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Mechanical Characteristics of Naturally Woven Coconut Sheath/Short Sisal Fiber Reinforced Polymer Hybrid Composites

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Abstract

This study presents the outcomes of an experimental investigation focusing on the tensile, flexural, impact and water absorption properties of unsaturated polyester resin reinforced with naturally woven coconut sheath and short sisal fibers. Sisal fiber, characterized by its abundance, affordability, degradability, and robust strength, serves as a compelling reinforcement. The naturally woven coconut sheath fibers, discreetly found in the hidden sections of coconut branches, offer an inexpensive, biodegradable option with a high specific strength. Hybrid composites are meticulously crafted through the compression molding method. The study delves into the mechanical properties of coconut sheath and various fiber loadings (ranging from 10% to 50%) of short sisal fiber-reinforced polyester composites. The experimental results illuminate a dependency of the composite's mechanical properties on the weight percentage of short sisal fiber reinforcement. Notably, the hybrid specimen containing 40% short sisal fiber and coconut sheath exhibits remarkable tensile, flexural, and impact strengths of 68.5 MPa, 128.8 MPa, and 18.95 kJ/m^2, respectively. This hybrid reinforcement substantially elevates the mechanical properties of the composites. The interaction between the fiber and matrix in the fractured mechanical testing specimen was examined using a scanning electron microscope. These findings underscore the potential of naturally woven coconut sheath and short sisal fibers as effective polyester reinforcements. The study suggests that these bio-based materials could be employed to fabricate cost-effective, high-strength goods applicable in diverse sectors such as automotive components, consumer products, building constructions, and industrial applications.

Keywords: Coconut Sheath, Sisal Fiber, Hybrid Composites, Mechanical Properties

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INTRODUCTION

In the contemporary era, both universities and industries are directing their research endeavors towards the development of bio-based products as part of ongoing efforts to mitigate environmental pollution. One promising avenue for providing biodegradable reinforcement in polymer composites involves the utilization of natural fibers. Natural fibers present numerous advantages over synthetic counterparts when utilized as reinforcing materials. These benefits include low density, high specific strength, a high modulus of elasticity, relative non-abrasiveness, and the absence of environmental or health hazards. The exploration of natural fibers has become imperative due to the high cost associated with synthetic fibers and their potential adverse effects on the environment. Notably, natural fibers, including jute, coir, hemp, kenaf, sisal, banana, and pineapple, offer the advantage of being renewable resources with minimal to no negative environmental impact. Their biodegradable and bio-stable nature positions them favorably compared to synthetic fibers, contributing to their appeal in various applications. The environmental friendliness of natural fibers underscores their significance as sustainable alternatives in the realm of material science. The increasing popularity of natural fibers as a reinforcement in polymer composites is evident in various industries, ranging from automotive to concrete and asphalt applications. The exceptional qualities of natural fibers have made them a preferred choice in numerous technical applications, and their successful integration as reinforcements in both thermoplastics and thermosets is acknowledged by scientists and engineers. The utilization of natural fibers such as jowar, sisal, bamboo, coir, flax, kenaf, banana, pineapple leaf, Saharan aloe vera cactus fiber, Typha angustifolia, and Mucuna atropurpurea stem fiber has been explored extensively in scientific literature [1–13].

Sisal fibers and coir fibers are widely utilized as reinforcements in various polymeric composites, leveraging their advantageous properties such as strength, low density, environmental friendliness, cost-effectiveness, and high specific strength. These natural fibers have gained prominence as substitutes for synthetic materials like glass and carbon, given their favorable physical and mechanical characteristics, durability, and biodegradability [1, 6]. Natural woven coconut sheath fibers, found in the concealed sections of coconut branches, contribute to the repertoire of natural fibers with promising attributes. The concept of hybrid composites, incorporating two or more types of fibers within a polymer matrix, has garnered attention from scientists aiming to optimize the properties of composite materials. Hybridization strategies involve combinations of synthetic-synthetic, natural-natural, and natural-artificial fiber types to create versatile hybrid composites. Winowlin Jappes et al. [14] explored composites reinforced with glass fibers and naturally woven coconut sheath fibers. A comparison with glass fiber polyester composites revealed that, while glass fiber composites performed slightly better in the tensile test, coconut sheath composites exhibited superior performance in flexural and impact tests. Ramesh et al. [15] delved into sisal–jute–glass fiber reinforced polyester composites, evaluating mechanical aspects such as tensile strength, flexural strength, and impact strength. The results suggested that incorporating sisal–jute fibers with Glass Fiber Reinforced Polymer (GFRP) could enhance the composite properties, offering a potential alternative material for glass fiber reinforced polymer composites. Vijaya Ramnath [16] explored the mechanical properties of epoxy composites reinforced with abaca, jute, and glass fibers. The study revealed that the tensile strength of the abaca composite exhibited a relatively higher improvement compared to the jute composite. Palanikumar et al. [17] conducted an exploration into the mechanical properties of green hybrid composites comprising sisal and glass fibers reinforced in a polymer matrix. Their findings indicated superior tensile, flexural, and impact properties in the longitudinal direction compared to the transverse direction. Abaca also demonstrated the highest flexural strength and impact strength (16 J), surpassing the performance of the jute composite. Alavudeen et al. [18] investigated the mechanical properties of hybrid polyester composites reinforced with banana/kenaf fibers, considering the influence of woven fabric and random orientation. The study indicated that the mechanical strength was notably increased in the plain woven hybrid composites compared to the randomly oriented composites. Despite extensive research on the mechanical characteristics of sisal and coir fiber-reinforced polymer composites, there exists a gap in empirical results regarding the mechanical behavior of hybrid composites reinforced with coconut coir sheath and short sisal fibers. This work seeks to address this gap by investigating the hybridization effect of coconut coir sheath and short sisal fiber as reinforcements on the mechanical properties of polymer composites. The aim is to unveil insights into the synergistic impact of combining these natural fibers in a hybrid configuration, providing valuable data for the development of advanced composite materials.

