Research Article

Journal of Environmental Nanotechnology

Investigation of Mechanical Properties of a Hybrid Composite of Ramie Fiber, Coir Fiber and Silicon Carbide

T. Sathish and R. Saravanan*
Department of Mechanical Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai, TN, India
Received: 20.02.2024 Accepted: 09.05.2024 Published: 30.06.2024
*saravananr.sse@saveetha.com

ABSTRACT

This research explores the mechanical properties of a new hybrid composite comprising 30% ramie fiber, 15% coir fiber and 2% silicon carbide particles. Ramie fiber, recognized for its superior tensile strength and rigidity, and coir fiber, celebrated for its natural abundance and ability to biodegrade, are amalgamated with silicon carbide particles to augment the mechanical attributes of the composite. Various mechanical tests including tensile, flexural, impact and hardness, were conducted to characterize its behavior. The results were promising, with an average tensile strength of 66.14 MPa, flexural strength of 86.46 MPa, impact strength of 35.88 kJ/m2 and hardness of 181.8 HV, for the composite, revealing the material's potential for applications in engineering fields necessitating high levels of strength, stiffness, impact resistance and hardness. The combined reinforcement from coir fibers, ramie fibers and silicon carbide particles provides a harmonious balance between performance and sustainability. Ongoing research in this domain shows promise for advancing composite materials technology, thereby contributing to creating sustainable and high-performance materials across diverse industries.

Keywords: Ramie fiber; Coir fiber; Silicon carbide; Mechanical characterization.

1. INTRODUCTION

Composite materials have garnered significant attention in recent times owing to their adaptability, superior mechanical characteristics, and potential for sustainable advancement (Bogard *et al.* 2022). Among the diverse array of composite materials, natural fiber-reinforced composites have emerged as promising alternatives to conventional synthetic fiber-reinforced composites, primarily due to their environment-friendly attributes, renewable sourcing, and biodegradability (Sathish *et al.* 2021). This shift towards natural fiber composites resonates with global endeavors to address environmental concerns linked with the widespread utilization of synthetic materials, while fulfilling the escalating demand for lightweight and high-performance materials across various sectors (Djafar *et al.* 2021).

This study centers on the development and evaluation of a pioneering hybrid composite material composed of ramie fiber, coir fiber and silicon carbide (SiC) particles (Cheng *et al.* 2021). Ramie fiber, extracted from the stems of the Boehmeria nivea plant, is esteemed for its outstanding tensile strength, rigidity and resistance to microbial degradation. Coir fiber, derived from coconut husks, is distinguished by its abundance, cost-effectiveness and biodegradability, rendering it an appealing reinforcement material for composite applications (Cheng *et al.* 2023). Conversely, silicon carbide (SiC) particles are selected as reinforcement additives due to their remarkable hardness, thermal stability and chemical inertness, which can significantly enhance the mechanical properties and longevity of the composite material (Hasan *et al.* 2021).

The rationale underlying the integration of ramie fiber, coir fiber and SiC particles lies in harnessing their synergistic effects to attain a composite material with enhanced mechanical performance and environmental sustainability (Walte *et al.* 2020). By amalgamating the high tensile strength of ramie fiber, the abundant nature of coir fiber and the reinforcing attributes of SiC particles, it is envisaged that the resultant hybrid composite will manifest improved strength, stiffness and impact resistance while upholding eco-friendly characteristics (Sathish *et al.* 2021; Singh *et al.* 2022).

The fabrication process of the hybrid composite entails a combination of manual lay-up technique and compression molding, facilitating the efficient impregnation of fibers with the matrix material and ensuring uniform dispersion of reinforcement throughout the composite structure (Sathish *et al.* 2020). Subsequently, the mechanical properties of the composite are methodically assessed through a battery of standardized tests, encompassing tensile, flexural and impact evaluations, to gauge its performance under diverse loading conditions (Mishra *et al.* 2021). The outcomes of this study are poised to enrich the existing corpus of knowledge on natural fiber-reinforced composites and their potential utility across various engineering realms, encompassing automotive, aerospace, construction and consumer goods (Ramasamy *et al.* 2023; Parai *et al.* 2023). The development of sustainable and high-performance composite materials heralds promising prospects for tackling challenges associated with resource depletion, environmental degradation and energy consumption, while concurrently fostering innovation and economic prosperity (Ramesh *et al.* 2023; Safaat *et al.* 2023).

