Experimental Investigation on Performance of Short Pineapple Leaf Fiber Reinforced Tapioca Biopolymer Composites

Jamiluddin Jaafar,[a,*] Januar P. Siregar,[a] Ahmed N. Oumer,[a] Mohammad Hazim M. Hamdan,[a] Cionita Tezara,[b] and Mohd Sapuan Salit [c,d]

The performance of short pineapple leaf fiber (PALF) reinforced tapioca biopolymer (TBP) composites were investigated, specifically the effect of fiber length and fiber composition on mechanical properties (tensile properties, flexural strength, and impact strength). Composite samples with different fiber lengths (< 0.50 mm, 0.51 mm to 1.00 mm, and 1.01 mm to 2.00 mm) and different fiber compositions (10%, 20%, 30%, and 40%) were prepared through crushing, sieving, internal mixing, compression molding, and machining processes. The combination of PALF and TBP enhanced the mechanical properties of composites with 30% as the optimum fiber content. However, the influence of different fiber lengths up to 2.00 mm provided no significant effect on producing maximum tensile properties. Good interfacial adhesion between PALF and TBP was evident from scanning electron microscopy analysis. Therefore, the combination of PALF and TBP has great potential as a renewable and biodegradable polymer. Moreover, PALF-TBP composites are expected to become alternatives to petroleum-based polymers.

Keywords: Bio-composites; Natural fiber composites; Pineapple leaf fiber; Starch-based polymer; Tapioca biopolymer

*Contact information: a: Structural Material and Degradation Focus Group, Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia; b: Department of Mechanical Engineering, Faculty of Engineering and Quantity Surveying, INTI International University 71800 Nilai, Negeri Sembilan, Malaysia; c: Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia; d: Laboratory of Biocomposite Technology, Institute of Tropical Forestry and Forest Products, Universiti Putra Malaysia, Selangor 43400, Malaysia; *Corresponding author: jamiluddin@ump.edu.my*

INTRODUCTION

Development of bio-composites or natural fiber reinforced polymer composites has become very popular and attractive as an alternative for petroleum-based polymers. This interest is due to adverse effects on the environment that have been generated by the accumulation of non-biodegradable waste from petroleum-based polymers (Hubbe *et al*. 2008; Theng *et al*. 2017; Tian *et al*. 2017). Therefore, environmental friendly materials such as natural fiber composites have great potential for overcoming the issue of waste accumulation. Bio-based composites offer many advantages because they are biodegradable, renewable, recyclable, nonabrasive to the equipment, do not irritate the skin, and pose less health risks (Ban *et al.* 2006; Shah *et al.* 2017; Sun *et al*., 2018; Yi *et al.* 2017).

In this study, pineapple leaf fiber (PALF), which is obtained from pineapple leaves, was selected as a reinforcement agent due to its low commercial value and high availability. There are approximately 2.1 million acres of pineapple cultivation worldwide, including some of the major producers such as Malaysia, Thailand, Indonesia, Philippines, Brazil, Costa Rica, and Hawaii. The primary problem for these producer countries is the pineapple leaf waste, which is

approximately 20,000 to 25,000 tons per acre after the harvesting process (Nanthaya and Amornsakchai 2014). Traditionally, pineapple leaves are dumped or burned, which causes serious environmental problems. Therefore, PALF obtained from pineapple leaf waste in bio-composites development can be utilized as an alternative raw material and provide a use for pineapple leaves left over after harvesting. Additionally, PALF has relatively good potential as filler/reinforcement materials due to their high crystalline cellulose but lower hemicellulose and lignin contents. Therefore, it has higher mechanical properties compared with other natural fibers (Liu *et al.* 2005; Neto *et al*. 2013; Nanthaya and Amornsakchai 2014; Neto *et al*. 2015). In most previous bio-composites, PALF was used as reinforcement in either petroleum-based thermoset or thermoplastic polymers such as polypropylene (PP) (Arib *et al*. 2006; Nanthaya and Amornsakchai 2014), polyurethane (PU) (Cherian *et al*. 2011), low-density polyethylene (LDPE) (George *et al.* 1996), high-density polyethylene (HDPE) (Aji *et al*. 2011), epoxy (Sastra *et al.* 2006), nylon (Panyasart *et al*. 2014), polycarbonate (PC) (Threepopnatkul *et al*. 2009), and elastomer (Kalapakdee and Amornsakchai 2014). However, there has been limited development of entirely biodegradable composites using a PALF-reinforced biodegradable matrix polymer.

