

The Effect of Fibre Length on Flexural and Dynamic Mechanical Properties of Pineapple Leaf Fibre Composites

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Abstract: The present paper deals with the effect of loading different pineapple leaf fibre (PALF) length (short, mixed and long fibres) and their reinforcement for the fabrication of vinyl ester (VE) composites. Performance of PALF/VE composites was investigated through three-point bending flexural testing and visco-elastic (dynamic) mechanical properties through dynamic mechanical analysis (DMA). DMA results revealed that the long PALF/VE composites displayed better mechanical, damping factor and dynamic properties as compared to the short and mixed PALF/VE composites. The flexural strength and modulus of long PALF/VE composites were 113.5 MPa and 14.3 GPa, respectively. The storage (E') and loss (E'') moduli increased to 2000 MPa and 225 MPa respectively for PALF/VE composites. Overall result analysis indicated that increasing the length of the reinforcement fibre results in satisfactory mechanical performance and dynamic properties of composites.

Keywords: Pineapple leaf fibre; vinyl ester resin; flexural strength; dynamical mechanical properties; damping factor

1 Introduction

Recently, natural composite materials have become widely used in aerospace, oil and gas industries, as well as in automotive and marine industries, compared to common metals, due to the higher stiffness and strength to weight ratios of the former [1]. Natural fibres, such as kenaf, jute, oil palm, sisal, pineapple leaf fibre (PALF) etc., have become one of the most important research topics due to their specific strength, durability, continuous supply, biodegradability, eco-friendliness and unique easy handling properties [2]. Moreover, until now several studies have been conducted in determining the varied factors such as fibre length or aspect ratio on the performance of the natural fibre reinforced with thermoset and thermoplastic composites [3–5].

Fibre length is one of the factors that could affect the performance of natural fibre composites. Previous studies have been conducted on the effect of fibre length on the mechanical and thermal properties of the



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natural fibre composites. Recently, a research has been conducted to determine the mechanical and thermal properties of roselle fibre-reinforced thermoplastic polyurethane (TPU) composites at different fibre sizes < 125 μm , 125–300 μm and 300–425 μm [3]. The flexural properties of the composite increase as the size of the fibre increase due to the effective stress transfer between fibres and matrix and it was found that 300–425 μm provide the best flexural strength. The flexural properties of short random oriented jute fibre reinforced epoxy composites was investigated [4]. The research done was in line to previous research work where it was found that 2 mm of jute fibre length provide the best mechanical properties compared to other tested length [5]. They claimed that the higher in fibre length created better adhesion between jute fibre and epoxy matrix. Other than that, the effect of fibre volume and length of kenaf and bagasse with length of 1.5 mm, 2.8 mm, 10.9 mm and 16.9 mm reinforced with corn-starch biodegradable resin composites on their flexural properties was evaluated [6]. It was found that fibre length higher than 2.8 mm provide better flexural properties compared to other length tested. Researchers justified the effect of fibre length of banana fibre (5 mm, 10 mm, 15 mm and 20 mm) reinforced epoxy composite on their flexural properties [7]. Mechanical properties of mengkuang fibre reinforced thermoplastic natural rubber composites were analysed based on different fibre length; 125 μm , 250 μm and 500 μm , and it was concluded that 250 μm of fibre length provide the best mechanical properties [8]. The mechanical and thermal properties of schumannianthus dichotomus (murta) fibre reinforced epoxy composites on 5 mm, 15 mm, 25 mm and 35 mm of fibre length was tested and it was identified that murta fibre with 25 mm of length provide the best mechanical properties [9]. The mechanical properties of wood-plastic reinforced polypropylene composites on different fibre length was evaluated between 1.5 mm and 3 mm [10]. It was proven that the variation on length of fibre could affect the mechanical and thermal properties of the natural fibre composites.

