



Effect of Biopolymer Composition of Natural Fibers on Thermal Properties of Kenaf Core and Oil Palm Hybrid Fiber Reinforced Poly (lactic acid) Bio-composites

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Abstract

This work demonstrates the combination of cellulose-rich oil palm empty fruit bunch fiber (EFBF) and lignin-rich kenaf core fiber (KCF) as hybrid reinforcement in poly (lactic acid) (PLA) matrix for a novel fabrication of hybrid bio-composites. Physicochemical characteristics of EFBF and KCF were determined. Single-fiber bio-composite were fabricated, and the hybrid bio-composite was achieved by manually mixing 55% (wt) EFBF with 5% (wt) KCF. The mixture was melt-blended with 40% (wt) PLA, and subjected to compression-molding. Characterizations *via* dynamic mechanical analysis and thermogravimetric analysis revealed synergistic improvement in the thermal performance of the hybrid bio-composites compared to their single-fiber bio-composite. This implies that hybridization of the cellulose-rich EFBF with lignin-rich KCF is viable approach to achieving novel application of oil palm fiber in bio-composite fabrication and potential applications.

Keywords: Biopolymer, Natural Fiber, Poly (lactic acid), Thermal properties

1. Introduction

Oil palm tree (*Eleis guineensis*) is a natural reservoir of biomass resource such as oil palm mesocarp fiber (OPMF), empty fruit bunch fiber (EFBF), oil palm trunk (OPT), oil palm fond (OPF), presses fruit fiber (PFF) etc. Report indicated that EFBF was the most abundant oil palm fiber among the major oil palm producers such as Nigeria and south-eastern Asian countries. Malaysia has ca. 12.4 million tons of EFBF per year [1].

Growing research interest in polymer composites have been dedicated to utilizing the oil palm fibers particularly empty fruit bunch fiber (EFBF) and oil palm mesocarp fiber (OPMF) [2–9]. Medium density fiberboard (MDF) mills depend heavily on rubberwood for raw materials. Though, recent development has shown a shift of attention to oil palm fiber-based MDF in order to supplement or substitute the rubberwood [10–12]. The major issue worthy of concern is sustaining the supply chain of the oil palm fibers (OPFs) raw materials as there could be likelihood that the demand may outstrip supply in the foreseeable future.

Kenaf plant (*Hibiscus cannabinus L.*) is rich in both bast and core fiber [13]. The core fiber is light weighted and rich in lignin, though its high content of hemicellulose and low content of cellulose are its major drawbacks for composites fabrication. Therefore, it will be impressive to mix the cellulose-rich oil palm fiber and lignin-rich kenaf core fiber to form hybrid. By so doing, the

synergistic performance obtained will be as a result of complementing the fiber properties lacking in both oil palm fibers and the kenaf fiber. Previous works reported the hybrids of Kenaf fiber and Banana peels [14], and the hybrid of Kenaf fiber and Wood [15]. Herein, the dynamic mechanical and thermal properties of the EFBF, KCF and EFBF-KCF reinforced PLA hybrid bio composites were reported.

2. Experimental

2.1 Materials

Poly(lactic acid) was purchased from Nature Work LLC (Minnetonka, MN) under the trade name, polylactide resin 3052D. The melting point ranged between 170 and 190 °C, and the density ranged from 1.4 to 1.5 g/cm³. EFBF was obtained from Sabutek (M) Sdn. Bhd. (Malaysia), and FELDA Seriting Hilir Oil Palm mill (Malaysia) respectively. The KCF was supplied by the Lembaga Kenaf dan Tembakau (Malaysia).

2.2 Methods

2.2.1 Fiber Purification

To remove impurities from the EFBF and KCF, they were physically treated by sorting and soaking in distilled water for 24 h at 25 °C, washed with heated water at 60 °C, cleaned with acetone, and oven-dried at 60 °C for 24 h. The oven-dried fibers were then ground into smaller particles, followed by sieving into sizes ranging from 300

to 400 µm. The purified fibers were then stored in sealed plastic bags at 25 °C for subsequent investigations.

