Original Article

Characterization of alkali treated new cellulosic fibre from *Cyrtostachys renda*

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A R T I C L E   I N F O

A B S T R A C T

This study aims to explore the potential of the NaOH-treated *Cytostachys renda* fibre to be reinforced in the polymeric composites. The NaOH concentrations were prepared as 1, 3, and 5 wt% for soaking time of 1 and 2 h. The treated fibres were characterized in terms of density, chemical composition, Fourier Transform Infrared Spectroscopy (FTIR), X-ray Diffractometry (XRD), and Thermogravimetric analysis (TGA). The results revealed that the density is improved with an increase in the concentration and soaking time. NaOH treatment has reduced the amorphous hemicellulose and lignin content. On the other hand, the improved crystallinity index by 6% was observed for fibre treated at 3% NaOH for 1 h, along with the enhancement of cellulose content as much as 0.27%. From the FTIR analysis, it was observed that the presence of C—H stretching vibration from the ether in the treated fibre for 1 h soaking time would form a strong interaction with the polymeric matrix. The TGA results showed that fibre treated at 3% NaOH for 1 h exhibited the highest thermal stability compared to the untreated and other treated fibres. Therefore, it can be concluded that the fibre treated with 3% of NaOH for 1 h soaking time could act as a potential reinforcement in the polymeric composites for light weight applications.

1. Introduction

Lignocellulosic fibres are extracted from various parts of plants, such as bast, leaf, seed, fruit, wood, stalk, or grass. In this research, the *Cyrtostachys renda* (CR) fibre was investigated

as a new cellulosic fibre for polymer composites reinforcement. CR, known as red sealing wax palm or lipstick palm, is an interior ornamental plant [1]. Their frond and stalk leaf in attractive red make them unique from other Arecaceae species. The stalk leaf of CR is a lignocellulose-rich agricultural wastes/residues that are abundant and renewable resources [2] for fibre-reinforced bio-based composites. To date, this fibre is discarded after grooming, and no significant effort has been made to process residues to efficiently use these bio-wastes as an added value of resources.

CR fibre shares the same genus of Areca catechu. Areca catechu is considered as another alternative source of highly promising fibres; however, limited research has been conducted on areca fibre as reinforcement in polymer composites. Furthermore, Shanmugasundaram et al. recently investigated the areca leaf stalk fibre as a new cellulosic fibre that has potential as fibre reinforcement for polymer composites [3]. Their study found that the cellulose content of areca leaf stalk fibre was 57.49% which then increased to 68.54% when treated with 5% of NaOH which remarkably increased the mechanical properties. Binoj et al. characterised the properties of areca husk fibre and concluded that low density (0.78 g·cm^{-3}) and moderate tensile strength are suitable for light weight applications [4]. The high crystalline index of 55.5% and crystalline size of 7.9 nm which is higher in comparison with corn stalk and flax fibre indicated reduction in water and chemical absorption of the fibres when reinforced in polymer composites. However, there are limited researches with regard to the characterisation of areca fibre. Ranganagowdaa et al. found that the reduction of broadening of hydroxyl peak at 3442.64 cm^{-1} due to alkali treatment on areca fibre [5]. Conversely, the NaOH-treated areca fibre improved the thermal stability up to 259 °C as compared to raw fibre at 241.5 °C [5].

Table 1 shows a few chemical treatments that were carried on areca fibre before mechanical testing. For the alkali treatment, the fibres were treated with 6 wt% of NaOH concentration solution at room temperature for 1 h. The results indicated that treated fibre provides enhanced properties than untreated areca fibre.

Chemical modification against the lignocellulosic fibre as a surface treatment, such as alkalization [10–13], benzoylation [14–16] and acetylation [14,17], and silane treatment [18,19], enhances the strength of fibre by overcoming drawbacks such as water absorber and low thermal stability [20,21]. Alkali treatment is the least expensive, most efficient, and practical technique for enhancing the moisture resistance of lignocellulosic fibres compared to other chemical modification [22–24], which reduces water intake ability and modifies the surface of fibres. The modification occurs due to the removal of hemicellulose and lignin. Wang et al. carried out sodium hydroxide treatment on rice husk cellulosic fibres and found that lignin reduced to 14.71% from 27% at a soaking temperature of 40 °C and reduced to 6.5% at 80 °C for a similar soaking time of 24 h [25]. On the other hand, Thomas et al. found that the amount of lignin was reduced to 11 at 3 wt% NaOH [26]. Hemicellulose was partly removed with 6%, 8%, and 10% of NaOH treatment, while the surface roughness increased and accessibility of hydroxyl groups decreased with increasing NaOH concentration. However, the higher concentration of NaOH may completely remove the binding substance of the fibre leading to weaker fibre, consequently failing in terms of strength. Chandrasekar et al. claimed that elevated NaOH concentration contributes to the deterioration of the mechanical characteristics owing to fibre [27]. Therefore, it is suggested that lower concentration of alkali treatments (less than 5% of NaOH) are highly beneficial to enhance the surface properties and performance of lignocellulosic fibres. Most alkalization using NaOH at 2%–10% NaOH concentration for 10 min to a few hours [28,29] intended to enhance the mechanical characteristics of by reducing the moisture absorption. They also highlighted that 10 min of NaOH treatment of the natural fibres was satisfactory to attain the optimal properties [30].

