International Journal of Biological Macromolecules 162 (2020) 1807–1815

Contents lists available at ScienceDirect

International Journal of Biological Macromolecules

journal homepage: http://www.elsevier.com/locate/ijbiomac

Characterization of natural cellulosic fibers from Nendran Banana Peduncle plants

P. Manimaran [a], G. Pitchayya Pillai [b], V. Vignesh [b,*], M. Prithiviraj [c]

[a] Department of Mechanical Engineering, Karpagam Institute of Technology, Coimbatore 641 105, Tamil Nadu, India
[b] Department of Mechanical Engineering, Sethu Institute of Technology, Kariapatti 626 115, Tamil Nadu, India
[c] Department of Mechanical Engineering, Kamaraj College of Engineering and Technology, Madurai 625 701, Tamil Nadu, India

ARTICLE INFO

Article history:
Received 20 May 2020
Received in revised form 9 August 2020
Accepted 12 August 2020
Available online 16 August 2020

Keywords:
Nendran banana peduncle fiber
Single fiber tensile test
Atomic force microscopy

ABSTRACT

The objective of this work is to explore the natural cellulosic fibers extracted from Nendran Banana Peduncle plants. This is the first time, the tests are carried out in the Nendran Banana Peduncle Fiber (NBPF) to measure the properties of the chemical, physical, mechanical, thermal (TGA/DTG), X-ray Diffraction (XRD) analysis, Fourier-transform Infrared spectroscopy(FT-IR), Nuclear Magnetic Resonance (NMR) analysis and Atomic Force Microscopy (AFM) furnished in this work. The Weibull distribution analysis was adopted for the analysis of diameter, tensile strength and Young's modulus of the fiber. The XRD analysis for the NBPF shows that the crystallinity index of 53.3%and crystallinity size of 4.72 nm. Thermogravimetric analysis depicted that NBPF can withstand thermally up to 356 °C. FT-IR results proved the existence of different chemical compositions and their corresponding functional groups. AFM analysis revealed the surface of the fiber found as rough. From the results, it is concluded that NBPF utilized as a polymer matrix composite for manufacturing light load automotive components and construction equipment.

1. Introduction

Natural fibers have considered as a polymeric composite materials in recent times. Natural fibers have potential to serve as a replacement to synthetic fibers owing to their significant properties like biodegradability, abundant availability, low density, recyclability, sustainability, non-toxicity, non-corrosive, eco-friendly and low carbon emissions [1–4]. In order to protect the environmental damages due to the usage of petroleum based fiber reinforced composites, many researchers have identified the green composites are prepared from natural cellulosic fibers. Then the proper utilization of new natural cellulosic fibers emerges the significant role in preparing the polymeric composite materials [5–7]. Due to the environmental consciousness, various researchers have to identify the natural new cellulosic fibers for the replacement of the synthetic fibers to save the environment. The natural fibers were introduced from plenty of renewable resources make use of reinforcements in polymer matrix for fabricating the various end components. These natural fiber reinforced composites in the form of degradability and utilization of natural products to protect the environment [8]. Many researchers have been analyzed the fibers, prepared from various parts of the plant such as stem, leaf, bark, roots, fruits and seeds and examined the different plant fibers like banana, hemp, sisal, coir, bamboo for reinforcement to prepare the polymer composites. Recently some researchers examined the appropriateness of natural fibers such as *Sansevieria cylindrica*, Sansevieria ehrenbergii, *Prosopis juliflora*, Indian mallow, Saharan *Aloe vera*, *Furcraea foetida*, *Thespesia populnea*, aerial roots of banyan tree, Red banana Peduncle, *Calotropis gigantea*, Leucas Aspera [9–19]. The final properties of polymer composites are depending on the nature of resin, fiber alignment, and the bonding between the fiber and matrix [20].

Many researchers have extracted the fibers from the stem of Banana only. Usually the Banana Peduncle is disposed as a waste material. In order to beneficially utilize the waste into useful product, our study focused on the fiber extracted from banana Peduncle. Generally there are many varieties of bananas like red banana, nendran banana, rasthaly banana, morris banana and Poovan banana etc. For the first time, the novel natural fibers from Nendran Banana Peduncle (NBP) were prepared and its basic essential properties like density, chemical composition, crystallinity index (CI), crystalline size (CS), Fourier Transform-Infrared (FT-IR) Analysis, X-ray diffraction (XRD) analysis, Single fiber tensile test and Weibull distribution analysis, Thermogravimetric analysis (TGA/DTG), Nuclear Magnetic Resonance (NMR) and Atomic Force Microscopy (AFM) analysis was executed and compared with other fibers.

* Corresponding author.
E-mail address: vigneshv914@sethu.ac.in (V. Vignesh).

https://doi.org/10.1016/j.ijbiomac.2020.08.111
0141-8130/

2. Materials and methods

2.1. Materials

Nendran Banana is a breed of banana which was initially cultivated in the village of Chengazhikodu, in the district of Thrissur, Kerala, India. Nendran Banana Peduncle (NBP) plants for a length between 40 cm and 50 cm have collected from Nagercoil city in Kanniyakumari district, Tamilnadu, India.

2.2. Extraction of the fiber from Nendran Banana peduncle (NBP)

NBP is peeled with the help of a knife. It is cleaned with purified water so as to make it free of dust and other pollutants. The retting process was carried out by, the NBP was immersed in purified water at atmospheric temperature until the fiber loosened from the peduncle. The fibers were prepared by using a comb having multiple teeth. The extracted fibers are prepared free from the undesired contents by the NBP fibers were cleaned many times in demineralized water [21]. The process of extraction and retting process of NBPF was shown in Fig. 1.

2.3. Single Fiber tensile test and Weibull distribution

Single fiber tensile tests were carried out by using INSTRON Universal Testing Machine (5500R) with a load cell capacity of 100 N. As per ASTM D3822–07, twenty five samples were considered for examination is tested and Weibull distribution analysis is used to analyze the results using Minitab 17 software. The diameter of the fiber, tensile strength and Young's modulus is statistically analyzed by Weibull distribution.

The microfibril angle (α) was estimated though the following Eq. (1) [13].

$$\varepsilon = \ln\left(1+\frac{L_f - L_o}{L_o}\right) = \ln\left(Cos\alpha\right) \quad (1)$$

where ε denotes the beginning of the final linear part of the stress–strain curve, L_f refers the degree of a microfibril, and L_o represents the gauge length and α indicates the microfibril angle.

2.4. Chemical properties

The chemical constituents of the NBP fibers such as α-cellulose, hemicellulose, and lignin content were determined by using the established test methods [12]. Conrad method was used to evaluate the wax content in the fiber [22]. ASTM E1755-01 standard was adopted to measure the percentage of ash content of the fibers.