2.2.2 Fabrication of single and hybrid fiber-PLA bio composites

To prepare the single fiber-PLA bio composites, the oven-dried EFBF and KCF together with the PLA were melt blended at the fiber-to-PLA loading formulations presented in Table 1 using a Brabender Internal Mixer (Germany) at 170 °C with a rotor speed of 50 rpm for 15 min. Initially, the PLA was loaded into the mixing chamber to melt for 2 min; then, the fibers were added to the molten PLA and mixing continued for 13 min. The single fiber-PLA bio composites were further compression molded into sheets with dimensions of 1 mm × 150 mm × 150 mm and 3 mm × 150 mm × 150 mm (thickness × length × width). The compression molding was performed using a hydraulic hot press at 170 °C, 150 kgf^m⁻², and 10 min molding temperature, pressure, and time, respectively. Furthermore, cooling was performed at 30 °C for 5 min.

The hybrid fiber-PLA bio composite was prepared following a similar method. The hybrid fiber-PLA bio composite was fabricated by mixing two different fibers together manually prior to melt blending with PLA. The fiber mixing formulations are presented in Table 2.1.

Table 2.1: Single and hybrid fiber-PLA mixing formulations.

Sample code	EFBF (%)	KCF (%)	PLA (%)
Neat PLA	-	-	100
EFBF-PLA	60	-	40
KCF-PLA	60	-	40
EFBF-KCF-PLA	55	5	40

2.3 Characterization of natural fibers

2.3.1 Bulk density measurement

The bulk density of the oven dried EFBF and KCF was determined by filling up a funnel suspended above a measuring cylinder with the test samples, as previously reported [16,17]. The sample was allowed to flow through the suspended funnel and into the measuring cylinder. The weight of the sample laden cylinder was measured using weighing balance. The volume was also recorded and used to calculate the density of each sample using the following equation 1. Triplicate experiments were performed and average was reported.

$$\text{Bulk Density}(gcm^{-3}) = \frac{\text{Weight}}{\text{Volume}} \quad (1)$$

2.3.2 Determination of chemical components of Natural fibers

To determine the holocellulose content, *i.e.*, the cellulose and hemicellulose contents, the oven-dried EFBF and KCF were reacted with acidified aqueous sodium chlorite

(NaClO₂) solution to delignify the fibers, as previously reported in the literature [16,18,19]. The NaClO₂ solution was acidified with a H₂SO₄ solution until a pH of 4 was reached. The fibers were soaked in 5 wt. % NaClO₂ solution at 70 °C for 1 h, at a weight ratio of 1:20 fiber-to-NaClO₂ solution. After the treatment, the fiber was filtered and washed thoroughly with distilled water and oven-dried at 60 °C until a constant weight was obtained. The cellulose content was determined by treating the holocellulose with 6 wt. % potassium hydroxide solution at 25 °C for 24 h. The mixture was filtered and the solid residue obtained was washed thoroughly with distilled water and oven-dried at 60 °C until a constant weight was obtained. Afterwards, the difference between the holocellulose and cellulose contents represented the hemicellulose content of the fibers.

The lignin content was determined by submerging the oven-dried EFBF and KCF, respectively, in 72 wt. % H₂SO₄ at 30 °C for 1 h. Then, the solution was diluted to 3% H₂SO₄ and refluxed for 2 h. The mixture was filtered and the insoluble solid residue obtained was washed thoroughly with distilled water and oven-dried at 60 °C until a constant weight was obtained.

2.3.3 Determination of the moisture and ash contents

The moisture content was determined by placing weighed amounts of oven-dried EFBF and KCF in an oven at 105 °C for 4 h, respectively. Thereafter, the weights of the oven-dried samples were recorded. The moisture content was calculated by obtaining the difference between the weight of the fibers before and after oven-drying as previously reported by Then *et al.* [8].