Tapioca biopolymer (TBP) is a starch-based biodegradable and renewable polymer. However, TBP is derived from renewable resources, namely tapioca. TBP provides an alternative to petroleum-based matrices in the manufacturing of natural fiber composites. As a starch-based polymer, TBP has better compatibility with natural fibers during composites manufacturing. Jamiluddin *et al*. (2016) revealed that 165 °C is the optimum processing temperature for TBP. However, the majority of natural fibers including PALF have a degradation temperature close to 200 °C (Ku *et al*. 2011; Azwa *et al*. 2013). This range of processing temperatures technically makes TBP compatible with almost all types of natural fibers, especially with PALF, and manufacturing of natural fiber composites can be performed before the degradation of the natural fibers occurs. Given these factors, the combination of PALF and TBP in bio-composites is a good balance between ecology and economy perspectives.

In this work, the mechanical properties of short PALF reinforced TBP were determined. The short fiber was selected due to its ease of processing, anisotropy behavior, better dispersion, and low cost (Liu *et al*. 2009). In PALF-reinforced LDPE composites, fiber with 2.00 mm length is better in dispersion, alignment, and distribution along the direction of flow than fibers with longer lengths (George *et al.* 1996). This phenomenon produces better mechanical properties in the resulting composites. Moreover, the influences of different fiber compositions were identified. Theoretically, increasing fiber concentration in high strength fibers should enhance the mechanical properties of the bio-composite. However, experimental investigations show that increasing the fiber percentage higher than the optimum value deteriorates the mechanical properties of the bio-composite (Ku *et al*. 2011; El-Shekeil *et al*. 2012). Therefore, the primary objective of this research was to evaluate the influence of fiber length and justify the optimum fiber composition in short PALF-TBP composites.

EXPERIMENTAL

Materials

The PALF bundles were purchased from Permalang, Central Java, Indonesia (Fig. 1). PALF were obtained from the leaf bunches by scraping. The fibers were crushed using a RL-L10 MPL crusher (RGPS Plast., Tamil Nadu, India) to reduce the length of the fibers, which were then sieved using the SS304 GMP automatic sieving machine (Xinxiang Nice Machinery, Henan, China). After sieving, the fibers were segregated into three groups of fiber lengths, *i.e.*,

less than 0.5 mm, 0.51 to 1.00 mm, and 1.01 to 2.00 mm.

Fig. 1. Bundles of pineapple leaf fiber (PALF)

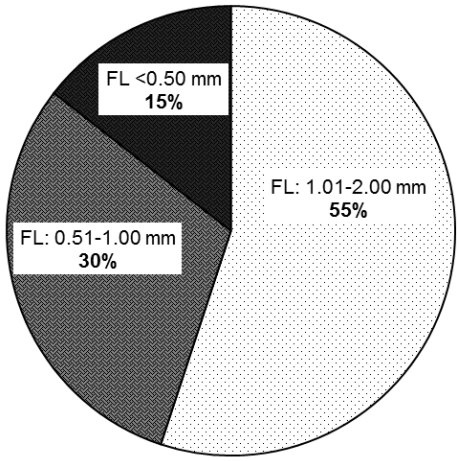

Fig. 2. Distribution of PALF fiber lengths (FL) after sieving

Figure 2 shows the distribution of different fiber lengths after crushing and sieving. The overall output for the crushing process was less than 2.00 mm of fiber length. To study the influence of different fiber length on tensile properties, the crushed fibers were separated into three groups, which were less than 0.50 mm, 0.51 to 1.00 mm, and 1.01 to 2.00 mm. The group with a fiber length from 1.01 to 2.00 mm represented 55% of the total output. Fibers of less than 0.50 mm and from 0.51 mm to 1.00 mm comprised 15% and 30%, respectively, of the total fibers. Thus, a conventional crushing process using a plastic crusher produced short fibers with lengths less than 2.00 mm.

For the polymer matrix, the TBP derived from the industrial *Manihot esculenta* species was purchased from Indochine Bio Plastiques (Johore, Malaysia). The physical and mechanical properties of TBP used in this study are shown in Table 1.

Table 1. Thermo-Physical and Mechanical Properties of TBP

Properties	Unit	Value
Density	g/cm³	1.1
Melt index	g/10 min	36
Optimum processing temperature	°C	165
Degradation temperature	°C	185

Composites Manufacturing

All raw materials for composites sample preparation, including TBP and sieved PALF, were first dried in an oven at 80 °C for 4 h (W. Liu *et al*. 2005). The TBP subsequently compounded with the fiber according to following equation,

$$1 = v_f + v_m \quad (1)$$

where v_f is fiber composition, and v_m is TBP composition by weight. Each composite sample weight was 120 g, which contained various compositions of TBP and PALF. The detailed mixing for sample preparation is displayed in Table 2.