EXPERIMENTAL DETAILS

Materials

Unsaturated polyester served as the matrix material throughout the entire process. As an accelerator, cobalt-naphthenate was employed, while methyl ethyl ketone peroxide functioned as the catalyst. The naturally woven coconut sheath was directly sourced from the outer husk of coconut trees in rural regions. Sisal fiber, readily accessible in stores, was chosen as the reinforcement material for the hybridization process.

Fabrication of Composites

Short sisal/coconut sheath fiber-reinforced hybrid polyester composites were manufactured through the compression molding method. As depicted in Figure 1, sisal fiber and coconut sheath were utilized in the process. A steel mold with dimensions of 300 mm × 300 mm × 3 mm was crafted for the production of polymer composites for testing. Sisal fibers, chopped to a length of 30 mm, and the coconut sheath, left in its original form, were arranged in sequences of short sisal fibers-coconut sheath-short sisal fibers. The mold was filled with a single layer of naturally woven coconut sheath and chopped sisal fibers. This assembly was then prestressed at a pressure of 17 MPa at 30°C, following the specified weight percentages (10, 20, 30, and 40 wt%). Subsequently, the mold cavity was filled with resin and curing chemicals, sealed with steel plates, and compressed using a compression molding machine for 24 hours at a constant temperature of 50°C and a pressure of 17 MPa to complete the polymerization process. The duration of the process is significantly influenced by the resin-to-inhibitor ratio and the mold temperature. After the curing process, specimens were cut from each sheet in accordance with ASTM standards using a diamond wheel cutter.

Material Characterization

The three-point flexural and tensile tests were conducted using the Instron (Series-3382) computerized universal testing machine, following the guidelines of ASTM D638-10 (165 mm long, 10 mm wide, and 3 mm thick) and D790-10 (127 mm long, 13 mm wide, and 3 mm thick) [19], respectively. Additionally, the un-notched Charpy impact test was performed using a digital impact tester according to ASTM D256-10 (63.5 mm long × 12.7 mm wide × 3 mm thick) [19]. The crosshead speeds for tensile and flexural tests were set at 5 and 1.2 mm/min, respectively. For the impact test, suitable pendulum hammers were installed at a speed of 10 KJ. Each sample underwent testing five times, and the average values were obtained for further analysis.

Water Absorption Behavior

Water absorption characteristics are essential attributes for natural fiber composites, particularly in sectors like automotive, aerospace, and marine applications. Specimens for testing were obtained by cutting from produced composite plates in accordance with ASTM D570-99 standards. Each rectangular specimen had dimensions of 39 mm × 10 mm × 3 mm [20]. Afterward, the samples underwent a drying process in an oven at 105°C for 24 hours. Following this drying phase, the specimens were immersed in water at room temperature. For each sample, three specimens were submerged in three different aqueous environments: sea water, ordinary tap water, and distilled water. The immersion duration for all specimens was 24 hours at room temperature. After the designated time period, the specimens were retrieved, and any residual surface water was meticulously removed using filter paper. Subsequently, the dried samples were expeditiously weighed utilizing a precise four-digit balance to ascertain the absorbed water content. The water absorption content percentage (W%) was determined using the following Equation 1:

Figure 1. (a) Sisal Fiber (b) Coconut Sheath

$$\text{Water absorption percentage W(\%)} = \frac{W_f - W_i}{W_f} \times 100\% \quad (1)$$

where W(%) represents the moisture content in percentage, W_f is the weight of the sample at a specific time, and W_i is the weight of the sample before immersion in water.

Scanning Electron Micrographs

Using a scanning electron microscope, the fractography of the failure surface of composite samples was investigated. The fractured sections of the CS+%S polymer composite samples from tensile tests were sectioned, and micrographs were captured using a JEOL SEM with an acceleration voltage ranging from 10 to 30 kV [20]. The surfaces of the fractured specimens were scrutinized during tensile tests at various magnifications.