Vinyl ester (VE) resin is a thermosetting resin that was used in the polymer matrix composites. VE resin provides high resistance towards the alkalis, acids, solvents and peroxide. From the perspective of its cost, the cost of VE much cheaper compared to polyester and epoxy, without compromising its ability. VE offers better corrosion resistance and high elongation to failure while allow the loads to be transferred to the reinforcements. VE is cheaper and yet, it can be a high-performance epoxy resin. The usage of vinyl ester resin as reinforcement has enhanced its mechanical properties. Several researchers have conducted the experiment on natural fibre reinforced VE resin. Researchers [11] determined the mechanical properties of bagasse fibre reinforced vinyl ester composites. Generally, mechanical properties of composites enhanced due to the good interfacial bonding between the vinyl ester resin and bagasse fibre. Previous researchers [12] investigated the impact behaviour of rice husk impregnated coir reinforced VE composites. The effect of surface modification of flax reinforced different treatment of vinyl ester on the mechanical properties of composites was investigated [13]. Scientists [14] determined the mechanical and thermal properties of PALF reinforced vinyl ester composites.

In evaluating the properties of natural fibre polymer composites, instead of their mechanical properties, it is also very important to analyse their thermal characteristics. Until now, several studies have been reported on the PALF reinforced thermoplastics and thermoset composites. Another study [15] determined the dynamic mechanical properties of silane treated kenaf/pineapple leaf fibres phenolic hybrid composites. Researchers [16], mentioned that weight loss at $T_{10\%}$ and $T_{50\%}$ occurred at temperature of 212°C and 306°C respectively. Chemical modification on the PALF improved significantly the modulus and heat distortion temperature (HDT) [17]. Scientists [18] concluded that the ability of 12 type of PALF to withstand the high temperature can be used for reinforcement for most commercial polymers.

Like other natural fibres, PALF are also gaining huge attention as every year, tonnes of PALF are produced, although only small portions of it are used as feedstock and for energy production. At present, the use of pineapple leaf is still limited because of lack of information and facilities available to process and turn the leaf into potential materials for various applications [19]. The pineapple leaves wastes are

burned excessively and composed in the plantation lead to the environmental and air pollution such as haze. However, recently, the usage of bio composites has attracted the researchers' attention due to their excellent performance over that of synthetic fibre reinforced composites, such as glass and carbon fibre composites, along with their advantages, such as biodegradability, low cost and eco-friendly nature [20].

Interestingly, all the positive results from the previously published literature motivate us to carry out the current study. In this study, flexural properties and DMA of PALF/VE composites on different fibre length such as short (15 mm), mixed (15–30 mm) and long (30 mm) were evaluated and discussed. From the literature, it was found that no work has been done on the effect of fibre length of PALF on flexural and dynamic mechanical properties. Previous research work tends to investigate the effect of fibre content and fibre orientation of PALF composites. At the same time, no other research work investigates the properties of composites made from PALF and VE. Therefore, this research are focusing on the effect of fibre length of PALF on the PALF/VE composites using flexural and DMA testing. The findings of the present study will reveal the usage of PALF as a cheaper and safe reinforcement in VE and the effect of varied fibre length as potential factors for improving the flexural as well as dynamic properties of polymer composites while working on the structural application.

2 Experimental Procedure

2.1 Materials and Methods

PALF, in the roving form of a thin yarn, with the average thickness of 1 mm, was used as reinforcement material. PALF generally contains 82% cellulose, 18.8% hemicellulose and 12.7% lignin as major chemical components. Prior to reinforcement, the PALF was chopped to two different lengths, of 15 mm and 30 mm, labelled as short and long PALF, by using a chopper gun. The resin used was MFE-11, a premium standard Bisphenol-A type epoxy VE resin supplied by Sino Polymer Co., Ltd. Low-viscosity MFE-11 was used to avoid the possibility of corrosion in many chemical processing industrial applications. The physical and mechanical properties of VE resin are listed in [Tab. 1](#).