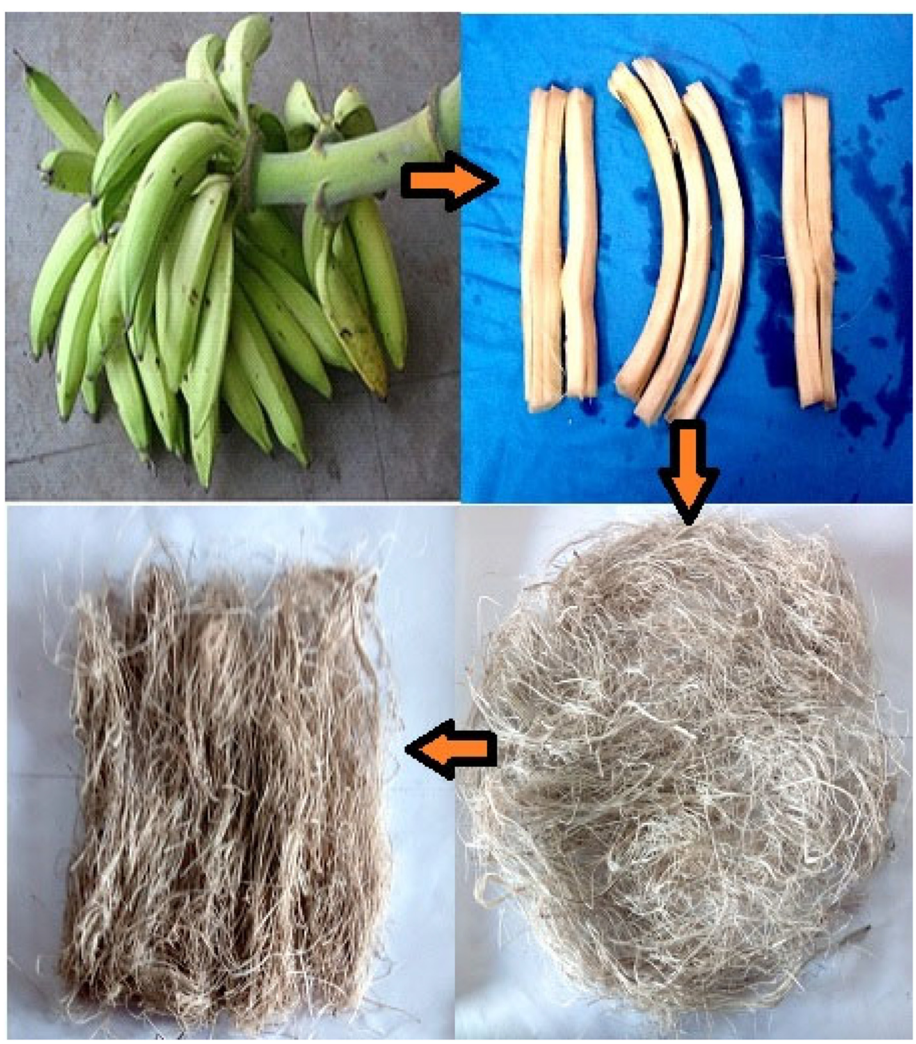

Fig. 1. Preparation of Nendran Banana Peduncle Fiber.

2.5. Physical properties

A pycnometer was used to examine the density of fiber. Initially, NBPFs were located in the silica cell packed desiccators to eliminate the moisture present in the fibers for 5 days. After that they were sliced into the size of 5 mm small pieces through chopping and placed in the instrument. The NBPFs were submerged in a toluene filled container about 2 h before conducting the experiment so as to eliminate the micro bubbles from the fibers. The density of NBPFs (ρ) was obtained through the following Eq. (2).

$$\rho_{NBPF} = \left(\frac{(m_2 - m_1)}{(m_3 - m_1) - (m_4 - m_2)}\right)\rho_T \tag{2}$$

where m_1 denotes the mass of the empty pycnometer, m_2 indicates the mass of the pycnometer packed with chopped fibers, m_3 represents the mass of the pycnometer filled with toluene, m_4 refers the mass of the pycnometer filled with chopped fibers and toluene solution and ρ_t is the density of toluene (i.e., 790 kg/m^3).

Through optical microscope the fiber average diameter is determined. This was performed for 25 samples of fibers. The measurement was taken along the fiber randomly at various positions. The fiber average diameter probability is analyzed though Weibull distribution statistical analysis. It is observed that the cross section is almost a regular circular cross section.

2.6. Thermogravimetric analysis (TGA)

Jupiter simultaneous thermal analyzer, Model STA 2500, NETZSCH, Germany was deployed for the thermal stability of the NBPFs to guarantee the strength of fibers for higher temperature applications. The analysis was performed in the crucible cup kept in the nitrogen atmosphere for a flow rate of 20 ml/min from the ambient temperature to 800 °C with 10 °C/min as an incremental heating rate. Nitrogen Gas flow at a rate of 40 ml/min and Nitrogen gas protective flow rate at 60 ml/min [23–25].

The Broido's equation and Briodo's plot [$\ln(\ln(1/y))\, vs\, (1/T)$] were adopted to determine the thermal stability of NBPFs in the form of kinetic activation energy (E_a) by using the Eq. (3) [26–29].

$$\ln\left[\ln\left(\frac{1}{y}\right)\right] = -\left(\frac{E_a}{R}\right)\left[\left(\frac{1}{T}\right) + K\right] \tag{3}$$

where y denotes normalized weight (w_t/w_o), w_o indicates initial weight, w_t represents weight of the sample at anytime t, E_a refers kinetic activation energy, R is the Universal gas constant (8.32 kJ/mol-K), T denotes temperature in K and K indicates the reaction rate constant.

2.7. Fourier transform infrared spectroscopy (FT-IR) analysis

Fourier transform infrared spectrometer Perkin Elmer Spectrum RX I was deployed to observe the presence of chemical functional groups in the NBFs by forming an infrared absorption spectrum. The FT-IR spectrum was obtained in the range of frequency between 500 and 4000 cm^{-1} with a scan rate of 32 scans at 4 cm^{-1} as resolution in total reflectance mode [12,15].

2.8. X ray diffraction (XRD) analysis

X Ray Diffractometer (X'Pert Pro) was employed to observe the crystallographic structure of NBPFs at wavelength 0.154 nm of using Cu-Kα radiation. The electric current 30 mA was carried out at 40 kV as the operating voltage. The scanning was performed in the range between 10° and 80° (2θ) with the increment of 0.05° [28].

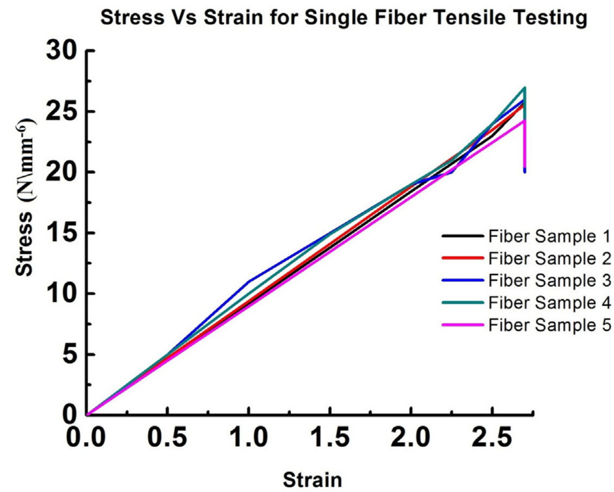

Fig. 2. Tensile stress- strain curve of Nendran Banana Peduncle Fiber.

