Research Article

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Comparative Study of Mechanical Properties of Coir–jute Fiber-reinforced Composites Enhanced by SiC Nanoparticles

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ABSTRACT

Natural fiber composites are increasingly explored as sustainable alternatives to synthetic materials, but their limited mechanical strength and poor moisture resistance often restrict their applications. This study investigates the mechanical characteristics of hybrid coir–jute fiber-reinforced composites incorporating silicon carbide (SiC) nanoparticles, fabricated using the manual lay-up technique, to address these challenges. Water absorption behavior was evaluated alongside three-point bending, hardness, and impact resistance tests to determine performance improvements. The results showed that incorporating SiC nanoparticles significantly enhanced the properties of the composites. In particular, composites containing 8 wt.% SiC nanoparticles exhibited the lowest water absorption (1.7%) and the highest hardness value (104 HV). They also achieved superior flexural strength (82 MPa), modulus of elasticity (4.38 GPa), and impact energy absorption (19 J). These outcomes demonstrate that SiC nanoparticle reinforcement can effectively improve the durability, strength, and reliability of coir–jute fiber-reinforced composites, highlighting their potential as sustainable alternatives to conventional synthetic fiber composites in structural and industrial applications.

Keywords: Coir fiber; Jute fiber; Silicon carbide nanoparticles (SiC); Mechanical properties; Natural fiber composites; Nanoparticle reinforcement.

1. INTRODUCTION

Natural fiber composites have gained a lot of attention recently as environmentally friendly substitutes for traditional synthetic fiber-reinforced materials. Because of their abundant supply, renewable nature, and advantageous mechanical qualities, coir and jute have become formidable competitors among the diverse array of natural fibers. Furthermore, adding nanoparticles like silicon carbide (SiC) to these composites has demonstrated potential in improving mechanical and thermal properties, opening up new avenues for a range of engineering uses. Natural fibers and synthetic reinforcements are combined to create composite materials, which have drawn a lot of interest due to their improved mechanical qualities and environmental sustainability. The main goal of this study is to investigate the mechanical properties of composites composed of jute and coir fibers reinforced with SiC nanoparticles. Jute and coir fibers are well known for their superior mechanical properties, affordability, and sustainability, which make them suitable options for composite reinforcement. In order to improve the mechanical and durability characteristics, the composites were reinforced with SiC nanoparticles, which are distinguished by their superior hardness and thermal stability. To ensure the homogeneous dispersion of SiC nanoparticles, the experimental setup involves creating composite specimens by combining coir and jute fibers with a polymer matrix.

The objective of this research is to investigate the effect of SiC nanoparticle reinforcement on the mechanical behavior of coir–jute fiber-reinforced composites. To evaluate these composites' resistance to deformation, moisture absorption, bending stresses, and heat dissipation, a range of mechanical tests was conducted, including impact testing, three-point bending tests, hardness tests, and water absorption tests. These insights are crucial for determining the applicability of these materials in real-world situations. For example, hardness testing evaluates the composites' resistance to indentation, which is indicative of their durability and structural strength. Similarly, water absorption tests gauge the materials' ability to withstand moisture, which is vital for applications in high-humidity environments.

Moreover, the three-point bending test measures a material's ability to withstand bending forces, providing insights into its load-bearing capacity and stiffness by

analyzing flexural strength and elasticity modulus. The impact test assesses the composite's ability to absorb energy and resist fractures, which is vital for applications that require impact resistance.

This study adopts a thorough experimental approach to explore the effects of fiber type (coir vs. jute) and the integration of SiC nanoparticles on the mechanical and thermal characteristics of composite materials. By conducting a comparative analysis, the research aims to highlight the performance variations between the two fibers and demonstrate the enhancing role of SiC nanoparticle reinforcement in boosting the composites' strength and overall durability. The findings of this investigation will contribute to the development of high-performance, sustainable composite materials, accelerating the industrial adoption of nanoparticles-enhanced natural fiber composites across diverse engineering sectors.

Extensive research on natural fiber composites reinforced with nanoparticles consistently reveals substantial improvements in their mechanical properties. These enhancements become particularly pronounced with the incorporation of SiC nanoparticles into the composite matrix. Reinforcing natural fibers such as coir and jute with nanoparticles has shown marked improvements in overall strength, durability, and resilience against environmental stressors, highlighting the transformative potential of nanoparticle integration in enhancing composite performance (Stalin *et al.* 2024).