To determine the ash content, weighed amounts of oven-dried EFBF and KCF were heated in a furnace at 600 °C for 2 h, respectively. Afterward, the fibers were cooled in a desiccator and re-weighed. The ash content was calculated as the difference between the weight of the fibers before and after furnace heating [9].

2.4 Characterization of Single and hybrid fiber-PLA composites

2.4.1 Dynamic Mechanical Analysis (DMA)

The stiffness and damping (*i.e.* modulus and tan delta) of the neat PLA, single and hybrid fiber reinforced PLA composites samples were measured using the Perkin Elmer dynamic mechanical analyzer by means of bending mode according to previously reported [20]. The samples were analyzed at a temperature scan range of 25 to 200 °C, heating rate of 2 °C/min and 1 Hz frequency of dynamic force under nitrogen atmosphere. The stiffness or modulus *i.e.* storage modulus (E') and loss modulus (E'') as well as damping or tan delta *i.e.* loss factor (tan δ) of each sample were recorded and plotted as function of temperature.

2.4.2 Thermogravimetric Analysis (TGA)

Thermogravimetric analysis (TGA) was employed to investigate the thermal stability of both the treated and untreated natural fibers reinforced PLA hybrid bio composites using Perkin Elmer TGA7 Thermogravimetric analyzer. About 10 mg of neat PLA, single and hybrid fiber reinforced PLA composites samples were analyzed at 10 °C/min heating rate and 25 to 500 °C heating range under nitrogen atmosphere of 20 mL/min nitrogen flow rate. The sample weight loss was noted and plotted against the heating temperature.

3. Results and Discussion

The influence of biopolymer contents viz. cellulose, hemicellulose and lignin on viscoelastic and thermal properties of KCF and EFBF hybrid fiber reinforced PLA bio composites was assayed.

3.1 Characterization of Natural Fibers

3.1.1 Bulk density of natural fibers

The results on bulk density of the natural fiber measured are presented in Figure 3.1. The analysis of the natural fiber bulk density is necessary in order to assay the preliminary biopolymer content of those fibers. Natural fibers possessing high composition of cellulose, lower hemicellulose and lignin, tend to present relatively higher bulk densities compared to those having less [20,21]. From Figure 1, EFBF recorded highest bulk density (i.e. 0.98 gcm⁻³), and considerably larger bulk density than KCF (i.e. 0.19 gcm⁻³). The fiber bulk density observed for the EFBF and KCF concurred with the reported range by [22]. This finding suggests that hybridization of the EFBF with KCF could perhaps influence the density of the hybrid fiber composites.

3.1.2 Analysis of the chemical constituents

The cellulose, hemicellulose, lignin, moisture, and ash for EFBF and KCF are presented in Table 3.1. The chemical constituents of natural fibers are important in determining the material performance of the composites fabricated from them. Cellulose-rich natural fibers allow formation of strong fiber-polymer interfacial bond which consequently improve material properties. Lignin-rich natural fibers also have reinforcing ability [23–25].

It can be seen from Table 3.1, EFBF presented highest cellulose content. KCF recorded the least cellulose content. Thus, the oil palm fibers possess better fiber

quality than KCF based on cellulose content. Therefore, the composites fabricated using the oil palm fibers are expected to demonstrate better material properties than KCF. On the other hand, KCF recorded highest lignin than EFBF. Thus, due to lignin, KCF can show reinforcing ability and enable synergistic performance in terms of material properties. The hemicellulose content of the natural fibers is rather noticeable, because the fibers were only treated with distilled water which cannot effectively eliminate hemicellulose. The presence of the hemicellulose can add up to the hydrophilicity of the natural fibers, thereby obstructing their ability to form strong adhesions with the hydrophobic polymer [16,26].