2.8.1. Evaluation of crystalline index (CI) and crystallite size (CS)

The degree of CI in the cellulosic materials is calculated according to the peak height method. The empirical equation proposed by [28] for calculating the crystalline index is given in Eq. (4).

$$CI = \frac{I_{200} - I_{AM}}{I_{200}} \tag{4}$$

where I_{200} refers the maximum intensity of the 200 lattice plane at 2θ angle between 22° and 23° and I_{AM} indicates the amount of non-crystalline or amorphous material measured by the height of valley of the minimum between the peaks, at an angle of 2θ about 18°.

The crystallite size (CS) was examined by using Scherrer's formula [30] given in Eq. (5).

$$CS_{200} = \frac{k\lambda}{\beta_{200}\, Cos\theta} \tag{5}$$

where K = 0.89, is the Scherrer's constant, λ = 0.1541 nm is the wavelength of the radiation, β refers the peak's full-width at half-maximum in radians and θ indicates the corresponding Bragg angle.

2.9. Atomic force microscopy (AFM) analysis

This analysis was performed by Park XE-70 Model AFM (Korea Make) with XEI image processing software to assess the roughness of

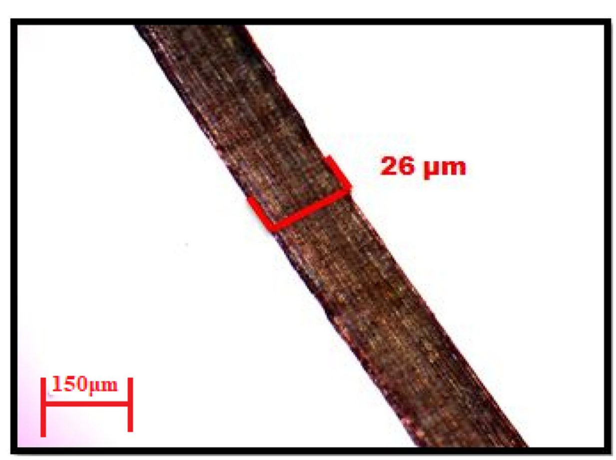

Fig. 3. Optical microscopic image of Nendran Banana Peduncle Fiber.

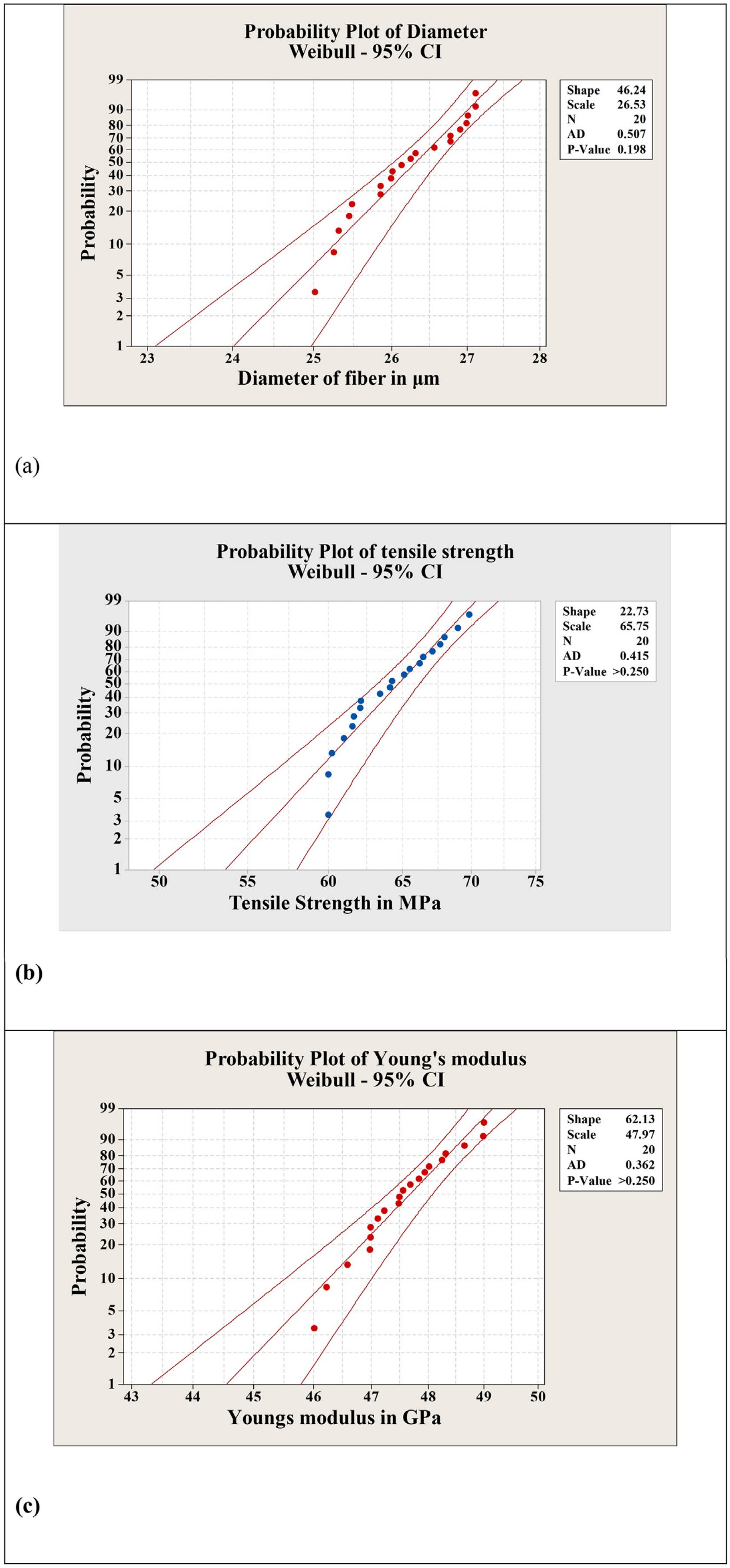

Fig. 4. Weibull distribution plot for (a) diameter, (b) tensile strength, (c) Young's modulus of Nendran Banana Peduncle Fiber.

NBPFs. The resolution range of the scanner scale in x, y and direction is 10 μm × 10 μm × 70 μm. The surface roughness parameters like average surface roughness (S_a), Root mean square roughness (S_q or S_{rms}), Ten point average roughness (S_z), skewness (S_{sk}), and kurtosis (S_{ku}) were determined [13].

2.10. ^{13}C (CP-MAS) nuclear magnetic resonance (NMR) spectroscopy analysis

Solid state NMR model DELTA2 NMR 400 MHz spectrometer was deployed to estimate the presence of chemical constituents present in the NBPFs. The NMR spectroscopy of the NBPFs was set in cross-polarization mode with magic angle sample spinning (MAS) at room temperature at the rate of 10 KHz. The operating frequency of was positioned at 75.46 MHz.