Table 1: Properties of VE resin matrix [21]

VE Properties	Values	Standard
Flexural Strength (MPa)	80–95	ASTM D790
Flexural Modulus (GPa)	3.2–3.9	ASTM D648
Heat Distortion Temperature (°C)	105–110	ASTM D2583
Barcol Hardness	34 ± 4	ASTM D2583

2.2 Fabrication of PALF/VE Composites

In this study, three different types of PALF/VE composites were fabricated, comprising short, long and mixed PALF fibres. The moulding method was used to prepare the composites. Based on previous studies on natural composites, the ratio used for PALF to VE resin was 30:70. The respective amounts of PALF and VE, based on their ratio, were mixed together in a container before being poured and distributed evenly into an aluminium mould with random orientation of the fibre. The composites were allowed to cure at room temperature for 24 hours. [Fig. 1](#) showed the short PALF/VE composite that has been fabricated.

2.3 Characterization

2.3.1 Flexural Testing Analysis

The three different PALF/VE composites fabricated were characterized to evaluate and compare their flexural properties. Three-point bending flexural testing was carried out according to ASTM D-790, using a 30 kN INSTRON 5567 Universal Tensile Machine as in [Fig. 2](#).



Figure 1: Short PALF/VE composite

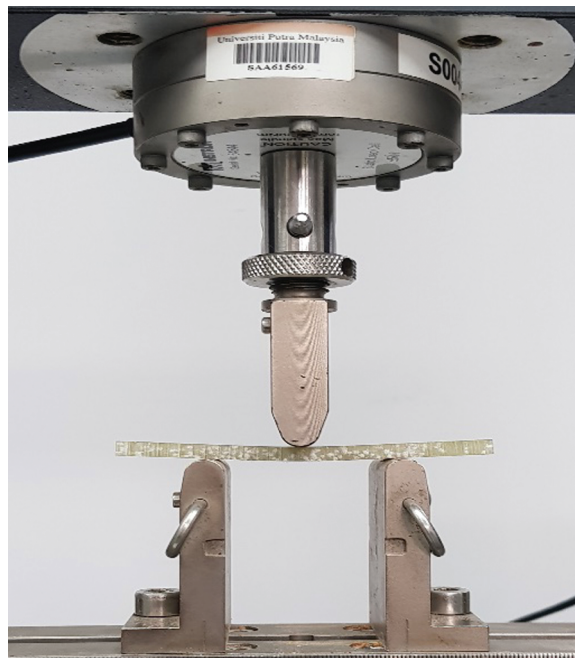


Figure 2: Three-point flexural testing

2.3.2 Dynamic Mechanical Analysis (DMA)

Three-point bending DMA was performed by using TA (DMA Q500) instrument at an oscillation frequency of 1 Hz under controlled amplitude with the temperature ranged from 30°C to 150°C under controlled sinusoidal strain at a heating rate of 5 °C/min. The typical dimension of DMA samples was 60 mm × 1.2 mm × 5 mm.

3 Results and Discussion

3.1 Flexural Properties

Flexural testing was conducted to determine the flexural strength and modulus of the composites. In structural application, the flexural properties in one of most important parameters that should be looked for. Fig. 3 presents the flexural strength and modulus of short, mixed and long PALF/VE composites.

