Composites from the Aquatic Environment
Composites Science and Technology

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Composites from the Aquatic Environment
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Development of Nipah Palm Fibre Extraction Process as Reinforcing Agent in Unsaturated Polyester Composite

Syed Tarmizi Syed Shazali, Tracy Dickie, and Noor Hisyam Noor Mohamed

1 Introduction

Nipah palm or scientifically known as *Nyipa fruticans* is a palm that grows in an aquatic environment as shown in Fig. 1. Nipah is the most abundant palm in the mangrove forest of the South, Southeast Asia and the Oceania. Nipah palm grows in the mangrove forest, it is also known as mangrove palm. The growth area of nipah palm is where the fresh water meets the salt water of the mangrove forest. The muddy and brackish water of this area are the natural habitat of nipah palm. Nipah palm are rarely seen on the seashores, but more to the estuarine area. This palm is trunkless and has its fronds grow from the roots. The trunk submerged in the water during high tide and exposed to the air during low tide. The submerged fronds are bulky and spongy compared to the upper fronds. The spongy nature of the lower fronds is assumed to provide the palm the buoyancy during high tide. The upper frond is rigid and study, supporting the towering. They can grow up to 10 m tall [1, 2] (Fig. 1).

Historically, this palm provides a wide diversity of use towards the indigenous people living near the forest [1]. Nipah palm is abundant along the riverbanks of Sarawak River. It is locally known as *pokok apong* by the Sarawakians. It is well-known for its sugar sap; it has been collected by the population nearby and has been used as sweetener in local delicacies known as *gula apong* by locals as shown in Fig. 3a. This sugar sap is also the source of income for them. Besides that, the dried and fresh young leaves of nipah palm are traditionally used to make baskets, roof thatches, food wrappers, cigarette wrapper (Fig. 3b) and many more.

There are two forms of nipah found in Malaysia, *nipah gala* and *nipah padi*. Nipah palm found in Malaysia and Papua New Guinea is bigger than the one found in Philippines. Nipah palm largest population is found in Indonesia (700,000 ha), Papua New Guinea (500,000 ha) and Philippines (8,000 ha) [4]. Mangrove forest

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Fig. 1 Nipah palm along Sungai Kuap, Kuching (red arrow is showing the lower frond)

Fig. 2 Mangrove forest distribution. a Sarawak, b Kuching, Samarahan, Sibu and Sarakei [3]
occupying slightly more than 0.09 million hectares in Sarawak [3]. Figure 2 show the distribution of mangrove forest in Sarawak as marked in red. Mangrove forest is concentrated within Kuching, Samarahan, Sarikei and Sibu division as shown Fig. 2b. The actual data for nipah palm population within the mangrove forest is not available. It has yet been explored by the Forest Department of Sarawak due to no requirement for the actual population. Sarawak has nine major type of forest, which is rich and diverse with flora and fauna species. This explained the lack of work done on nipah palm in Sarawak, as priority is given to other flora and fauna in the deep rainforest.

Nipah palm is the most utilised mangrove species. It is the most valued palm for the population living at the growth area. Nipah palm is known as *pokok apong* in Sarawak and *attap palm* in Singapore. The commercial value of nipah palm in Sarawak is still lacking compared to its neighbouring country. Indonesia and Philippines are conducting studies to diversify the usage of nipah palm product. For instance, Indonesia is exploring renewable energy derived from plant to meet their growing demand on energy. Recent work reported on nipah palm fibre is to extract fibre from nipah flower stalk to produce composite based on recycled polypropylene matrix [5]. Nipah palm sap has been investigated for its potential as bioethanol production [6]. Ethanol produced from nipah sap was reported to be better than sugarcane, cassava, coconut and potato [7]. Philippines is the third largest area with nipah plantation in Southeast Asia [8]. It is reported that a group of enterprising farmers in Philippines has come out with natural sweetener from nipah sap besides its common usage such as roofing material, vinegar (*sukang paombong*) and wine (*laksoty*). Another application of nipah as reported in the literature is as MDF board, made with coconut [9].

Natural fibre composite has been utilized in automotive industry. The trend has shown tremendous increased by most major vehicle manufacturers [10]. The urge to reduce fuel consumption of motor vehicle and improving its energy efficiency can be achieved by reducing the weight of the vehicle, natural fibre composite fits in the criteria as lightweight and strong material to achieve this. A few research works were investigating natural fibre-based packaging materials suitable for food and
pharmaceutical application. Another emerging area is focusing the used of bio-based polymers and composites is the electronic application [11].