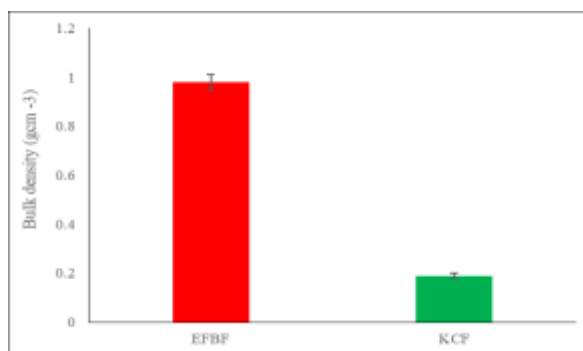


Figure 3.1: Bulk Density of Oil Palm Fibers and Kenaf Core Fiber.

However, the hemicellulose content influences the moisture content of the natural fibers (Table 3.1). KCF with highest hemicellulose content recorded highest moisture content, while recorded least moisture content due to its least hemicellulose content. The ash content is related to the cellulose content. Therefore, the oil palm fibers with highest cellulose content recorded highest ash content while KCF recorded least ash content due to its least cellulose content.

3.2 Characterization of Neat PLA, Single and hybrid fiber-PLA composites

3.2.1 Dynamic Mechanical Analysis (DMA)

The results on dynamic mechanical properties which depict the temperature dependence on dynamic storage modulus, loss modulus and tan δ for the neat PLA, single fiber-PLA bio composites and hybrid fiber-PLA bio composites respectively, are presented in Figure 3.2a through 3.2c.

Table 3.1: Chemical Constituents of Oil Palm Fibers and Kenaf Core Fiber

Sample	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Moisture (%)	Ash (%)
EFBF	39.50 ± 0.31	34.87 ± 0.42	14.32 ± 0.38	8.19 ± 0.28	3.12 ± 0.69
KCF	19.82 ± 0.17	37.10 ± 0.60	33.15 ± 0.50	8.86 ± 0.47	1.07 ± 0.53

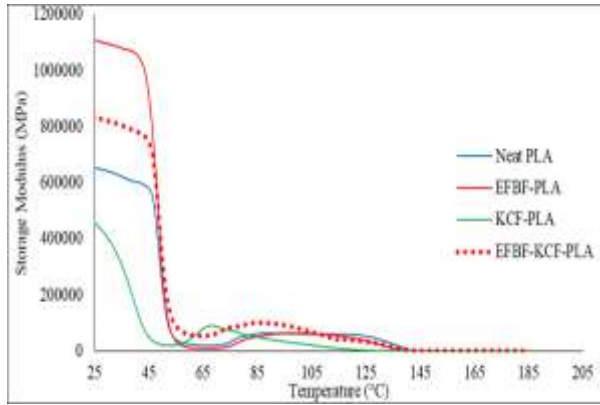


Figure 3.2a: Storage Modulus of Neat PLA, Single and Hybrid Fiber-PLA Bio Composites

3.2.2 Storage modulus, E'

The load carrying capacity of natural fiber thermoplastic composites is closely related to its storage modulus [27]. The dynamic storage modulus at 25 °C (i.e. within the glassy state) for the single fiber-PLA bio composites (Figure 3.2a) revealed that the neat PLA recorded 653.14 GPa which increased to 1018.68 GPa representing 55.96% increment for EFBF bio composites, suggesting an effective stress transfer between the fiber and the matrix. This indicates that the PLA stiffness rises upon EFBF inclusion. Previous research also observed rise in storage modulus of polymer matrix as a result of natural fiber reinforcement [28]. It is noticeable that the storage modulus of EFBF-PLA bio composites is higher than that of KCF-PLA bio composite, which indicates that the EFBF is stiffer and tougher than KCF, thusly, can withstand greater stress transferred from the PLA matrix. Similar observations regarding higher stiffness and toughness of EFBF was also reported [29].

On the other hand, the storage modulus of the neat PLA dropped upon reinforcement with KCF. The KCF-PLA bio composites recorded 440.12 GPa representing 48.40% diminution. This decrease could be ascribed to

the poor fiber quality (i.e. high hemicellulose and low cellulose content) of the KCF thereby reducing the stiffness of the composites. The KCF's poor fiber quality was described to be associated with its weak material performance in natural fiber reinforced composites [30].