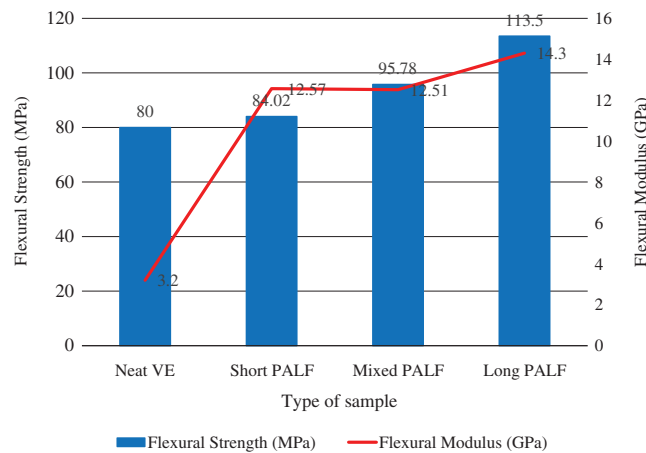


Figure 3: Effect of fibre length on flexural properties of PALF/VE composites

Increasing in fibre length enhanced the flexural properties of PALF/VE composites. From the Fig. 3, it is interesting to note that long PALF/VE composites have higher flexural strength and modulus compared to mixed and short PALF/VE composites. It can be observed that the highest flexural strength obtained was 113.5 MPa that produced by the long PALF/VE composites while the short PALF/VE composites showed the lowest flexural strength which was 84.02 MPa. Long PALF/VE composites even possessed better flexural strength compared to neat VE composites. The flexural strength increases 35.09% as the fibre length increase from short to long PALF. The flexural strength and modulus are found to be maximum by long PALF/VE composites. This is due to the fact that the longer the length of fibre, the higher the capability to withstand higher bending load. Previous study highlighted the same reason that higher in fibre length enhanced the flexural properties [1]. Therefore, This finding is in line with other reported research work, stating that one of the factors that affect the flexural strength value of PALF composites is fibre length [22]. The authors declared that an increase in the length of fibre enhances the flexural strength of composites due to a more effective stress transfer between the fibre and the matrix.

For the flexural modulus, the results showed that the values reached for the short, mixed and long PALF/VE composites were 12.57 GPa, 12.51 GPa and 14.30 GPa, respectively. The flexural modulus of neat VE is taken from the Tab. 1 which is 3.2 GPa. The flexural modulus of PALF/VE composites showed a significant difference value with the neat VE composite. This shows that there is an improvement in the flexural modulus of the neat VE after adding PALF into the composites. It may be noted that there was a slight decrease in the flexural modulus of 0.48%, from the value for the short PALF/VE composites to that of the mixed PALF ones. This is due to the fact that if the short and long fibre mixed together, the interaction between the short and long fibres will disrupt the interfacial bonding between these two different lengths of fibre and matrix. This is supported by the previous research work that has been conducted before [23]. Therefore, there is an increasing in flexural modulus of 14.31%, from the mixed to long PALF/VE composites. The positive trend happened due to the larger surface area contacted between the long PALF and VE resin. This is supported by the research work conducted which stated that the high in surface area enhanced the performance of composites [24]. Therefore, it has been

concluded that, as the length of PALF increases, the flexural modulus of the composites is enhanced [22]. This relation can be ascribed to the high content of cellulose and low microfibrillar angle, of 14°, in PALF [25].

3.2 Dynamic Mechanical Properties

3.2.1 Storage Modulus (E')

The viscoelastic behaviour of polymer composites at high temperature required an effective thermomechanical DMA technique for accurate evaluation. In this subtopic, E' refer to the Young's modulus or stiffness of the material or composites. Fig. 4 showed that the E' at various temperature of PALF/VE composites of three different type of fibres. From the Fig. 4, it can be observed that as the temperature increases the E' decrease. At low temperature which is from 30°C to 70°C, the E' values gave a huge difference in their characteristics, short PALF/VE composites shown better E' compared to long PALF/VE composites, but lower than E' of mixed PALF/VE composites. As the temperature increase, the materials' component transforms into mobility and disrupt the close packing structure. It is turned out that long PALF/VE composites produce the minimum E' while the mixed PALF/VE composites produced the maximum E' . In comparison between these three composites, the long PALF/VE composites showed the lowest modulus which make the material flexible characteristics and low degree of stiffness [26]. This trend was in the agreement with the previous highest value of flexural modulus of long PALF/VE composites showed. It is important to note that the stiffness of the composites influenced by the inherent stiffness of the PALF which enable the effective stress transfer [27]. In a similar study conducted [28], the results obtained clearly showed that fibre length affect the E' of composites.

