 2 provide an overview of the mechanical characteristics of *A. catechu* fiber modified epoxy composites.

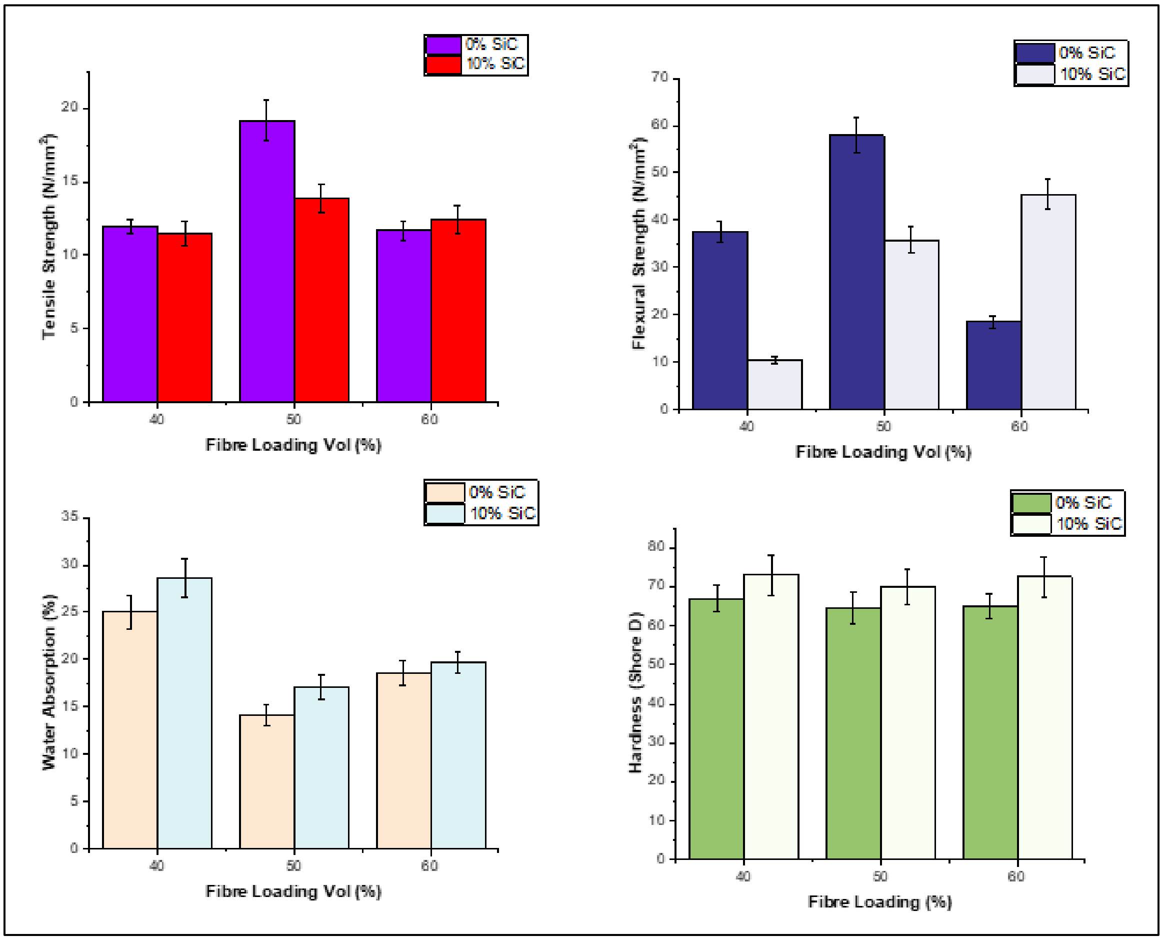

Fig. 4. Mechanical and water absorption characteristics of ACF epoxy composites

Table 2. Mechanical Properties and Water Absorption Behaviour of ACF Epoxy Composites

Sample Code	Flexural Strength (N/mm^2)	Shore D Hardness	Tensile Strength (N/mm^2)	Water Absorption (%)
S1	37.6	67.0	12.0	25.0
S2	57.8	64.5	19.2	14.1
S3	18.6	65.0	11.7	18.6
S4	10.4	73.0	11.5	28.6
S5	35.8	70.0	13.8	17.2
S6	45.5	72.5	12.4	19.7