Recent research has increasingly highlighted the impact of SiC nanoparticles on the mechanical performance of composites. Ramasamy *et al.* (2022) explored the influence of SiC nanoparticles on banana and ramie fiber composites through a series of mechanical evaluations, including impact resistance, three-point bending, water absorption, and hardness tests. Their findings showed a significant enhancement in the mechanical properties attributed to the presence of SiC nanoparticles. In another study, Jagadeesh *et al.* (2022) investigated the mechanical behavior of hybrid composites composed of coir, jute, and bamboo fibers within an epoxy matrix. Their results revealed that the integration of coir fibers notably increased both tensile and flexural strengths, surpassing the performance of pure bamboo-based composites. This suggests that incorporating coir fibers alongside other natural fibers yields a synergistic improvement in mechanical properties (Siva *et al.* 2021). Similarly, Devi *et al.* (2022) conducted an experimental study on hybrid composites made from sisal and banana fibers, focusing on the enhancement of tensile, flexural, and impact strength in hybrid configurations compared to single-fiber composites. Their results demonstrated that fiber hybridization leads to improved load distribution and superior mechanical strength, underscoring the benefits of multi-fiber composite structures (Sathish *et al.* 2022).

While these studies have contributed significantly to the knowledge of natural fiber composites, much of the existing research has primarily examined individual fibers or isolated mechanical properties. This study seeks to bridge these gaps by analyzing hybrid coir–jute fiber-reinforced composites incorporating SiC nanoparticles. The study aims to provide a more comprehensive understanding of their mechanical behaviour, thereby expanding their potential applications across a wider range of engineering fields (Muthukumar *et al.* 2020; George *et al* 2024).

2. MATERIALS AND METHODS

In this research, coir and jute fibers were procured from suppliers, while SiC nanoparticles were sourced from a reputable provider. The composite samples were fabricated using the manual lay-up technique, which involved cleaning, drying, and integrating the fibers with SiC nanoparticles using polyester resin as the matrix. Following the preparation process, the samples underwent curing at ambient room temperature for 24 hours to ensure proper consolidation.

The physical and mechanical properties of the fibers, including diameter, length, and modulus of elasticity, were evaluated using standardized testing procedures. Mechanical tests on the composite samples included hardness measurements, water absorption tests, and three-point bending tests (Chenrayan *et al.* 2023; Samuel *et al.* 2024).

Stringent quality control measures were applied throughout the research to ensure accuracy and consistency. These protocols included consistent sample preparation, precise calibration of testing instruments, and strict adherence to industry testing standards. Ethical standards were meticulously followed, covering safe handling and disposal of hazardous materials and ensuring proper attribution of all references (Raja *et al.* 2022; Patil *et al* 2024). Comprehensive documentation was maintained across the research process, recording all procedures, observations, and results. The final report presented the findings in a clear and structured manner, utilizing tables, charts, and graphs to visually represent the data, and addressed any limitations or uncertainties identified during the study (Murthy *et al.* 2023; Kumar *et al.* 2024).

The experimental setup comprised four main tests: the impact test, the three-point bending test, the water absorption test, and the hardness test. A fixed force was applied to composite samples on a stable surface during the hardness test, and the resulting indentation was measured. To guarantee correctness, this procedure was carried out several times. A Rockwell hardness tester was used to measure the hardness of the coir–jute fiber-reinforced composites and they were immersed in water for 24 hours as part of the water absorption test. The

water absorption properties of composites composed of coir and jute fibers with varying SiC nanoparticle concentrations were also investigated in this study. The three-point bending test was used to evaluate the flexural behavior of the composites using a universal testing machine that has the necessary fittings. Special emphasis is paid to the impact of the SiC nanoparticle content (Vijayan *et al.* 2023; Goutham *et al.* 2023). Additionally, a Charpy impact tester was used to assess the composites' impact resistance at different SiC concentrations.

The composite sample was mounted in a holder for the impact test, and the pendulum was raised to a predetermined height of approximately 150° from the vertical starting position before being released to strike the sample. The energy absorbed by the sample upon impact, prior to fracture, was recorded. To ensure reliable results, multiple samples were tested. Trends in modulus of elasticity, impact resistance, hardness, water absorption, and flexural strength were examined to assess the mechanical performance of coir–jute fiber-reinforced composites incorporated with SiC nanoparticles. The analysis examined the effect of SiC nanoparticle concentration on the mechanical performance of the composites. To ensure accurate results, all tests were conducted in a controlled environment, using regularly calibrated equipment and following standardized testing procedures (Fig. 1).