This investigation is to extract nipah palm fibre as reinforcing agent in polyester composite. The characterization of fibre in terms of its physical properties, chemical composition, thermal behaviour and its morphology were investigated. This investigation will provide new knowledge on the extraction method, composite fabrication, characterization of nipah fibre, mechanical test, namely, tensile test and water absorption test.

2 Materials and Method

2.1 Preparation of Raw Materials

Nipah fronds were collected from Sungai Kuap, Samarahan Division, Sarawak. The source of nipah palm fibres is from the fronds. Nipah fronds are found to have two distinctive parts, the lower fronds and upper fronds. The lower fronds are the submerged fronds during high tide and it has spongy structure inside, surrounded by hard and waxy dark brown bark. The upper fronds contain more rigid bundles of fibres as compared to the lower fronds as they are less spongy.

2.1.1 Fibre Extraction

Nipah fibre palm was extracted using wet extraction method or also known as water retting process. A whole lot of nipah fronds were prepared for retting process in a fresh water fish pond. Fresh water pond was chosen to allow biodegradation of the non-cellulosic component of the fronds. Nipah fronds were cut to about 50 cm length, placed into a plastic bag, weighted down with big stone and dropped into the fish pond. At 12 weeks as in Fig. 4a, b, the fronds emitted an extremely strong decompose odour. When the fronds were opened and cleaned under running water, the fibres were separated easily from the fibre bundles as shown in Fig. 4c. The extraction process of the fibre was done manually under running tap water. The source of the tap water is directly from the water catchment area at Mount. Sadong, Serian Division, Sarawak. The water-retted fibres were easier to be pulled out from its fibre bundles as the viscid substance has loosened up. Figure 4d shows the extraction process of fibres consisting of entangled Fibre A and Fibre B. Fibre bundles were easily separated once the water retting process is optimum. Fibres were pulled out one by one and cleaned at the same time. The extracted Fibre A are as shown Fig. 4e, while Fibre B are the remaining of the fibre bundle once Fibre A had been pulled out. It was placed in a basin that contains water as it was easier to remove the dirt. Figure 4f shows the extracted Fibre B. The detail of the extraction process of nipah palm fibre is published in previous work [12].
Fig. 4 Water retting process a 12 week—upper frond, b 12 week—lower frond, c extracting process, d extracting Fibre A and Fibre B, e freshly extracted Fibre A, f freshly extracted Fibre B

2.1.2 Cleaning and Drying Process

The cleaning process of the fibres after the extraction process was carried out by soaking the fibres in detergent (Sunlight Dishwashing Liquid) for one hour at 70 °C. The fibres were then cleaned under running pipe water for about 15 min and dried under the hot sun and proceeded to oven drying at 80 °C for 48 h. Distilled water soaking was not conducted in this work. Preliminary soaking test of the frond was conducted using tape water (chlorinated), however due to extremely slow decaying process, the test was discontinued.

2.2 Sample Preparation

2.2.1 Single Fibre Test

The single fibre test was performed on nipah palm fibre to determine its axial tensile modulus, ultimate strength and failure strain according to ASTM D3379-75. The gauge length was set at 50 mm and the test speed was set at 0.5 mm/min.
Table 1  Composite loading and treatment condition

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Composite loading condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 W/0 N</td>
<td>5 wt% fibre with untreated condition</td>
</tr>
<tr>
<td>5 W/4 N</td>
<td>5 wt% fibre with 4% NaOH</td>
</tr>
<tr>
<td>5 W/10 N</td>
<td>5 wt% fibre with 10% NaOH</td>
</tr>
<tr>
<td>15 W/8 N</td>
<td>15 wt% fibre with 8% NaOH</td>
</tr>
</tbody>
</table>

2.2.2 Composite Preparation

The composites were fabricated using hand lay-up and compression moulding technique. The composites were fabricated using a 230 mm x 230 mm aluminium mould. Vaseline pure petroleum jelly was used as a release agent to ease the removal process of composites as it was effective and low cost. Fibres were dried in the oven at 70 °C for 1 h prior to the fabrication process. The polyester resin was mixed with two to three drops of hardener while the fibres were in the final drying stage in the oven. The dried fibres were then arranged on the mould and the resin was poured into the mould cavity. The mould was covered when the resin had reached the gelling stage, this is to reduce the formation of air bubbles in the composite plate. The loading condition of nipah composite is in Table 1.