The tensile strength of various samples was measured to determine the effect of incorporating silicon carbide (SiC) particles into *A. catechu* fiber epoxy composites. Comparison of the tensile strengths of the samples shows that the addition of silicon carbide particles modified the mechanical properties of *A. catechu* fiber epoxy composites. The sample with the highest tensile strength was S2 with 19.2 MPa, followed by S5 with 13.8 MPa. The composites containing silicon carbide (S4, S5 and S6) had lower tensile strength than the composites without silicon carbide (S1, S2 and S3). The stress-strain relation of each type of sample is presented in Fig. 5. Notable differences in the stress–strain curves were observed for different strain rates, showing that the elastic modulus and the strength can change with the loading rate of the ACF and SiC.

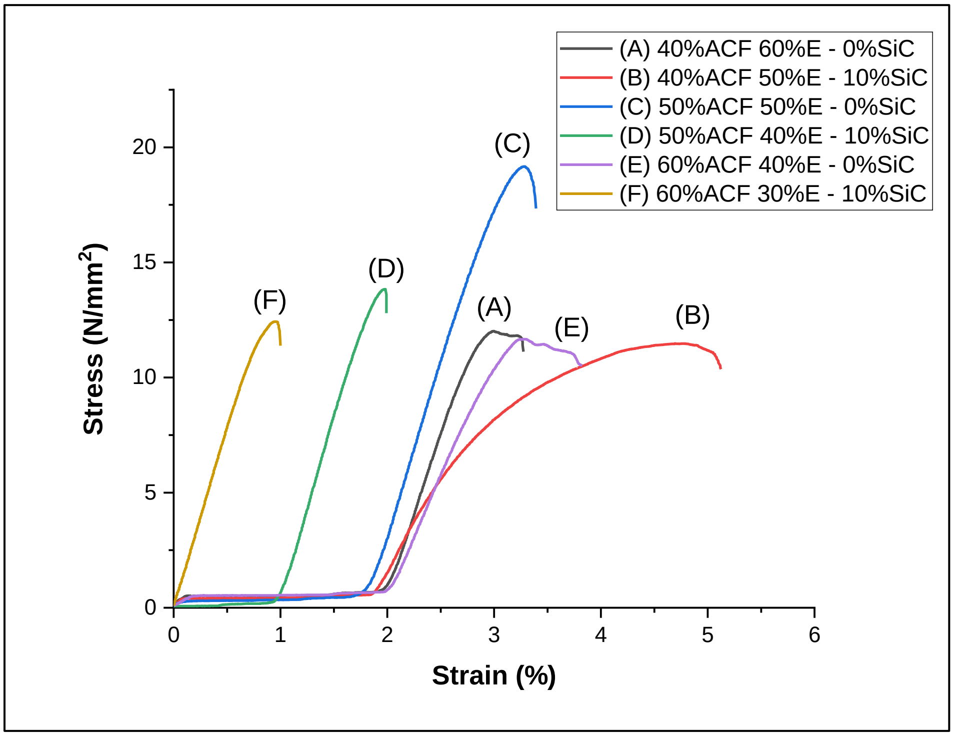

Fig. 5. The stress-straing graph of each type of sample

The test results indicated that excessive addition of silicon carbide had an adverse effect on tensile strength in this study. The accumulation or agglomeration of silicon carbide particles throughout a composite can lead to the formation of weak zones where stress can be concentrated, resulting in a non-uniform structure. These agglomerates can act as stress concentrators, thus reducing the overall strength of the material (Faruk *et al.* 2014). The decrease in the tensile and flexural properties may be partly explained by microvoids near the loading area or imperfections in the matrix and at the fiber-matrix interface (Fig. 5d). Similar results were observed in previous studies (Sukhtesaraie and Hosseini 2016; Kamaraj *et al.* 2018; Moharana *et al.* 2022). For example, Sukhtesaraie and Hosseini (2016) reported that tensile, flexural, and impact properties of polypropylene composites filled with Virgin NSSC pulp produced from mixed hardwoods was decreased by increasing SiC particles (5 to 15 wt%). This was explained by the agglomeration occured by addition of the silicon carbide in the matrix, which subsequently creates stress concentration points in the composite. In other study, the addition of SiC particles up to 10 wt% to sisal fiber/epoxy composites drastically reduced the tensile strength. When the weight % of SiC was increased up to 10%, the ultimate tensile strength was reduced from 18 MPa and 10.9 MPa respectively (Kamaraj *et al.* 2018). Moharana *et al.* (2022) reported that the fracture surface analysis revealed that the composites had the composites had a brittle fracture, following the tensile and impact testing. In the other hand, Athith *et al.* (2021) determined that the tensile strength of epoxy resin hybrid (glass fiber, jute fiber, sisal fiber) polymer composites fabricated by hand layup technique improved effectively with increasing the silicon carbide (SiC) content (0 wt%, 5 wt%, and 10 wt%).