It can also be noted that the storage modulus of the neat PLA and the single fiber-PLA bio composites tended to decline upon increase in temperature (Table 3.2). Initially, the storage modulus decreases at glass transition region (50 – 65 °C), and furthermore at higher temperature (100 °C), which is indicative of the composites becoming rubbery, and then soften respectively. Hence, their stiffness lessens due to weaker fiber-PLA interface bonding. Similar trend of stiffness diminution of natural fiber reinforced polymer composites as a result of rise in temperature was also observed elsewhere [31].

However, the dynamic storage modulus of the EFBF-PLA composites at 25 °C tended to decline upon kenaf core fiber (KCF) incorporation revealing *ca.* 833.37 (Figure 3.2b) for EFBF-KCF-PLA. This reduction in storage modulus could be because of increased fiber-fiber interaction due to KCF addition which prevent sufficient wetting of the fibers by the PLA. The decline could also be attributed to high content of hydrophilic groups (e.g. hemicellulose) in the hybrid fibers, considering the fact that both the fibers in the hybrid were untreated. Natural fibers that are not treated contain impurities which can affect the viscoelastic properties of their polymer composites [3,20].

Although, at higher temperatures i.e. glass transition and melting regions, the storage modulus of the hybrid fiber PLA composites exhibit improvement suggesting enhanced thermal stability of these hybrid composites. This could be attributed to the rich lignin content of the KCF which provided compatibilizing ability thereby strengthening the interface bonding with PLA [32].

Table 3.2: Thermo-mechanical properties of neat PLA, Single and Hybrid Fiber-PLA bio composites

Sample	Storage modulus (GPa) at 25 °C	Storage modulus (GPa) at 60 °C	Storage modulus (GPa) at 100 °C	Tg (°C) (obtained from Loss modulus)
Neat PLA	653.14	46.18	27.34	60.99
EFBF-PLA	1100.00	46.18	27.34	56.88
KCF-PLA	440.12	42.39	26.62	50.72
EFBF-KCF-PLA	833.37	87.50	64.31	62.23

Generally, the hybridization of the EFBF with KCF shows decrease influences on the storage modulus at the plastic region whereas, the storage modulus increases in the rubbery region at higher temperatures which is indicative of enhanced thermal stability.

3.2.3 Loss Modulus E''

The variation of loss modulus (E'') of neat PLA and PLA based single and hybrid-fiber composites as a function of temperature is shown in Figure 3.2b. The loss modulus represents the viscous responses of the composites. It can be noted that, at plastic region, the loss modulus tended

to rise, and upon increase in temperature it declined in the rubbery region.

The neat PLA and single fiber-PLA composites showed minimal value of loss modulus, with the least values obtained from the neat PLA below the glass transition temperature. Similar minimal loss modulus value was also observed [33]. This could be because of lack of heat dissipation as a result of PLA brittleness and poor interfacial bond in the single fiber-PLA composites. Moreover, hybridization of KCF with EFBF improved the loss modulus which could be due to enhanced fiber-polymer interfacial bonding, occurring due to reinforcing ability of lignin-rich KCF.

The glass transition temperature (T_g) of the systems is often described to be derived from the loss modulus curve [34,35]. The T_g of the composites (Table 3.2), represents the maximum heat dissipation which occurred at the temperature where loss modulus is maximum.

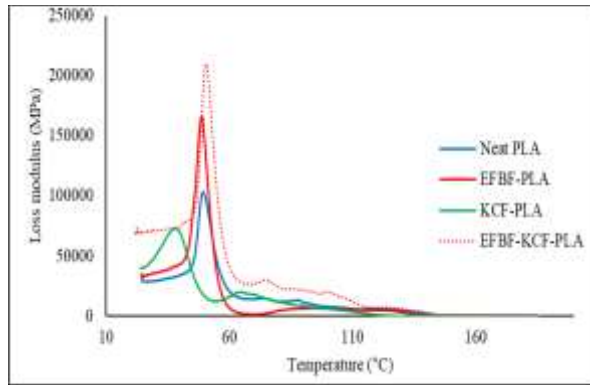


Figure 3.2b: Loss modulus of neat PLA, Single and Hybrid fiber-PLA bio composites

Figure 3.2b shows T_g of neat PLA shifted to lower temperature in the EFBF-PLA and KCF-PLA composites which can be associated to the physical interaction between the fibers and the crystalline region of PLA causing retardation of amorphous region.