The groomed CR stalk leaf is an agricultural waste product which is not utilized for any purpose. In addition, the exploration of new cellulosic fibre could fill the gap on exploration of new cellulosic fibre as a supply demand for natural fibre polymer composites. Although a variety of natural fibres have been investigated in detail, the CR fibre has not been utilised as a reinforcement in the polymeric composite to date. In this work, the leaf stalk of CR fibre was extracted manually by water retting for six weeks and subjected to NaOH treatment. Three different NaOH concentrations were prepared as 1%, 3%, and 5 wt% NaOH at soaking time of 1 and 2 h. Then, the treated and untreated CR fibres were investigated in terms of density, chemical composition, FTIR, XRD, and TGA in order to identify the optimum parameter for the NaOH treatment for CR fibres to be used as fibre reinforcement in the polymeric composites.

2.   Materials and methods

The leaf stalks were collected from landscaping around the Wetland, Putrajaya, Malaysia area and NaOH pellets brand R&M Chemicals with molarity 0.1 M was supplied by Evergreen Engineering & Resources, Malaysia.

2.1.   Fibre extraction

The stalk leaf of CR, which was 1.5 m long, was chopped into logs of approximately 8 cm long. The logs were immersed in fresh water for three days in order to soften them. Then, the logs were crushed gently with pestle in order to loosen and separate the fibres. The CR fibres were manually extracted from the crushed log after water retting for six weeks. The fibres were washed to remove dirt and impurities. Next, the fibres were dried in the oven at a temperature of 80 °C for 24 h. The overall extraction process was shown in Fig. 1.

2.2.   Chemical treatment

The dried fibres were immersed in NaOH solution with 100 mL of distilled water, 1%, 3%, and 5 wt.% for 1 and 2 h of soaking time at room temperature. The NaOH solution was mixed with the fibre (wt ratio of NaOH solution: fibre = 10:1). The mixture was stirred throughout the treatment duration. The mixture was then filtered using a cloth filter. Next, the fibres were removed from the NaOH solution and washed several times using distilled water until the fibres were neutralized by removing the sodium hydroxide residue. Subsequently, the

Table 1 – Mechanical properties of untreated and treated areca reinforced polymer composites.

| Treatment	Matrix	Properties	Areca fibre loading at (%)				Refs.
			40	50	60	70	
Untreated	Epoxy	Impact energy (J)	8.64	9.68	10.24	7.64	[6]
Alkali-treated			9.62	10.28	21.22	9.54	
Potassium permanganate treated			10.42	12.68	22.64	10.24	
Benzoyl chloride treated			11.56	14.58	24.56	10.86	
Acrylic acid-treated			12.54	16.24	28.28	11.56	
Untreated	Epoxy	Flexural strength (N/mm^2)	30.24	38.48	42.68	24.28	[7]
Alkali-treated			52.54	61.28	84.86	26.84	
Potassium permanganate treated			54.38	64.96	88.98	27.26	
Benzoyl chloride treated			56.02	66.58	94.28	28.46	
Acrylic acid treated			57.54	68.52	96.84	28.98	
Untreated	Polypropylene	Tensile strength (MPa)	20.26	21.84	25.04	18.86	[8]
Alkali-treated			22.46	22.84	28.04	20.32	
Potassium permanganate treated			24.22	24.96	28.86	22.86	
Benzoyl chloride treated			26.28	28.62	30.52	24.52	
Acrylic acid treated			28.04	30.24	36.86	26.52	
Untreated	Natural rubber	Tensile strength (MPa)	87.24	112.28	126.48	108.32	[9]
Alkali-treated			92.26	116.82	130.82	109.26	
Potassium permanganate treated			94.28	118.28	134.56	110.52	
Benzoyl chloride treated			94.86	118.98	138.52	112.26	
Acrylic acid treated			96.86	122.84	140.82	113.56	
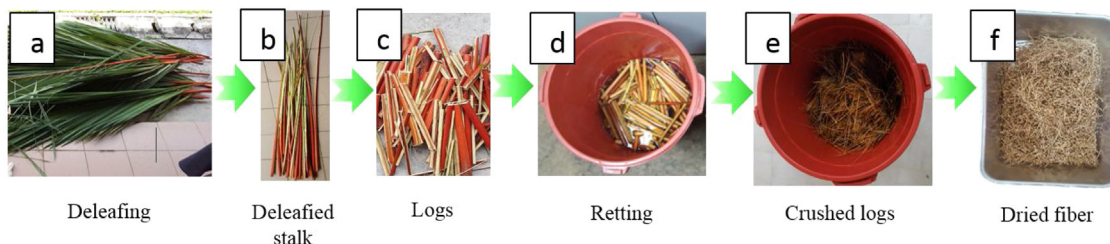
Fig. 1 – Extraction of CR fibres.
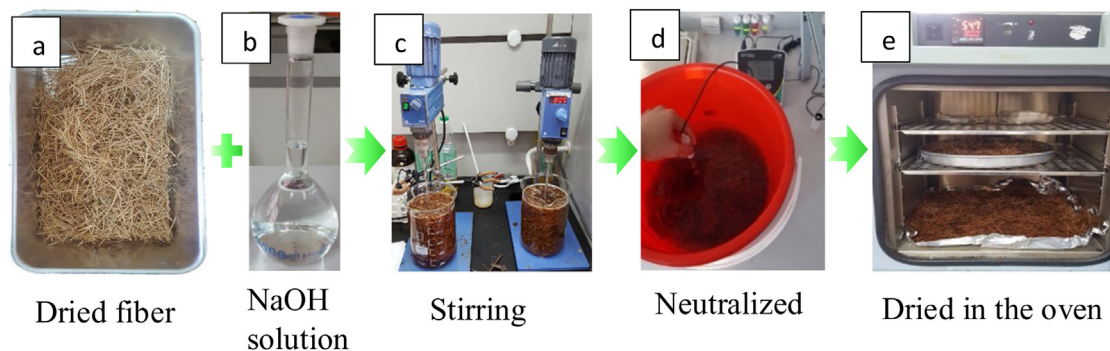
Fig. 2 – Alkali treatment on CR fibres.

