Hindawi
Advances in Materials Science and Engineering
Volume 2022, Article ID 8099500, 10 pages
https://doi.org/10.1155/2022/8099500

Research Article

Comprehensive Characterization of *Furcraea selloa* K. *Koch* Peduncle Fiber-Reinforced Polyester Composites—Effect of Fiber Length and Weight Ratio

D. Divya,[1] **I. Jenish**,[2] **and S. Raja**[3]

[1]*Research and Development Department, Pinnacle Bio-Sciences, Kanyakumari, Tamil Nadu, Postal Code 629701, India*
[2]*Department of Applied Mechanics, Seenu Atoll School, Hulhu-medhoo, Postal Code 19060, Addu, Maldives*
[3]*Department of Mechanical Engineering, Noorul Islam Centre for Higher Education, Kumaracoil, Tamil Nadu, Postal Code 629180, India*

Correspondence should be addressed to I. Jenish; jenish@satollschool.edu.mv

Received 2 April 2022; Accepted 12 April 2022; Published 10 May 2022

Academic Editor: V. Vijayan

Nowadays, scientists and researchers working on polymer composites are paying much attention to the discovery of prospective plant fibers in order to build a promising fiber-reinforced polymer composite. The present study investigated the efficacy of using a novel *Furcraea selloa* K. *Koch* peduncle fiber in reinforced composites, and the specific composite characterization was done to explore the absolute fiber length and weight ratio to accomplish superior composite properties. For that, peduncle fibers with different length-to-weight ratios were reinforced with unsaturated polyester and the corresponding composites were tested to decide the optimum fiber length-to-weight ratio for obtaining the utmost composite properties. The results indicated that the highest mechanical properties were allied with a composite reinforced with 30 mm fiber length and 30 wt.% with the tensile strength of 103.51 MPa and flexural strength of 144.65 MPa. While the remaining tested volumes showed decreased properties as compared to optimal, which might be due to debonding effects or less interfacial bonding as examined clearly in SEM images of fractured samples. Enhanced thermal stability with 390°C and relatively reduced water absorption rate was observed in the case of optimal range when compared to other testing dimensions. Moreover, the current study confirmed that FSPF composites possess promising comparable properties which would be a good alternative to existing synthetic composites.

1. Introduction

Polymer composites have become more popular in the twenty-first century because of the increasing depletion of conventional reserves and the excellent specific features of such polymeric composites. A variety of industrial sectors, including automotive, sports, aircraft, marine, oil, and construction, now use polymer composite materials extensively. Despite the lightweight nature, such materials have been gaining much attraction in the global market to replace traditional materials such as aluminum, steel, etc. A reinforcing phase and a matrix are often blended together to form composite materials, which are not soluble in each other, that offer incorporated properties of two or more classes of materials while using together, thereby making them more versatile. The natural plant fibers can be cast-off in the reinforcement phase to frame biopolymeric composites; which has more attention today. Such plant fiber reinforced-polymer composites showed good strength, stiffness, thermal stability, and other mechanical properties since that can be used as an alternative to conventional materials [1, 2].

There is a great deal of interest in fiber-yielding plants since they may be easily accessed and renewed for sustainable composite fabrication without creating any environmental issues. As compared to conventional sources, their processing and handling are easy and need little investment only. Natural plant fiber composites need an overall manufacturing cost of 20 to 40% in contrast to synthetic fibers, which makes them a cost-effective alternative to traditional materials. Additionally, biodegradability, recyclability, and favorable environmental impacts of plant fibers compete with the properties of conventional nonrenewable materials. Hence, the identification of novel plant fibers with significant specific properties is a need of the hour [3]. Matrixes or polymers are long-chain molecules made up of atoms linked together by strong bonds in a repeating pattern. Polyesters are one of the thermoset polymers, which contain strong covalent bonds and can offer good interfacial bonding with fibers, as reported in earlier [4, 5]. Thus, the current study tried to explore a potential novel fiber reinforced unsaturated polyester composites.

The performance of composite is usually affected by a variety of variables. Interfacial adhesion between the reinforcement and matrix is heavily influenced by the type of constituent materials, its dimensions, and distribution. Although, the interface area, texture, and strength of the whole composite material are governed by the reinforcement's size and orientation [6, 7]. Mainly, the age of the plant and position of the fiber in plants determines the mechanical characteristics of fibers. Since, the determination of appropriate fiber loading rate is having paramount importance in fiber research. A few investigations were done on the same aspect to explore the critical fiber length and weight percentage earlier, which disclosed that the fiber lengths ranging from 30 mm to 40 mm and fiber content ranging from 30 wt.% to 40 wt.% provided better mechanical properties. However, these properties vary with natural plant fibers obtained from different sources. Hence, the identification of suitable length or size and volume (weight fraction) of reinforcement is an adequate step in composite research studies to assure maximum strength of the material [8]. Diverse studies carried out earlier for the investigation of natural fibers by varying weight and loading on polymer composites are summarized in Table 1.