Table 2. Detail Mixing Ratio of PALF and TBP

Sample	FL (mm)	PALF (wt.%)	TBP (wt.%)
TBP	-	-	100
PALF10FL0.5	Less than 0.50	10	90
PALF10FL1.0	0.51 to 1.00	10	90
PALF10	1.01 to 2.00	10	90
PALF20	1.01 to 2.00	20	80
PALF30	1.01 to 2.00	30	70
PALF40	1.01 to 2.00	40	60

Before the compounding process, a Brabender PL2000-6 internal mixing machine (Duisburg, Germany) was preheated at 165 °C and set to a processing speed of 40 rpm. The TBP, in the form of pellets, or a mixture of TBP and coupling agent was blended and allowed to stabilize before the fiber was introduced. The total time used for mixing the composites was 20 min. The mixed compounds obtained from the internal mixer were cut into pellets. The composite plate was then formed with dimensions of 200 × 200 × 3 mm using compression molding. The mold temperature was set at 165 °C, and a constant pressure of 6.0 MPa was applied for 5 min of preheating and 10 min of the full press. This was followed by cooling under the same pressure for 5 min (Arib *et al*. 2006; Nanthaya and Amornsakchai 2014; Siregar, 2011). The tensile samples were fabricated through the machining process by using a HASS VF 6 CNC milling machine (HAAS Automation Inc, Oxnard, CA, USA) according to ASTM D638 (2014) Type V as shown in Fig. 3.

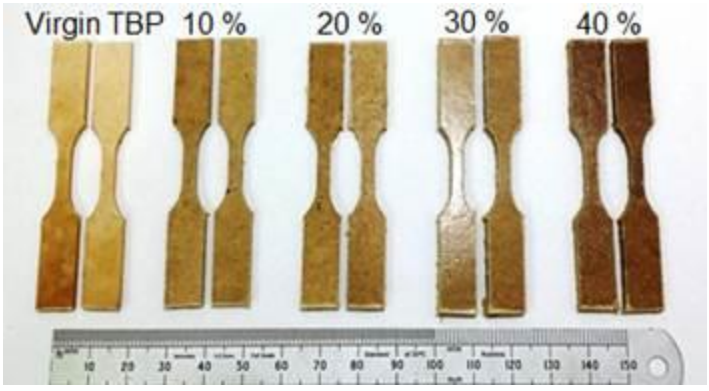

Fig. 3. Tensile test sample of PALF-TBP composites

The flexural and impact test samples were fabricated by using the T-Jaw 400 vertical saw machine (T-Jaw Machinery Works, Taichung, Taiwan). The flexural sample was prepared

according to ASTM D790 (2002), and the impact test sample was prepared according to ASTM D256 (2010). The "V" notch for the impact test sample was fabricated using an EI 1705 manual notch cutter (Eco Instrument, Seremban, Malaysia).

FTIR Analysis

Fourier transform infrared spectroscopy (FTIR) was used to identify the functional groups in virgin TBP, PALF, and PALF-TBP composites. In this research, FTIR was conducted using a Nicolet iS50 instrument (Thermo Fisher Scientific, Waltham, MA, USA) with diamond attenuated total reflectance (ATR) techniques. Samples were analyzed in the wave number range of 500 to 4000 cm^{-1}.

Mechanical Testing

The tensile and flexural tests were conducted with a 3kN Instron 5967 universal testing machine (Norwood, MA, USA) at the temperature of 23 ± 2 °C and relative humidity of 50 ± 5%. The tensile test was conducted according to ASTM D638 (2014) with the crosshead speeds set at 1 mm/min. Tensile modulus calculation was set at the test machine according to Chord modulus, *E*. The Chord modulus was calculated after the toe correction region from the 0.1% strain value to the 0.5% strain value, which is the end of a straight line for the stress-strain curve. The modulus was calculated as follows,

$$E = (\sigma_{0.5\%} - \sigma_{0.1\%})/(\varepsilon_{0.5\%} - \varepsilon_{0.1\%}) \quad (2)$$

where σ is stress value, and ε is the strain value from stress-strain curve. The flexural test was conducted according to ASTM D790 (2002), and crosshead speed was set at 1.28 mm/min. The span length for the flexural test was 48 mm. The third mechanical analysis was the Izod impact test. The Izod impact test was conducted by using the Zwick B 5113.300 impact test machine (Zwick Roell, Ulm, Germany) according to ASTM D256 (2010) at a temperature of 23 ± 2 °C and relative humidity of 50 ± 5%. The impact load applied was a 1 J pendulum at a maximum pendulum height of 160°. All test results were examined by ANOVA variance analysis to justify the significance of PALF as reinforcement for TBP.

Morphology Analysis

After being subjected to tensile testing, the fractured surfaces were visually inspected using a Carl Zeiss Evo 50 scanning electron microscope (SEM) (Oberkochen, Germany) at 1000× magnification. The samples were mounted onto an SEM holder using double-sided electrically conducting carbon adhesive tapes to prevent surface charge on the specimens when exposed to the electron beam. The PALF-TBP composites were sputtered with titanium before observation. This examination was used to evaluate the interfacial bonding between the fibers and matrix.