2.2.3 Alkali Treatment

Fibre A were treated with 6, 8, 10 and 15% natrium hydroxide, while fibre B were treated with 2 and 4% natrium hydroxide. Composites for fibre A were fabricated with 6, 8 and 10% natrium hydroxide treatment while only for 2% natrium hydroxide treatment for fibre B.

2.3 Characterisation

2.3.1 Diameter and Density Measurement

The diameter of the fibre was measured from observation under the optical microscope. The measurement was taken at 100 different locations along each fibre, and four fibre samples were measured for each type of fibre. The average cross-sectional area (A) was calculated from two fibre perpendicular diameters, \(d_1\) and \(d_2\), \(A = \pi d_1 d_2 / 4\). The density of Fibre A and B were measured using water pycnometer procedure according to ASTM D 854.
2.3.2 Chemical Analysis

The chemical composition evaluation of the fibres was carried out at Forest Research Institute of Malaysia (FRIM) and ENVIC Laboratory Sdn. Bhd. The standards are TAPPI T 203CM-99 (α-cellulose), TAPPI T 222 om-02 (lignin) and aqueous alkali extraction (hemicellulose).

2.3.3 Fourier Transforms Infrared Spectroscopy (FTIR)

FTIR was carried out using Nicolet iS10. All the spectra were recorded in the wavenumber range between 400 and 4000 cm\(^{-1}\).

2.3.4 Thermogravimetric Analysis (TGA)

TGA was carried out using Mettle Toledo with the nitrogen was used as the carrier gas, and the heating rate of 10 °C/min heated ranging from 30 to 700 °C.

2.3.5 X-Ray Diffraction (XRD)

XRD (P8Advane-Bruker) was used to analyse the crystallinity before and after alkali treatment. Measurement was taken from 2θ of 10–90 °C using Cu Kα X-ray source.

2.3.6 Morphology

Scanning Electron Microscopy (SEM) was used to study fibre morphology. Hitachi TM3030 at an acceleration voltage of 15 kV, samples were gold coated to improve the surface conductivity.

2.3.7 Mechanical Test

Tensile test for nipah composites was performed using the Testometric (25 kN) according to ASTM D638-03. The crosshead speed was set at 2 mm/min, with the gauge length of 50 mm.

2.3.8 Water Absorption

Water absorption test was conducted based on ASTM D570-98. A long-term immersion in distilled water up to 28 days at normal room temperature.
3 Results and Discussions

Water retting process for nipah fronds was conducted at a fresh water fish pond, which took about 12 weeks to be completed. This was when the fibres could be easily extracted without too much force and most unlikely to introduce premature defects to the fibres. As reported in the literature, water retting process is a time-consuming process [13]. At this particular point of 12 weeks, the fibre separation was very easy, because each fibre strand could be pulled, leaving behind the non-cellulosic substance. The whole fronds emitted strong decomposed odours, as compared to the previous checking points at week 8 and week 10. The wet extraction process produced two types of fibres, namely Fibre A and Fibre B, only Fibre A is discussed in this chapter. It was observed that lower fronds of nipah palm were easier to be extracted due to the larger number of spongy media as compared to the upper fronds. The lower fronds were normally bigger in diameter compared to the upper fronds and were observed to be softer once they reached the 12 weeks water retting process. They were easily split up manually requiring less force. The less exposed part of the fronds was at times difficult to be extracted even though the 12 weeks of water retting process were completed. This could be due to the age of the palm itself. The effects of harvest time were studied on hemp fibres [14]. During the collection process, the fronds were not collected from one single palm tree but also from other nipah palms. Another reason could be the effect of fronds diameter, where the lower fronds could reach 200–300 mm in diameter while the upper fronds were around 100 mm. The fibres extracted from this process are shown in Fig. 4e, f. Some of the nipah fronds were left in the pond for more than 12 weeks, to observe the over retting condition of the fibres. The fibres were brittle and broke into tiny pieces due to the excessive water retting process. Fibre separation was difficult as the tiny pieces of Fibre A entangled within the Fibre B mesh. This study concluded that 12 weeks is the optimum period for nipah fibre to be easily extracted.