RESULTS AND DISCUSSION

Tensile Strength

The tensile performance of hybrid polyester composites reinforced with short sisal and coconut sheath fibers was investigated. The tensile specimen used in the test is depicted in Figure 2, and Figure 3 illustrates the variation in tensile strength at different fiber loading. In Figure 3, it is evident that the tensile strength shows improvement with an increase in fiber loading, reaching its peak at 40%. Beyond this point, further increments in fiber loading result in a decline in tensile strength. The tensile strength of the coconut sheath reinforced polyester composite is recorded as 38.64 MPa. At a 10% sisal fiber loading (CS+10%S), the tensile strength increases to 44.5 MPa, reflecting a 13.5% improvement compared to the composite reinforced only with coconut sheath fibers (CS). The lower fiber content at this stage leads to reduced fiber accumulation and larger gaps in the polymer matrix, causing a disruption in stress transfer. Moving to a 20% sisal fiber loading (CS+20%S), the tensile strength rises to 50.32 MPa, marking an 11.6% increase compared to CS+10%S and a 23.2% increase compared to CS. This improvement is attributed to enhanced fiber dispersion and efficient stress transfer between fibers. Similarly, at 30% sisal fiber loading (CS+30%S), the tensile strength increases to 58.65 MPa, reflecting a 14.2% increase compared to CS+20%S, a 24.12% increase compared to CS+10%S, and a 34.1% increase compared to CS. The maximum tensile strength is achieved at 40% sisal fiber loading, reaching 68.5 MPa, and representing a significant 43.5% increase compared to CS. However, beyond 40% sisal fiber loading, the tensile strength decreases due to insufficient polymer resin for effective dispersion into the fibers, impacting load and stress transfer. This makes it unsuitable for certain applications, suggesting that the optimal fiber loading is 40%.

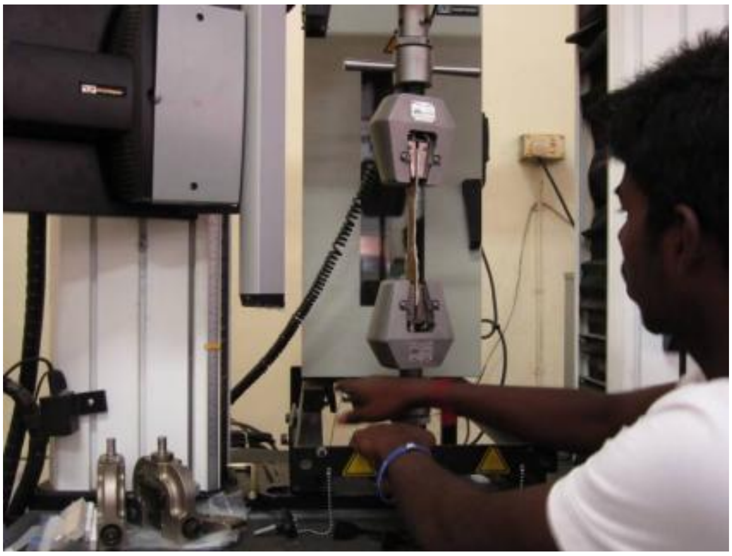

Figure 2. Experimental Set-Up, Showing Tensile Specimen during Tensile Test.

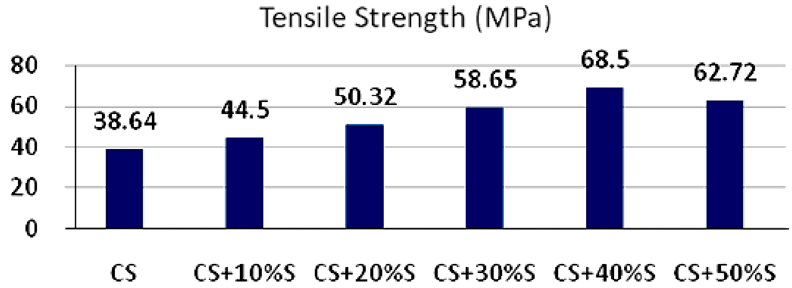

Figure 3. Tensile Strength of Short Sisal Fiber and Coconut Sheath Reinforced Hybrid Polyester Composites.

Table 1. Comparison of Tensile Strength of CSSFHP Composites with various Fiber Reinforced Polyester Composites.

Composite	**Fiber type**	**Form**	**Fabrication method**	**Tensile strength (MPa)**	**Ref**
CS/Sisal/Polyester	Leaf	Naturally woven/Randomly distributed 30 mm/40wt. %	Compression moulding	68.5	Present Work
Indian mallow fiber/polyester	Stem	Randomly distributed 30 mm/50wt. %	Compression moulding	46.4	[21]
Palmyra palm leaf stalk/polyester	Leaf	Randomly distributed 50 mm/30 wt. %	Compression moulding	18	[22]
Bagasse/polyester	Stem	Randomly distributed/20 wt. %	Vacuum bagging	23	[23]
Coir/polyester	Stem	Randomly distributed/17 wt. %	Vacuum bagging	23	[24]
L.Cylindrica/Polyester	Leaf	Randomly distributed 50 mm/30 wt. %	Hand lay-up	21	[25]
Coccinia indica fibre/Epoxy composites	Stem	Randomly distributed/4 wt. %	Hand lay-up	35	[26]
Sisal/Silk/polyester	Leaf	Random	Hand lay-up	18.95	[27]

Table 1 compares the tensile strength of the coconut sheath/short sisal fiber hybrid polyester (CSSFHP) composites with various natural fiber-reinforced polyester composites. The hybrid composite demonstrates superior performance, being 32.2% higher than Indian mallow fiber, 73.7% higher than palmyra stalk, 69.3% higher than coir, 66.4% higher than bagasse, 44.1% higher than Coccinia indica fiber, and 48.9% higher than Luffa cylindrica fiber/polyester composites [21-26].