RESULTS AND DISCUSSION

FTIR Analysis

Figure 4 presents the FTIR spectra for virgin TBP, PALF, and PALF-TBP composites. In the TBP spectrum, the combined peaks at approximately 2900 cm^{-1} and 1740 cm^{-1} represent C-H stretching vibration from CH_2 or CH_3 and stretching vibration of the carbonyl groups (C=O) respectively. The peaks at around 1460 cm^{-1} and 1376 cm^{-1} were assigned to O-H bonding and methyl (CH_3) bending respectively (Jumaidin *et al*. 2017b)**.** The characteristics of the anhydro-

glucose ring C-O stretch were associated with the peak at approximately 1078 cm^{-1}. This band was also associated with the C-O-C group stretching from glucose in starch, and the bands at 718 to 573 cm^{-1} were assigned to cassava skeletal (C–C–O) modes (Mutungi *et al*. 2012). The band at 3300 cm^{-1}, which appeared in the PALF spectrum, was associated with the hydrogen bonded hydroxyl group (O-H) from complex vibrational stretching, which is related to free, inter, and intra molecular bound hydroxyl groups (Peng and She 2014). The peak at 2918 cm^{-1} was associated with C-H stretching vibration from CH_2 or CH_3. This band was related to the hemicellulose and cellulose components in PALF. The peak at 1238 cm^{-1} and 1370 cm^{-1} referred to the carbonyl and -CH_2 deformations vibration, respectively. Another broad peak at 1031 cm^{-1} was associated with C-H group vibration in cellulose and C-H vibration of lignin (Jumaidin *et al*. 2017a).

The interaction between the individual components in PALF-TBP composites can be established by recognizing the band position shifting of the spectra. The bands at 3331 cm^{-1} were gradually reallocated to a lower wavenumber following the compounding between PALF and TBP. This shift indicated the enhancement of intermolecular hydrogen in PALF-TBP composites. This phenomenon might be attributed to the same hydrophilic behaviour of TBP and PALF. This finding is consistent with the previous FTIR analysis of coconut fiber and cassava starch bio-composites (Lomelí-Ramírez *et al*. 2014). In addition, the characteristic peak of carbonyl at 1538 cm^{-1} diminished, as shown in Fig. 4. The findings suggest a possible carbonyl interaction between PALF and TBP. This finding is consistent with the previous FT-IR analysis of alkali treated agave fiber reinforced high-density polyethylene (HDPE) (Valadez-Gonzalez *et al.* 1999).

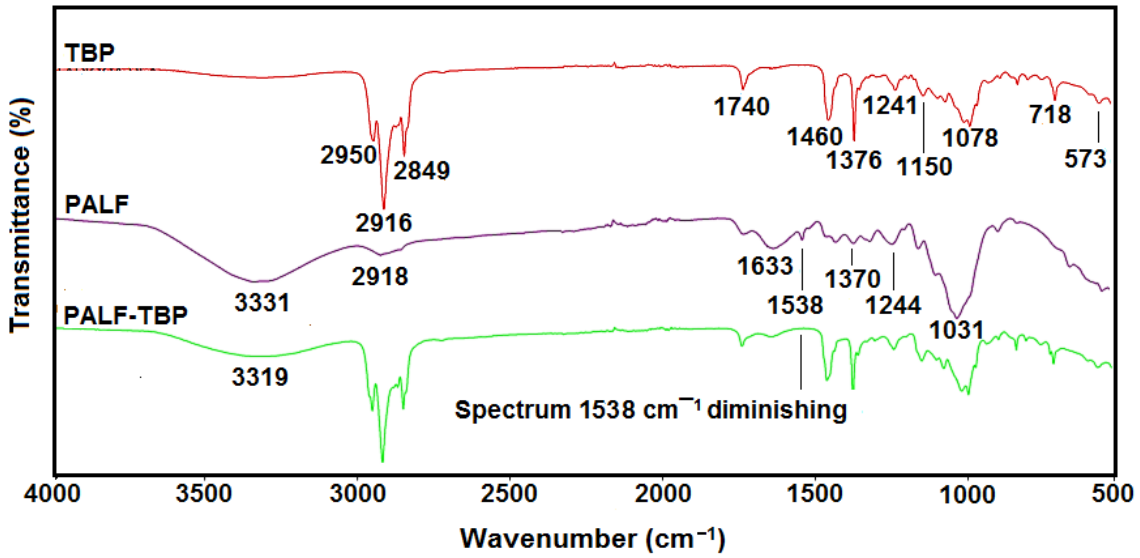

Fig. 4. Comparison of FTIR spectra between TBP, PALF and PALF-TBP composites

Effect of Different Fiber Length

The combination of TBP and short PALF had positive effects on the increase in tensile strength and tensile modulus of the final composite product. Figure 5 shows the comparison of tensile properties between virgin TBP and PALF-TBP composites with different fiber lengths (less than 0.50 mm, 0.51 mm to 1.00 mm, and 1.01 mm to 2.00 mm). The composite samples show good increments compared with the virgin TBP, with a 10.7% to 15.8% increment for tensile strength and 10.8% to 16.2% for tensile modulus. However, the effect of various fiber lengths on tensile properties of PALF-TBP sample was not significantly visually different in