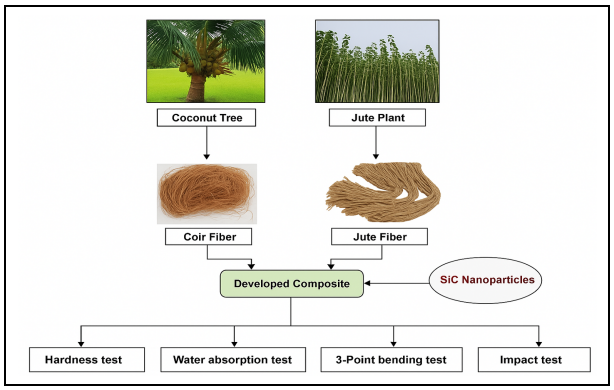


Fig. 1: Preparation and testing methods

3. RESULTS AND DISCUSSION

3.1 Hardness Test

The primary focus of the study was to assess the hardness of composite materials made from jute and coir fibers with varying proportions of SiC nanoparticles. Hardness readings increased as the fraction of SiC nanoparticles increased, indicating that their presence improves the composites' hardness. The intrinsic hardness and rigidity of SiC nanoparticles, which reinforce the composites and increase their total strength, can be attributed to this improvement. The composition of the five samples (CJS 1–CJS 5) and the total impact of SiC nanoparticles on the performance of the composites are presented in Table 1. The uniform dispersion of nanoparticles throughout the matrix, which enhances the composites' load-bearing capacity and indentation resistance, primarily accounts for the observed improvement in hardness. Surface imperfections, potential measurement mistakes, and inconsistent particle dispersion within the composite matrix can all cause variations in hardness values. Achieving homogeneous nanoparticle dispersion during composite fabrication and conducting multiple hardness measurements at different locations on each sample are essential to minimize such variations. The hardness values of hybrid composites containing SiC nanoparticles are shown in Fig. 2. At 104 HV, the CJS 5 sample had the maximum hardness, whereas at 88 HV, the CJS 1 sample had the lowest (Table 1). As a result, the CJS 5 sample with 8% SiC nanoparticles exhibited the highest hardness, achieving a value 18% greater than that of the specimen without SiC nanoparticles.

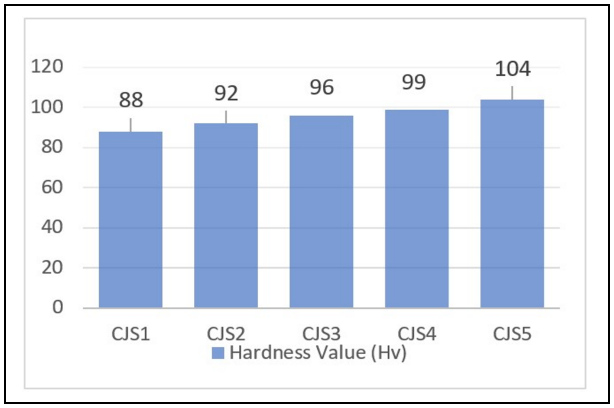


Fig. 2: Hardness test

Table 1. Hardness test results on composites with SiC nanoparticles

Composite	Coir Fiber (%)	Jute Fiber (%)	SiC Particles (%)	Hardness (HV)
CJS 1	60	40	0	88
CJS 2	59	39	2	92
CJS 3	58	38	4	96
CJS 4	57	37	6	99
CJS 5	56	36	8	104

Future studies incorporating microstructural analysis and additional mechanical property evaluations could provide a more comprehensive understanding of the overall effect of SiC nanoparticles on the performance of these composites.

3.2 Water Absorption Test

To evaluate the water absorption capacity of composite samples, they were immersed in distilled water for 24 hours. The impact of varying concentrations

of SiC nanoparticles on water intake was investigated by computing the percentage increase in weight resulting from water absorption. The results showed that SiC nanoparticles effectively reduced the water absorption capacity of the composites (Table 2).

The hydrophobic characteristics of SiC nanoparticles, which prevent water molecules from penetrating the composite matrix in the CJS 5 sample, are responsible for this decrease in water absorption. The uniform dispersion of nanoparticles within the matrix acts as a barrier, preventing water penetration and thereby reducing the composites' water absorption. The water absorption rates of hybrid composites with SiC nanoparticles are shown in Fig. 3. The CJS 5 sample performed the best, with the lowest water absorption rate of 1.7%, while the CJS 1 sample recorded the highest rate of 2.8%. Compared to the specimen without SiC nanoparticles, the composite with 8% SiC nanoparticles showed a minimal water absorption rate of 1.7%, which is 65% lower. Uneven dispersion of nanoparticles, surface imperfections, and measurement errors can all lead to variations in water absorption values. It is crucial to perform several water absorption tests on every sample and guarantee uniform nanoparticle distribution throughout the production process in order to reduce these disparities.