NaOH-treated fibres were dried in the oven at 80 °C for 24 h. The alkali treatment process was shown in Fig. 2.

2.3. Density

Density testing was carried out at the Department of Food Science, UPM. The true density of untreated and NaOH-treated fibres were determined using Gas Pycnometer of AccuPyc II 1340 brand by Micromeritics Instrument Corp., USA. Prior to this testing, the mass of the empty pycnometer and pycnometer filled with chopped fibres were measured in order to obtain the mass of the fibre as shown in Equation 1. The volume of the fibre was measured according to a gas displacement method. The weight of the fibre was recorded in the Quick start Analysis software to obtain the density.

$$Mass_{fibre} = Mass_{pycnometer + fibres} - Mass_{pycnometer} \quad (1)$$

2.4. Chemical composition of the fibre

The chemical composition analysis was carried out at Malaysian Agricultural Research and Development Institute (MARDI), Serdang, Malaysia. The analysis of untreated and NaOH-treated stalk leaf of CR were carried out where the

percentages of Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF), and Acid Detergent Lignin (ADL) were obtained using a machine named Fibertec system. ADL corresponds to the lignin content whereas the hemicelluloses content could be obtained by subtracting the value of ADF from NDF; however, the cellulose content is obtained by the subtracting the value of ADF from ADL [31].

2.5. Fourier Transform Infrared Spectroscopy (FTIR) analysis

Fourier Transform Infrared Spectroscopy (FTIR) analysis was conducted at Institute of Tropical Forestry and Forest Products (INTROP), UPM. The NaOH-treated and untreated fibres were powdered and tested with FTIR test using Thermo Scientific, Nicolet iS10 type device with Attenuated Total Reflectance (ATR) technique. It is analysed by a quantitative software named OMNIC which has the capacity of a scanning speed of 32 acquisitions between 500 and 4000 cm^{-1} with a resolution of 2 cm^{-1}.

2.6. X-ray diffractometer (XRD)

The X-ray diffractometer analysis was performed at Faculty of Science, UPM. An X-ray diffractometer (PANalytical Philips X'Pert PRO MPD PW3040 model) was used to analyse the untreated and NaOH-treated fibres. 2θ angles were ranged from 5° to 80° with a step size of 0.0330° and a step time of 19.685 s to characterize natural fibres' crystallographic properties. The read noise of XRD data was corrected and normalized with transmission calculated from the primary beam before air scattering was subtracted. The crystallinity index of the fibres, CI%, was calculated using the Segal's equation as below:[32]

$$CI\% = \frac{I_{002} - I_{min}}{I_{002}} \times 100\% \qquad (2)$$

2.7. Thermogravimetric analysis (TGA)

Thermogravimetric analysis (TGA) was conducted at Institute of Tropical Forestry and Forest Products (INTROP), UPM. The Mettler Toledo TGA (Schwerzenbach Switzerland) analyser was used to analyse the thermal stability of fibres in accordance to the ASTM E1131-03 standards. The fibres with a weight of ±15 mg were placed in an alumina crucible and underwent the pyrolysis process with nitrogen (30 mL/min). The temperature was set between 30 °C and 580 °C with a heating rate of 20 °C/min. The TGA analysis was employed to measure the changes in mass loss of the fibre sample subjected to temperature changes in a controlled atmosphere condition.

3. Results and discussion

3.1. Density

Fig. 3 displays the density of the untreated and NaOH-treated CR fibres. The fibres in the NaOH treatment were denser

Table 2 – The chemical composition of untreated and NaOH-treated CR fibre.