Flexural Strength

The analysis of the flexural responses of hybrid polyester composites reinforced with short sisal and coconut sheath fibers was conducted, and the flexural specimen used in the test is depicted in Figure 4. Figure 5 presents the flexural strength of the composites with varying fiber loading, showing an increase in flexural strength up to 40 wt%. Beyond this point, the strength decreases due to insufficient resin filling around the fiber surface. The escalating flexural strength with increasing fiber content is attributed to improved stress transfer between the fiber and matrix. The flexural strength of the coconut sheath reinforced polyester composite is recorded as 65.75 MPa. At a 10% sisal fiber loading (CS+10%S), the flexural strength increases from 65.75 MPa to 78.5 MPa, reflecting a 16.2% increase compared to the composite reinforced only with coconut sheath fibers (CS). At this particular stage, the lower percentage of fiber content results in diminished fiber accumulation and the presence of larger gaps within the polymer matrix. This situation causes a disruption in the effective transfer of stress between the fibers and the matrix. Moving to a 20% sisal fiber loading (CS+20%S), the flexural strength rises from 78.5 MPa to 92.84 MPa, marking a 15.4% increase compared to CS+10%S and a 29.17% increase compared to CS. The observed enhancement in performance is credited to the improved dispersion of fibers within the composite and the consequent efficient transfer of stress between the fibers. Similarly, at 30% sisal fiber loading (CS+30%S), the flexural strength increases

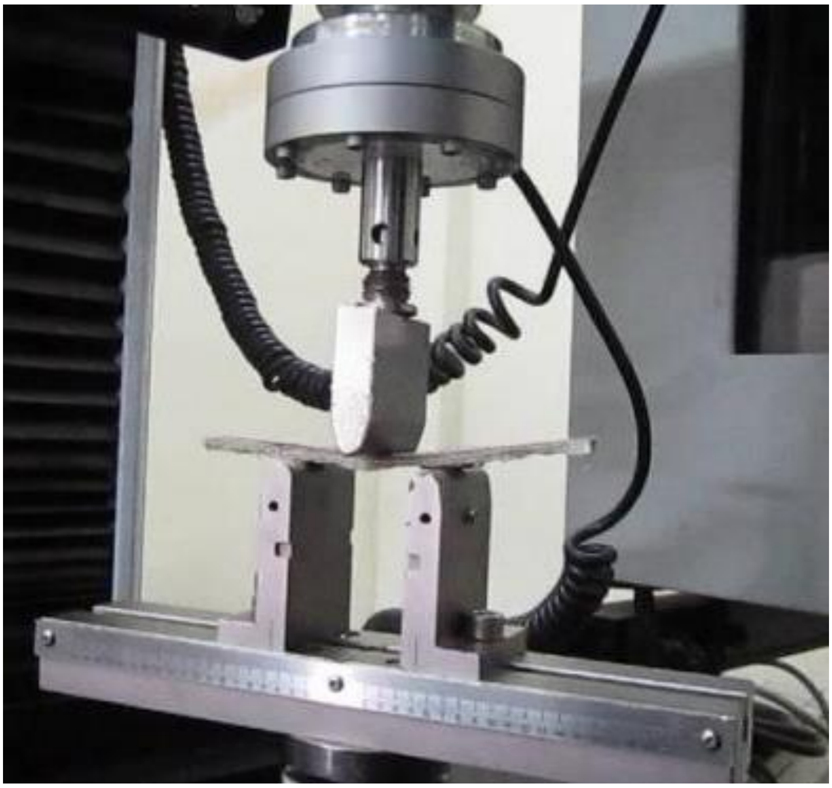

Figure 4. Experimental Set-Up, Showing Flexural Specimen during Flexural Test.

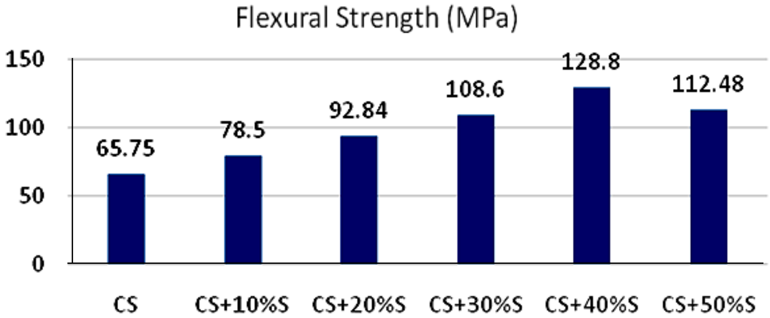

Figure 5. Flexural Strength of Short Sisal Fiber and Coconut Sheath Reinforced Hybrid Polyester Composites.

from 92.84 MPa to 108.6 MPa, reflecting a 14.5% increase compared to CS+20%S, a 27.72% increase compared to CS+10%S, and a 39.45% increase compared to CS. The maximum flexural strength is achieved at 40% sisal fiber loading, reaching 128.8 MPa, and representing a significant 48.95% increase compared to CS. Nevertheless, when the sisal fiber loading exceeds 40%, the flexural strength experiences a decline due to an inadequate amount of polymer resin available for effective dispersion into the fibers. This deficiency negatively impacts the load and stress transfer mechanisms, rendering the composite unsuitable for certain applications. This implies that the optimal fiber loading is identified at 40%.