The fracture toughness of the composites increased (with less deformation), and their percentage elongation at break decreased relative to the unfilled matrix. The elongation at break decreased with increasing filler loading, possibly because the filler-matrix contact became less deformable (Neitzel *et al.* 2011). The addition of silicon carbide particles to *A. catechu* fiber epoxy composites influenced the samples' flexural strength (Ashok *et al.* 2023). In particular, the flexural strength of samples S4, S5, and S6 containing 10% silicon carbide was lower than that of samples without silicon carbide. Inadequate dispersion of silicon carbide particles and their agglomeration within the composite matrix can result in the formation of weak regions and stress concentrations, leading to a reduction in flexural strength (Njuguna *et al.* 2008).

Shore D hardness was measured on composite samples S1, S2, and S3. The examination was carried out over 10 different regions within each sample and the resulting averages were calculated. The average hardness values of the composites are shown in Fig. 4. The results showed that S2 had the lowest hardness value while S1 had the highest. The addition of 10% silicon carbide increased the hardness of the samples. The hardest and softest samples were S4 and S5, respectively. Silicon carbide particles are known for their high hardness and superior mechanical properties (Manickaraj *et al.* 2023). When incorporated into composites they act as a reinforcing additive, increasing the overall hardness of the material (Nirmal *et al.* 2012). The presence of hard silicon carbide particles increased Shore D hardness and improved indentation resistance.

Water absorption was determined according to the specifications of ASTM D570 (2022) (Lazrak *et al.* 2023). Each individual sample was immersed in distilled water at room temperature for 120 h. After removal, the samples were carefully cleaned and weighed using an auto-calibration machine (MH-200) with a precision of 0.01 g (Ashok and Kalaichelvan 2020). Figure 4 and Table 2 show the absorbed water fractions in the composites. Samples S4 and S1 showed the highest water absorption, mainly due to the hydrophilic nature of their fibers. These fibers contain unbound hydroxyl groups capable of forming hydrogen bonds with water molecules and their porous tubular structure facilitates the diffusion of water molecules into the composites. It is important to note that voids or imperfections in the matrix and at the fiber-matrix interface can also contribute to the infiltration of water molecules into the composites. Microvoids and flaws between filler and polymer matrix are mainy responsible for water absorption. The results of the present study indicated that the amount of water absorbed by all developed biocomposites increased over time (Fick 1995).

SEM images of the fractured specimens after tensile testing are presented in Fig. 6(a). The SEM images of 50% *A. catechu* fiber reinforced epoxy composites are shown in Fig. 6(b). The micrographs show the presence of bundles of *A. catechu* fibers in the fracture surface of the epoxy composites. The epoxy resin was observed to wet the fibers uniformly.