However, KCF incorporation into EFBF greatly influences the T_g of the hybrid fiber-PLA composites (Table 3.2 and Figure 3.2b). The T_g exhibited enhancement in the case of EFBF-KCF-PLA composites by shifting to higher temperatures in relation to those of neat PLA. This shifting to higher temperatures indicates improvement in thermal stability of the hybrid fiber-PLA composites compared to the single fiber-PLA composites. Previous research also reported higher T_g value for hybrid natural fiber composites compared to single fiber composites [36,37].

3.2.4 Damping factor, $\tan \delta$

The dynamic loss factor or $\tan \delta$ which is also known as the damping factor, referred to the dissipation of energy in the polymer composite materials under cyclic load. It

is the measure of the composites ability to extricate energy [38]. The balance between the viscous and elastic responses (i.e. loss and storage moduli) of the polymer composites is often presented by their damping properties. The damping factor of the neat PLA, single and hybrid fiber-PLA composites are given in Figure 3.2c.

It can clearly be seen that the loss factor peak of the EFBF-PLA, KCF-PLA are lower than that of neat PLA. This indicate that the single fiber-PLA composite possesses better material property than the neat PLA. The EFBF-PLA have better interfacial bonding compared to KCF-PLA, thus, it demonstrated lesser energy dissipation than the KCF-PLA as well as neat PLA. This suggest that, natural fiber providing good interfacial bonding in polymer composites, facilitates greater stress withstanding ability and consequently, less energy dissipation [27]. Additionally, the $\tan \delta$ peak for the hybrid (i.e. EFBF-KCF-PLA), around glass transition temperature (T_g) are slightly lower than both EFBF-PLA and considerably larger than KCF-PLA, indicating enhanced damping characteristics of the hybrid fiber composites in relation to the single fiber-PLA composites. This agreed with the findings of Jawaid and Khalil [39].

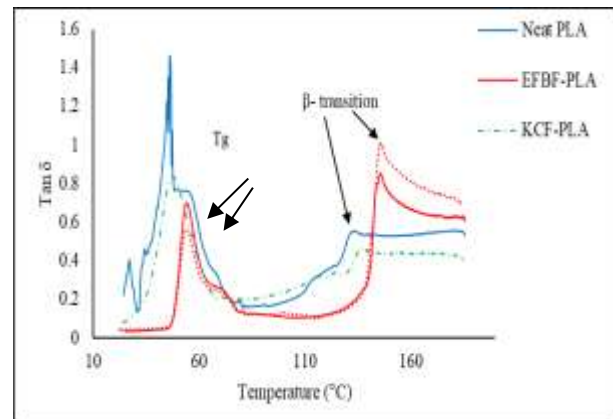


Figure 3.2c: Tan δ of neat PLA, single and hybrid fiber-PLA bio composites

However, neat PLA showed sharp and intense peak around 30 °C and 60 °C respectively, perhaps due to the amorphous nature of the material which do not restrict chain mobility [35]. The glass transition temperature (T_g) and β -transition peaks appeared clearly in the $\tan \delta$ curve. The T_g peak for neat PLA and all PLA-composites appeared at higher temperature compared to those in loss modulus curve. This is because $\tan \delta$ often provides over-estimated T_g value, and as such not as reliable as those from loss modulus [40]. The β -transition peaks for neat PLA and all PLA-composites appeared around 140 °C-155 °C, may be ascribed to moisture evaporation process, mobility of side groups located on molecular chain as a

result of absorbed kinetic energy or onset degradation of natural fiber component (e.g. lignin) of the composites [39,40].