In essence, this research endeavor epitomizes a multidisciplinary approach that amalgamates principles from materials science, mechanical engineering and environmental sustainability, to propel the frontier of composite materials technology. By harnessing the distinctive attributes of natural fibers and integrating advanced additives such as SiC particles, the aspiration is to engender composite materials that not only fulfill the exacting performance requisites of contemporary engineering applications but also contribute to a more sustainable and resilient future.

2. MATERIALS AND METHODOLOGY

The primary aim of this study is to develop and investigate a hybrid composite material incorporating components such as coir fibers sourced from coconut husks, ramie fibers derived from the stems of Boehmeria nivea plants and SiC particles. To incorporate these fibers and particles into the composite structure, an appropriate matrix material was employed. The composite fabrication involved utilizing the hand lay-up technique, wherein the fibers and particles were systematically layered in a mold according to a predetermined orientation, with SiC particles interleaved between them. Subsequently, thorough impregnation of the fibers and particles with the selected matrix material was achieved using a brush or roller, ensuring complete wetting. Compression molding was then employed under controlled temperature and pressure conditions to facilitate the curing and consolidation of the composite structure. Fig. 1 shows the preparation method for testing samples.

The process of preparing composite specimens encompasses various steps, including mold creation, material cutting and shaping and surface finishing. Mechanical testing, including tensile testing, using a Universal Testing Machine (UTM) and flexural testing employing a three-point bending setup, was conducted to assess the material's mechanical properties. Additionally, impact testing was performed by subjecting specimens to impacts in a pendulum or drop tower configuration.

Statistical analysis of the mechanical test data, including the evaluation of variability, standard deviations and mean values, was carried out to ascertain the reliability and consistency of the composite material properties. Furthermore, environmental testing was conducted to evaluate the composite material's durability and longevity under real-world conditions. By amalgamating diverse materials and methodologies, this study enabled the creation and examination of the hybrid composite material's microstructure, mechanical properties and potential applications across various engineering domains.