In this study, a peduncle fiber extracted from *Furcraea selloa* K. *Koch* (FSPF) was employed for the first time in composite manufacturing. The main aim of this study was to explore the potentiality of FSPF as a reinforcement in polyester composites and to optimize a standard length to weight ratio of fiber for effective composite fabrication. Composites with varied fiber lengths to weight ratio were experienced to optimize the flexural, impact, hardness, and tensile properties of the composite. Fractography analysis was conducted to examine the interfacial adhesion property of the fractured surface. The water absorption analysis and thermal characterization of the composites were performed to establish the processability of specific composite in diverse environmental conditions.

2. Experimental Details

2.1. Materials. Furcraea selloa K. *Koch* peduncle was collected from the village Asarivilai of Kanyakumari district, Tamil Nadu, India, and used for the extraction of respective fibers through the water retting process. The plant material, fiber extraction process, and extracted fibers and its polyester based composites are presented in Figure 1. The average diameter of the fiber was identified as $94.40 \pm 2.12\,\mu$m. The extracted fibers were cut into appropriate lengths (10 mm, 20 mm, 30 mm, 40 mm, and 250 mm) and employed for composite manufacturing. An unsaturated polyester resin (98 vol.%) was used as a matrix for fiber reinforcement. Methyl ethyl ketone peroxide (MEKP) (1 vol.%) was used as the setting catalyst and cobalt naphthenate (1 vol.%) was cast-off for accelerating curing process, for composite structuring.

2.2. Composite Fabrication. For composite preparation, the unsaturated polyester resin (98 vol.%) was mixed with the curing catalyst MEKP and the accelerator cobalt naphthenate. The physical and chemical properties of the resin was tested in its both solid and liquid forms (Table 2). The composite specimens were made using a mild steel mold that possess dimensions of 300 mm × 125 mm × 3 mm. The hand layup-cum-compression molding technique was used for the fabrication of FSPF fiber reinforced polyester composites. For that, the chopped fibers with desired lengths and weights were evenly dispersed within the mold with utmost care. The resin was then poured over the pre-pressed fibers and then allowed it to infuse into the fiber layers. A grooved roller was used to physically integrate the matrix through the fibers manually without trapping air, and the mixture was then allowed to cure at room temperature under a 400 kN load. There were 26 sets of composite sheets were constructed for composite testing with different fiber lengths (10 mm, 20 mm, 30 mm, 40 mm, and 50 mm) and weight percentage (10%, 20%, 30%, 40%, and 50%) (Figure 1(d)) [19].

2.3. Characterization of FSPF Reinforced Composites. The obtained composite plates were used to prepare test specimens as per ASTM standards for further characterization. Then, the specimens were subjected for evaluation of its mechanical properties such as tensile strength, flexural strength, impact strength, and hardness features. For analyzing degradation behavior, the water uptake test was opted. The thermal behavior and fractography analysis were performed to recognize the thermal stability and fracture mechanics of specific composites. Conversely, the fractured surface of the composites was also examined [9].

2.4. Mechanical Characterization. For tensile testing, samples with 100 mm gauge length were prepared according to the ASTM *D* 3039 M-95 standard and the tests were executed in an Instron S-series H25K–S UTM (H25 K–S, S-Series, USA). Conversely, a three-point flexural test was performed in the same machine for the samples with 30 mm gauge length, where the samples are prepared as per ASTM *D* 790–10 standard to analyze flexural strength of composites. A transverse speed of 1 mm/min was admirable for conducting both the tests. The energy absorption capacity of the material was evaluated by conducting an Izod impact test (ASTM *D* 256–10) and the hardness property was determined by using a Digital Rockwell hardness testing machine by means of the ASTM D785-98 standard [20].

Table 1: Listing the properties of *Furcraea selloa* K. *Koch* peduncle fiber/polyester composite in comparison with other natural fiber reinforced composites.

Fiber	Matrix	Method	Optimum fiber		Tensile strength MPa	Tensile modulus GPa	Flexural strength MPa	Flexural modulus GPa	Impact strength J/cm^2	Hardness (HRRW)	Reference
			Length mm	Loading %							
Furcraea selloa K. *Koch* peduncle fiber	Polyester	Compression molding	30	30	103.5	2.35	144.65	2.93	10.08	92	Present work
Cymbopogon flexuosus stem	Polyester	Hand layup	40	30	84.773	1.310	93.53	1.87	10.1	90	[9]
Tamarind fruit fiber	Polyester	Compression molding	50–100	40	77.4	1.4	88.5	1.5	7.3	90	[10]
Sansevieria cylindrica fiber	Polyester	Compression molding	30	40	75.75	1.102	84	3	9.5	—	[11]
Cissus quadrangularis stem	Polyester	Hand layup	40	30	90.200	1.400	103.040	2.250	10.7	92	[12]
Red banana peduncle fiber	Polyester	Compression molding	300–400	—	11.61	—	2	—	4.6	—	[13]
Sisal fiber	Epoxy	Hand layup	10	30	40.25	0.187	104.78	11.896	1.366	—	[14]
Calotropis procera fiber	Epoxy	Hand layup	30	30	11.43 ± 0.06	—	26.38 ± 0.47	—	0.167	—	[15]
Jute fiber	Epoxy	Hand layup	30	20	75.15	0.638	124.01	2.61	3.25	—	[16]
Coconut coir fiber	Epoxy	Hand layup	30	30	13.05	2.064	35.42	—	1.75	16.9 (hv)	[17]
Calotropis gigantea	Epoxy	Hand layup	0.149–0.100	10	48.73		195.19		6.34	67	[18]

(a) (b) (c)

(d)

Figure 1: Photographs of (a) *Furcraea selloa* K *Koch* plant with peduncle; (b) Peduncle under microbial degradation process; (c) Extracted fibers; and (d) FSPF reinforced composite at different weight percentages.