No	Sample	Cellulose in wt%	Hemicellulose in wt%	Lignin in wt%
1	Untreated	45.15	22.88	18.77
2	1% NaOH-1h	48.43	19.77	19.57
3	1% NaOH-2h	48.93	19.88	17.01
4	3% NaOH-1h	45.42	18.97	20.70
5	3% NaOH-2h	47.78	18.99	17.08
6	5% NaOH-1h	47.31	19.68	18.46
7	5% NaOH-2h	42.26	23.09	22.08

compared to the untreated CR fibres. The alkali treatment played a role as a dissolver of the non-cellulosic components such as lignin, hemicellulose, and pectin which are characterized by weight and also contributed to the increase of fibre volume by minimizing the pores and lumen. Therefore, the elimination of these components contributed to the decrease of fibre volume, which lead to the increase of fibre density by rearranging the packing structure. Similar findings were perceived by Shanmugasundaram et al. that the density of the fibres has been improved with the reduction of fibre diameter due to the alkali concentration [33]. Fibre treated at 3% of NaOH for 1 h showed the lowest density among the treated fibres, by reduction of 0.6% of cellulose, and 17% of hemicellulose compared to the untreated fibre.

3.2. Chemical composition

Table 2 demonstrates the chemical composition of the untreated and NaOH-treated of CR fibres. These results indicate that the cellulose component has an increasing trend while hemicellulose has a decreasing trend for all the configurations of treatment except for 5% NaOH concentration for 2 h. The results also showed that the lignin amount decreased for fibres treated at 1% NaOH for 2 h, 3% NaOH for 2 h, and 5% NaOH for 1 h compared to that of the untreated fibre. The highest amount of cellulose and the lowest amount of lignin was produced by 1% NaOH for 2 h. Whereas, the highest amount of hemicellulose and lignin hydrolysis was recorded in 3% NaOH with an immersion time of 2 h. This indicates that the removal of lignin or hemicelluloses from fibres and the creation of a free −OH band due to hydrolysis may lead to an increase in the cellulose molecular structure by the breakdown of ester or ether bonding after NaOH treatment. In addition, the removal of lignin and hemicellulose is also a good indication for polymer composite fabrication from natural fibres. However, the accessibility of hydroxyl groups was reduced with the removal of hemicellulose and lignin when NaOH concentration was increased to 5% with 2 h of immersion time, as cellulose closely packed itself with hydrogen bonding [30] and led to a reduction in cellulose content. Therefore, the concentration of 1% NaOH with 2 h of immersion time enhances the chemical composition of CR fibre by 8% in cellulose content, while decreased in hemicellulose and lignin content by 13% and 9%, respectively. Fibre treated at 3% NaOH for 1 h could be potentially used as fibre reinforcement due to its lowest hemicellulose content which consequently resulted in lower moisture absorption capacity and minimised thermal
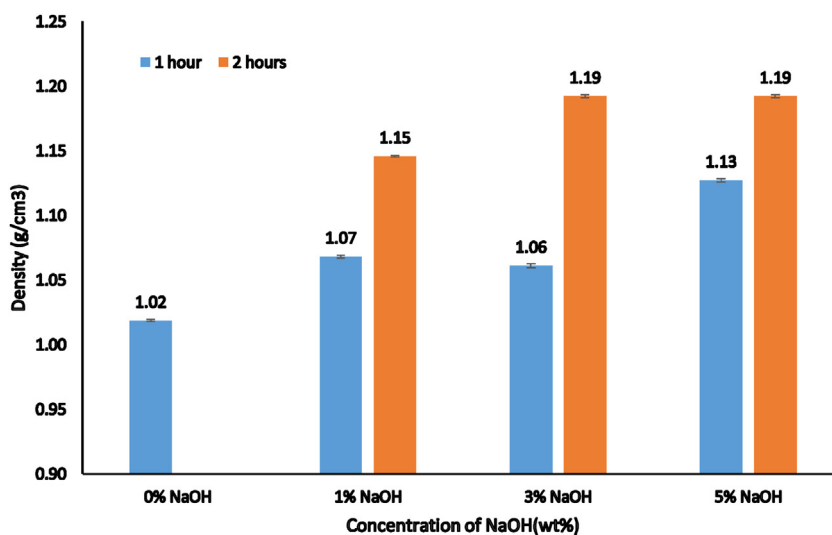
Fig. 3 – Density of the untreated and NaOH-treated CR fibre.

and biological degradation. In addition, the higher content of lignin in fibre treated with 3% NaOH for 1 h could contribute to improved char formation and led to improved thermal stability of the fibre.