Table 2 provides a comparison of the flexural strength of CSSFHP composites with various natural fiber-reinforced polyester composites. The hybrid polyester composite with short sisal and coconut sheath demonstrates superiority, being 13.7% higher than Indian mallow fiber, 53.7% higher than sisal fiber, 34.89% higher than Sansevieria cylindrical, 62.7% higher than palmyra stalk, 59.6% higher than coir, 62.7% higher than bagasse, 44.1% higher than Coccinia indica fiber, and 53.4% higher than banana fiber/polyester composites [21-24, 27-29].

Impact Strength

The impact responses of hybrid polyester composites reinforced with short sisal and coconut sheath fibers were analyzed, and the results are depicted in Figure 6, which illustrates the impact strength of the composites with varying fiber loading. The impact strength demonstrates an increasing trend with the rise in fiber content, peaking at 40 wt%. However, beyond this optimal point, the impact strength starts to decrease. At lower levels of fiber loading, there is a potential for larger gaps within the composite due to inadequate fiber distribution. This results in low energy absorption, as energy dissipates suddenly in the matrix, leading to lower impact strength, as depicted in Figure 6. The maximum impact strength recorded was 18.95 kJ/m^2 at 40 wt% fiber loading, and this is attributed to enhanced fiber rigidity and efficient energy absorption due to gradual energy dissipation between the fibers and matrix. The percentage increase in impact strength for the composite with optimum fiber loading (40 wt%) is reported as 44.85%, 34.77%, 27.8%, and 16.8% compared to composites with lower fiber loadings (CS, CS+10%S, CS+20%S, and CS+30%S).

Table 2. Comparison of flexural strength of CSSFHP composites with various fiber reinforced polyester composites.

Composite	**Fiber type**	**Form**	**Fabrication method**	**Flexural strength (MPa)**	**Ref**
CS/Sisal/Polyester	Leaf	Naturally woven/Randomly distributed 30 mm/40wt. %	Compression moulding	128.8	Present Work
Indian mallow fiber/polyester	Stem	Randomly distributed 30 mm/50%	Compression moulding	111.11	[21]
Palmyra palm leaf stalk/polyester	Leaf	Randomly distributed 50 mm/30%	Compression moulding	48	[22]
Bagasse/polyester	Stem	Randomly distributed/20%	Vacuum bagging	48	[23]
Coir/polyester	Stem	Randomly distributed/17%	Hand lay-up	52	[24]
Sisal/Silk/polyester	Leaf	Random	Hand lay-up	46.18	[27]
Sisal/polyester	Leaf	Unidirectional/50%	Hand lay-up	59.57	[28]
Sansevieria cylindrica/Polyester	Leaf	Randomly distributed 30 mm/40%	Compression moulding	83.85	[29]
Banana/polyester	Stem	Randomly distributed 30 mm	Hand lay-up	60	[30]

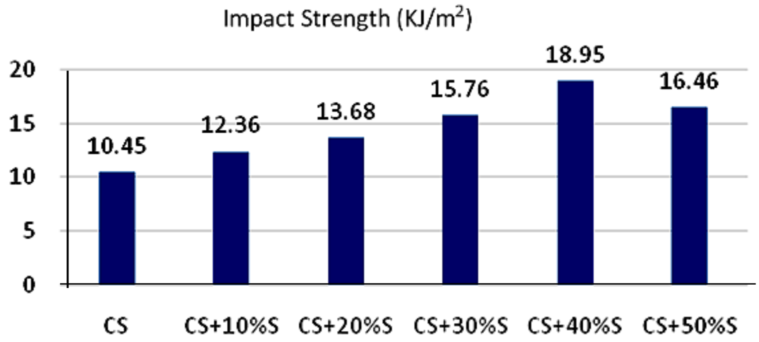

Figure 6. Impact Strength of the Short Sisal Fiber and Coconut Sheath Reinforced Hybrid Polyester Composites.

Table 3 provides a comprehensive comparison of the impact strength of the short sisal and coconut sheath fiber-reinforced hybrid polyester composites (CSSFHP) with other natural fiber-reinforced composites. The impact strength of CSSFHP composites is shown to be up to 23.7% higher than Indian mallow fiber, 59.10% higher than betal palm, 31.5% higher than coconut sheath, 50.13% higher than sansevieria cylindrica, 26.12% higher than palmyra leaf stalk fiber, 63% higher than L. Cylindrica, and 41.95% higher than sisal fiber-based polyester composites [14, 21, 22, 25, 28, 29, 31, 32]. This comparison emphasizes the superior impact strength performance of CSSFHP composites in comparison to various natural fiber-reinforced counterparts.