resulting tensile properties. The different resulting tensile strength and tensile modulus increments between these three different fiber lengths were 0.1% to 4.5% and 2.4% to 4.9% respectively. Therefore, more comprehensive analysis needs to be done to determine the effect of different fiber lengths on tensile properties of PALF-TBP composites.

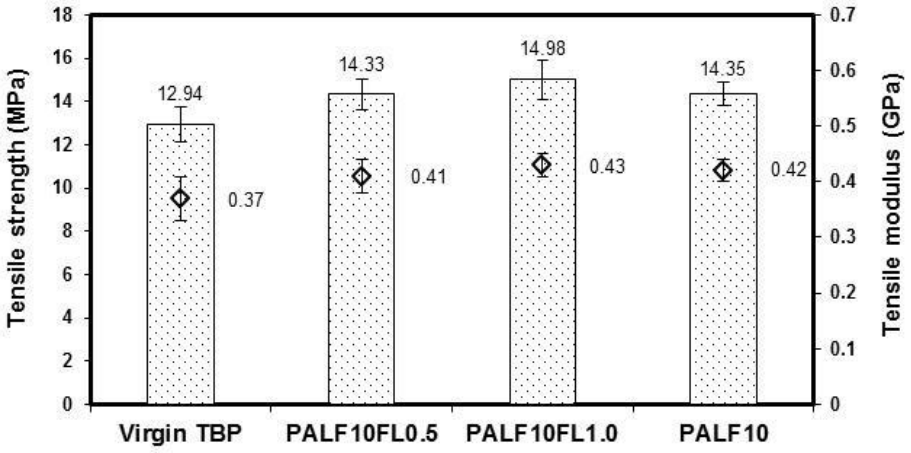

Fig. 5. Effect of different fiber length

According to variance analysis (ANOVA), the *p*-value for comparison of tensile strength results between virgin TBP and PALF-TBP composite samples (PALF10Fl0.5, PALF10FL1.0, and PALF10) were 0.0039, 0.0008, and 0.0018, respectively. Moreover, a *p*-value of 0.0000 was presented in the comparison of modulus result between virgin TBP and all composite samples. These findings showed significant improvements by PALF in enhancing the tensile properties of TBP due to *p*-value less than 0.05. However, variance analysis on tensile strength and tensile modulus between three different fiber lengths presented contradictory findings where the *p*-value for tensile strength and tensile modulus was 0.1975 and 0.0751, respectively. Therefore, the findings of variance analysis revealed that PALF had a positive contribution to PALF-TBP composites development. However, the influence of different fiber length up to 2.00 mm length produced no significant effect on tensile properties. This finding is consistent with previous research of PALF-HDPE composites where different fiber lengths of 0.25 mm, 0.50 mm, 0.75 mm, and 2.00 mm presented, differences in tensile strength and tensile modulus results that were not significant (Aji *et al*. 2011).

Effect of Different Fiber Composition

The current study also measured the mechanical properties of PALF-TBP composites at various PALF compositions to justify optimum fiber composition. Table 3 illustrates the effect of PALF with different fiber contents on mechanical properties (tensile strength, tensile modulus, maximum strain, flexural strength, and impact strength) of the reinforced TBP composites.

The tensile strength of the composite increased with the increase of PALF composition up to 30% of fiber loadings. However, a decrease of 14.1% was detected in tensile strength when the fiber content further increased from 30% to 40%. The sample PALF30 presented the highest enhancement in tensile strength, 42.0%, compared with virgin TBP. In the tensile test, the applied stress transmitted from the matrix to the fibers across the interface. Hence the interfacial adhesion between fiber and matrix plays a significant role in crack propagation (Liu *et al*. 2005; Ku *et al*. 2011).

At higher fiber content, the reduction in the matrices composition caused the interfacial adhesion between the fibers and matrix to become weak. In addition, the fibers with higher fiber composition tended to aggregate in the composite (Shalwan and Yousif 2013). This phenomenon led to low tensile strength results in the composites.