The nipah fibre density and the diameter are shown in Table 2. The chemical analysis of nipah fibre is shown in Table 3. As stated in the literature, the nipah palm chemical composition is said to be very similar to oil palm [15, 16]. Nipah and oil palm are from the same palmae family, therefore, it is expected that there are some similarities in terms of its chemical composition.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Nipah palm fibre physical properties (average)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Physical properties</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>1.00</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>0.53 ± 0.06</td>
</tr>
</tbody>
</table>
Table 3  Chemical composition of nipah fibre

<table>
<thead>
<tr>
<th>Natural fibre</th>
<th>α-Cellulose (% w/w)</th>
<th>Hemicellulose (% w/w)</th>
<th>Lignin (% w/w)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nipah fibre</td>
<td>27.0</td>
<td>23.0</td>
<td>21.0</td>
<td>–</td>
</tr>
<tr>
<td>Oil palm (frond)</td>
<td>39.5</td>
<td>29.8</td>
<td>21.2 (Klason)</td>
<td>[15]</td>
</tr>
<tr>
<td>Oil palm (trunk)</td>
<td>30.6</td>
<td>33.2</td>
<td>24.7 (Klason)</td>
<td></td>
</tr>
</tbody>
</table>

3.1 Effect of Alkali Treatment Towards Nipah Fibre

From Fig. 5, it is clear that alkali treatment has effected significant physical changes towards nipah palm fibre. The effect of 6, 8, 10 and 12% alkali treatment had changed the physical appearance of the fibres. The colour of the fibres had turned from a light shade of brown to dark brown due to the alkali treatment. All the treated fibres showed fibre bending and twisting. The higher the alkali concentration, the greater the effect of fibre twisting. The 12% alkali treated nipah fibres were badly twisted and fibre breakage was noticeable. This indicates that nipah fibres undergone destruction due to high alkali concentration. This could be due to excessive stripping of undesirable outer layer of the fibres such as hemicellulose and lignin. Hemicelluloses are amorphous and hydrophilic and soluble in alkali solution. Lignin is known to provide structural strength towards the fibre. Lignin is amorphous and hydrophobic in nature and soluble in alkali solution [17]. Both hemicellulose and lignin can be removed by alkali solution. Once removed, the bulk lignin will be disrupted, causing disaggregation of micro fibril of the fibres [18]. This is concluded by some shrinkage of the fibres in Fig. 6. The shrinkage values are almost similar for 6% alkali, 10% alkali and 12% alkali, which are between 54 and 55%. Fibre treated with 8% alkali shows shrinkage at 59%. The value of area reduction showed fluctuating pattern, it did not show a continual decrease pattern as the alkali concentration increase. This result is in agreement with the finding by [19] on hemp fibre. These reductions were due to fibre degradation and delignification of the treated fibres. Sugarcane fibre bundles were reported to show better lignin and hemicellulose removal at 5% alkali [20, 21], while Napier grass experienced 12–45% diameter reduction after alkali treatment [17]. Screw pine (Pandanus Odoratissimus) fibre reported the highest cross-sectional area reduction of 42.1% for alkali concentration of 15% [22]. Kenaf fibre cross-sectional area was reported to show rapid decrement pattern when subjected to various immersion time, alkali concentration and temperature [23].

The thermogravimetric analysis result for untreated and alkali treated nipah fibres are shown in Fig. 7. The results are tabulated in Table 4. The residue values were similar to the value of 32.8% reported for lignin. More residues indicating that the alkali treatment has indeed increased the temperature stability of the treated fibres even at a higher temperature.