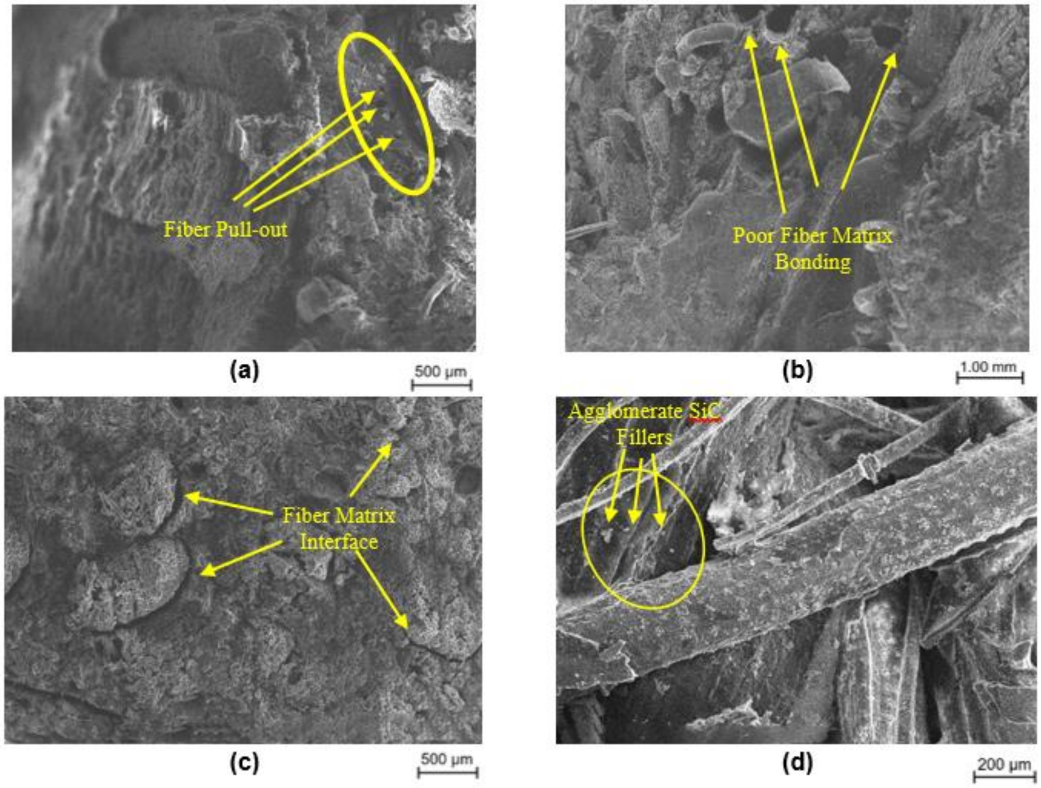

Fig. 6. SEM Image of ACF epoxy composites: (a) Fiber pull–out, (b) Interfacial bonding between fiber and matrix, (c) Fiber matrix interface, and (d) Agglomeration of SiC particles

The superior wetting of the epoxy contributes to its superior strength. The presence of river-like formations on the fracture surface of the composites confirms their ductile properties. Comparable SEM images were observed for the fracture surface of the hybrid composites containing 10% SiC (Fig. 6(d)). In the 10% SiC composites there was a noticeable clustering of SiC powder within the epoxy - *A. catechu* fiber reinforced matrix. The micrograph shows examples of both fiber breakage and fiber pulling. Some fibers delaminated from the epoxy matrix due to the applied load (Manickaraj *et al.* 2022). The influence of SiC was clear in that it alters the bond between the fiber and the epoxy, leading to instances of fiber pull-out and debonding. Consequently, the reduced mechanical properties observed in hybrid composites with higher SiC content can be attributed to fiber fragmentation and aggregation of powder particles. Fiber pull-out voids and fiber debonding (Fig. 6(c)) at the surface of natural fiber-reinforced epoxy composites increased with increasing SiC powder concentration in the polymer matrix, probably due to insufficient fiber wetting (Dasari *et al*. 2009).

It is concluded that the agglomeration of silicon carbide causes an increase in water absorption rate. It is important to note that excessive addition of silicon carbide could exacerbate this effect. The water absorption tests showed that the percentage of water absorbed by the composites increased when 10% silicon carbide was incorporated. The study provides valuable insights into the mechanical and water absorption properties of *A. catechu* epoxy composites with different fiber weight ratios and the effect of silicon carbide addition. The results highlight the need for precise control of the amount of silicon carbide to achieve desirable mechanical properties and mitigate water absorption issues in potential applications of these composites.

CONCLUSIONS

1. The addition of 10 wt% silicon carbide had a negative effect on the tensile and flexural strength of the composites, mainly due to agglomeration of the silicon carbide particles. Excessive addition of silicon carbide further contributed to the reduction in material strength. It is therefore recommended that the amount of silicon carbide added to composites be carefully controlled to avoid compromising their mechanical properties. The results of this study indicate that the SiC content in the natural fiber filled epoxy composite should not be higher than 10 wt% in order not to adversely affect the tensile and flexural properties.
2. The hardness of the composites increased with the addition of 10 wt% silicon carbide. This suggests that the inclusion of silicon carbide increases the hardness of the material.
3. The resulting composites with 10 wt% silicon carbide can be used for outdoor decking, railing, garden fencing, cladding, and siding applications.
4. Future research could focus on optimising the formulation and dispersion of silicon carbide to further improve the overall performance of the composites.

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Data Availability Statement

Data is available on request from the authors.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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