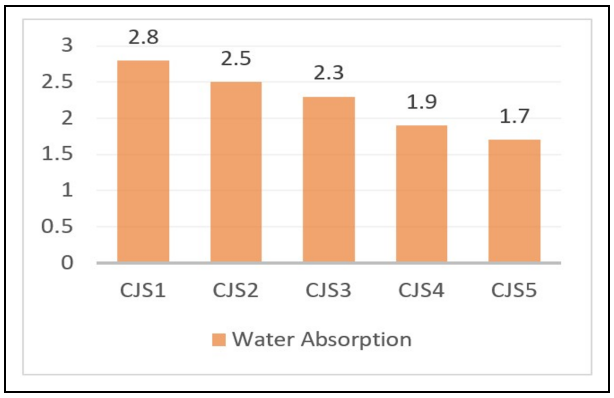


Fig. 3: Water Absorption Test

Table 2. Water absorption test results

Composite	Coir Fiber (%)	Jute Fiber (%)	SiC Particles (%)	Water Absorption (%)
CJS 1	60	40	0	2.8
CJS 2	59	39	2	2.5
CJS 3	58	38	4	2.3
CJS 4	57	37	6	1.9
CJS 5	56	36	8	1.7

3.3 Three-point Bending Test

The flexural properties of the composite samples were assessed in this work using a three-point bending test device. The bending strength and modulus of elasticity were evaluated by examining the effects of varying SiC nanoparticle ratios on the mechanical performance of the hybrid composite samples. The results showed a positive correlation between the amount of SiC nanoparticles added to the composite samples and the observed performance, as shown in Table 3. This suggests that adding SiC nanoparticles to the composites improves their mechanical properties under bending. SiC nanoparticle reinforcement improves the composites' stiffness and load-bearing capacity, leading to better flexural performance.

Their even dispersion throughout the matrix reduces crack formation and promotes efficient stress transmission, improving overall mechanical efficiency. The flexural strength of the hybrid composites enhanced with SiC nanoparticles is shown in Fig. 4.

Table 3. Flexural strength test results

Composite	Coir Fiber (%)	Jute Fiber (%)	SiC Particles (%)	Flexural Strength (MPa)	Modulus of Elasticity (GPa)
CJS 1	60	40	0	62	3.58
CJS 2	59	39	2	67	3.78
CJS 3	58	38	4	73	4.02
CJS 4	57	37	6	78	4.22
CJS 5	56	36	8	82	4.38

Variability in the measured flexural properties may result from changes in sample configurations, testing conditions, and nanoparticle distribution. Maintaining uniform nanoparticle distribution during composite fabrication and adhering to standardized testing procedures are essential to minimize such discrepancies. In general, the results show that adding SiC nanoparticles to coir–jute fiber-reinforced composites greatly improves their flexural properties, making them suitable for applications requiring high stiffness and strength, as demonstrated by the CJS 5 sample.

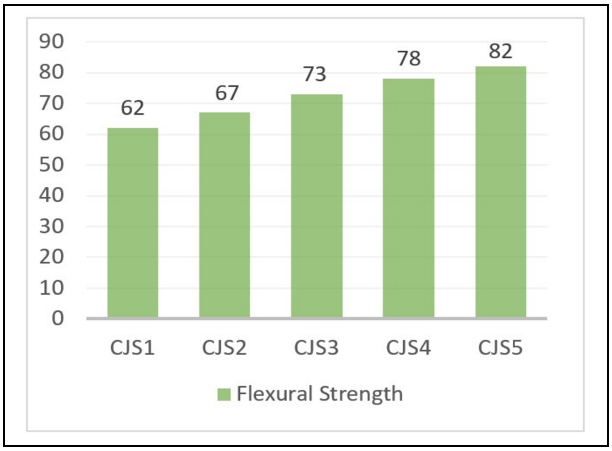


Fig. 4: Flexural strength

The improved performance of the CJS 5 composite was confirmed by its flexural strength of 82 MPa, which was higher than that of the CJS 1 sample (62 MPa). Fig. 5 shows the modulus of elasticity for the hybrid composite samples. It shows that the CJS 5 is more elastic than the CJS 1 sample, with a modulus of elasticity of 4.38 GPa as opposed to 3.58 GPa.