It was observed from Fig. 7 that the untreated line shows two decomposition steps, 300 and 470 °C and the 6% alkali treated fibres also shows two decomposition steps at 250 and 550 °C. The two steps exist may be due to partial removal of
Fig. 5  a Untreated and 6% alkali treated fibres, b 8% alkali treated fibre, c 10% alkali treated fibre, d 12% alkali treated fibre

Fig. 6  Fibre cross-section area before and after alkali treatment

Fig. 7  TGA analysis
Table 4  Residue results of based on treatment condition

<table>
<thead>
<tr>
<th>Treatment condition</th>
<th>Residue</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>400 °C (%)</td>
</tr>
<tr>
<td>Untreated</td>
<td>20</td>
</tr>
<tr>
<td>6%</td>
<td>35</td>
</tr>
<tr>
<td>8%</td>
<td>38</td>
</tr>
<tr>
<td>10%</td>
<td>45</td>
</tr>
<tr>
<td>12%</td>
<td>45</td>
</tr>
</tbody>
</table>

hemicellulose, lignin and waxes. However, at 8, 10 and 12% alkali treatment, it shows one decomposition step, which was the decomposition of α-cellulose and lignin. This indicates that a higher alkali percentage completely removes hemicellulose, lignin and waxes [24]. Similar observation was made in other natural fibres [25–27]. In order to probe further, spectral analysis was carried for the untreated and alkali treated fibres.

The FTIR spectra of nipah palm fibre are as shown in Fig. 8. Untreated, 6, 8, 10 and 12% alkali treated FTIR spectra show peaks dominated at 3335.03 cm⁻¹. These spectra could be attributed by O–H stretching vibration. The peak for treated nipah is broader and more intense indicating more –OH group existed due to the treatment. The peak at 1726.26 cm⁻¹ for treated nipah fibre slowly disappears after the treatment with an increasing alkali aqueous solution. This is due to the removal of acid, lignin and other natural fibre constituents [28, 29].

Hydrolysis occurs after the alkali treatment. This breaks down the ester bond, which explains the disappearance of 1726.26 cm⁻¹ peak. The disappearance of the 1726.26 and 1665.81 cm⁻¹ peaks after alkali treatment indicates that either the carboxylic acid and acetyl groups were destroyed by the alkali treatment or the macromolecules containing these functional groups were selectively dissolved from the fibre bundles under strong alkali condition. The peaks observed the 1000 and 1500 cm⁻¹ range show the presence of hemicellulose [24]. Based on peaks for nipah fibre between untreated and 6, 8, 10 and 12% alkali treated, the intensity of the peaks

![Fig. 8 FTIR](image-url)
is slightly reduced, which indicates a slight removal of hemicellulose compounds, while the peaks at 1031.20 and 1030.90 cm$^{-1}$ of the untreated and treated fibre indicate the stretching vibrations of C–O. The peak at 1241.48 cm$^{-1}$ can also readily assigned to the C–O stretching mode of acetyl groups in lignin [30]. All the major peaks of nipah palm fibre are similar with the findings found by [31].

The X-ray diffraction graph obtained for nipah fibres is shown in Fig. 9. The major peaks observed for all fibre samples were at 20 diffraction angles of 16°, 22° and 35°. The overall pattern shows amorphous structure of the nipah fibres. The sharpest peak was observed for 8% alkali, indicating highest crystallinity value of 50%, due to the removal of amorphous structure [32]. This result is supported by the single fibre tensile strength, where the 8% alkali depicted the highest tensile strength as shown in Fig. 10. The alkali treatment has removed fractions of amorphous in the fibre, leaving behind the crystalline structures in the fibres. This explains the sharpest peak at 8% alkali. The crystallinity index calculation was based on Segal Empirical method [33]. The degree of crystallinity of untreated fibre was 39.7 and the 8% alkali treated fibre was 50%. The overall result is in Table 5. This shows that the percentage of crystallinity index of treated 8% alkali fibre was 11% higher than the untreated nipah fibre. The increase of the percentage of crystallinity contributes to the enhancement of the tensile properties of the 8% alkali nipah fibre due to the restructuring of cellulose [34].

The single fibre tensile strength as depicted in Fig. 10a, shows the overall tensile strength between untreated and treated single fibres. All the symbols show individual result from each of the test. This shows the variation of the result instead of the average result. The result clearly showed that 8% alkali treated fibres had a higher tensile strength compared to the other treated fibres. The alkali treatment caused the removal of non-cellulosic content in the fibre. This removal allowed the cellulose to position itself when subjected to loading and facilitate better load transfer [35]. The cellulose chains were no longer in constraint state, therefore the fibrils were able to position itself towards closer packing arrangement to improve fibre strength and tensile properties [36]. However, at higher alkali concentration, the tensile strength drops. This was due to fibre damage caused by extreme reaction of the alkali towards

![Fig. 9 X-ray diffraction](image-url)
the fibres. This could also due to the existence of deep pores at higher alkali concentration. The increase number of deep pores leads to the decreasing of tensile strength [37].