Table 3. Mechanical Properties of PALF-TBP Composites at Different Fiber Composition

Sample	Tensile Strength (MPa)	Tensile Modulus (GPa)	Maximum Strain (%)	Flexural Strength (MPa)	Impact Strength (kJ/m²)
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Virgin TBP	12.94 ± 0.90	0.37 ± 0.03	9.23 ± 0.42	10.68 ± 0.95	15.07 ± 0.35
PALF10	14.35 ± 0.53	0.42 ± 0.02	9.18 ± 0.57	14.16 ± 0.82	15.64 ± 0.46
PALF20	16.60 ± 0.82	0.73 ± 0.03	8.83 ± 1.35	16.60 ± 0.80	15.91 ± 0.99
PALF30	18.37 ± 0.78	0.98 ± 0.07	6.84 ± 0.96	18.05 ± 0.92	16.53 ± 0.56
PALF40	15.78 ± 0.76	1.03 ± 0.10	5.73 ± 0.59	19.34 ± 0.37	18.10 ± 0.65
SD standard deviation					

The tensile modulus results showed an increase in fiber composition up to 40% of fiber. According to Table 3, virgin TBP showed a tensile modulus of 0.37 GPa. An increment of 178.4% in tensile modulus was discovered as the fiber content was increased up to 40%. During the tensile condition, partially separated micro-spaces were created. These obstructed the stress propagation between the PALF and TBP as a matrix. Thus, the degree of obstruction increased, which resulted in stiffness increase (Lomelí-Ramírez *et al*. 2014; Pickering *et al*. 2016). The result in the present study was consistent with the findings of previous studies in which the tensile strength showed a decrease after the optimum fiber composition and the tensile modulus showed compliance with the percentage of fiber (Liu *et al*. 2005; Threepopnatkul *et al*. 2009). Furthermore, the maximum strain of the PALF-TBP composite decreased consistently with the increase of fiber composition. The value of maximum strain decreased by almost 38% from 9.23% for virgin TBP matrix when PALF fiber content was increased to 40%. This phenomenon was attributed to the addition of fiber into the polymer matrix, which reduced the matrix mobility. As a result, tensile modulus increased and maximum strain decreased for the composites due to the increase in fiber loading.

Like tensile strength, the flexural strength of the composites increased considerably with the addition of PALF. As the fiber content was increased up to 40%, the flexural strength increased up to 81.1%. The above finding is consistent with the previous finding of PALF-PP composites and hybrid PALF, and kenaf reinforced HDPE composite where the flexural strength increased by the increase of fiber percentage up to 40% (Aji *et al*. 2011; Nanthaya and Amornsakchai 2014). Additionally, there was a consistent increase in the impact strength. An impact strength of 18.1 kJ/m² was observed for the sample PALF40, which was nearly 20.1% higher than the virgin TBP matrix. This was because the utilization of PALF increased the amount of energy required for pulling it out. The impact strength results in this research were consistent with the findings of previous studies in which the impact strength showed enhancement with the fiber composition up to 60% for short basalt fiber reinforced polyester (Amuthakkannan *et al*. 2013). Also, rice husk-PE and ramie-poly lactic acid (PLA) composites showed the enhancement in impact strength with the increasing of fiber content up to 30% (Tao *et al*. 2009; Rahman *et al*. 2010).

Table 3 shows that the sample containing 40% of fiber loading generated maximum flexural strength, impact strength, and tensile modulus. However, sample PALF30, which contained 30% of fiber loading, was shown to produce the maximum value in its resulting tensile strength. More comprehensive analysis is needed to justify the optimum fiber composition for PALF-TBP composites. Therefore, analysis of variance (ANOVA) was carried out in order to understand the significance of fiber composition in influencing the mechanical properties. All *p*-values for variance analysis of tensile strength between sample PALF30 and other samples were less than 0.05.

The findings indicated that 30% fiber content presented a significant effect on reinforcement for maximum tensile strength results compared to other samples. However, the variance analysis of tensile modulus and flexural strength results between PALF30 and PALF40 were 0.3351 and 0.0089, respectively. The results presented no significant difference between both samples even though sample PALF40 visually presented the highest mean values. On the other hand, only variance analysis on impact strength results verified that the sample of 40% fiber composition generated the maximum result among the samples. Thus, the 30% of fiber composition composites were the optimum composition for PALF-TBP composites.

In addition, Fig. 6 compares the tensile and flexural strength between virgin TBP, 30% of PALF reinforced TBP composite, and selected petroleum-based polymers, which were LDPE, HDPE, high impact polystyrene (HIPS), PP, and poly vinyl chloride (PVC). Virgin TBP presented the lowest tensile and flexural strength value compared to the selected petroleum-based polymer. However, the combination of PALF and TBP with 30% fiber composition increased both tensile and flexural properties and were thus better than the properties of LDPE and more similar to the HDPE. The present finding showed that PALF-TBP composite has tremendous potential in the development of entirely biodegradable composites. Moreover, TBP and PALF-TBP presented higher impact strengths compared to most of the petroleum-based polymers, as shown in Fig. 7. Therefore, the improvement on the PALF-TBP composite development in the future is expected to improve its tensile and flexural properties and is expected to make it an alternative to petroleum-based polymers for engineering applications.