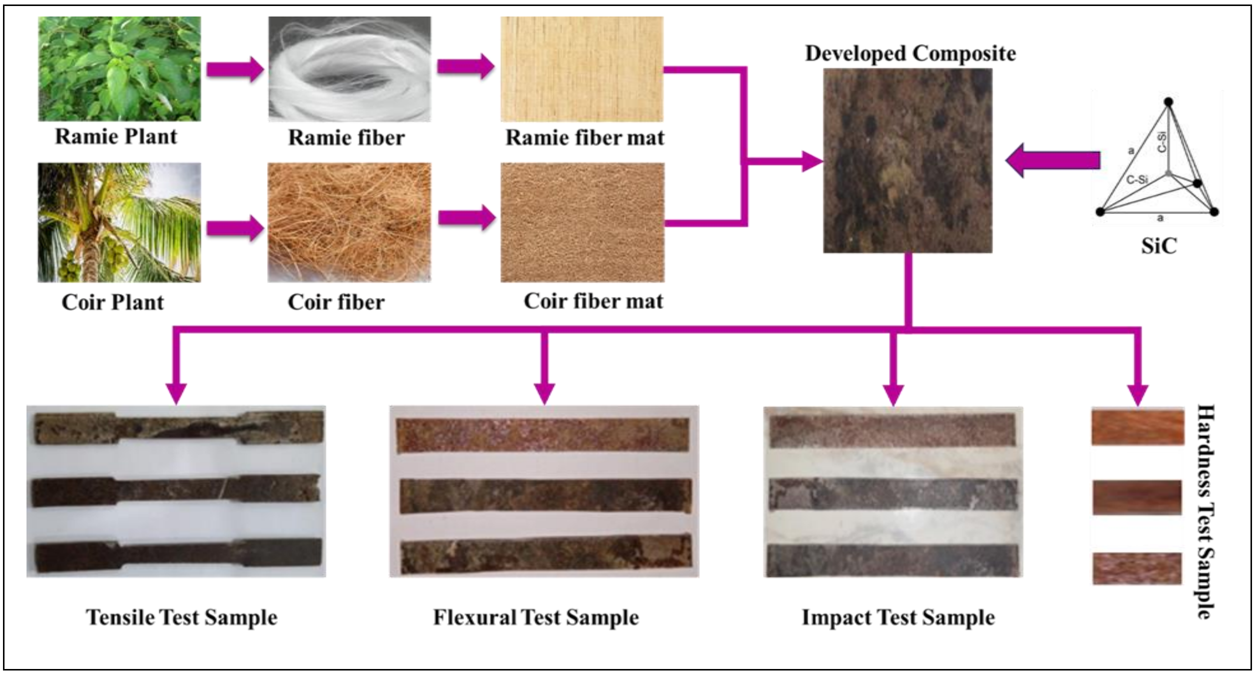

Fig. 1: Testing sample preparation method

3. RESULTS AND DISCUSSIONS

3.1 Tensile Test

The examination of the tensile test data reveals that the hybrid composite material displays an average tensile strength of 66.14 MPa, with individual samples demonstrating values ranging between 63.5 MPa and 67.8 MPa as shown in Fig. 2. Furthermore, the calculated average Young's modulus for the composite is 3.9 GPa, indicating its stiffness under tensile loads. Additionally, the average elongation at break for the composite material is measured at 2.6%, signifying its capacity to undergo deformation before reaching failure. Table 1 showcases the outcomes of the tensile tests conducted on the hybrid composite material, incorporating coir fibers, ramie fibers and SiC particles.

Table 1: Tensile test results for the hybrid composite specimens

Specimen	Ramie %	Coir %	SiC %	Epoxy %	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation at Break (%)
RCS 1	30	15	2	53	65.2	3.8	2.5
RCS 2	29	15	2	54	67.8	4.1	2.8
RCS 3	28	15	2	55	66.7	4.0	2.7
RCS 4	27	15	2	56	66.1	3.9	2.6
RCS 5	26	15	2	57	64.9	3.7	2.4
Average					66.14	3.9	2.6
Standard Deviation					1.56	0.19	0.21

The standard deviation values for tensile strength, Young's modulus and elongation at break are documented as 1.56 MPa, 0.19 GPa and 0.21%, respectively. These metrics depict the level of variation observed within the sample set, reflecting the uniformity of material properties across different specimens.

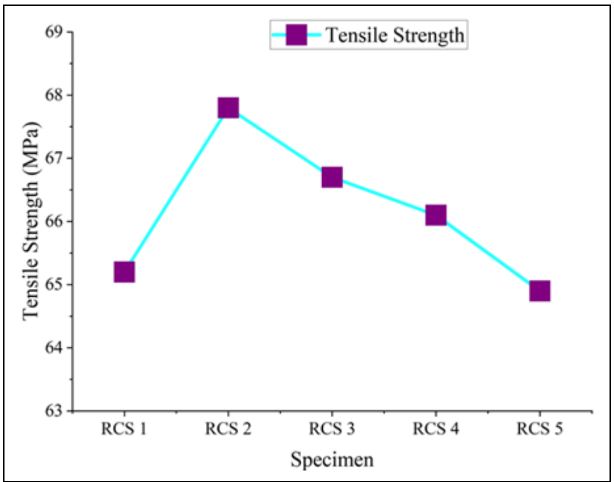

Fig. 2: Tensile strength based on the specimen

The observed tensile strength of the hybrid composite material can be attributed to the synergistic reinforcement provided by coir fibers, ramie fibers and SiC particles. The inherent tensile strength and stiffness of coir and ramie fibers contribute significantly to the composite's overall strength, while the SiC particles act as reinforcing agents, enhancing the material's mechanical properties. Fig. 3 depicts the Young's Modulus of the specimens.

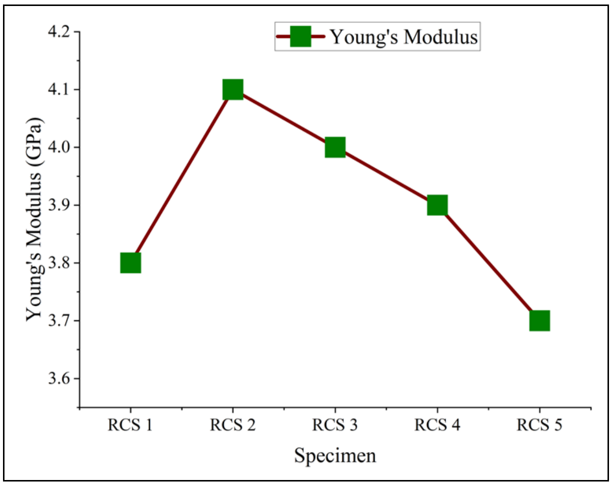

Fig. 3: Young's Modulus based on the specimen

Additionally, effective interfacial adhesion between the fibers and the matrix material plays a crucial role in transferring stress and preventing delamination, thereby boosting the tensile strength of the composite. Fig. 4 shows the elongation at break of the specimens.