As for the fracture surface of the single fibres shown in Fig. 11, they were almost similar, literary not flat surface, which are basic criteria for fibrous material. The vessel of the fibre for untreated and 6% alkali was round at the centre and the fibre lumen was elliptical for nipah fibre, and this can also be observed in bagasse fibre [38]. The presence of vessel and lumens at the fibre surface explained the light weight of the fibre. The vessel had a very smooth internal surface. The elliptical lumen for
treated fibres showed some compression. However, no change was observed for the vessel, and this might be due to the location of the vessel deep inside the fibre, which was affected by the alkaline solution. The compressed lumen could be due to the sodium ion deposited on the wall, subsequently increasing the thickness and thus, reduces the lumen size [39]. The compressed lumen reduces the void content and fibre water absorption [17, 36]. Click or tap here to enter text. The compressed lumen was obvious in the 8, 10 and 12% alkali treated fibres, and the similar result was also observed in abaca treated fibres [30].

Fibrillation could be observed in 12% alkali treated fibre, and the strong alkali concentration removed the binding material at the primary nipah fibre bundle. This explained the low tensile strength of the 12% alkali fibres. The fibrillation in treated fibres could increase the surface contact areas for matrix interlocking as reported [22]. However, for nipah fibre, fibrillation was only observed clearly in the 12% alkali fibres and this leads to poor tensile strength result. Fibrillation could exist in other treated nipah palm fibre, but its existence may not be obvious to be observed and captured by SEM.

3.2 Effect of Alkali Treatment Towards Nipah Composites

The variation of tensile strength as a function of fibre loading and the alkali concentration is presented in Fig. 12. It was observed that the 5 W/0 N and 15 W/8 N alkali composites showed tensile strength at 29.36 MPa and 28.29 MPa respectively.

Similar pattern was observed for the Young’s modulus value for the composites, and the highest was contributed by the 5 W/10 N composites at 471 MPa. There was an improvement of 42% of tensile strength, 35% of Young’s modulus value and 70% of strain at break between 5 W/0 N composites and 5 W/10 N composites.

It was noted that the 10% alkali treated fibre composites at a lower loading condition produced the best tensile strength, whereas, the 8% alkali treated fibre composites produced the best result at the highest loading condition. The single fibre test result showed 8% alkali had the highest tensile strength value and it was expected that the nipah fibre reinforced polyester composites would yield the same result. However, the result showed the opposite. It was believed that the 5 W/10 N composites had better interlocking and load transfer between fibres and polyester matrix. At higher loading the fibre direction might not be favourable to the load direction and packed fibre agglomeration may result to improper wetting condition. It was reported that alkali treatment can have different effect towards the mechanical properties of the fibres and its composites when they were used as reinforcement agent [24]. This could be the reason of fibre strength variation. Since the single fibre test of the 8% alkali showed the highest value, its composites strength showed a significant increase from 5 to 15 wt% loading. The 10% alkali nipah fibre reinforced polyester composites showed a reduction in strength as the loading gets higher. It was believed that a rougher fibre with a lower loading leads to a greater strength, but as the amount of fibre increases, it leads to improper wetting condition. From this result, it should be
Fig. 11 Fibre a untreated, b 6% alkali, c 8% alkali, d 10% alkali, e 12% alkali
noted that the incorporation of nipah fibre failed to reinforce polyester composites as compared to the neat polyester strength. There were a few possible factors contribute to this result. First, the existence of air bubbles in the fabricated composites as the polyester mixture was not vacuum prior to pouring into the mould. Second, the brittleness of the polyester might lead to the formation of micro cracks during cutting process. The samples were hand saw, even though great care was taken into account during the cutting process. Third, the compatibility between nipah palm fibre and the polyester matrix may not ideal to provide the reinforcement to the composites as can be seen in Fig. 13a, fibre breakage was observed at some point of the fracture surface as shown in Fig. 13b. Fourth, the fabrication method, hand lay-up may not suitable to produce this composite. A good cold or hot press machine that is able to maintain its pressure for 24 h and equip with a vacuum pump to suck out all the air bubbles during the pressing process might produce a good plate of composite. However, the alkali treatment had successfully increased the tensile strength of the composites compared to the untreated nipah fibre composites.
This observation was also observed in other natural fibre polyester composites [40, 41]. It was reported that coir fibre has to be loaded up to 45% or higher in order to obtain a significant reinforcing effect, and lack of reinforcing effect was due to low modulus of elasticity as compared to neat polyester [42]. Piassava fibres reinforced epoxy composites was reported to show similar findings as the composites failed to reinforce up to 30% of volume fraction [43]. The napier grass fibre was reported to reinforce the polyester composites at a value of 15.64 MPa for short fibre. The tensile strength of the pure polyester is 10.1 MPa [44]. The strength value obtained in nipah fibre composites was much higher than the value reported by napier grass. However, the alkali treatment had indeed improved the wetting between nipah fibres and polyester matrix. The removal of surface impurities, non-cellulosic material and waxes resulted in cleaner and rougher fibre surface and improves the composite strength. This observation was observed somewhere else [22, 35].

