FABRICATION OF ALIGNED PINEAPPLE LEAF FIBRE REINFORCED POLYLACTIC ACID COMPOSITE FOR HIGH-PERFORMANCE BIOCOMPOSITES

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Abstract. The growing concern on the environmental issue has increased the demand for eco-friendly and sustainable biodegradable composite. Natural fibres provide an alternative to using non-degradable fibre such as glass and carbon fibre, but their mechanical properties are still inferior. Thus, in this present work, an attempt has been carried out to produce biocomposites with high strength that are potential to be used in structural applications. The uniaxial composites were fabricated by drawing the pineapple leaf yarn in polylactic acid (PLA) solution via the pre-pregging method followed by hot compression moulding. The chemical analysis of the fibres was carried out using Fourier transform infrared spectroscopy. Flexural properties with different fibre loadings were tested. Results showed the composite with 60 wt. % of alkali-treated pineapple leaf fibre has the optimum flexural strength and stiffness, which are 145.1 MPa and 9.35 GPa, respectively, significantly higher than the neat PLA. In contrast, the flexural strain reduced as the fibre loading increased. Surface morphology observed using SEM indicated that the composite failed due to fibre breaking, and favourable interfacial adhesion is present in the composites. These findings suggest that fabrication methods used in this study can improve the matrix impregnation around the fibres hence contributing to their high mechanical performance.

Keywords: pineapple leaf fibre, polylactic acid, continuous yarn, pre-preg, fibre loading, flexural properties, compression moulding.

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Introduction

As the increasing awareness of the impact of non-degradable materials on the environment has led to the growing demand for eco-friendly and sustainable biodegradable composite. Thus, natural fibre as reinforcement is recognised as a potential eco-friendly material. Moreover, natural fibre provides attractive mechanical properties and degradability as an alternative to non-degradable fibres [1-2]. Among the well-known natural fibre plants, pineapple leaf fibre (PALF) is by far one of the most promising reinforcements in biocomposites due to its high specific strength and high cellulosic content [3-7].

Polylactic acid (PLA) is the most studied bio-thermoplastic material for applications requiring biodegradability. PLA has good strength and modulus properties and is one of the highest biopolymers produced for industry applications [2]. However, it is also quite brittle. Thus, the mechanical performance of PLA can be enhanced by adding natural fibre reinforcement to maximise its industrial use potential [2-3, 8]. As a result of its appealing features, the current work used PALF fibre as reinforcement for PLA composites.

Fibre architecture such as orientation, alignment, and length must be managed to ensure that the fibre's mechanical qualities are effectively utilised to produce a high-performance composite [9-10]. Melt impregnation is the most common method of producing fibre-reinforced thermoplastic composites. Often sandwich method is adopted for long fibre, in which it is stacking together in between the matrix film and compresses at high temperature. Our previous study has demonstrated that using the sandwich and compression method to produce the aligned long fibre PALF significantly improve the PALF/PLA composite [9, 11]. However, it is only limited to 30 wt. % PALF, as the effort to increase the fibre fraction beyond that significantly reduced their performance due to poor matrix wettability. The natural fibre is low in density; thus, the effort to improve the mechanical properties by increasing their fibre loading is often challenging due to the large number of fibre filaments that need to be used. Thus, it prevents good wetting by the matrix during the sandwich and hot compression moulding. Apart from surface treatment, fibre and resin adherence can be improved using the impregnation method. Baghaei and co-workers [8, 12-13] reported that using fabrication of hemp/PLA composites by using orientated pre-impregnated technique showed a promising mechanical property. Pre-impregnated technique is often used in synthetic fibre such as carbon fibre to produce aligned and high mechanical performance.

Thus, this study aims to produce high strength natural fibre composite by adopting the advanced fabrication process away from the conventional method to improve their wettability and hopefully increase their mechanical performance.