2.5. Thermal Analysis. The thermal stability of the selected optimal composite was evaluated by thermogravimetric analysis (TGA/DTG) to find out the suitability of composite for higher temperature required functioning. This test was executed in a thermal analyzer model Jupiter STA 449 F3 under nitrogen (20 ml/min) having an environment with a frequent increase in temperature by 10°C/minute, from 28 to 1000°C [1]. The mass changes in the material were recorded with respect to the time and used to assess the thermal stability of composites.

2.6. Water Uptake Test. Water absorption characteristics of the square composite specimens with 30 mm size with different weight percentage (10–50%) (ASTM *D* 570–98) were studied by immersing composite specimens in water along with a polyester sample, for varied time intervals from 0–24 hours [13]. The percentage of water absorption was calculated by weighing the specimens before and after conducting test by employing a 10^{-4}g accuracy electronic mass balancer (model AUX220; Shimadzu, Japan) as per the following (1). In this relation, w_0 denotes the specimen's weight before immersion (mg) and 'w_t' symbolizes the specimen's weight after a specified duration of immersion in water (mg) [21].

Table 2: Properties of liquid and cured polyester resin utilized to prepare composites.

Liquid resin	
Acid value	25 mg KOH/g ± 3 mg KOH/g
Appearance	Yellow coloured viscous liquid
Density	1.25 ± 0.10 gm/cc
Specific gravity at 25°C	1.20 ± 0.02
Viscosity at 25°C	200–300 cP
Volatile content	37 wt.% ± 2 wt.%
Cured resin	
Elongation at break	1.20% ± 0.24%
Flexural modulus	1.73 GPa ± 0.38 GPa
Flexural strength	42.70 MPa ± 2.15 MPa
Impact strength	0.65 J/cm2 ± 0.05 J/cm2
Melting point	280°C
Rockwell hardness	64 HRRW ± 3 HRRW
Shear strength	4.10 MPa ± 1.34 MPa
Tensile modulus	1.0 GPa ± 0.2 GPa
Tensile strength	35.0 MPa ± 1.5 MPa

$$\% \text{ of water absorption}, W = \left(\frac{w_t - w_0}{w_0}\right) \times 100. \quad (1)$$

2.7. Fractography Analysis. The fractured surface of optimum composite was examined under a scanning electron microscope model S-1500, Hitachi, Japan, to explore the surface features of the composites. For analysis, the specimen was coated with a thin gold layer to avoid the electron beam charging effects during the examination and thereby to assure good image quality. The examination was conducted with an electron beam charging of 10 kV [4].

3. Result and Discussion

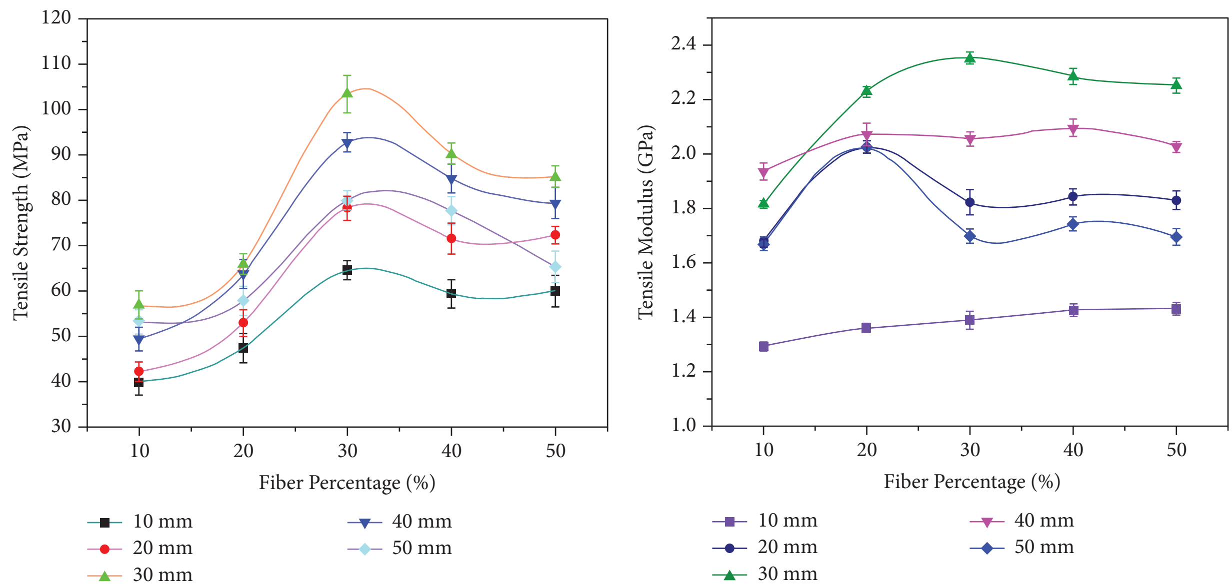
The tensile, flexural, impact, hardness, water absorption, thermal, and fractography studies of FSPF-polyester composites (FSPFC) were done and the experimental outcomes of the characterization of composites are discussed in detail in this section.