3. Results and discussion

3.1. Single fiber tensile test and Weibull distribution

The tensile stress-strain curves of NBPF samples can be found in Fig. 2. The single fiber tensile strength of the NBPFs was identified to be 65.51 MPa and 2.17% of strain rate. The optical microscopic image of the fiber to measure the diameter is shown as Fig. 3. The average value of the young's modulus of NBPFs and diameter was found to be 47.45 GPa and 26 μm. The microfibril angle of NBPFs was determined as 9.45–13.87° from the deformation Eq. (1). The microfibril angle of the proposed fiber is remarkably higher than that of *Cissus quadrangularis* (5.89°), *Arundo donax* (6.85°) and closely allied to *Prosopis juliflora* (10.64°) and Saharan *Aloe vera* (11.1°) [10,13,31–32].

The Weibull distribution plot curves of diameter, Young's modulus and tensile strength of NBPFs were shown in Fig. 4. It can be reported that the values of diameter, tensile strength and Youngs modulus of all the fiber samples were positioned within limits and fit perfectly the Weibull distribution. From this analysis, it can understand that the Weibull distribution with three parameters provides the mechanical properties very close to the experimental mean values obtained.

3.2. Chemical composition

The chemical composition analysis results arrived for the NBPFs were compared with that of other natural fibers was presented in Table 1.The chemical properties of the NBPFs have a significant effect based on the maturity age of the plant and soil characteristics. NBPFs are composed of cellulose (73.20 wt%), packed as helically wound cellulose microfibrils, banded together by an amorphous lignin. Moreover, the NBPFs confirms the hemicellulose content of (10.85 wt%) was thought to be a catalyst between cellulose and lignin. The lignin content of the NBPFs were found up to 15.32 wt% which keeps moisture and acts as a biological protection against microbes [11,34] The wax content of NBPFs (0.25 wt%) exhibits better interfacial bond between the fibers and polymer matrices [18,34] and is lower than other natural fiber obtained from *Prosopis juliflora* (0.61%), *Thespesia populnea* (0.76%) and *Coccinia grandis*. L (0.79%). The moisture and ash content of the NBPFs consists of 9.01 wt% and 4.23 wt%.

3.3. Thermal stability analysis of fiber using TGA

Thermo gravimetric analysis (TGA) is used to analyze most dominant components like cellulose, hemicellulose & lignin in the fibers degradation temperature and thermal stability. The TG, DTG curve and Broido's plot of NBPF are shown in Figs. 5 and 6 respectively. The degradation of different ingredients of NBPF undertaken in three stages. In the first stage, the degradation of NBPFs starts under (100 °C), this could be due to vaporization of moisture and removal of waxy material from the fiber. The second peak shows the mass loss (around 50%) takes place in the second phase (356 °C) where most of cellulose content, hemicellulose and lignin content is degradation occurs at this phase. The final phase of cellulose degradation occurs from (357 °C - 520.16 °C) which corresponds to the degradation of wax as well as lignin which leaves ash as residue. In addition, the thermal stability of the NBPF was found to be relatively similar than that of Thespesia populnea [15], Coccinia grandis.L [33], Kusha Grass [34,36] and *Aristida adscensionis* [37].

The minimum energy necessary to begin the fiber degradation is known as kinetic activation energy (E_a) shown in broads curve (Fig. 4) and the kinetic activation energy of NBPF is 89 kJ/mol. The results of the TGA analysis reveals that the NBPFs are appropriate material to be acts as a better reinforcement for industrial application, which requires high resistance to withstand the temperature.

3.4. FT-IR analysis

Table 2 shows the FT-IR Peak Positions, corresponding chemical functional groups, and composition in the NBPF, The identified spectrum for different regions are diagnostics region ranges from 3400 to 3423 cm^{-1} (1) ascribed to O—H stretching in carboxylic acid group of

Table 1
Comparison of chemical composition and tensile properties of NBPF with other natural fibers.

Fiber	Density (kg/m^3)	Cellulose (wt%)	Hemi-cellulose (wt%)	Lignin (wt%)	Wax (wt %)	Moisture (wt%)	Ash (wt %)	Tensile strength (MPa)	Elongation at break (%)	Young's modulus (GPa)	Microfibril angle (°)	Ref
NBPF	972	73.20	10.85	15.32	0.25	9.01	2.59	65.51 ± 1.15	2.17	49.50 ± 1.31	9.45–13.87	Present work
Sansevieria cylindrica	915	79.70	10.13	3.80	0.09	6.08	–	673.12 ± 51	10.04 ± 1.5	6.72 ± 1.9	–	9
Prosopis juliflora	580	61.65	16.14	17.11	0.61	9.48	5.20	558 ± 13.4	1.77	–	10.64 ± 0.45	10
Sansevieria ehrenbergii	887	80	11.25	7.8	0.45	10.55	0.6	50–585	2.8–21.7	1.5–7.97	–	11
Saharan aloe vera	1325.1	67.4	8.2	13.7	0.24	5.8	–	805.5	42.29	2.39	11.1	13
Thespesia populnea	1412	70.12	12.64	16.34	0.76	10.83	1.80	557.82 ± 56.29	2.80 ± 0.56	20.57 ± 4.46	13.94 ± 1.21	15
Leucas Aspera	1118	50.7	13.2	9.7	–	11.31	–	–	–	–	–	18
RBPF	990	72.90	11.01	15.99	0.32	9.36	2.79					21
Cissus quadrangularis	1510	77.17	11.02	10.45	0.14	7.30	–	1857–5330	3.57–8.37	68–203	5.89 ± 0.27	32
Arundo donax	1168	43.2	20.5	17.2			1.9	248	9.4	3.4	6.85 ± 1.23	33
Coccinia grandis.L	1243 ± 22.64	62.35	13.42	15.61	0.79	5.6	4.388	273 ± 27.74	10.17 ± 1.261	2.703 ± 0.2736	13.25 ± 0.6641	[33]
Red banana	–	–	–	–	–	–	–	567	30	–	–	[35]
Rasthaly banana	–	–	–	–	–	–	–	388	27.8	–	–	[35]
Morris banana	–	–	–	–	–	–	–	282	24.2	–	–	[35]
Poovan banana	–	–	–	–	–	–	–	206	21.8	–	–	[35]

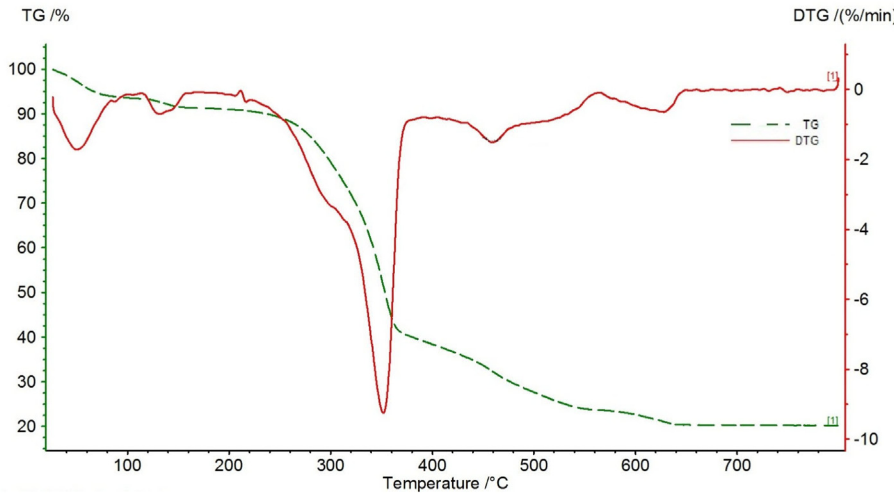

Fig. 5. TGA and DTG curve of Nendran Banana Peduncle Fiber.