3.3. Fourier transform infrared spectroscopy (FTIR) analysis

FTIR was used to analyse the functional groups by the effects of alkali treatments on the stalk leaf of fibres as shown in Fig. 4. The absorption band around 3328–3340 cm^{-1} is due to the hydrogen bonded O—H stretching the vibration [34] of cellulose which is present in all the natural fibres. This band was attributed at 3339 cm^{-1} for untreated fibres and was found to have a slight shift and variation in terms of the intensity upon the treated fibres. This shows the reduction in hydrogen bonding in cellulosic hydroxyl groups, resulting in a decreased hydrophilic behaviour [35] and the free —OH presence in carboxylic groups does not participate in the formation of hydrogen bonding [36] throughout the alkali treatment. Based on the comparison, the observation peak at 2849 cm^{-1} was only formed in alkali treatment for 1 h, indicating that C—H stretched the vibration from the presence of ether [37]. The hydroxyl groups engage in hydrogen bonding within the cellulose, thereby decreasing the reactivity of the polysaccharide [38]. As a consequence of breaking the crosslink between lignin and hemicelluloses, the alkaline treatment produces more —OH groups. Hydrolysis due to the effect of NaOH treatment caused breakdown of ester or ether bonding and leads to the removal of lignin or hemicelluloses from fibres and creates a free —OH group [39]. It is also supported by the chemical composition, where cellulose content increases and hemicellulose content decreases for all the NaOH treated fibre compared with untreated fibre. Nonetheless it was exceptional for fibre treated at 5% NaOH for 2 h. This is due to excessed exposure of NaOH treatment, would weaken the fibre.

However, this band is absent in the alkali treated for 2 h due to the breakdown of the ester or ether bond [5]. The peaks at 2915 cm^{-1} correspond to the C—H stretching vibration of methyl and methylene groups in cellulose and hemicellulose [41]. The peak of the band at 1730 cm^{-1} was clearly observed in the untreated fibre. According to Abdullah et al., this band indicated to C=O stretching in the ester linkages of carboxylic groups of lignin [42]. However, another source by Senthamaraikannan & Kathiresan, indicated that it is related to the C=O stretching of hemicelluloses [43]. Nevertheless, it was noticed that this band was not present in other treated fibre due to the dissolution of lignin and hemicellulose in alkaline solution. Whereas, the band at 1,235 cm^{-1} for untreated fibre is associated with the presence of C—O—C stretching vibration in cellulose chain [44,45] and can be split as shown in Table 3. However, for the alkali-treated fibres, the peaks at 1730 cm^{-1} and 1235 cm^{-1} were eliminated. These phenomena proved the removal of hemicelluloses and lignin upon alkaline treatment. The highest removal of hemicellulose content in 3% NaOH treated for an hour, fibre indicated that the strong formation of ester group compared to untreated and other treated fibre.

3.4. X-ray diffractometry (XRD)

Fig. 5 shows the X-ray diffractometry of the untreated and NaOH-treated with different concentration and soaking hour of the CR leaf stalk fibre. According to Fig. 5, the peaks at approximately $2\theta = 16°$, $22°$, and $34.5°$ arose from the cellulose (110), (002), and (004) planes, respectively as similar findings of the planes were obtained from previous studies [36,37]. The longer exposure in a higher concentration leads to weakening of the fibre. A higher cellulose content provides a higher crystallinity index as shown in Fig. 6. The higher NaOH concentration reduces the crystallinity index which contradicts with the reported results by Chandrasekar et al. [47] that the crystallinity index of natural fibre increases with the increase in alkali concentration; however, this is true for a certain extent only. The cellulose has a semi-crystalline structure contrary to the hemicellulose and lignin that are naturally amorphous; however, the alkaline hydrolysis purifies the cellulose of CR fibres by the dissolution of the amorphous cellulosic content, subsequently increasing the CI%. The ester
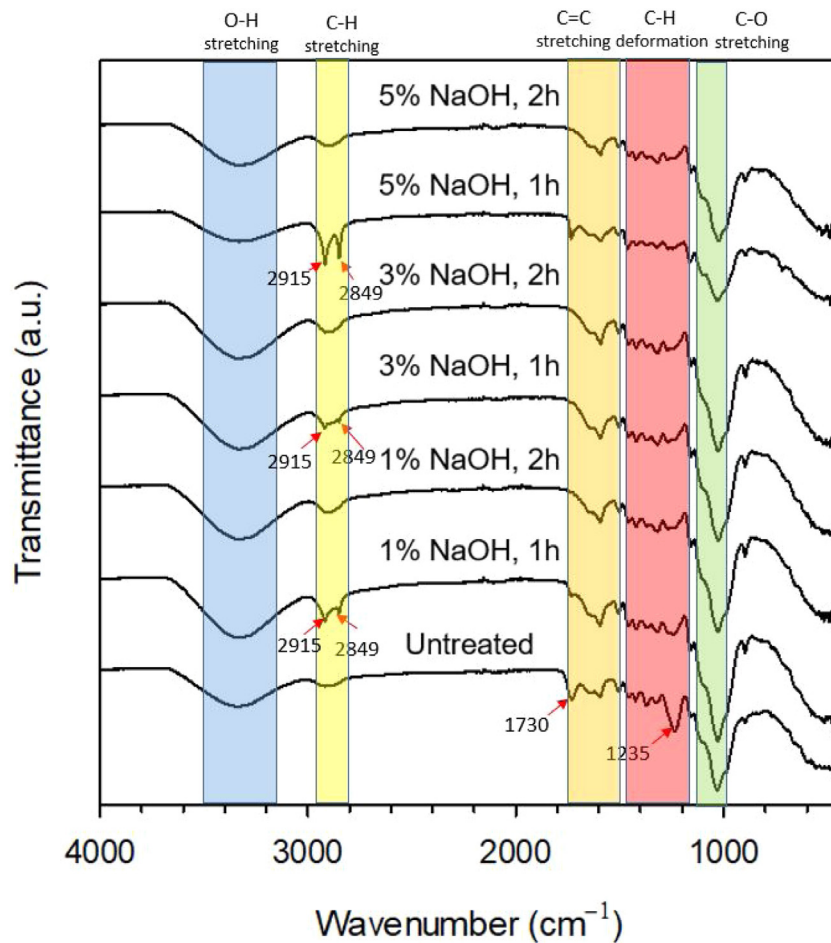
Fig. 4 – FTIR spectra of the untreated and NaOH-treated CR fibre.