Materials and Methods

The PALF fibre is used in the form of 2 plies yarn with a density of 1.526 g/cm^3. The fibres were alkaline treated with 5 wt.% NaOH as reported by our previous study [11]. The PLA grade 6100D (Nature works, USA) was dissolved in chloroform solution at a ratio of 1:2. The chemicals were purchased from Sigma Aldrich (USA) with a 99.95 purity grade. The PALF fibres were then weighted and pulled through a PLA matrix solution bath using an in-house pre-preggers machine, forming a thin coating around the fibres (Figure 1). The pre-preg was then collected onto a rotating drum and left overnight at room temperature. PLA solution was also cast onto the glass panel to produce a thin film. Both PLA film and pre-pregs were then dried under vacuum for further 24 hours to ensure the solvent's removal. The prepreg's weight was measured to determine the weight fraction of fibre (wt. %) in each prepreg and then stored in a desiccator before testing. The aligned PALF/PLA pre-pregs and PLA thin film were layered in a 150 mm x 80mm x 3 mm mould and were compressed moulded at 175 °C to produce composites with two different fibre loading (40, 50 and 60 wt. % PALF).

FT/IR- 6100 (Jasco, German) was used to observe the changes in the chemical bonding nature of the PALF after alkaline treatment. The frequency ranges were measured as wave numbers over the range of 4000 – 600 cm-1. Flexural testing was carried out at room temperature using a three-point bending test on a 20 kN Universal Testing Machine (Shimadzu, Japan) per ASTM 790. A strain rate at a crosshead speed of 5 mm/min and a span length of 110 mm was used. Five samples were tested for each fibre loading. The fractured surface of the neat PLA and PALF/PLA composites were studied by using EVO 50 VP Scanning Electron Microscope (SEM) (Carl Zeiss, UK). The specimens were gold-coated using a sputtering machine coated to prevent electrostatic charging during sample examination.

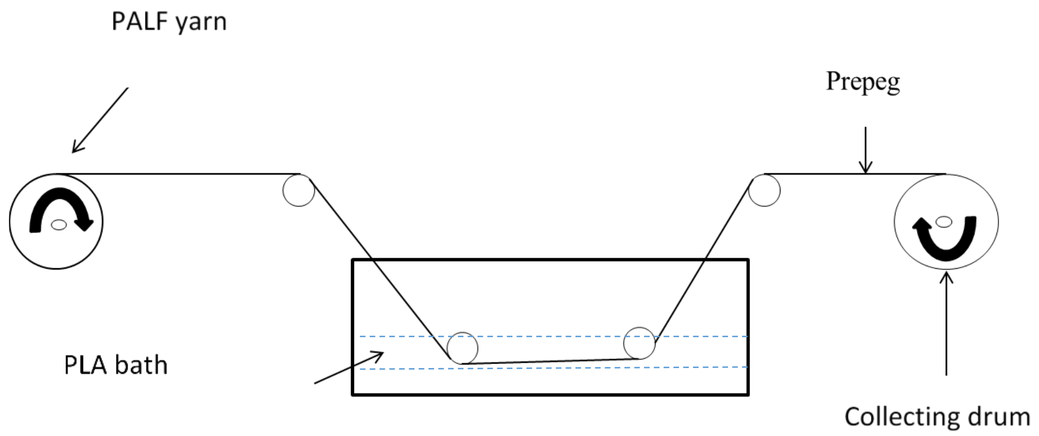

Figure 1. Schematic diagram of the pre-pregging process

Results and Discussion

Fibre analysis. The FTIR spectrum of untreated PALF and alkaline treated PALF is shown in Figure 2. For untreated PALF, the occurrence of vibration peaks at 1254, and 1436 cm^{-1} indicated the presence of lignin and hemicellulose structure, respectively [6, 11]. The alkaline treated PALF showed non-appearance vibration at peaks 1200 cm^{-1} and 1650 cm^{-1}. The vibration peak at 1229 cm^{-1} for the untreated pineapple leaf fibre corresponds to the C-O stretching vibration of the acetyl group in lignin materials is also not present in the NaOH treated pineapple leaf fibre spectrum. It was also observed there is a reduction in peak intensity at 1436 cm^{-1}. Furthermore, the C=O stretching vibration of carboxylic acid at peak 1724 cm^{-1} is associated with ester disappearing in the spectrum. Therefore, it can be concluded that the alkaline treatment successfully reduces the lignin and hemicellulose contents in the PALF. A similar observation was reported in the literature [9, 14-15].