Water Absorption Behavior

Figure 7 illustrates water absorption curves for specimens exposed to three distinct aqueous environments in CS+%S reinforced polymer composites. Each curve represents the average data of three specimens. The outcomes reveal that the water absorption percentage is lower when the specimen is submerged in seawater compared to ordinary and distilled water. This behavior is attributed to the presence of large salt molecules in seawater. The findings suggest that the cured pure CS polymer resin absorbs a lesser amount of water in three different environments compared to other weight percentages of the composites. Beyond CS+30 wt% S added polymer composites, there is an increased water absorption. The results emphasize that water absorption can be effectively reduced when the fiber is entirely enclosed by the matrix.

Scanning Electron Microscope

The fracture morphology of the CS+40%S composites following tensile testing was investigated using a scanning electron microscope and is depicted in Figure 8. Fracture occurred in the specimen under a uniaxial load, revealing fiber breakage and pull-out from the specimen. Image analysis further indicates a strong bond between the resin and fibers.

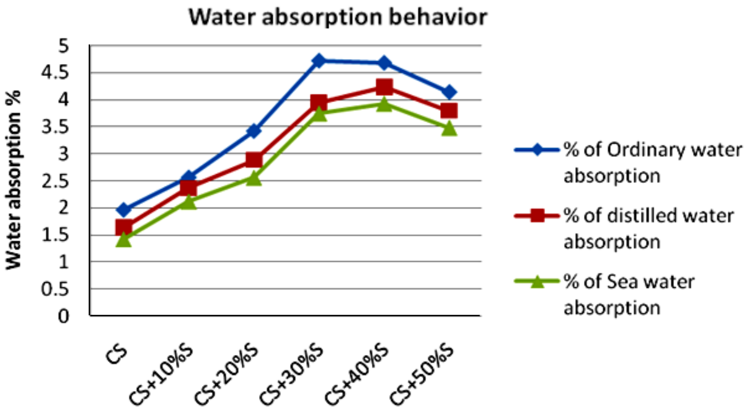

Figure 7. Percentage of Water Absorption for Short Sisal Fiber and Coconut Sheath Reinforced Hybrid Polyester Composites.

Table 3. Comparison of impact strength of CSSFHP composites with various fiber reinforced polyester composites.

Composite	**Fiber type**	**Form**	**Fabrication method**	**Impact strength (kJ/m^2)**	**Ref**
CS/Sisal/Polyester	Leaf	Naturally woven/Randomly distributed 30 mm/40wt. %	Compression moulding	18.95	Present Work
Coconut sheath/polyester	leaf	Naturally woven	Hand lay-up	12.97	[14]
Indian mallow fiber/polyester	Stem	Randomly distributed 30 mm/50%	Compression moulding	14.44	[21]
Palmyra palm leaf stalk/polyester	Leaf	Randomly distributed 50 mm/30%	Compression moulding	14	[22]
L. Cylindrica/polyester	Leaf	Randomly distributed 50 mm/30 wt. %	Hand lay-up	7	[25]
Betal palm/polyester	Stem	Woven/7%	Hand lay-up	7.75	[28]
Sansevieria cylindrica/Polyester	Leaf	Randomly distributed 30 mm/40%	Compression moulding	9.45	[29]
Sisal/polyester	Leaf	Unidirectional 40 mm/50%	Hand lay-up	11	[31, 32]