The water absorption curve tested in distilled water at normal room temperature (28 °C) is presented in Fig. 14. The results showed an increase in total absorption for up to 28 days, and as can be observed, the weight increased as a function of its fibre loading. This was expected as natural fibre like nipah fibre is hydrophilic in nature. The water absorption of nipah fibre composites followed the Fickian’s behaviour, and this was also observed in kenaf fibre reinforced polyester composites as reported
The highest fibre loading conducted was at 20 wt% of the untreated fibres. There was an increase of 7% weight gain between the 15 and 20 wt% fibre loading.

It should be noted that the untreated fibres had a maximum peak at day 22 while the treated fibres had its maximum peak at day 18. The surface treatment has shortened the peak period for treated fibres. The treated fibres regardless of its loading condition, its weight gain curve falls below the untreated fibres. The alkali treatment had significantly reduced the water absorption rate in treated fibres. It had created a protective layer on the fibre surface that was resistant to water absorption. The compressed lumen of treated fibres also reduced the water absorption capacity. It was also reported in the literature that alkali treated fibres showed a compressed lumen structure, and this caused the reduction of void content and less water absorption capacity of the treated fibres [17, 36, 39].
4 Conclusion

The main objective of this research work is to investigate the physical, thermal, chemical and morphological properties of nipah fibre. This research work provides a new knowledge on nipah palm fibre characterisation and its composites properties.

The alkali treatment conducted on nipah fibre had shown better interfacial properties on its composite properties. Similar improvement reported by other natural fibre treated with alkali is also observed in nipah palm fibre. This provides a full potential for nipah palm fibre as reinforcing agent in composites. The 8% alkali treatment showed the highest strength on single fibre, while the 10% alkali treatment displayed the highest strength of its composites.

Microstructural changes of the treated fibres showed improvement due to the alkali treatment, where the roughened surface provides a good site for fibre interlocking and improving the strength of its composites. The collapsed lumen of treated fibres had improved its water absorption capacity. The water resistance layer provided by the alkali treatment helped in resisting water absorption of the composites.

There are a few future recommendations for future research such as to conduct the various fibre loading condition such as long and continuous composites. Long and continuous was not investigated in this research work, due to the difficulty to align the mould. Proper equipment to align the fibre during fabrication is needed to successfully produce long and align nipah fibre composites.

Impact and flexural strength for nipah composites are recommended to be investigated. It is also recommended to use vacuum bagging method to fabricate the composites. This is to eliminate issues with air bubbles. The air bubbles are due to the reaction between unsaturated polyester resins with MEKP hardener.
The fabrication of nipah fibre composites with other polymer matrices is also recommended such as polypropylene. This will open more research opportunities for nipah fibre.

The application of nipah palm fibre composite is recommended to be used as a reinforcing agent in a non-load bearing structure, or as filler in composite as the strength of its composites is much lesser than its neat polyester. The automotive industry has been using natural fibre reinforced composites in cars component to reduce its weight. Weigh reduction is important for fuel consumption and this indirectly reduces the greenhouse gas emission. The non-load bearing structures for automotive components are the internal door cover, door panel, dashboard, tyre cover, interior carpets, seat backrest panel and many more. Other possible application of nipah palm fibre composites is in the food and pharmaceutical packaging as well as in bio-based electronics.

References