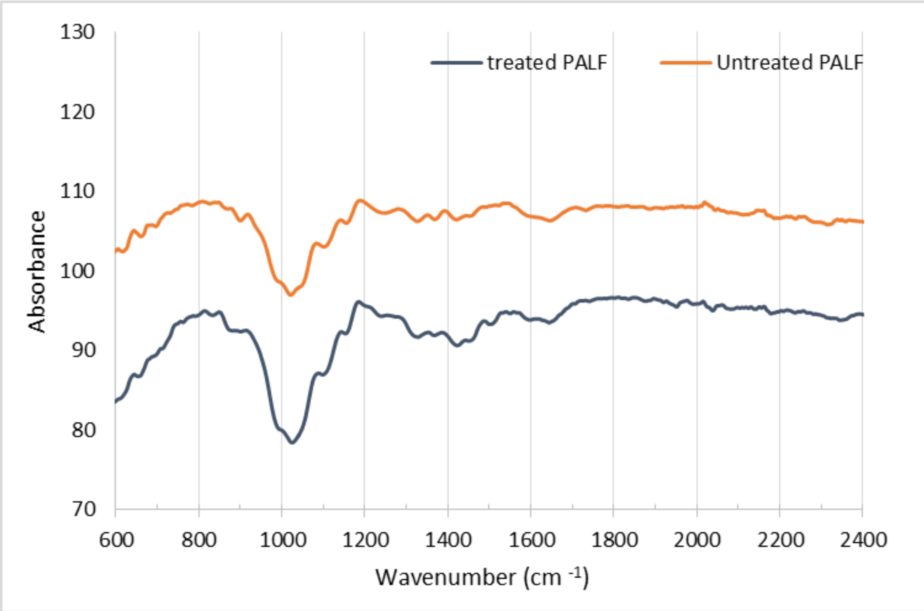

Figure 2. FTIR analysis of the untreated and alkaline treated PALF fibres

Mechanical properties. The flexural strength and modulus of the composites increase when the fibre content increases (Figure 3). The flexural strength and modulus of the PALF/PLA composite increases to 132.78 (±9.3) MPa and 7.32 (±0.9) GPa, a significantly ($p<0.01$) higher than neat PLA (45.52 ±4.2 and 0.79± 0.1 GPa), respectively. Optimum flexural strength and modulus are when 60 wt. % PALF was added, yielding 145.09 ±24.0 MPa and 9.36 ±1.5 GPa, respectively. Figure 4 shows that close contact of the matrix around the fibre bundles is observed throughout the composite. The fracture surface of PALF/PLA composite revealed that the failure was due to fibre breakage and de-bond and drawn out from the matrix. Evidence of matrix left behind on the fibre surface indicated good fibre/matrix adhesion that might contribute to the effective reinforcement, as shown by the increase of their mechanical properties [6, 11].