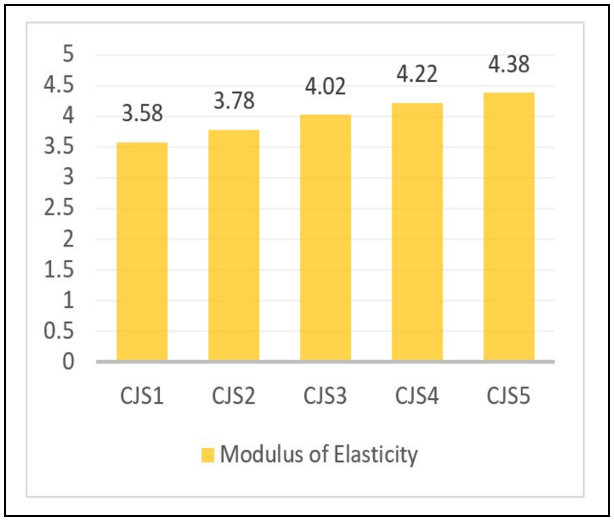


Fig. 5: Modulus of elasticity

The greatest observed flexural strength and modulus of elasticity were 82 MPa and 4.38 GPa, respectively (CJS 5), representing 33% and 22% improvements over the SiC nanoparticle-free specimen. This improvement in flexural characteristics is due to the reinforcing impact of SiC nanoparticles, which increases the load-bearing capacity and stiffness of the composites.

3.4 Impact test

The Charpy impact testing was conducted to evaluate the impact resistance of the hybrid composites. The evaluation focused on the effect of varying SiC nanoparticle concentrations on the energy absorbed by the samples prior to fracture. The results revealed that composites containing higher SiC nanoparticle contents exhibited greater energy absorption, indicating that these nanoparticles significantly enhance the impact resistance of the materials (Table 4).

SiC nanoparticles, which efficiently collect and release energy during impact events, are primarily responsible for the improvement in impact resistance. Their even dispersion throughout the composite matrix promotes effective energy dissipation and lowers the risk of crack development, thereby enhancing the overall impact resistance of the CJS 5 sample. The CJS 5 sample, which contained 8% SiC nanoparticles, produced a substantially greater impact energy of 19 J, representing an 73% increase compared to the specimen without SiC (Fig. 6).

Table 4. Impact test results

Composite	Coir Fiber (%)	Jute Fiber (%)	SiC Particles (%)	Impact Energy Absorbed (J)
CJS 1	60	40	0	11
CJS 2	59	39	2	13
CJS 3	58	38	4	15
CJS 4	57	37	6	17
CJS 5	56	36	8	19

Future studies employing dynamic mechanical testing and fractographic analysis may provide further insight into how SiC nanoparticles influence the impact performance of these composites.

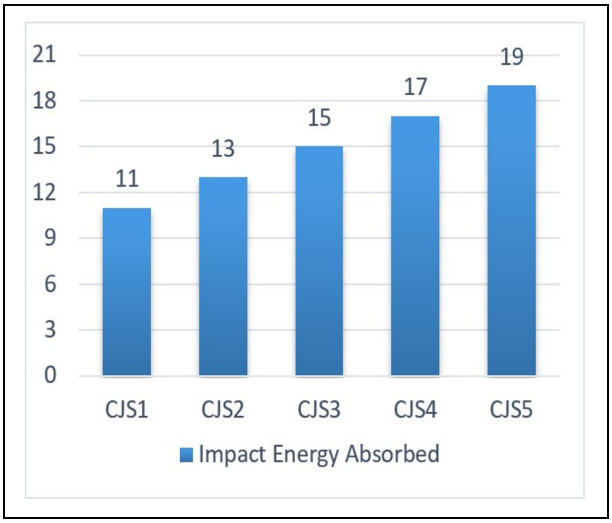


Fig. 6: Impact strength

4. CONCLUSION

The study establishes that reinforcing coir–jute fiber-reinforced composites with SiC nanoparticles offers a promising pathway to overcome the traditional limitations of natural fiber composites. Beyond measurable gains in strength and durability, this work underscores the broader significance of integrating sustainable natural fibers with advanced nanomaterials to produce lightweight, moisture-resistant, and mechanically robust composites. This approach not only enhances the performance of renewable resources but also positions these materials as viable alternatives to synthetic counterparts in structural and industrial applications. Looking ahead, further research on interfacial bonding mechanisms, long-term durability, and large-scale processing could expand the applicability of these composites and accelerate their role in advancing sustainable material technologies.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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