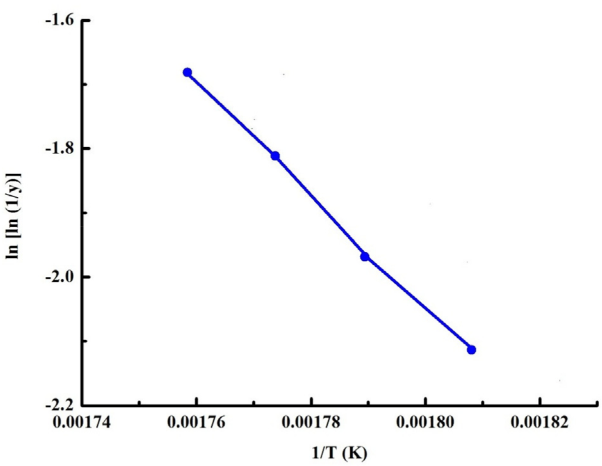

Fig. 6. Broidos curve of Nendran Banana Peduncle Fiber.

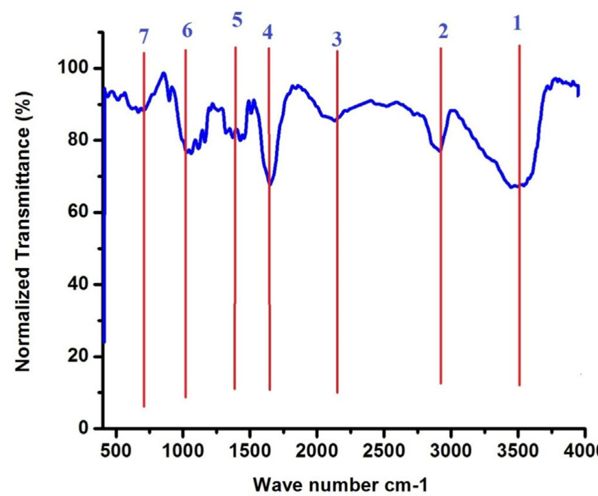

Fig. 7. FTIR spectra of Nendran Banana Peduncle Fiber.

cellulose [29]. The peaks at 2923 $cm^{-1}$is attributed to the CH2 asymmetric stretching of the cellulose fiber and peaks at 2855 $cm^{-1}$is attributed to C—H stretching vibration of CH and CH2 due to the presence of cellulose and hemicellulose components. The band peak at 2342 cm^{-1} which correspond to CH2 symmetrical stretching of wax (3). The FT-IR spectra of NBPFs is shown in Fig. 7.

The peak at 1659 cm^{-1}(4) shows the presence of lignin and hemicelluloses which corresponds to C—O stretching vibration of the acetyl group. The Peak at 1467 cm^{-1} (5) ascribed to the –C-H bending of lignin and peak at 1397 $cm^{-1}$is attributed to the strong acetyl -C-O- with overlapped of –C-H- stretching of phenolic and esters. The peak at 1105 cm^{-1} (6) is seen in the C-O-C asymmetric bridge oxygen stretching in cellulose and hemicellulose [18]. The band at 770 $cm^{-1}$is owed to the presence of saline. The peak at 692 cm^{-1} is attributed to the C-OH out of phase bending motion. The peak at 597 cm^{-1} described to the C-OH bending in cellulose (7).

3.5. XRD analysis

Fig. 8 shows the X-ray diffractogram of the Nendran banana Peduncle fiber. It can be observed that first peak occurred at $2\theta = 15.34°$ which belong to the evidence of the amorphous fraction (I_{am}) in cellulosic fibers. The second peak occurred at $2\theta = 24.16°$ which belong to cellulose content in the fiber (I_c). The value of

Table 2
FT-IR Peak positions, corresponding chemical functional groups, and composition of the NBPF.

Peak positions (Wave number (cm^{-1}))	Functional group	Respective chemical composition	Reference
3400 cm^{-1}	OH-stretching	Cellulose	10,12
2923 cm^{-1}	CH2 asymmetric stretching	Cellulose	13
2855 cm^{-1}	C–H stretching	Cellulose and Hemicellulose	12
2342 cm^{-1}	CH2 symmetrical stretching	Wax	36
1659 cm^{-1}	C–O stretching	Lignin and Hemicelluloses	33
1467 cm^{-1}	–C-H bending	Lignin	29

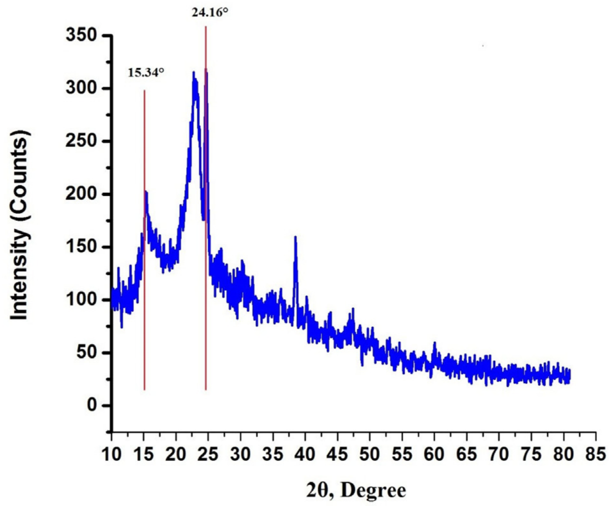

Fig. 8. XRD spectra of Nendran Banana Peduncle Fiber.

crystallinity index (CI) for the nendran banana fiber was 53.3%, which is higher than for the Ferula (48%), Borassus (38.4%), Century (53%), Thespesia (48%) and lower than for jute (65.8%) and hemp (80%) [35]. The crystalline size was found to be 4.72 nm respectively which is lower than that of Jute (29.5 Nm), Prosopis Julifora (15 Nm) Mending Grass (14.3 Nm) Sisal (16.9 Nm), Cotton (7 Nm) and Flax (5.4 Nm) [13].