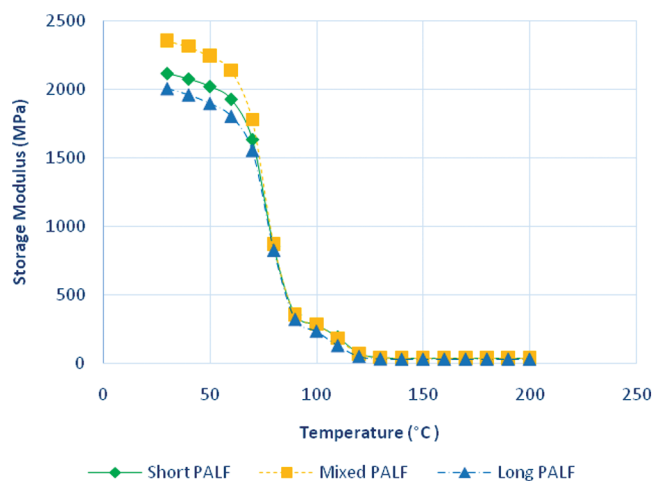


Figure 4: Effect of fibre length on the E' of PALF/VE composites

Besides, the E' curve that decreasing gradually indicating the transition state of glass to rubbery. After 70°C there is gradually fall in E' during passing through the glass transition temperature (T_g). This is because due to the instability molecular mobility of the polymer chain above T_g . In addition, gradually decreased in the E' of PALF/VE corresponds to the highly crosslinked density of the composites, meaning to say that it has good stiffness and close network structure [29]. From the Fig. 4, it can be observed that the drops in E' of these three PALF/VE composites were similar but the fibre length in the composites showed the various E' . Long PALF/VE composites produced the lowest E' . However, as the fibre length was mixed which is mixture of short and long PALF/VE composites, they improved the stiffness behaviour and enhanced the interfacial bonding with the VE resin matrix.

3.2.2 Loss Modulus (E'')

The E'' is known as the energy dissipation as heat/cycle under the deformation of viscous response of the composites. Tab. 2 and Fig. 5 showed the effect of E'' on dynamic properties of PALF/VE composites. When the temperature shows the maximum heat dissipation, the E'' will be at maximum. The E'' value of mixed PALF/VE composites was the highest among the other PALF/VE composites. This is due to the internal friction that improved the dissipation of energy within the composites [30]. This is also due to the previous E' of mixed PALF/VE decreased considerably that led to highest E'' . The findings are in line with other researchers [31] who reported the maximum E'' occurred during the rapid decrease of E' . The E'' decreased as the length of fibre increase.

Table 2: Peak Height, $\tan \delta$ max (T_g) and E'' max (T_g) of short, mixed and long PALF/VE composites

Composites	Peak Height of $\tan \delta$ curve	T_g from $\tan \delta$ max ($^{\circ}\text{C}$)	T_g from E'' max ($^{\circ}\text{C}$)
Short	0.8267	123.7.6	104.4
Mixed	0.8661	120.6	104.4
Long	0.8629	102.7	88.59

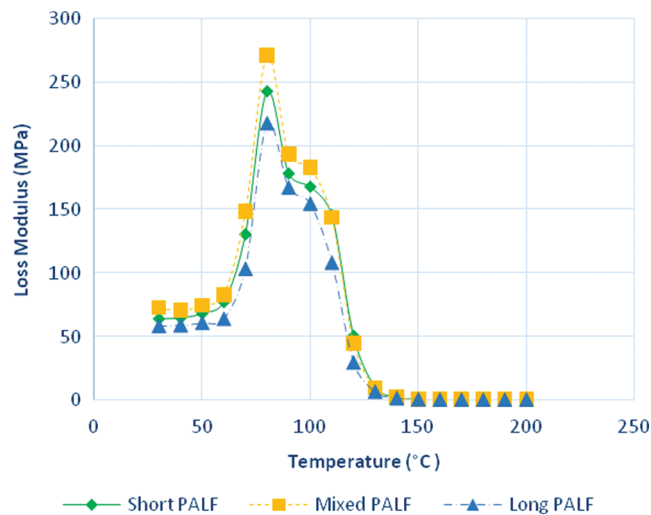


Figure 5: Effect of fibre length on the E'' of PALF/VE composites

3.2.3 Damping Factor ($\tan \delta$)

The measurement and information of the damping factor brief about the polymeric system, not to mention that to give the balance between the viscous phase and elastic in a polymeric materials [32]. The addition of fibres into the composites affects the damping factor. An expected trend of the damping factor's graph showed increase until maximum during transition region and decrease during rubbery region [33]. It indicated that during initial or frozen state, there is no mobility of small groups of material. When the temperature increase, the mobility of small groups of materials and molecules within the polymer composites exists [26]. Tab. 2 and Fig. 6 showed the damping factor value of the short, mixed and long PALF/VE composites with a temperature frequency of 1 Hz. The curve of damping factor was initially low below the T_g in all samples due to the chain segment that was in the frozen stage. As the temperature increase, it increase until it reaches maximum at the point of transition region which indicated the higher degree of molecular mobility and declined in the rubbery region [34].