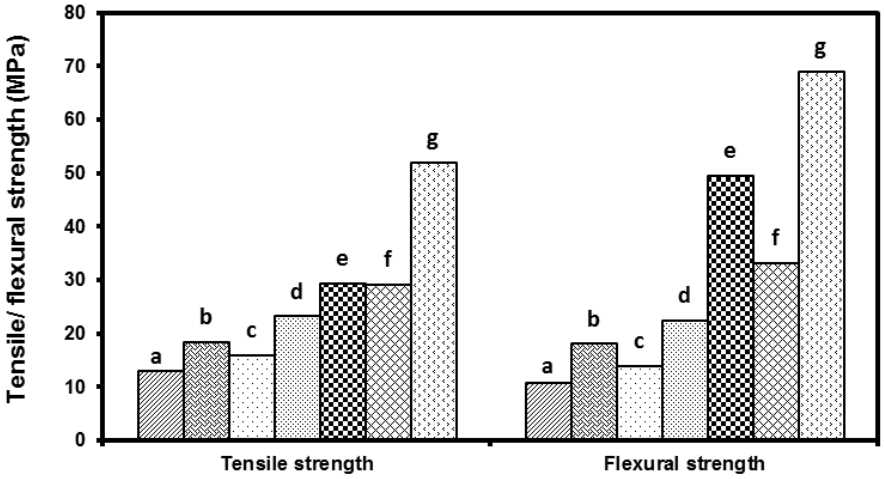

Fig. 6. Comparison of tensile and flexural strength between a: TBP; b: 30 PALF-TBP composites; c: LDPE; d: HDPE; e: HIPS; f: PP; and g: PVC (Rana *et al*. 1998; Yang *et al*. 2007; Ahmad *et al*. 2008; Siregar *et al.* 2010; Hashemi 2011; Panyasart *et al*. 2014; Threepopnatkul *et al*. 2009)

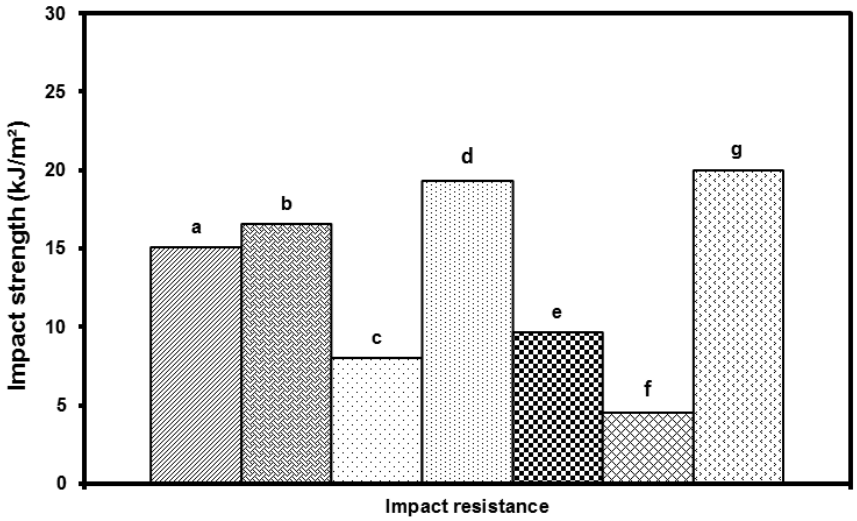

Fig. 7. Comparison of impact strength between TBP, PALF-TBP composites a: TBP; b: 30 PALF-TBP Composites; c: LDPE; d: HDPE; e: HIPS; f: PP; and g: PVC and selected petroleum-based polymers (Rana *et al.* 1998; Yang *et al.* 2007; Ahmad *et al.* 2008; Threepopnatkul *et al.* 2009; Siregar *et al.* 2010; Hashemi 2011; Panyasart *et al.* 2014)

Morphology Analysis

The scanning electron micrograph images presented in Fig. 8 show the tensile fracture of PALF-TBP composite samples. There was better compatibility between PALF and TBP compared with previous PALF reinforced petroleum-based polymer composites.