3.6. Atomic force microscopy (AFM)

The surface roughness profile of NBPF in 2-D and 3-D images are obtained by AFM is shown in Fig. 9. From the results, it is concluded that the surface roughness has the peak of maximum at 25.484 and minimum at −16.548. It is known that the surface of NBPF is rough and indicates the average roughness kurtosis (S_{ku}) value of NBPF is 2.99. The average roughness (S_a) rate of NBPF is 13 nm. Roughness skewness (S_{sk}) value obtained for NBPF is 0.214. In addition to that the root mean square roughness (S_q) is 16.3 nm, ten-point average roughness (S_z) is 119 nm indicates that rough apparent surface. The comparison of roughness parameters of NBPF with other natural fibers was presented in the Table 3.

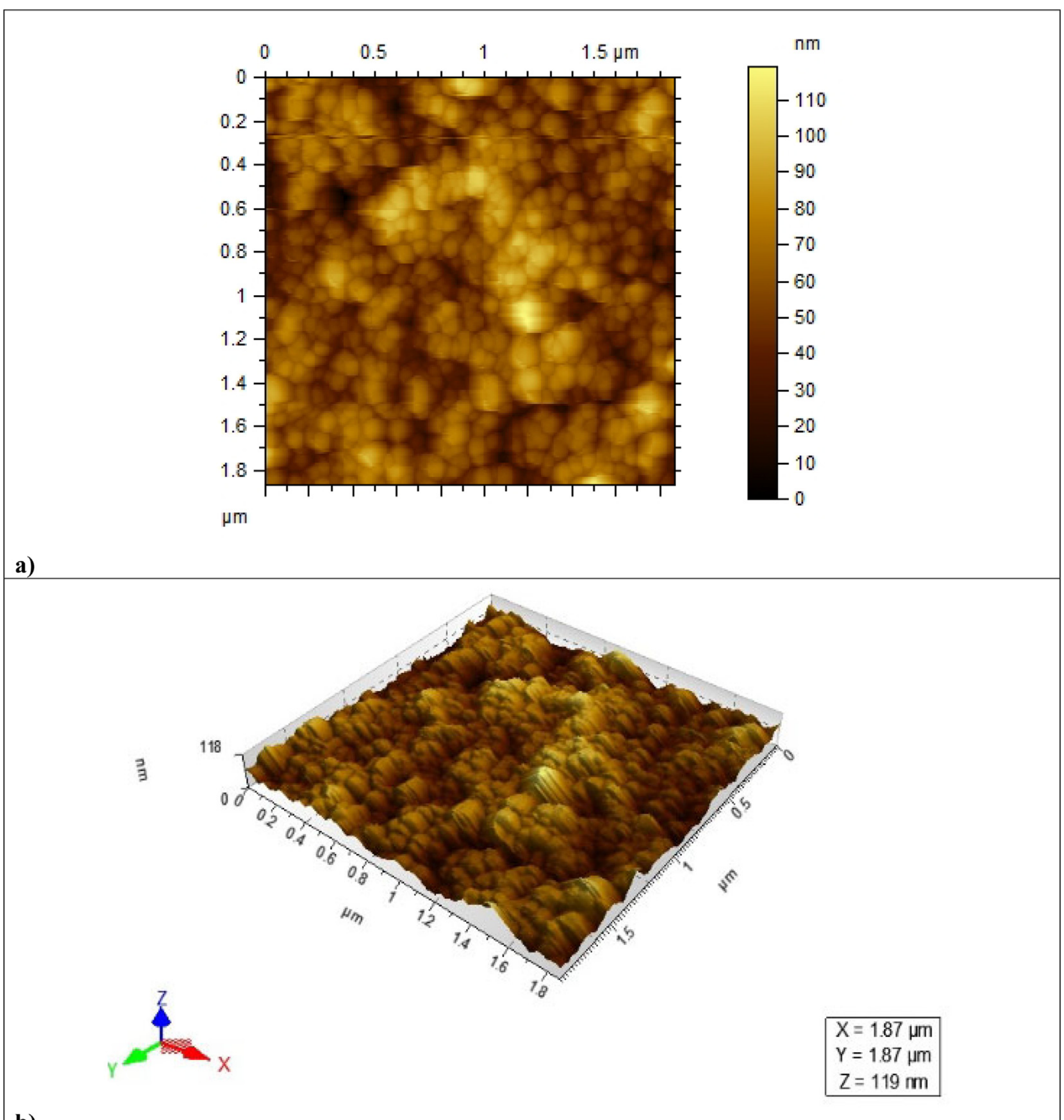

Fig. 9. AFM images on Nendran Banana Peduncle Fiber in (a) 2D, (b) 3D.

Table 3
Comparison on roughness parameter of NBPF with other natural fibers.

Fiber name	S_{pv}	S_q	S_a	S_z	S_{sk}	S_{ku}	Reference
Nendran Banana Peduncle fiber	25.484	16.3	13	119	0.214	2.99	This work
Thespesia populnea barks	–	–	3.002	–	−2.282	9.096	[15]
Calotropis gigantea fruit fiber	104.52	36.42	800	–	0.234	5.111	[19]
Red Banana Peduncle Fiber	51.049	10.087	8.099	45.506	0.110	2.766	[21]
Acacia Concinna plant	82.608	14.808	11.217	60.083	−0.507	3.473	[27]
Root of *Ficus religiosa* tree	23.077	3.100	2.374	13.901	−1.540	4.370	[38]
Pongamia pinnata L. Bark Fiber	35.33	6.502	4.88	29.46	−1.35	5.10	[39]

3.7. ^{13}C solid (CP-MAS) nuclear magnetic resonance (NMR) spectroscopy analysis

The variant peak positions of ^{13}C solid NMR spectrum of NBPF to show the variation of carbon atoms in the cellulose are illustrated in Fig. 10. C-1 Cellulose presence is shown at the peak of 106 ppm. Another peak available at 83.5 ppm corresponds to cellulose C-4. The presence of C-2, C-3 and C-5 carbon atoms in cellulose is in between 75.94 ppm and 73.63 ppm. The presence of C-6 carbon atom is available at the peak of 63.2 ppm. The peak available at 26.63 ppm indicated to acetyl groups of hemicelluloses. The minor peaks available between 119.12 ppm and 137.12 ppm indicate the peaks of lignin. Thus, ^{13}C NMR spectrum substantiates the presence of cellulose, hemicellulose and lignin in NBPFs.

4. Conclusion

The present investigation demonstrates the properties like physical, chemical, thermal and surface roughness of NBPF.

- The diameter and density of NBPF as 26 μm and 972 kg/m^3 respectively.
- The single fiber tensile strength was estimated as 65.51 ± 1.15 MPa and Young's modulus of NBPF was found to be 49.5 ± 1.31GPa.
- The cellulose of NBPF is 73.20 wt%, which exhibits better cellulose content when compared with other cellulosic fibers.
- The XRD analysis displays that the crystalline Index (CI) and crystalline size (CS) as 53.3% and 4.72 nm respectively.
- The TGA results confirmed that NBPF withstand up to 356 °C with the reduction in mass of 50%.
- From the results NBPFs substantiate the suitability of the fiber to prepare the polymer composites for light load automotive components and construction equipments.