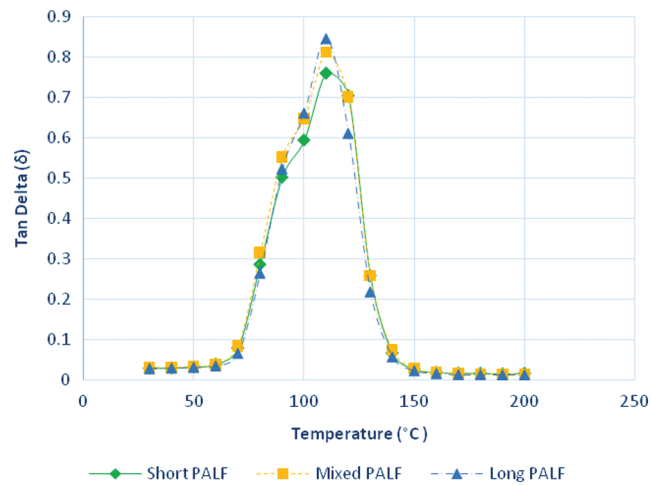


Figure 6: Effect of fibre length on the Tan δ of PALF/VE composites

As the temperature increase from 30°C to 110°C, the value of the damping factor increased. In the rubbery region, as the length of fibre increase, the damping factor decreased. The short PALF/VE composites has smaller energy dissipation coefficient than the mixed and long PALF/VE composites. The incorporation of higher fibre length restrained the mobility segment of the composite's molecules. As the fibre length increase from short to long PALF/VE composites, the damping factor increase. The long PALF/VE composites showed the highest (Tan $\delta = 0.8629$) while the short PALF/VE composites showed the lowest damping factor (Tan $\delta = 0.8267$). One of the reasons this situation occurred because of good interfacial bonding and incompatibility within the fibre itself. In this case, the short PALF/VE illustrated the better adhesion between the fibre and matrix, since the damping factor is the lowest. The low in damping factor lead to high Tg of tan δ max (123.7°C). As the interfacial bonding between the fibre and matrix is increase, the mobility of molecules in the molecular is restricted. Eventually, only a small amount of friction is produced. This is supported [35] who clarified that the high restriction in the mobility of molecular segment will resulted in low damping factor value. Therefore, the adhesion between fibre and matrix influenced the fibre length. From another study it is evident that the strong adhesion bonding between fibre and matrix causing the damping factor to be small [36]. Thus, in this case, the short PALF/VE composites produced the lowest tan δ peak values that lead to good interfacial adhesion between fibre and matrix.

4 Conclusion

In this study, an effort has been made to fabricate VE composites from abundantly available PALF fibres with different fibre length (short, mixed and long fibres). Fabricated composites were characterized in terms of flexural strength, modulus, moduli and damping factor to determine the viable and effective PALF fibre length as reinforcement. Results analysis revealed that the flexural properties of the long PALF/VE were found superior compared to those of the short and mixed PALF/VE composites, which was ascribed to the existence of strong adhesion and effective stress transfer between the PALF and the VE matrix. The short PALF/VE composites showed the lowest damping factor that indicated the strong interfacial bonding between the fibres and matrix. Furthermore, it was also observed from the results that as the length of PALF increases, the mechanical properties will be enhanced and vice versa.

The satisfactory flexural strength and dynamic properties (E' , E'') achieved for long and short PALF reinforced with VE composites govern certain potential applications of the developed structures, where

poor damping factor and reliable dynamic mechanical performance, along with the prime benefits of renewability and economical issues associated with natural fibers are highly valued assets.

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Conflicts of Interest: The authors declare no conflicts of interest.

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