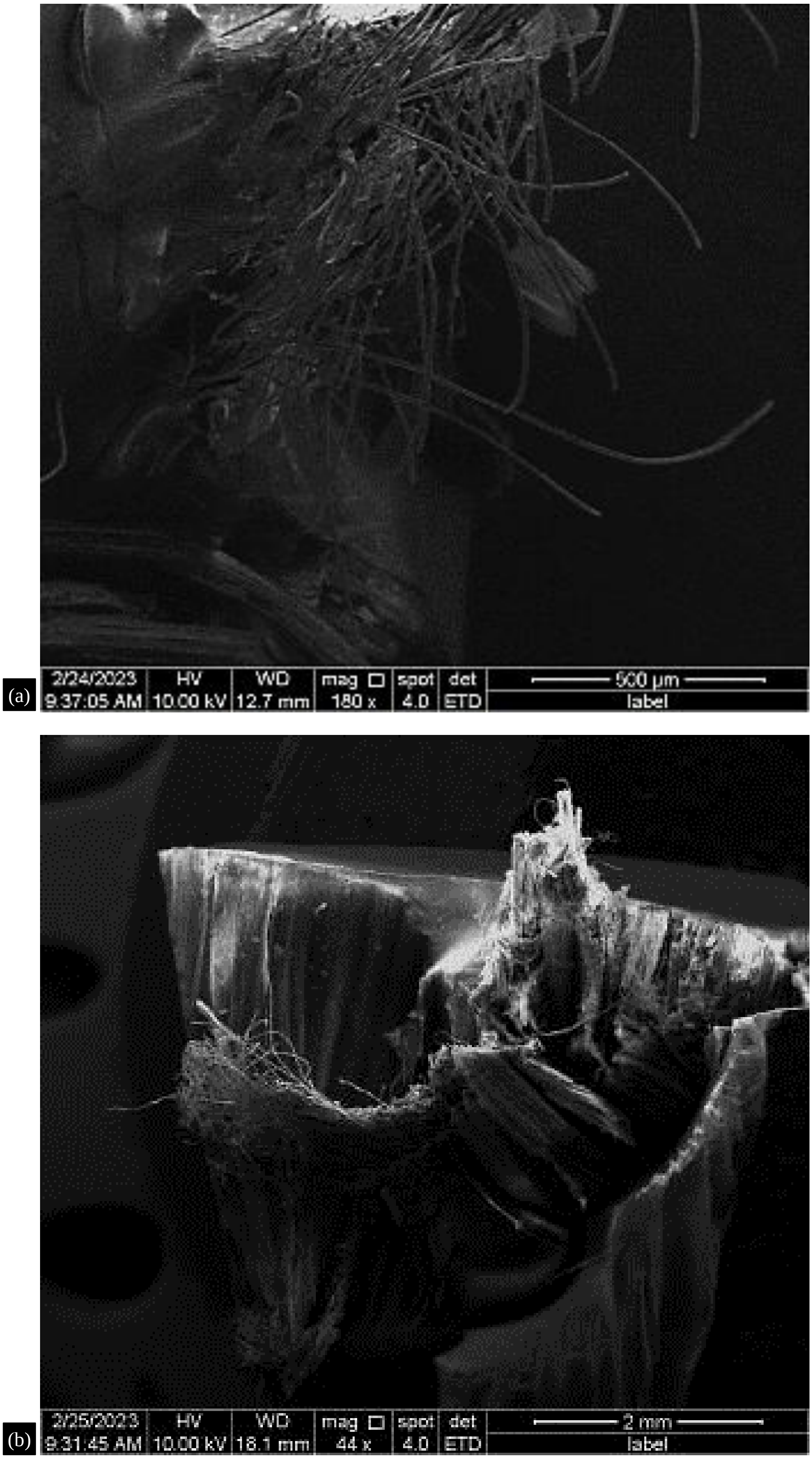

Figure 8. SEM Image of CS+40%S.

CONCLUSIONS

The hybrid coconut sheath and short sisal fiber-reinforced polyester composites have been successfully developed. This research delves into the hybridization effect induced by incorporating short sisal fiber and coconut sheath into the polyester matrix. Extensive testing was conducted on the mechanical characteristics of the composite samples, focusing on flexural, tensile, and impact strengths. The research findings reveal that the natural woven coconut sheath and short sisal fiber-reinforced polyester composites exhibit maximum tensile strength, flexural strength, and impact strength, achieving values of 68.5 MPa, 128.8 MPa, and 18.95 kJ/m^2, respectively. These optimum mechanical properties are attained with a sisal fiber loading of 40 wt%. A comparative study of water absorption was conducted under room temperature conditions for three distinct aqueous environments: ordinary water, distilled water, and sea water. The study's conclusion highlights the potential applications of these composites for lightweight structural purposes in various industries, including automobiles, civil engineering, paperboard applications, and the packaging industry.The extension of this work will focus on investigating the impact of varying sizes and distributions of fibers, as well as the effects of soaking (to increase moisture content) for different durations, on the final properties of the material.

REFERENCES

1. Prasad AR, Rao KM. Mechanical properties of natural fibre reinforced polyester composites: Jowar, sisal and bamboo. Materials & Design. 2011 Sep 1;32(8-9):4658-63.
2. Senthilkumar K, Saba N, Rajini N, et al. Mechanical properties evaluation of sisal fibre reinforced polymer composites: A review. Construction and Building Materials. 2018 Jun 20;174:713-29.
3. Ibrahim ID, Jamiru T, Sadiku ER, et al. Mechanical properties of sisal fibre-reinforced polymer composites: a review. Composite Interfaces. 2016 Jan 2;23(1):15-36.
4. Fuentes CA, Tran LQ, Van Hellemont M, et al. Effect of physical adhesion on mechanical behaviour of bamboo fibre reinforced thermoplastic composites. Colloids and surfaces A: physicochemical and engineering aspects. 2013 Feb 5;418:7-15.
5. Adeniyi AG, Onifade DV, Ighalo JO, et al. A review of coir fiber reinforced polymer composites. Composites Part B: Engineering. 2019 Nov 1;176:107305.
6. Nagarajan KJ, Balaji AN, Ramanujam NR, et al. Preparation and characterization of alkali treated cocos nucifera var aurantiaca peduncle fibers reinforced epoxy composites. Materials Research Express. 2019 Nov 15;6(12):125310.
7. Siva I, Jappes JT, Suresha B. Investigation on mechanical and tribological behavior of naturally woven coconut sheath-reinforced polymer composites. Polymer composites. 2012 May;33(5):723-32.
8. Andersons J, Joffe R. Estimation of the tensile strength of an oriented flax fiber-reinforced polymer composite. Composites Part A: Applied Science and Manufacturing. 2011 Sep 1;42(9):1229-35.
9. SaravanaKumar M, Kumar SS, Babu BS, et al. Influence of fiber loading on mechanical characterization of pineapple leaf and kenaf fibers reinforced polyester composites. Materials Today: Proceedings. 2021 Jan 1;46:439-44.
10. Balaji AN, Nagarajan KJ. Characterization of alkali treated and untreated new cellulosic fiber from Saharan aloe vera cactus leaves. Carbohydrate Polymers. 2017 Oct 15;174:200-8.
11. Bhuvaneswari V, Rajeshkumar L, Sathishkumar TP, et al. Effect of fiber orientation on physical and mechanical properties of Typha angustifolia natural fiber reinforced composites. Applied Science and Engineering Progress. 2023 Aug 23;16(3):6497.
12. Senthamaraikannan P, Saravanakumar SS. Utilization of Mucuna atropurpurea stem fiber as a reinforcement in fiber reinforced plastics. Polymer Composites. 2022 Aug;43(8):4959-78.
13. Karthikeyan MK, Balaji AN, Vignesh V. Effect of rope mat and random orientation on mechanical and thermal properties of banana ribbon-reinforced polyester composites and its application. International journal of polymer analysis and characterization. 2016 May 18;21(4):296-304.