3.1. Tensile Properties of FSPFC. The mechanical characteristics of the composites are largely influenced by the length and weight fraction of the fibers, and the optimum length to weight ratio is necessary to obtain composites with good quality (Indran et al., 2016). Since various lengths (from 10 to 50 mm) and weight percentages (from 10% to 50%) of reinforcing fibers were tested to recognize the maximum composite properties in this study. The impact of altering fiber length and weight % on tensile strength and tensile modulus are disclosed in Figures 2(a) and 2(b). The critical fiber length and critical weight percentage of FSPF-reinforced composites were determined as 30 mm, 30 wt.%, respectively. The optimum tensile strength was found to be 103.51 MPa, which is promising than that of most of the fibers experienced in earlier as *Sansevieria cyclindrica* (75.75 MPa, 30 mm/40 wt.%), Tamarind fruit fiber (77.4 MPa, 50 mm/40 wt.%), red banana peduncle fiber (11.61 MPa, 300–400 mm), *Cissus quadrangularis* stem (90.20 MPa, 40 mm/30 wt.%), *Cymbopogon flexuosus* stem (84.77 MPa, 40 mm/30 wt.%), Coconut coir fiber (13.05 MPa, 30 mm/30 wt.%), *Calotropis procera* (11.43 MPa, 30 mm/30 wt.%), and jute fibers (75.15 MPa, 30 mm/40 wt.%) (Table 1). Moreover, it is noted that tensile strength increased as fiber length and weight % increases up to 30 mm/30 wt.%, since the polyester matrix transmits and distributes the maximum applied stress to the fibers. Beyond the optimum range, the fiber curls are inadequate to disseminate the polyester resin within the fiber [22]. Thus, 30 mm fiber length with a 30% fiber weight percentage gives the optimum bonding between the FSPF and polyester matrix. The same trend is reflected in case of tensile modulus, where the optimum modulus of 2.35 Gpa was attained at 30 mm fiber length and 30 wt.% fiber loading rate. The FSPF polymer composite was significant that that of *Sansevieria cyclindrica* (1.10 GPa), Tamarind fruit fiber (1.4 GPa), *Cymbopogon flexuosus* stem (1.31 GPa), Coconut coir fiber (2.06 GPa), and jute fiber (0.638 GPa) in terms of their tensile modulus. Whereas, beyond this level, a decreasing trend was observed due to matrix/fiber incompatibility and inadequate interfacial bonding in fact of improper fiber length and loading ratio [9].

3.2. Flexural Properties of FSPFC. Flexural strength and modulus of FSPFC obtained with different fiber contents are demonstrated in Figures 3(a) and 3(b). Flexural strength has a similar drift as like tensile strength and beyond the optimum content the properties dropped. With 30 wt. % and 40 mm fiber length, the maximum flexural strength of 144.62 MPa and flexural modulus of 2.93 GPa were obtained. This might be due to the homogeneous distribution of the FSPF/polyester matrix and improved fiber matrix interaction developed during bending by the optimum fiber content of the composite. A reduced trend is found with other fiber concentrations that might be due to curling of the fiber beyond 30 mm/30 wt.%, which reduces flexural properties. The obtained flexural strength and was promising than that of *Acacia concinna* fiber (112.31 ± 4.1 MPa. 40 mm/30 wt.%), *Sansevieria cyclindrica* (84 MPa), Tamarind fruit fiber (88.5 MPa), red banana peduncle fiber (2 MPa), *Cissus quadrangularis* stem (103.04 MPa), *Cymbopogon flexuosus* stem (93.53 MPa), Coconut coir fiber (35.45 MPa), *Calotropis procera* (26.38 MPa), and jute fiber (124.01 MPa) [9, 20]. The flexural modulus of the respective composite was higher than the earlier reported fibers as *Cymbopogon flexuosus* stem, Tamarind fruit fiber, *Cissus quadrangularis* stem, and jute fiber. The obtained flexural properties can be corelated with the results of tensile properties in terms of fiber dimensions, which shows the necessity of optimization for absolute composite formulation.