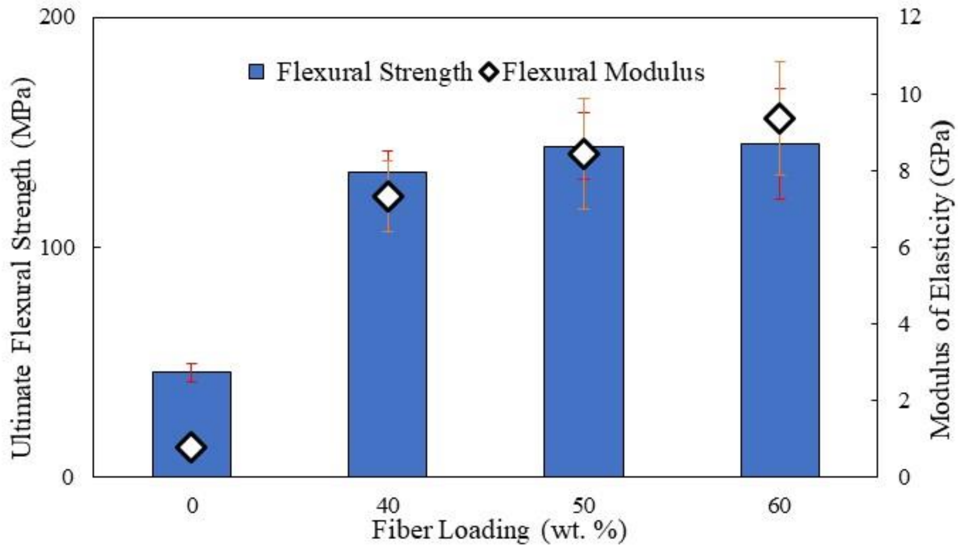

Figure 3. Effect of fibre loading on the flexural properties of PALF/PLA composites

The flexural strength and modulus are enhanced with increasing fibre contents; however, this is not the case for their flexural strain (Figure 5). The strain at break value of neat PLA is 7.43 ±0.6 % and the addition of 40 wt. % PALF reduces it to 3.30 ± 0.3 % as the fibre loading increases to 60 wt. %, there are significant changes in the strain at break in which it reduced to 3.35 ±0.4 %. While many findings are reported in the literature regarding the flexural strength and modulus, the information on their flexural strain is often rarely included [10, 16]. There is a combination of tensile and compressive stress in the flexural test. The top part of the specimens is subjected to compression, and the bottom side is subjected to tension. Thus, it is suggested that the compression part of the fibre in the matrix could be subjected to "kinking" [17]. The weak spot of the fibre may bend or kink, thus inducing stress concentration point in the matrix could promote fracture in the matrix and lead to the overall failure of the composite at strains below that of the reinforced PLA itself. The bend/kink fibres often occur when long fibre reinforcement is used [17]. The evidence of fibre kinks in the aligned long PALF composite fracture surface under the flexural stress is observed in Figure 6, which might reduce the strain at break as the fibre loading increases.

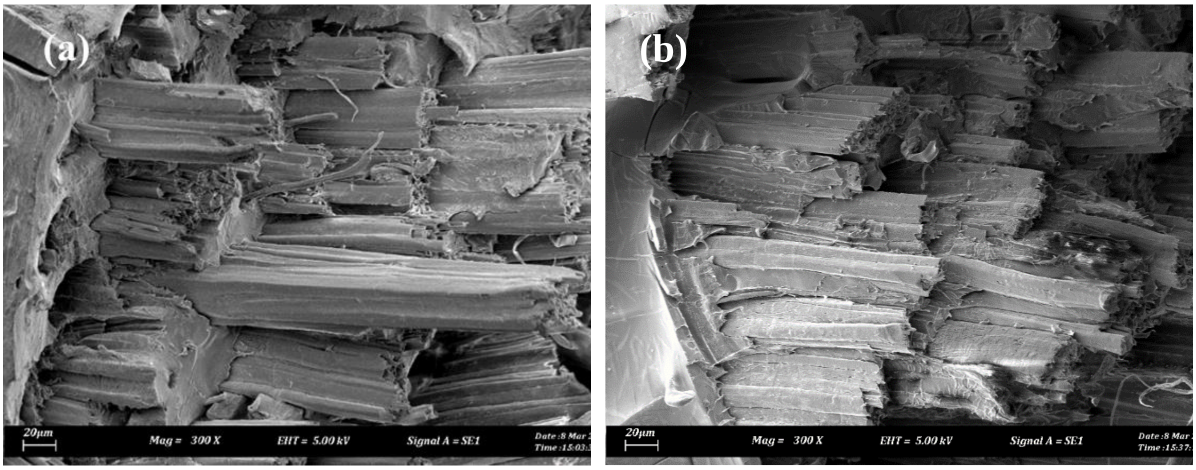

Figure 4. SEM micrograph of the flexural fractured surface of PALF/PLA composite at different fibre loading (a) 40 wt. % PALF and (b) 60 wt. % PALF.