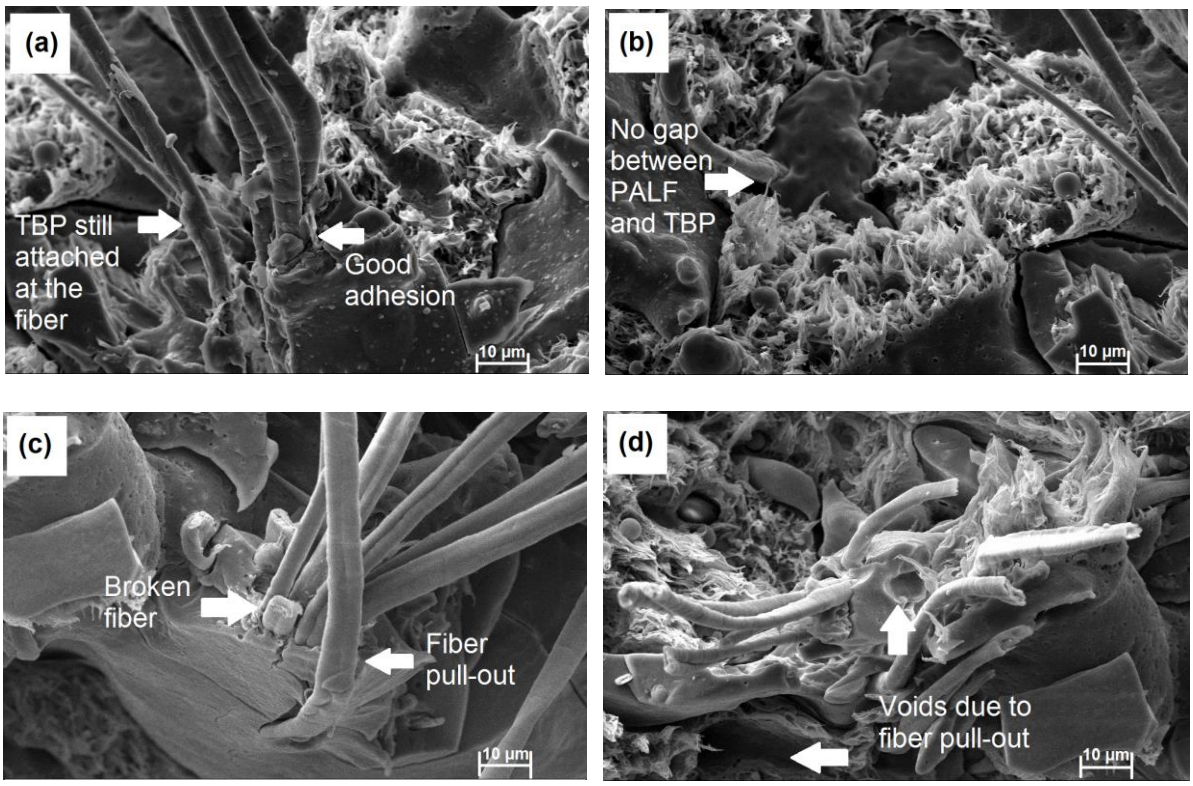

Fig. 8. Scanning electron micrograph of tensile fracture of PALF-TBP composite samples with different fiber composition: a: 10%; b: 20%; c: 30%; and d: 40%

Fiber pull-out is the primary cause of failure for PALF reinforced petroleum-based polymers (Aji *et al*. 2011; Siregar, 2011). However, the fiber failure in PALF-TBP is a combination of fiber pull out and fiber breakage. Also, TBP was still attached at the fully pulled-out fiber, and there was no gap between PALF and TBP even under 1000 magnification. The morphology analysis illustrated that PALF and TBP were highly compatible, which was indicated through the excellent fiber wetting by the matrix and fiber failure behaviour at the fracture surface. Again, this phenomenon might be attributed to a similar hydrophilic character between PALF and TBP. Because of the tensile fracture, the fiber crack phenomenon of PALF indicated that the stress was transferred efficiently from the matrix to fiber. This phenomenon produced fiber as efficient reinforcement in the composites. This corresponded to the significant percentage of enhancement in tensile strength results as discussed earlier.

CONCLUSIONS

1. The combination of short pineapple leaf fiber (PALF) and tapioca biopolymer (TBP) was capable of enhancing the mechanical properties of TBP biopolymer.
2. Variance analysis revealed that 30% of the optimum fiber composition successfully increased the tensile strength, tensile modulus, flexural strength, and impact strength by 42%, 165%, 69%, and 10%, respectively.
3. The variance analysis revealed that different fiber lengths up to 2.00 mm were not significant in affecting the tensile properties.
4. The PALF-TBP failure mode was comprised of a combination of broken fibers and no gaps between PALF and TBP, which showed better compatibility between PALF and TBP than PALF reinforced petroleum-based polymer composites.
5. Overall, the incorporation of PALF as reinforcement in TBP has great potential as a renewable and biodegradable polymer.

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