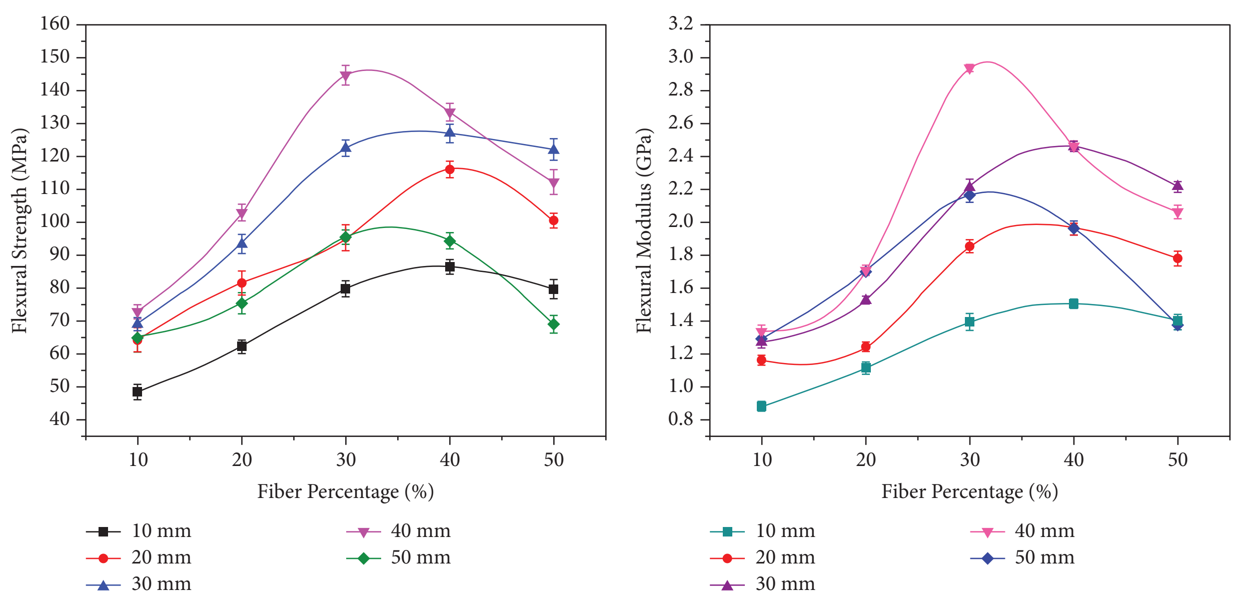
3.3. Impact Properties of FSPFC. Impact resistance refers to the ability of a material to resist under sudden stress conditions [23]. The toughness behavior of the composite was assessed using varied fiber lengths and loading rates and the results indicated that the impact strength rises linearly up to 30 wt.%/30 mm (10.8 ± 0.31 J/cm2) reinforcement owing to efficient stress transmission between the fiber and matrix with good fiber distribution (Figure 4). Beyond this concentration, there is a decline in impact strength that might be due to the increased fiber-to-fiber contact owing to increased loading or fiber breaking happens inside the composite. Moreover, the proposed plant fiber-polymer composite showed the maximum impact strength in course of all other fibers as presented in Table 1. Although, the composite possess better interfacial bonding as the composite absorbs a higher energy during the impact fracture.

3.4. Hardness. The hardness qualities of the composite were examined to determine its resistance to scratches and abrasion. Figure 5 depicts the influence of hardness on altering fiber weight and length ratio. A relatively good hardness value of 92 HRRW was allied with 30 wt.% and 40 mm length, while the cured resin's hardness is 90 HRRW. The hardness of a material is mainly influenced by the characteristics of the matrix and intermolecular bonding of



(a) (b)

Figure 2: Effect of fiber length and weight percentage on (a) tensile strength and (b) tensile modulus.



(a) (b)

Figure 3: Effect of fiber length and weight percentage on (a) flexural strength and (b) flexural modulus.

the material with the matrix [8]. The enhanced hardness value obtained in this study was attributed to the matrix's homogeneous distribution [24].

3.5. Thermal Properties. The TG-DTG test was used to assess the thermal stability of the prepared fiber and the resultant deterioration patterns are evident in Figure 6. The degradation of polyester was started at 360°C and for FSPF optimal composite degradation, it starts around 340°C; whilst, the complete decomposition for polyester has occurred at 495°C but for novel composite, it occurs around 390°C due to the natural fiber reinforcement, which is denoted by a sudden dip in the TG curve. This degradation temperature is reasonably higher than the thermal stability of most of the raw fibers and sufficient for composite manufacturing. Moreover, the thermal stability established for raw and treated composites were significant to withstand high temperature required applications [24, 25].

3.6. Water Absorption Property. Water absorption analysis was sufficient to examine the degradability of composites in aquatic environment. Figure 7 signifies the effects of water on the polyester resin sample and FSPFC with five distinct

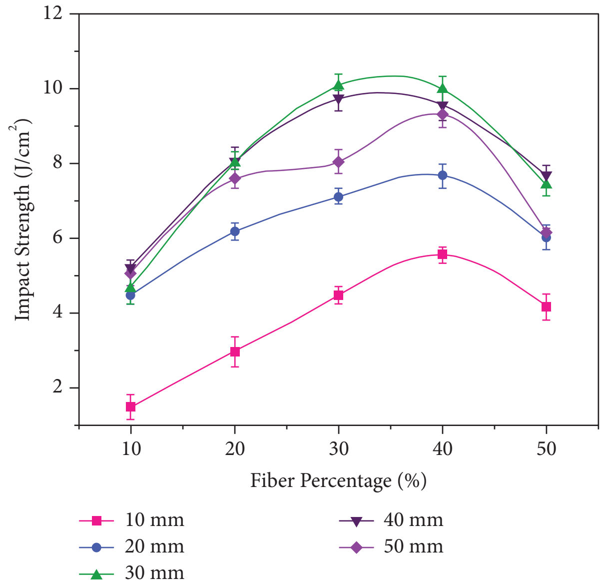


FIGURE 4: Effect of fiber length and weight percentage on the impact strength.