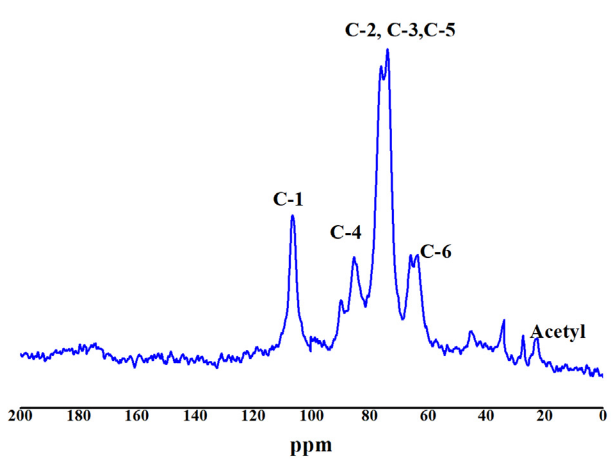

Fig. 10. NMR spectra of Nendran Banana Peduncle Fiber.

CRediT authorship contribution statement

P. Manimaran: Conceptualization, Investigation, Writing- original draft preparation, supervision
G. Pitchayya Pillai: Investigation, Formal analysis
V. Vignesh: Writing – Original draft preparation, Review and editing, Methodology, Validation
M. Prithiviraj: Writing- Review and editing, formal analysis

Acknowledgments

The authors wish to express their sincere thanks to the Management of Karpagam Institute of Technology, Coimbatore, Sethu Institute of Technology, Kariapatti and Kamaraj College of Engineering and Technology, Madurai.

Declaration of competing interest

The authors declare that there are no conflicts.

References

[1] P. Wambua, J. Ivens, I. Verpoest, Natural fibres: can they replace glass in fibre reinforced plastics, Comp. Sci. Tech. 63 (2003) 1259–1264, https://doi.org/10.1016/S0266-3538 (03)00096-4.
[2] S.V. Joshi, L.T. Drzal, A.K. Mohanty, S. Arora, Are natural fiber composites environmentally superior to glass fiber reinforced composites, Comp. Part A. 35 (2004) 371–376, https://doi.org/10.1016/j.compositesa.2003.09.016.
[3] M. Idicula, A. Boudenne, L. Umadevi, L. Ibos, Y. Candau, S. Thomas, Thermo physical properties of natural fibre reinforced polyester composites, Comp. sci. Tech. 66 (2006) 2719–2725, https://doi.org/10.1016/j.compscitech.2006.03.007.
[4] M.R. Sanjay, S. Siengchin, J. Parameswaranpillai, M. Jawaid, C.I. Pruncu, A. Khan, A comprehensive review of techniques for natural fibers as reinforcement in composites: preparation, processing and characterization, Carb. Polym. 207 (2018) 108–121, https://doi.org/10.1016/j.carbpol.2018.11.083.
[5] V.K. Thakur, M.K. Thakur, Processing and characterization of natural cellulose fibers/thermoset polymer composites, Carb. Polym. 109 (2014) 102–117, https://doi.org/10.1016/j.carbpol.2014.03.039.
[6] A.C. Kılınç, S. Köktaş, Y. Seki, M. Atagür, R. Dalmış, U.H. Erdoğan, A.A. Göktaş, M. Özgür Seydibeyoğlu, Extraction and investigation of lightweight and porous natural fiber from conium maculatum as a potential reinforcement for composite materials in transportation, Comp. Par. Engg. 140 (2018) 1–8, https://doi.org/10.1016/j.compositesb.2017.11.059.
[7] M.K.V. Karthikeyan, A.N. Balaji, V. Vignesh, Effect of rope mat and random orientation on mechanical and thermal properties of banana ribbon-reinforced polyester composites and its application, Int. J. poly. Anal. Char. 21 (2016) 296–304, https://doi.org/10.1080/1023666X.2016.1148235.
[8] J. Rout, M. Misra, S. Tripathy, S.K. Nayak, S.K. Mohanty, The influence of fibre treatment on the performance of coir-polyester composites, Comp. Sci. Tech. 61 (2001) 1303–1310, https://doi.org/10.1016/S0266-3538(01)00021-5.
[9] V.S. Sreenivasan, S. Somasundaram, D. Ravindran, V. Manikandan, R. Narayanasamy, Microstructural, physico-chemical and mechanical characterisation of Sansevieria cylindrica fibres – an exploratory investigation, Mat. Des. 32 (2011) 453–461, https://doi.org/10.1016/j.matdes.2010.06.004.
[10] S.S. Saravanakumar, A. Kumaravel, T. Nagarajan, P. Sudhakar, R. Baskaran, Characterization of a novel natural cellulosic fiber from Prosopis juliflora bark, Carb. Poly. 92 (2013) 1928–1933, https://doi.org/10.1016/j.carbpol.2012.11.064.
[11] T.P. Sathishkumar, P. Navaneethakrishnan, S. Shankar, R. Rajasekar, Characterization of new cellulose Sansevieria ehrenbergii fibers for polymer composites, Comp. Inter. 20 (2013) 575–593, https://doi.org/10.1080/15685543.2013.816652.
[12] V. Vignesh, A.N. Balaji, M.K.V. Karthikeyan, Extraction and characterization of new cellulosic fibers from Indian mallow stem: an exploratory investigation, Int. J. Polym Anal. Char 21 (2016) 504–512, https://doi.org/10.1080/1023666X.2016.1175206.