Table 3 – The corresponding peak for the untreated and treated CR fibre.			
Present	Band/peak position (cm^{-1})	Origin	Reference
Treated with 1h	2849	C—H stretching vibration from the ether	[37]
Untreated	1730	C═O stretching in the ester linkages of carboxylic groups	[42]
Untreated	1235	C—O—C stretching vibration	[44,45]

and ether bonding also contribute to the cellulose content [46]. The bonds increase the crystalline part of cellulosic contents, also known as the crystallinity index, when unwanted constituents are removed.

According to Fig. 6, it is proven that NaOH treatment at 1% NaOH for 2 h enhances the crystallinity of the natural fibre by up to 6%. Meanwhile, fibre immersed in 3% NaOH for 2 h showed the increment of crystallinity of 3% compared to the untreated fibre. This indicates that the concentration of NaOH at 1% with 2 h soaking time resulted in better improvement in the crystallinity structure than treatment with 1 h at the same concentration. It was found that the trend of the crystallinity curve follows a similar pattern. Nonetheless, there is a slight deviation on the peak was observed due to the molecular weight and dimensional distribution of cellulose crystals [48]. Based on Fig. 6, it can be concluded that the crystallinity

of the fibre depends predominantly on the concentration of NaOH because although the immersion time was lengthened to 2 h, the results exhibited are almost the same. Conversely, 5% of NaOH with 2 h immersion time showed a decrease in the crystallinity index compared to the untreated fibre. This could be due to the removal of impurities and other components such as hemicellulose, lignin, and waxy material from the fibre. This is corroborated by the physical appearance of the untreated and alkali-treated CR fibre as shown in Fig. 7. Fig. 7 shows the colour appearance of the NaOH treated fibres turned brown and the fibres were more twisted and finer based on the visual inspection. In addition, it was found that the surface of the fibre was sticky and rough due to the accumulation of microfibril in the cell wall of the fibre [40,49]. Similar findings were reported by Sinha and Rout that the rough fibre surface of the alkali-treated jute is due to the removal of lignin and
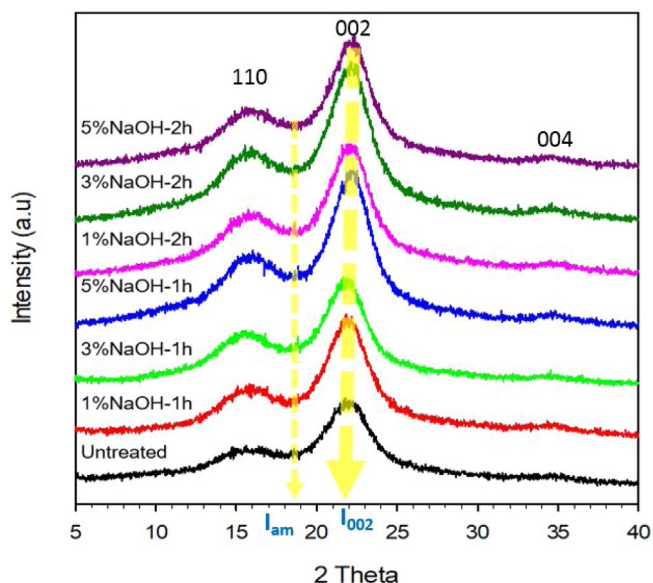
Fig. 5 – X-ray diffractometry of the untreated and NaOH-treated CR fibre.

Fig. 6 – The crystallinity index (CI%) vs the cellulose content of CR fibre.

hemicellulose with the increase in NaOH concentration and immersion time [50].