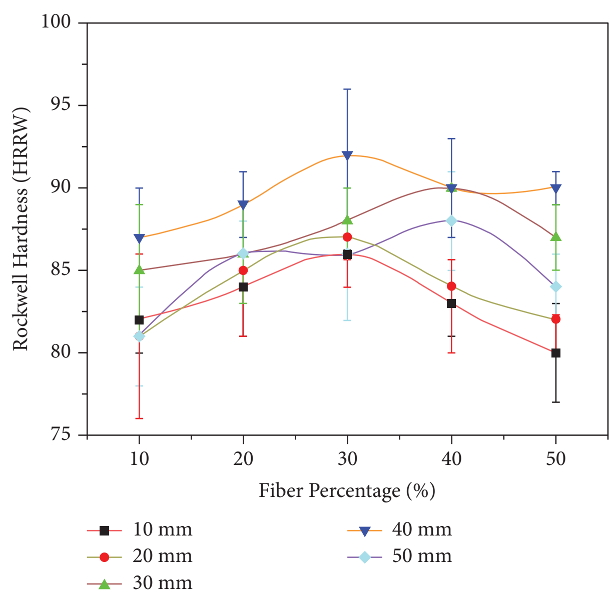


FIGURE 5: Effect of fiber length and weight percentage on Rockwell hardness.

fiber concentrations. This analysis revealed that there was an increase in water absorption observed from 10–50 wt.% except 30 wt.%, which might be due to the increased fiber weight fractions of the composites since polyester resin showed relatively lesser water absorption rate (7.25%). However, the optimal sample with 30 wt.% showed reduced water absorption (7.48%) than other weight percentages (7.6–8.5%). In fact, proper matrix-fiber adhesion and less microvoids are present in the optimal sample in contrast to other samples, which allows good interfacial bonding with the matrix by penetrating to lumen and reduces water absorption capacity [26, 27].

3.7. Fractography of FSPFC. Fractography of the FSPFC built-in with 30 mm/30 wt.% fiber content is presented in Figures 8(a) and 8(b). This study was ideal to examine the morphological features of the composite's fractured surface. It is clearly observed from the figures that the finest interlocking between fiber and matrix by the fact that the matrix is thoroughly infiltrated into fiber voids. The optimal composite fractography observed minimal fiber pull-out. More rough and uneven surface morphology of the fiber owing to the high interfacial strength leads to poor stress transfer, since a crack is initiated from the matrix followed by the fiber breakage occurred. Moreover, few voids remain

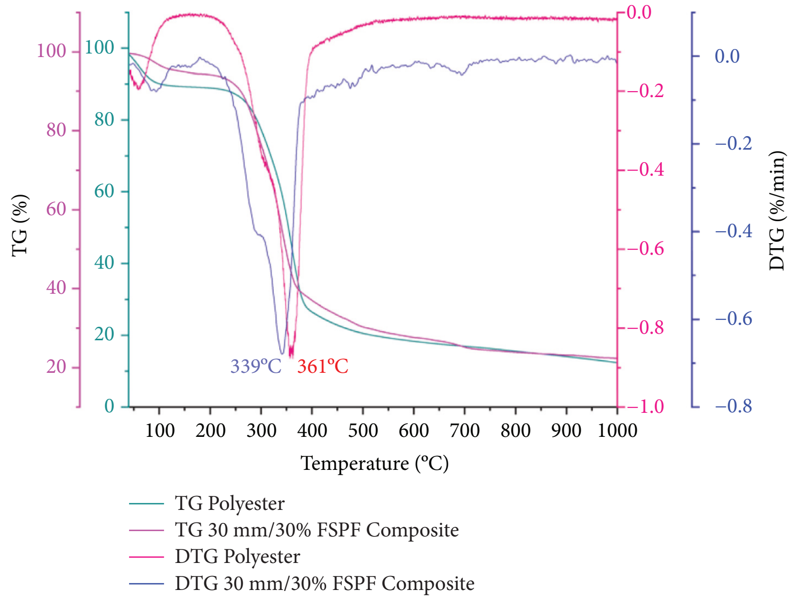


Figure 6: TG and DTG curves of the polyester and FSPF/polyester (30 mm length and 30wt.% fiber) composite.

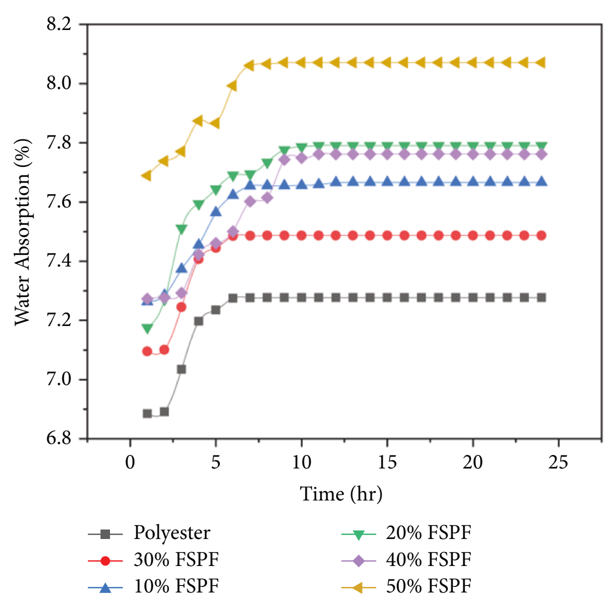


Figure 7: Effect of fiber length and weight percentage on water absorption.