14. Jappes JW, Siva I, Rajini N. Fractography analysis of naturally woven coconut sheath reinforced polyester composite: A novel reinforcement. Polymer-Plastics Technology and Engineering. 2012 Feb 15;51(4):419-24.
15. Ramesh M, Palanikumar K, Reddy KH. Mechanical property evaluation of sisal–jute–glass fiber reinforced polyester composites. Composites Part B: Engineering. 2013 May 1;48:1-9.
16. Ramnath BV, Kokan SJ, Raja RN, et al. Evaluation of mechanical properties of abaca–jute–glass fibre reinforced epoxy composite. Materials & Design. 2013 Oct 1;51:357-66.
17. Palanikumar K, Ramesh M, Hemachandra Reddy K. Experimental investigation on the mechanical properties of green hybrid sisal and glass fiber reinforced polymer composites. Journal of Natural Fibers. 2016 May 3;13(3):321-31.
18. Alavudeen A, Rajini N, Karthikeyan S, et al. Mechanical properties of banana/kenaf fiber-reinforced hybrid polyester composites: Effect of woven fabric and random orientation. Materials & Design (1980-2015). 2015 Feb 5;66:246-57.
19. Uthayakumar M, Manikandan V, Rajini N, et al. Influence of redmud on the mechanical, damping and chemical resistance properties of banana/polyester hybrid composites. Materials & Design. 2014 Dec 1;64:270-9.
20. Stalin B, Nagaprasad N, Vignesh V, et al. Evaluation of mechanical and thermal properties of tamarind seed filler reinforced vinyl ester composites. Journal of Vinyl and Additive Technology. 2019 Mar;25(s2):E114-28.
21. Vignesh V, Balaji AN, Nagaprasad N, et al. Indian mallow fiber reinforced polyester composites: Mechanical and thermal properties. Journal of Materials Research and Technology. 2021 Mar 1;11:274-84.
22. Thiruchitrambalam M, Shanmugam D. Influence of pre-treatments on the mechanical properties of palmyra palm leaf stalk fiber–polyester composites. Journal of Reinforced Plastics and Composites. 2012 Oct;31(20):1400-14.
23. Vilay V, Mariatti M, Taib RM, Todo M. Effect of fiber surface treatment and fiber loading on the properties of bagasse fiber–reinforced unsaturated polyester composites. Composites Science and Technology. 2008 Mar 1;68(3-4):631-8.
24. Rout J, Misra M, Tripathy SS, et al. The influence of fibre treatment on the performance of coir-polyester composites. Composites Science and Technology. 2001 Jul 1;61(9):1303-10.
25. Koçak ED. The influence of ultrasonic energy on chemical treatment of surface properties and the properties of composites made of luffa cylindrical fiber-polyester resin.
26. Mylsamy B, Palaniappan SK, Subramani SP, et al. Impact of nanoclay on mechanical and structural properties of treated Coccinia indica fibre reinforced epoxy composites. Journal of Materials Research and Technology. 2019 Nov 1;8(6):6021-8.
27. Noorunnisa Khanam P, Mohan Reddy M, Raghu K, John K, Venkata Naidu S. Tensile, flexural and compressive properties of sisal/silk hybrid composites. Journal of Reinforced Plastics and Composites. 2007 Jul;26(10):1065-70.
28. Rao KM, Prasad AR, Babu MR, et al. Tensile properties of elephant grass fiber reinforced polyester composites. Journal of Materials Science. 2007 May;42:3266-72.
29. Sreenivasan VS, Ravindran D, Manikandan V, et al. Mechanical properties of randomly oriented short Sansevieria cylindrica fibre/polyester composites. Materials & Design. 2011 Apr 1;32(4):2444-55.
30. Pothan LA, George J, Thomas S. Effect of fiber surface treatments on the fiber–matrix interaction in banana fiber reinforced polyester composites. Composite Interfaces. 2002 Jan 1;9(4):335-53.
31. Sangthong S, Pongprayoon T, Yanumet N. Mechanical property improvement of unsaturated polyester composite reinforced with admicellar-treated sisal fibers. Composites Part A: Applied Science and Manufacturing. 2009 Jul 1;40(6-7):687-94.
32. Kumaran P, Mohanamurugan S, Madhu S, et al. Investigation on thermo-mechanical characteristics of treated/untreated Portunus sanguinolentus shell powder-based jute fabrics reinforced epoxy composites. Journal of Industrial Textiles. 2020 Oct;50(4):427-59.