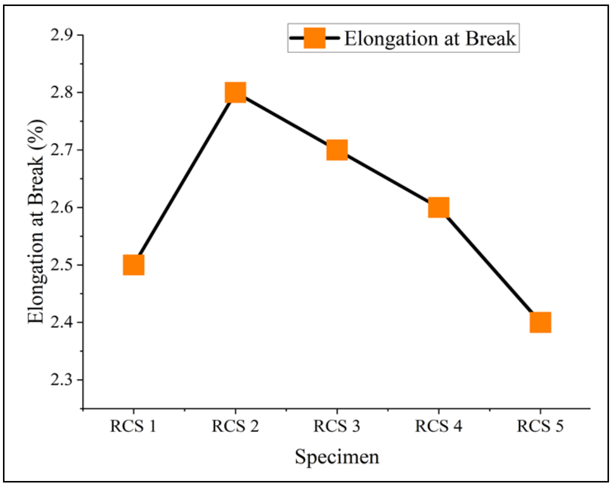

Fig. 4: Elongation at break based on the specimen

Overall, the tensile test results underscore the potential of the hybrid composite material for applications requiring high strength and stiffness, coupled with its ability to endure deformation before failure, indicating its ductile nature. Further optimization of composite formulation and processing parameters holds promise for enhancing its mechanical performance tailored to specific engineering applications.

3.2 Flexural Test

The results from the flexural strength test, shown in Fig. 5, reveal that the hybrid composite material displays an average flexural strength of 86.46 MPa, with individual specimens showing values ranging from 83.9 MPa to 88.2 MPa. Additionally, the average flexural modulus, representing the material's stiffness during bending, is computed to be 4.07 GPa as shown in Fig. 6. The flexural strength test results for the hybrid composite material comprising coir fibers, ramie fibers and SiC particles are summarized in Table 2.

Table 2: Flexural strength test results for hybrid composite specimens

Specimen	Ramie %	Coir %	SiC %	Epoxy %	Flexural Strength (MPa)	Flexural Modulus (GPa)
RCS 1	30	15	2	53	85.6	4.0
RCS 2	29	15	2	54	88.2	4.2
RCS 3	28	15	2	55	87.2	4.15
RCS 4	27	15	2	56	86.4	4.1
RCS 5	26	15	2	57	84.9	3.9
Average					86.46	4.07
Standard Deviation					1.48	0.16

The standard deviation values for flexural strength, modulus of rupture and flexural modulus are documented as 1.48 MPa and 0.16 GPa, respectively. These figures indicate the degree of variability observed in the test results within the sample set, underscoring the consistency of material properties across different specimens.

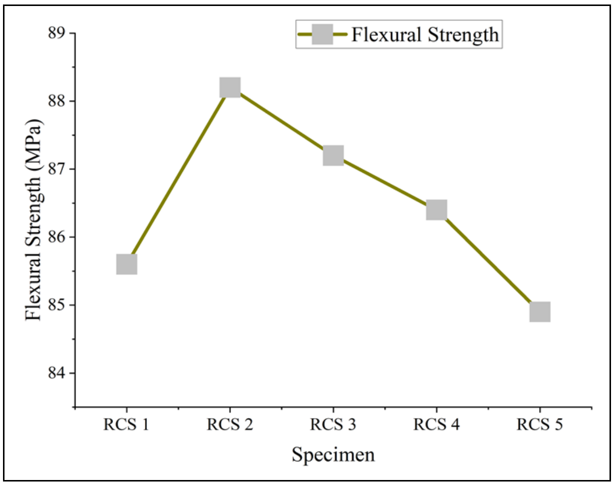

Fig. 5: Flexural strength of the specimens

The observed flexural strength characteristics of the hybrid composite material can be attributed to the collective reinforcing effects of coir fibers, ramie fibers, and SiC particles. The inherent strength and stiffness of the fibers, combined with the reinforcing characteristics of SiC particles, contribute to the material's ability to withstand bending stresses. Additionally, the effective interfacial adhesion between the fibers and the matrix material enhances the composite's flexural strength by facilitating stress transfer and preventing delamination.