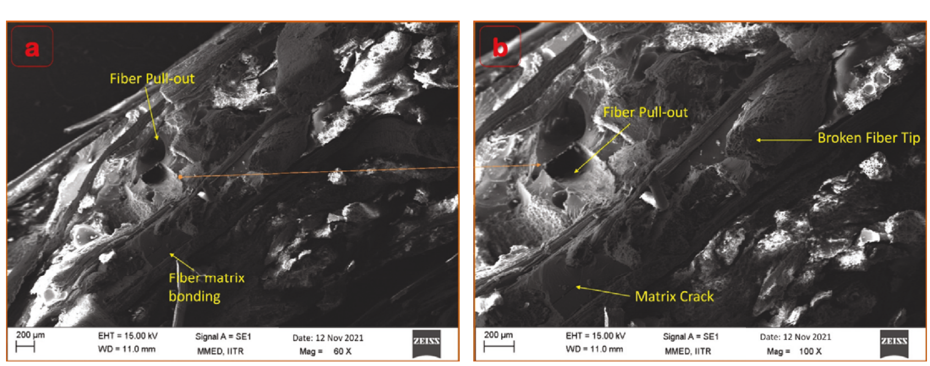


Figure 8: SEM micrograph of tensile fractured specimen with 30 mm fiber length and 30 wt.% fiber content composites.

unfilled in the matrix due to the limitation of the interface between the fibers and the matrix during manufacturing [12].

4. Conclusion

Fiber content has an important impact on the overall performance of a composite system; hence, the effect of different fiber content on the performance of specific FSPF reinforced polyester composites was tested. The optimum composite properties were analyzed by studying tensile strength, flexural strength, impact strength, hardness, and water uptake properties. Among the varied fiber length (10 mm, 20 mm, 30 mm, 40 mm, and 50 mm) and weight percentage (10%, 20%, 30%, 40%, and 50%) tested, the specific composite had its maximum stability with an ideal length of 30 mm and 30% weight percentage. The thermal analysis indicated that the composite material possesses good thermal stability and reduced water absorption property validated its usage in aquatic environments. The matrix and fibers in the optimal reinforcement were found to be well-bonded microstructurally, as evidenced by SEM analysis. Therefore, the present study suggested that the optimal FSPF reinforced polyester composite would be a promising alternative to conventional materials for the production of value-added products for the time being.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

References

[1] M. R. Sanjay, S. Siengchin, J. Parameswaranpillai, M. Jawaid, C. I. Pruncu, and A. Khan, "A comprehensive review of techniques for natural fibers as reinforcement in composites: preparation, processing and characterization," *Carbohydrate Polymers*, vol. 207, pp. 108–121, 2019.

[2] S. Indran, R. Edwin Raj, and V. S. Sreenivasan, "Characterization of new natural cellulosic fiber from Cissus quadrangularis root," *Carbohydrate Polymers*, vol. 110, pp. 423–429, 2014.

[3] B. G. Babu, D. Princewinston, S. S. Saravanakumar et al., "Investigation on the physicochemical and mechanical properties of novel alkali-treated Phaseolus vulgaris fibers," *Journal of Natural Fibers*, vol. 19, no. 2, pp. 770–781, 2020.

[4] B. Muthu chozha rajan, S. Indran, D. Divya et al., "Mechanical and thermal properties of chloris barbata flower fiber/epoxy composites: effect of alkali treatment and fiber weight fraction," *Journal of Natural Fibers*, vol. 00, pp. 1–14, 2020.

[5] S. Raja, R. Rajesh, S. Indran, and D. Divya, "Characterization of Industrial Discarded Novel Cymbopogon Flexuosus Stem Fiber: A Potential Replacement for Synthetic Fiber," *Journal of Industrial Textiles*, 2021.

[6] A. A. M. Moshi, D. Ravindran, S. S. Bharathi, S. Indran, S. S. Saravanakumar, and Y. Liu, "Characterization of a new cellulosic natural fiber extracted from the root of Ficus religiosa tree," *International Journal of Biological Macromolecules*, vol. 142, pp. 212–221, 2020.

[7] G. Rajeshkumar, V. Hariharan, S. Indran et al., "Influence of sodium hydroxide (NaOH) treatment on mechanical properties and morphological behaviour of phoenix sp. fiber/epoxy composites," *Journal of Polymers and the Environment*, vol. 29, no. 3, pp. 765–774, 2021.

[8] M. R. Sanjay, P. Madhu, M. Jawaid, P. Senthamaraikannan, S. Senthil, and S. Pradeep, "Characterization and properties of natural fiber polymer composites: a comprehensive review," *Journal of Cleaner Production*, vol. 172, pp. 566–581, 2018.

[9] R. S. Sundaram, R. Rajamoni, I. Suyambulingam, and R. Isaac, "Comprehensive characterization of industrially discarded cymbopogon flexuosus stem fiber reinforced unsaturated polyester composites: effect of fiber length and weight fraction," *Journal of Natural Fibers*, pp. 1–16, 2021.