3.3 Thermo gravimetric analysis (TGA)

Thermogravimetric analysis (TGA) was employed to probe the thermal stability of the composites by way of measuring the amount and rate of decomposition or change in mass of the composites as a function of temperature in a controlled atmosphere. The TGA for neat PLA, single and hybrid fiber-PLA composites and their corresponding derivative of thermogravimetric (DTG) curves are given in Figure 3.3a and 3.3b respectively.

It can be seen from Figure 3.3a that neat PLA undergo thermal degradation in a single stage, and starts to decompose around 250 °C and attained temperature of maximum weight loss (T_{max}) value at 395 °C. Then, neat PLA slowly degrades and recorded no residue char at 700°C as it can be seen in Table 3.3. The onset thermal degradation temperature of the neat PLA shifted to lower temperatures upon reinforcement with the natural fibers viz. EFBF and KCF respectively. This diminution in thermal degradation temperature as a result of natural fiber incorporation into the neat PLA could be as a result of increase in polymer chain mobility, though limited to different molecular fragments created by the fibers, and also the early thermal degradation of low molecular weight fiber constituents (e.g. hemicellulose) due to their weak bonds. Neat PLA is amorphous and lack restriction in chain mobility, thus, experienced a one-step thermal degradation [41].

However, the oil palm fibers i.e. EFBF-PLA showed slightly higher thermal degradation temperature compared to the KCF-PLA which recorded the least. This occurred perhaps due to better fiber surface characteristics of the oil palm fibers compared to the KCF. The KCF contain more hydrophilic constituents (e.g. hemicellulose) and lignin, which can lessen the thermal stability of the KCF-PLA relative to that of EFBF-PLA respectively.

Generally, the single fiber reinforced PLA composites revealed noticeable thermal stability at higher temperature (i.e. 700 °C) where higher residual char mass was observed, for example, 17.27% and 12.16% for EFBF-PLA and KCF-PLA compared to the -3.42% for neat PLA.

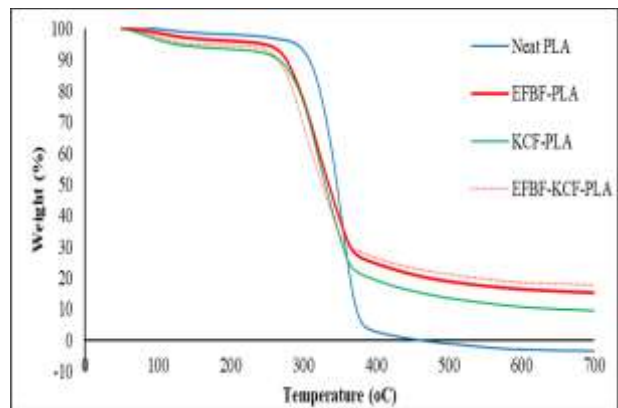


Figure 3.3a. TGA Thermograms of Neat PLA, Single and Hybrid Fiber-PLA Bio Composites

However, the onset thermal degradation temperature for the hybrid fiber-PLA composites shifted to lower temperature compared to the Single fiber-PLA composites (Figure 3.3a). This shifting to lower degradation temperature could be due to KCF incorporation which increases fiber-fiber interaction thereby restricting the range of molecular mobility in the composites. It can also be attributed to the initial decomposition of fiber constituents such as hemicellulose and lignin which broadened the degradation temperature. Hybridization with KCF, also means addition of more lignin into the EFBF, and due to the aromatic chemical bonds in lignin, it tended to exhibit a wide degradation temperature ranging from 100 °C to 800 °C [42]. Generally, increase in thermal degradation temperature and residue char formation was observed due to lignin-rich KCF incorporation into EFBF-PLA (Table 3.3). This finding is in agreement with previous literature [43]. The increase in residue char formation provided by the hybrid fiber composites is suggestive to improve thermal stability.

Table 3.3: TG Data of Neat PLA, Single and Hybrid Fiber-PLA Composites.