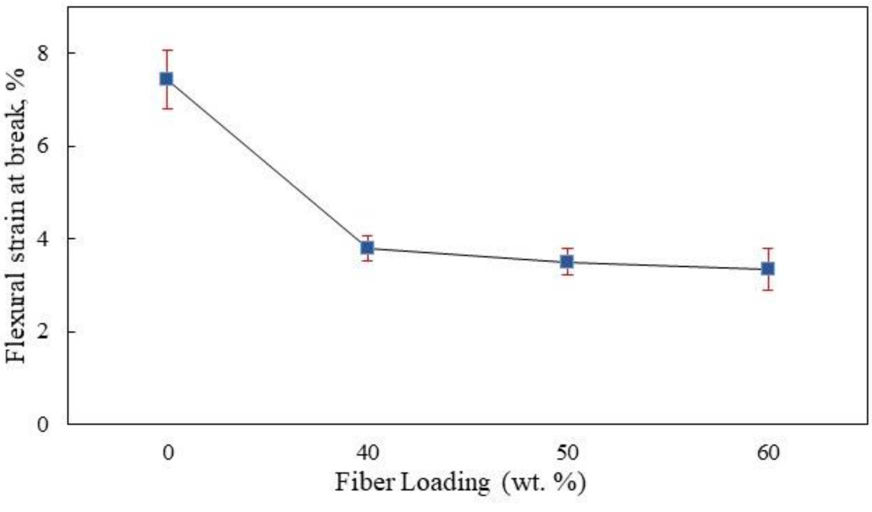

Figure 5. Effect of fibre loading on the flexural strain of PALF/PLA composites

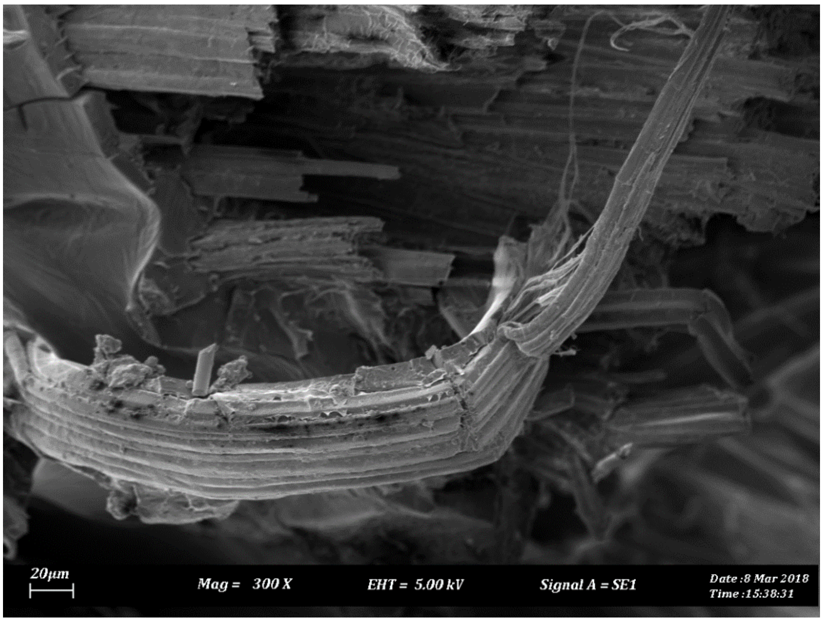

Figure 6. The presence of kink bank in 60 wt. % PALF/PLA composites

Conclusions

The flexural properties of the composites increased with increasing fibre loading. The composite with 60 wt. % of alkali-treated pineapple leaf fibre has the optimum flexural strength and stiffness, which are 145.1 MPa and 9.35 GPa, respectively, significantly higher than the neat PLA. In contrast, the flexural strain reduced as the fibre loadings increased. Surface morphology observed using SEM indicated that the composite failed due to fibre breaking, and favourable interfacial adhesion is present in the composites. These findings suggested that fabrication methods used in this study can improve the matrix impregnation around the fibres hence contributing to their high mechanical performance. A further recommendation is to carry out the durability study of the composite in the presence of high moisture and temperature.

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Author Contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure of Conflict of Interest

The authors have no disclosures to declare

Compliance with Ethical Standards

Not applicable

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