[10] J. S. Binoj, R. Edwin Raj, and B. S. S. Daniel, "Comprehensive characterization of industrially discarded fruit fiber, *Tamarindus indica* L. as a potential eco-friendly bio-reinforcement for polymer composite," *Journal of Cleaner Production*, vol. 142, pp. 1321–1331, 2017.

[11] V. S. Sreenivasan, S. Somasundaram, D. Ravindran, V. Manikandan, and R. Narayanasamy, "Microstructural, physico-chemical and mechanical characterisation of Sansevieria cylindrica fibres - an exploratory investigation," *Materials & Design*, vol. 32, no. 1, pp. 453–461, 2011.

[12] S. Indran, R. E. Raj, B. Daniel, and S. Saravanakumar, "Cellulose powder treatment on Cissus quadrangularis stem fiber-reinforcement in unsaturated polyester matrix composites," *Journal of Reinforced Plastics and Composites*, vol. 35, no. 3, pp. 212–227, 2016.

[13] P. Manimaran, M. R. Sanjay, P. Senthamaraikannan, M. Jawaid, S. S. Saravanakumar, and R. George, "Synthesis and characterization of cellulosic fiber from red banana peduncle as reinforcement for potential applications," *Journal of Natural Fibers*, vol. 16, no. 5, pp. 768–780, 2018.

[14] F. Sarasini and V. Fiore, "A systematic literature review on less common natural fibres and their biocomposites," *Journal of Cleaner Production*, vol. 195, pp. 240–267, 2018.

[15] R. Ramasamy, K. Obi Reddy, and A. Varada Rajulu, "Extraction and characterization of Calotropis gigantea bast fibers as novel reinforcement for composites materials," *Journal of Natural Fibers*, vol. 15, no. 4, pp. 527–538, 2018.

[16] M. Y. Mahmoud Zaghloul, M. M. Yousry Zaghloul, and M. M. Yousry Zaghloul, "Developments in polyester composite materials - an in-depth review on natural fibres and nano fillers," *Composite Structures*, vol. 278, Article ID 114698, 2021.

[17] A. G. Adeniyi, D. V. Onifade, J. O. Ighalo, and A. S. Adeoye, "A review of coir fiber reinforced polymer composites," *Composites Part B: Engineering*, vol. 176, Article ID 107305, 2019.

[18] R. Vijay, D. Lenin Singaravelu, A. Vinod et al., "Characterization of raw and alkali treated new natural cellulosic fibers from Tridax procumbens," *International Journal of Biological Macromolecules*, vol. 125, pp. 99–108, 2019.

[19] S. Indran, R. D. Edwin Raj, B. S. S. Daniel, and J. S. Binoj, "Comprehensive characterization of natural Cissus quadrangularis stem fiber composites as an alternate for conventional FRP composites," *Journal of Bionics Engineering*, vol. 15, no. 5, pp. 914–923, 2018.

[20] T. Sathishkumar, P. Navaneethakrishnan, S. Shankar, R. Rajasekar, and N. Rajini, "Characterization of natural fiber

and composites - a review," *Journal of Reinforced Plastics and Composites*, vol. 32, no. 19, pp. 1457–1476, 2013.

[21] J. S. Binoj, R. E. Raj, and S. Indran, "Characterization of industrial discarded fruit wastes (Tamarindus Indica L.) as potential alternate for man-made vitreous fiber in polymer composites," *Process Safety and Environmental Protection*, vol. 116, pp. 527–534, 2018.

[22] R. F. Buson, L. F. L. Melo, M. N. Oliveira, G. A. V. P. Rangel, and E. P. Deus, "Physical and mechanical characterization of surface treated bamboo fibers," *Science and Technology of Materials*, vol. 30, no. 2, pp. 67–73, 2018.

[23] N. Saba, M. Jawaid, M. T. H. Sultan, and O. Y. Alothman, *Green Biocomposites for Structural Applications*, Springer, Berlin, Germany, 2017.

[24] P. Madhu, M. R. Sanjay, P. Senthamaraikannan, S. Pradeep, S. S. Saravanakumar, and B. Yogesha, "A review on synthesis and characterization of commercially available natural fibers: Part II," *Journal of Natural Fibers*, vol. 16, no. 1, pp. 25–36, 2019.

[25] V. C. S. Gandhi, I. Jenish, S. Indran, and D. Y. Rajan, "Mechanical and thermal analysis of Cissus quadrangularis stem fiber/epoxy composite with micro-red mud filler composite for structural application," *Transactions of the Indian Institute of Metals*, vol. 75, no. 3, pp. 737–747, 2022.

[26] K. Mustapha, S. T. Azeko, E. Annan, M. G. Z. Kana, L. Daniel, and W. O. Soboyejo, "Pull-out Behavior of Natural Fiber from Earth-Based Matrix," *Journal of Composite Materials*, vol. 50, no. 25, 2016.

[27] P. Sahu and M. Gupta, "A review on the properties of natural fibres and its bio-composites: effect of alkali treatment," *Proceedings of the Institution of Mechanical Engineers - Part L: Journal of Materials: Design and Applications*, vol. 234, no. 1, pp. 198–217, 2020.