Sample	T_{onset} (°C)	$T_{50\%}$ (°C)	T_{max} (°C)	Residue at 700 °C (wt. %)
Neat PLA	288.00	346.33	384.33	-3.42
EFBF-PLA	260.17	327.83	370.83	17.27
KCF-PLA	248.16	311.83	367.50	9.50
EFBF-KCF-PLA	250.83	344.50	379.50	17.40

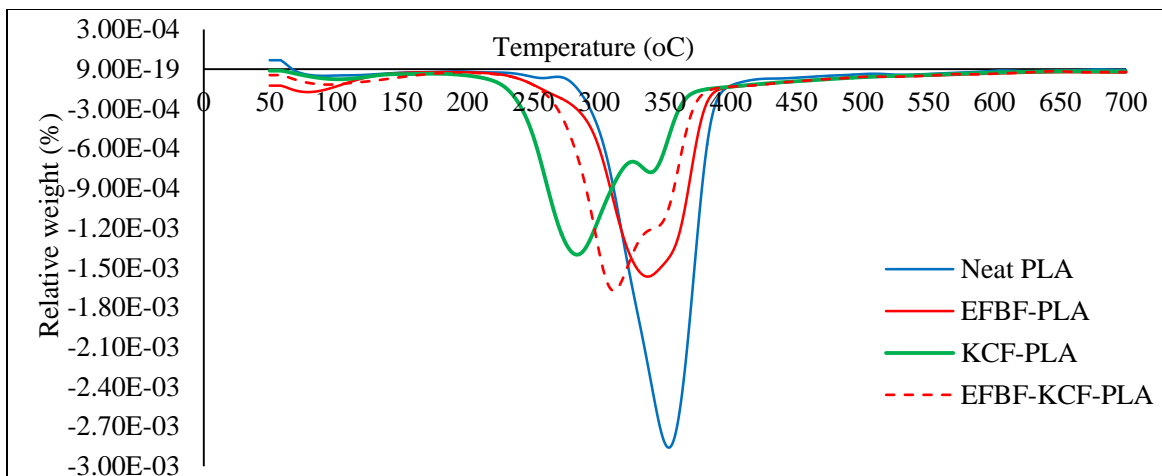


Figure 3.3b: Derivative of Thermogravimetric (DTG) Curve of Neat PLA, Single and Hybrid Fiber-PLA Composites.

However, the derivative of thermogravimetric (DTG) curve is another important parameter used to characterize the thermal properties of natural fiber thermoplastic composites. DTG is defined as the peak value of the derivative of the TGA curve. From figure 3b, neat PLA showed a single peak which is indicative that the material thermally degraded in only one step as previously observed [44]. The single fiber-PLA composites exhibited two peaks, the first and higher intensity peak appeared around 250 to 300 °C, while the second and lower intensity peak appeared around 300 to 350 °C. The first peak can be assigned to hemicellulose and cellulose decomposition. The hemicellulose degrades at higher rate as it is more thermally unstable than cellulose and lignin [45]. The second peak can be ascribed to lignin decomposition, which decompose slowly and cover a wide temperature range [46].

It can clearly be seen from Figure 3.3b that the second peak is more pronounced in KCF-PLA, perhaps as a result of rich lignin content of KCF. The lignin decomposition peaks for the hybrid fiber-PLA composites shifted to higher temperature which is indicative to those materials being more thermally stable than the single fiber-PLA composites. The decrease in the peak intensity relative to those of the single fiber-PLA composites is suggestive to hybridization between the lignin rich KCF and cellulose rich EFBF.

4. Conclusion

The research revealed that the oil palm fiber is cellulose rich while Kenaf core fiber is lignin-rich. This finding was supported by the chemical content analysis of the natural fibers. Hybridization of the two natural fibers and used as reinforcement into the PLA revealed synergistic improvement in the thermal properties of the corresponding hybrid bio composite compared to the single-fiber bio composite. This research, therefore,

suggested that hybridization of oil palm fiber with Kenaf fiber is potentially promising in achieving synergism in the thermal performances of hybrid polymer bio composites.

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