3.5. Thermogravimetric analysis (TGA)

Fig. 8 depicts the TGA and DTG of the untreated and alkalitreated stalk leaf of CR fibre. According to Table 4, the TGA curve of a lignocellulosic fibre shows three stages of weight loss and decomposition. In the first stage of thermal degradation, when the temperature was ranged from the room temperature to 134 °C, the highest peak occurred at 44 °C with a 3.57% weight loss. It indicates the evaporation of moisture and the volatile extractives decomposition of natural fibre as supported by similar findings from [51–53]. From the TGA graph, it is also observed that above 260 °C, the second
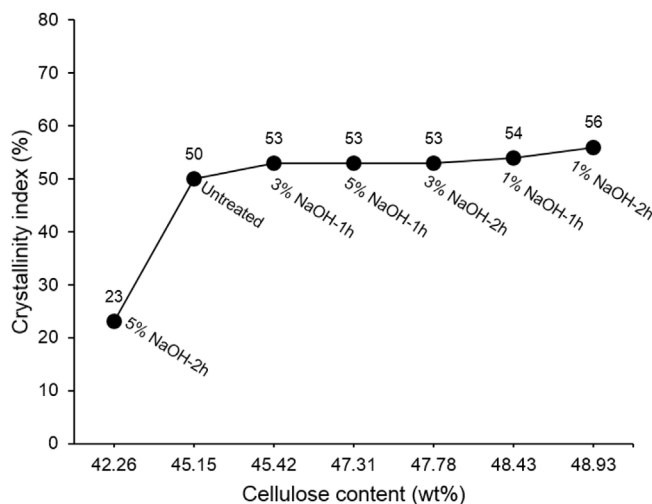
stage of thermal decomposition occurred at 297.15 °C with a weight loss of 31.71% corresponding to the polymerisation of hemicellulose, pectin, and wax as reported by Sampath kumar et al. [54]. Meanwhile, the major degradation occurred at 364.95 °C corresponding to the decomposition of α-cellulose with a weight loss of 44.97%. On the other hand, lignin is more difficult to pyrolysis and the weight loss occurred at a temperature ranging from 160 °C to 900 °C besides producing strong residue as reported by [55]. Therefore, the thermal stability of natural fibre depends on the main constituents like the hemicellulose and lignin. Hemicellulose, hydrophilic in nature, plays a major role in thermal degradation while lignin, hydrophobic in nature, is responsible for thermal stability [56,57]. The highest removal of hemicellulose content was found in fibre treated 3% of NaOH for 1 h of immersion time. It is also exhibited the highest thermal stability compared to the others owing to the fact that the highest char residual for-
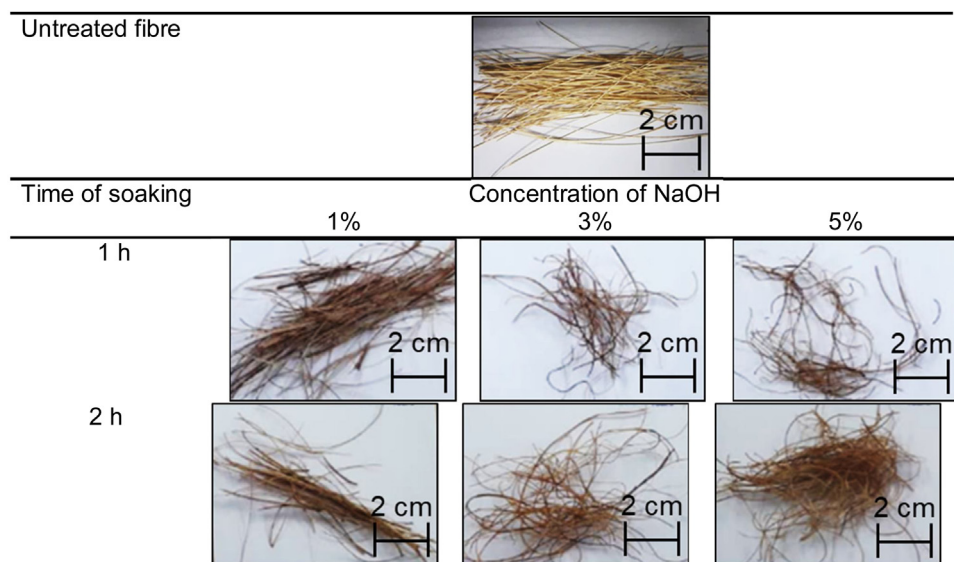