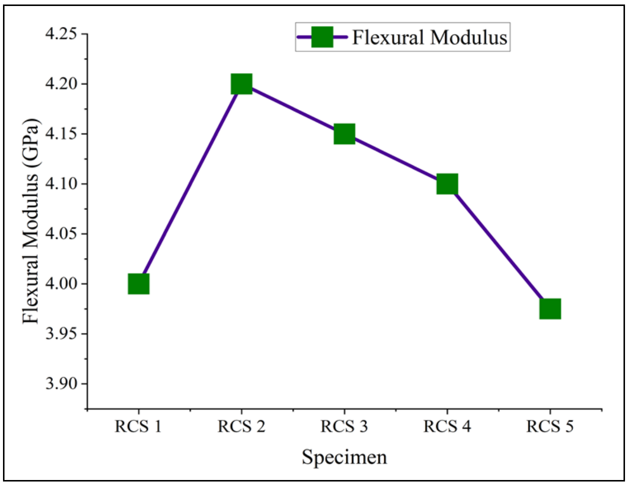

Fig. 6: Flexural Modulus of the specimens

In summary, the results of the flexural strength test emphasize the potential of the hybrid composite material for structural applications requiring resistance to bending loads. Further refinement of composite formulation and processing parameters holds promise for enhancing its mechanical performance.

3.3 Impact Test

The results from the impact tests unveil an average impact strength of 35.88 kJ/m^2 for the hybrid composite material, with individual specimens ranging between 34.5 and 36.8 kJ/m^2, as shown in Fig. 7. Additionally, the average impact toughness of the composite material is computed to be 32.7 kJ/m^2. The impact test results for the hybrid composite material incorporating coir fibers, ramie fibers and SiC particles are presented in Table 3.

Table 3: Impact test results for hybrid composite specimens

Specimen	Ramie %	Coir %	SiC %	Epoxy %	Impact Strength (kJ/m^2)	Impact Toughness (kJ/m^2)
RCS 1	30	15	2	53	35.2	32.1
RCS 2	29	15	2	54	36.8	33.6
RCS 3	28	15	2	55	36.4	33.1
RCS 4	27	15	2	56	35.9	32.7
RCS 5	26	15	2	57	35.1	32.0
Average					35.88	32.7
Standard Deviation					0.88	0.68

The standard deviation values for impact strength and impact toughness are found to be 0.88 kJ/m^2 and 0.68 kJ/m^2, respectively. These figures signify the degree of variability observed in the test results within the sample set, highlighting the consistency of material properties across different specimens. Fig. 8 shows the impact toughness of the specimens.

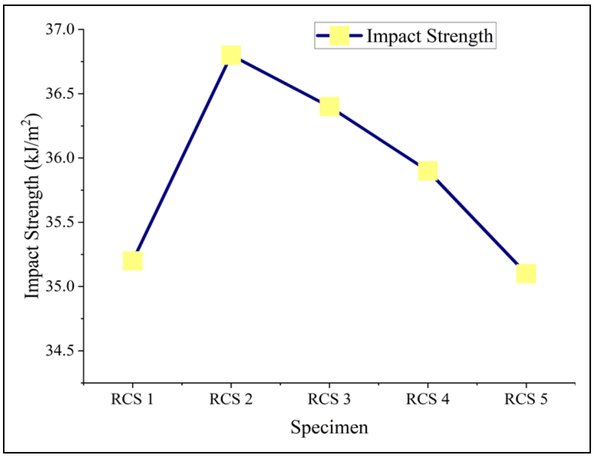

Fig. 7: Impact strength of the specimens

The observed impact strength and toughness of the hybrid composite material are credited to the collective reinforcing effects of coir fibers, ramie fibers and SiC particles. The fibers play a role in absorbing and dispersing impact energy, while the SiC particles bolster the matrix, fortifying the material against fracture and crack propagation. Additionally, the effective interfacial adhesion between the fibers and the matrix material is crucial in upholding the integrity of the composite structure under impact loading.