[13] A.N. Balaji, K.J. Nagarajan, Characterization of alkali treated and untreated new cellulosic fiber from Saharan aloe vera cactus leaves, Carb. Poly 174 (2017) 200–208, https://doi.org/10.1016/j.carbpol.2017.06.065.
[14] P. Manimaran, P. Senthamaraikannan, M.R. Sanjay, M.K. Marichelvam, M. Jawaid, Study on characterization of Furcraea Foetida new natural Fiber as composite reinforcement for lightweight applications, Carb. Poly. 181 (2018) 650–658, https://doi.org/10.1016/j.carbpol.2017.11.099.
[15] M. Kathirselvam, A. Kumaravel, V.P. Arthanarieswaran, S.S. Saravanakumar, Isolation and characterization of cellulose fibers from Thespesia populnea barks: a study on physicochemical and structural properties, Int. J. Bio. Macro. 129 (2019) 396–406, https://doi.org/10.1016/j.ijbiomac.2019.02.044.
[16] T. Ganapathy, R. Sathiskumar, P. Senthamaraikannan, S.S. Saravanakumar, Anish Khan, Characterization of raw and alkali treated new natural cellulosic fibres extracted from the aerial roots of banyan tree, Int. J. Bio. Macro. 138 (2019) 573–581, https://doi.org/10.1016/j.ijbiomac.2019.07.136.
[17] G. Pitchayya Pillai, P. Manimaran, V. Vignesh, Physico-chemical and mechanical properties of alkali-treated red banana peduncle fiber, J. Nat. Fib (2020)https://doi.org/10.1080/15440478.2020.1723777.
[18] R. Vijay, S. Manoharan, S. Arjun, A. Vinod, D. Lenin Singaravelu, Characterization of silane-treated and untreated natural fibers from stem of Leucas Aspera, J. Nat. Fib. (2020)https://doi.org/10.1080/15440478.2019.1710651.
[19] P. Narayanasamy, P. Balasundar, S. Senthil, M.R. Sanjay, Suchart Siengchin, Anish Khan, Abdullah M. Asiri, Characterization of a novel natural cellulosic fiber from Calotropis gigantea fruit bunch for eco-friendly polymer composites, Int. J. Bio. Macro. 150 (2020) 793–801, https://doi.org/10.1016/j.ijbiomac.2020.02.134.
[20] V. Vignesh, A.N. Balaji, M.K.V. Karthikeyan, Effect of wood sawdust filler on the mechanical properties of Indian mallow fiber yarn mat reinforced with polyester composites, Int. J. Polym. Anal Char. 22 (2017) 610–621, https://doi.org/10.1080/1023666X.2017.1356481.
[21] P. Manimaran, M.R. Sanjay, P. Senthamaraikannan, M. Jawaid, S.S. Saravanakumar, R. George, Synthesis and characterization of cellulosic fiber from red banana peduncle as reinforcement for potential applications, J. Nat. Fib. 16 (2019) 768–780, https://doi.org/10.1080/15440478.2018.1434851.
[22] C.M. Conrad, Determination of wax in cotton fiber, a new alcohol extraction method, Indus. Engg. Chem. Anal. Edi. 16 (1944) 745–748, https://doi.org/10.1021/i560136a007.
[23] B. Stalin, N. Nagaprasad, V. Vignesh, M. Ravichandran, Evaluation of mechanical and thermal properties of tamarind seed filler reinforced vinyl ester composites, J. Vin. Add. Tech. 25 (s2) (2019) E114–E128, https://doi.org/10.1002/vnl.21701.
[24] P. Manimaran, K. Solai Senthil Kumar, M. Prithiviraj, Investigation of physico chemical, mechanical and thermal properties of the Albizia Lebbeck bark fibers, J. Nat. Fib. (2019)https://doi.org/10.1080/15440478.2019.1687068.
[25] B. Stalin, N. Nagaprasad, V. Vignesh, M. Ravichandran, Nagarajan Rajini, Sikiru Oluwarotimi Ismail, Faruq Mohammad, Evaluation of mechanical, thermal and water absorption behaviors of Polyalthia longifolia seed reinforced vinyl ester composites, Carb. poly. (2020)https://doi.org/10.1016/j.carbpol.2020.116748.
[26] Broido, A simple, sensitive graphical method of treating thermo gravimetric analysis data, J. Polym. Sci. Poly. Phy. 7 (1969) 1761–1773, https://doi.org/10.1002/pol.1969.160071012.
[27] V. Amutha, B. Senthilkumar, Physical, chemical, thermal, and surface morphological properties of the bark fiber extracted from acacia concinna plant, J. Nat. Fib. (2019) https://doi.org/10.1080/15440478.2019.1697986.
[28] L. Segal, J.J. Creely, A.E. Martin Jr., C.M. Conrad, An empirical method for estimating the degree of crystallinity of native cellulose using the x-ray diffractometer, Tex. Res. J. 29 (1959) 786–794, https://doi.org/10.1177/004051755902901003.
[29] N. Nagaprasad, B. Stalin, V. Vignesh, M. Ravichandran, N. Rajini, Ismail Sikiru Oluwarotimi, Effect of cellulosic filler loading on mechanical and thermal properties of date palm seed/vinyl ester composites, Int. J. Bio. Macro 147 (2020) 53–66, https://doi.org/10.1016/j.ijbiomac.2019.11.247.
[30] P. Manimaran, M.R. Sanjay, P. Senthamaraikannan, B. Yogesha, Claudia Barile, Suchart Siengchin, A new study on characterization of Pithecellobium Dulce Fiber as composite reinforcement for light weight applications, J. Nat Fib. 17 (2020) 359–370, https://doi.org/10.1080/15440478.2018.1492491.
[31] S. Indran, R. Edwin Raj, V.S. Sreenivasan, Characterization of new natural cellulosic fiber from Cissus quadrangularis root, Carb. Poly 110 (2014) 423–429, https://doi.org/10.1016/j.carbpol.2014.04.051.
[32] V. Fiore, T. Scalici, A. Valenza, Characterization of a new natural fiber from Arundo donax L. as potential reinforcement of polymer composites, Carb. Poly. 106 (2014) 77–83, https://doi.org/10.1016/j.carbpol.2014.02.016.
[33] P. Senthamaraikannan, M. Kathiresan, Characterization of raw and alkali treated new natural cellulosic fiber from Coccinia grandis L, Carb. Poly. 186 (2018) 332–343, https://doi.org/10.1016/j.carbpol.2018.01.072.
[34] A. Stalin, S. Mothilal, V. Vignesh, M.R. Sanjay, Suchart Siengchin, Mechanical properties of hybrid vetiver/banana fiber mat reinforced vinyl ester composites, J. Ind. Tex. (2020)https://doi.org/10.1177/1528083720938161.
[35] T.P. Sathishkumar, P. Navaneethakrishnan, S. Shankar, Tensile and flexural properties of snake grass natural fiber reinforced isophthallic polyester composites, Comp. Sci. Tech. 72 (2012) 1183–1190, https://doi.org/10.1016/j.compscitech.2012.04.001.
[36] A.N. Balaji, V. Vignesh, M.K.V. Karthikeyan, Characterization of new natural cellulosic fiber from kusha grass, Int. J. Polym. Anal. Char. 21 (2016) 599–605, https://doi.org/10.1080/1023666X.2016.1192324.
[37] P. Manimaran, S.P. Saravanan, M.R. Sanjay, Mohammad Jawaid, Suchart Siengchin, Vincenzo Fiore, New Lignocellulosic Aristida adscensionis fibers as novel reinforcement for composite materials: extraction, characterization and Weibull distribution analysis, J. Poly. Envir. 28 (2020) 803–811, https://doi.org/10.1007/s10924-019-01640-7.
[38] A. Arul Marcel Moshi, D. Ravindran, S.R. Sundara Bharathi, S. Indran, S.S. Saravanakumar, Yucheng Liu, Characterization of a new cellulosic natural fiber extracted from the root of Ficus religiosa tree, Int. J. Bio. Macro. 142 (2020) 212–221, https://doi.org/10.1016/j.ijbiomac.2019.09.094 In this issue.
[39] M. Umashankaran, S. Gopalakrishnan, Effect of sodium hydroxide treatment on physico-chemical, thermal, tensile and surface morphological properties of Pongamia Pinnata. L. Bark Fiber, J. Nat. Fib. (2020)https://doi.org/10.1080/15440478.2019.1711287.