Fig. 7 – Visual inspection of leaf stalk of CR fibre before and after the NaOH treatment.
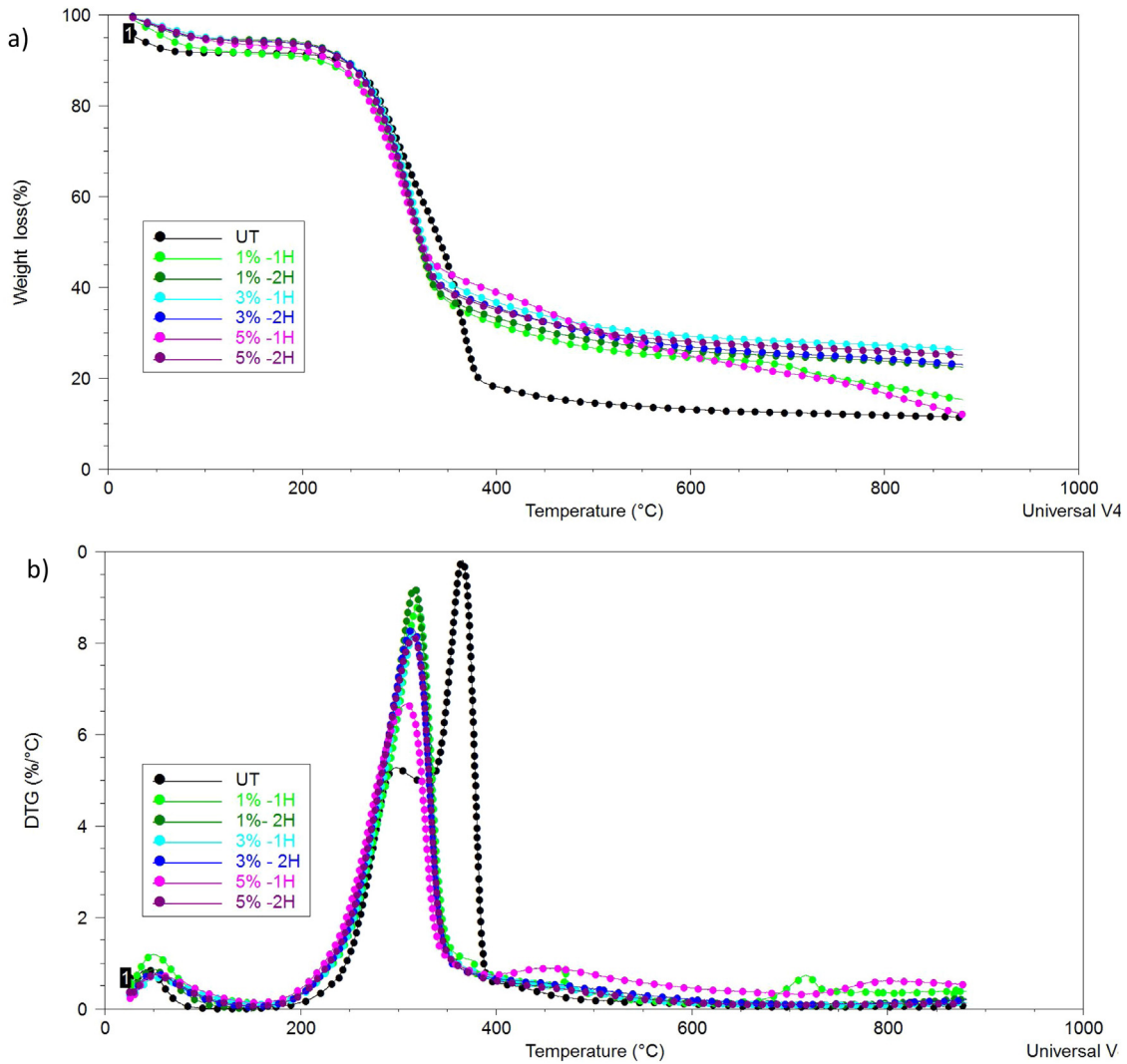
Fig. 8 – (a) TGA and (b) DTG of the untreated and NaOH-treated stalk leaf of CR fibre.

Table 4 – Thermal degradation and char residual of the raw and NaOH-treated CR fibre.

CR fibre	1st stage of degradation		2nd stage of degradation		3rd stage of degradation		Residual mass at 900 °C (%)
	Temperature range (°C)	% weight loss	Temperature (°C)	% weight loss	Temperature (°C)	% weight loss	
UT	0 to 134	3.57	297.15	31.71	364.95	44.97	11.41
1%-1H	0 to 134	7.60	318.99	67.05	718.25	4.61	15.25
1%-2H	0 to 134	4.73	316.73	69.97	–	–	22.39
3%-1H	0 to 134	5.92	316.73	66.41	–	–	26.22
3%-2H	0 to 134	5.26	315.22	69.16	–	–	22.97
5%-1H	0 to 134	5.98	308.44	54.02	449.32	18.45	12.04
5%-2H	0 to 134	5.18	315.22	67.08	–	–	25.07

mation produced by lignin. Furthermore, the content of lignin was increased by 10.3% of NaOH with 1 h soaking time compared to the untreated fibre. According to Naveen et al., the char presence during the TGA acts as an insulator against further thermal decomposition, preventing further degradation [51,58] and consequently, enhancing the overall thermal stability of the fibres. It is also observed that there is no peak within the temperature of 364.95 °C, unlike the untreated fibre,

due to the removal of hemicellulose, pectin, and wax by the alkali treatment as reported by Zhang et al. [59].

4. Conclusions

The effects of NaOH treatment on the CR fibres were concluded as follows:

1 3% of NaOH-treated CR fibre for 1 h showed the lowest density among the NaOH treated fibres by removal of 17% of hemicellulose.

2 The crystallinity index (53%) was observed for 3% of NaOH-treated CR fibre for 1 h compared to the untreated fibre (50%).

3 The functional groups present at 2849 cm^{-1} in the treated CR fibres would enhance the load carrying capability and stiffness while reinforcing with polymeric matrix.

4 3% NaOH-treated CR fibre for 1 h exhibited the highest thermal stability based on char residue formation (26.22%) compared to the untreated fibres (11.41%).

Based on the findings, it can be inferred that among all the parameters of the alkaline treatment, 3% NaOH concentration for 1 h of soaking time is the optimized concentration that provides the excellent properties in term of the lowest density and highest residual of char formation. Therefore, NaOH-treated fibre could be served as a new bioresources fibre reinforcement for polymer composites in light weight application.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgements

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jmrt.2020.01.091.

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