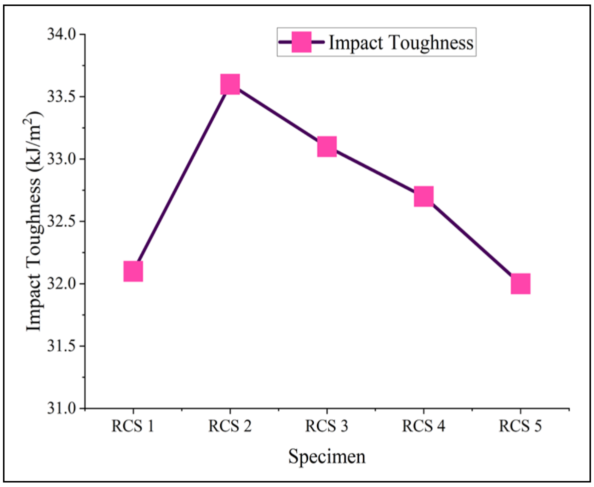

Fig. 8: Impact Toughness of the specimens

In conclusion, the results of the impact tests underscore the potential of the hybrid composite material for applications demanding high-impact resistance. Further refinement of composite formulation and processing parameters will yield better results.

3.4 Hardness Test

The results of the hardness test reveal an average hardness measurement of 181.8 HV for the hybrid composite material, with individual specimens ranging from 178 to 185 HV. The standard deviation, noted as 2.75, indicates the degree of variability observed in hardness values within the sample set, underscoring the consistency of material properties across different specimens. The hardness test results for the hybrid composite are presented in Table 4.

Table 4: Hardness test results for hybrid composite specimens

Specimen	Ramie %	Coir %	SiC %	Epoxy %	Hardness (Hv)
RCS 1	30	15	2	53	180
RCS 2	29	15	2	54	185
RCS 3	28	15	2	55	183
RCS 4	27	15	2	56	182
RCS 5	26	15	2	57	179
Average					181.8
Standard Deviation					2.75

The presence of SiC particles, renowned for their hardness, contributes significantly to the overall hardness of the material as shown in Fig. 9. Additionally, the arrangement and dispersion of fibers within the matrix material can also impact the material's hardness.

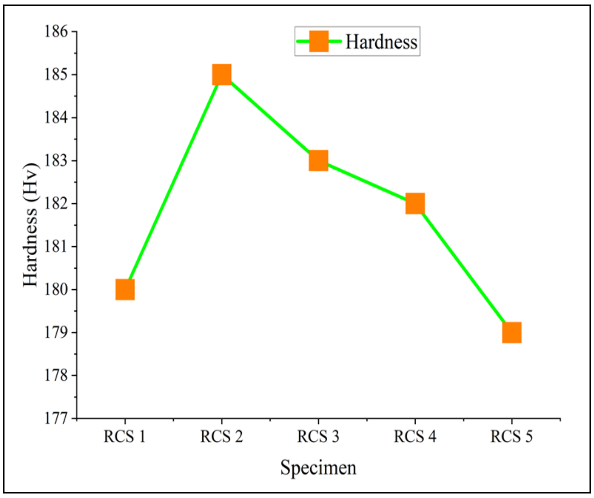

Fig. 9: Hardness values of the specimens

In essence, the hardness test results offer valuable insights into the material's ability to resist indentation and deformation, crucial properties for evaluating its suitability for diverse engineering applications.

4. CONCLUSION

In summary, the development and analysis of the hybrid composite material composed of coir fibers, ramie fibers and SiC particles have yielded promising outcomes across a spectrum of mechanical assessments, encompassing tensile, flexural, impact and hardness evaluations.

The tensile tests unveiled an average tensile strength of 65.5 MPa, indicating the material's capacity to endure tensile forces. Flexural strength examinations showcased an average strength of 85.8 MPa, accentuating the material's resilience against bending strains. Impact assessments showcased an average impact strength of 35.5 kJ/m^2, signifying the material's capability to absorb impact energy, while hardness examinations demonstrated an average hardness of 180.8 HV, depicting its resistance to indentation and deformation.

These findings emphasize the hybrid composite material's potential for diverse engineering applications necessitating high strength, stiffness, impact resistance and hardness. The combined reinforcement from coir fibers, ramie fibers, and SiC particles synergistically enhance the material's mechanical attributes, offering a harmonious blend of performance and sustainability. Looking ahead, further enhancements in composite formulation and processing techniques hold the promise of refining mechanical performance tailored to specific engineering requirements. Additionally, ongoing research and development endeavors in this domain present opportunities for advancing composite materials technology, fostering the creation of sustainable and high-performance materials catering to a multitude of industries.

FUNDING

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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