Thermal and Biodegradation Properties of Poly(lactic acid)/Fertilizer/Oil Palm Fibers Blends Biocomposites

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Poly(lactic acid) (PLA) and NPK fertilizer with empty fruit bunch (EFB) fibers were blends to produced bio-plastic fertilizer (BpF) composites for slow release fertilizer. Thermal properties of BpF composites were investigated by thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), and morphological and degradation properties were analyzed by scanning electron microscopy (SEM), soil burial test, respectively. TGA thermogram display that neat PLA, PLA/NPK, and BpF composites degrade at different temperatures. DSC curves of PLA and other composites exhibited same glass transition temperature (T_g) value indicating that both major blend components are miscible. The T_g, crystallization temperature (T_c), melting temperature (T_m) values also decreased with increased amount of fertilizer and fibers. The T_m of BpF composites did not change with an increase in fertilizer content because thermal stability of PLA and PLA/NPK composites was not affected. Soil burial and fungal degradation test of PLA, PLA/NPK, and BpF composites were also carried out. Soil burial studies indicated that BpF composites display better biodegradation as compared with neat NPK. Fungal degradation study indicated that fungi exposure times of BpF composites show higher value of degradation as compared with PLA/NPK. We attribute that developed BpF composites will help oil palm plantation industry to use it as slow release fertilizer. POLYM. COMPOS., 36:576–583, 2015. © 2014 Society of Plastics Engineers

INTRODUCTION

In the recent years many use of synthetic polymers and plastic materials produced from petroleum based materials which are non-degradable plastics. The residues of plastic wastes have led to the serious environment pollution and widely effecting human life on earth. There are many attempts to solve this problem such as recycling plastics, fighting to decrease demanding to use plastics of human including the production of biodegradable polymers derived from renewable resources. Biodegradable polymers produced from natural biopolymers are innovative for an environmentally-friendly material because it can be converted into the substrates for production of the monomer for polymerization later, as well as the cycle of plastics life. The biodegradation of polymers in nature involves several processes. The natural microorganisms influence abiotic degradation through physical, chemical and enzymatic reactions [1]. Degradation steps of biodegradable polymers started to hydrolyze polymers which are catalyzed by temperature control followed by microorganisms actions on the fragmented residues.

Polylactic acid (PLA) is the one type of biodegradable polymer based on renewable resources, as lactic acid which obtained from microbial fermentation. Under appropriate conditions, PLA can be degraded by the simple action of microorganisms in the environment. Moreover, PLA has been attentive to apply for packaging, clothing and biomedical products due to the good properties such as high-strength, high-modulus, brightness, barrier and good moisture management biocompatible and
TABLE 1. Composition of bioplastic fertilizer (BpF) composites.

<table>
<thead>
<tr>
<th>No. samples</th>
<th>PLA (g)</th>
<th>EFB (g)</th>
<th>NPK (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPK (control)</td>
<td>–</td>
<td>–</td>
<td>15</td>
</tr>
<tr>
<td>PLA25/NPK15</td>
<td>25</td>
<td>–</td>
<td>15</td>
</tr>
<tr>
<td>PLA20/NPK15/EFB5</td>
<td>20</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>PLA15/NPK15/EFB10</td>
<td>15</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>PLA10/NPK15/EFB15</td>
<td>10</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

bio-absorbable [2]. However, applications of PLA for materials production and ability of biodegradation depend on their molecular weight and chemical compositions. Therefore, there are several attempts to improve the properties of PLA for making the suitable polymers for a specific application including the appropriate biodegradation properties.

Bioplastic coated fertilizers (BpF) have been in use within the horticultural industry for decades. These fertilizers represent the most technically advanced state of the art among controlled-release fertilizers (CRF) in controlling product longevity and efficiency of nutrient delivery for plant uptake and BpF comprise the majority of CRF used in horticultural plant production [3, 4]. CRF often provide only nitrogen, but BpF may be blended to provide a balance of all macro and micronutrients. An advantage of BpF over conventional water soluble fertilizers (that is, fertigation) is that a single application of BpF can supply plants with extended nutrient availability, eliminating the need for labor costs associated with repeated fertilizer application. Additionally, clients occasionally request that BpF be incorporated into the media of seedlings grown on contracts. In theory, the BpF should begin to release nutrients during nursery propagation, and products with a longer time frame for nutrient release may continue to provide elevated levels of nutrients to seedlings following out planting [5]. Within this context, a number of strategies allowing for controlled (or slow) release fertilizers (CRF) have been devised in order to improve the efficiency of fertilizers, and decrease the frequency and concerns of their applications [6, 7].

Natural fibers such as hemp, kenaf, jute, sisal, banana, flax, oil palm, etc. have been in considerable demand in recent years due to their eco-friendly and renewable nature. Natural fibers received considerable attention as potential reinforcements in polymer composites [8–10]. The attraction toward utilization of natural fibers as a reinforcement of polymer-based composites is mainly due to their various advantages over synthetic fibers such as low density, lower cost, light weight, high strength to weight ratio, biodegradability, acceptable specific properties, better thermal and insulating properties [11, 12]. Natural fiber based polymer composites made of jute, oil palm, flax, hemp, kenaf have a low market cost, attractive with respect to global sustainability and find increasing commercial use in different applications [13].

In this study, NPK fertilizer was compounded in a matrix PLA and oil palm empty fruit bunch for melt processing techniques. From literature review it clear that slow releasing agent in market is using non biodegradable polymer/plastic and done by spraying, emulsion and dipping but here we used compounding technique to produce slow releasing fertilizer by using biodegradable polymer (PLA). Previously no body have used compounding Novelty of this work is to fabrication slow releasing fertilizer bioplastic composites by reinforcing bioplastic fertilizer with oil palm EFB fibers in PLA. Developed bioplastic composites can degrade in soil at short period of time as compared with conventional fertilizers and plant can uptake fertilizer for growth.

EXPERIMENTAL

Materials

Polyactic acid (PLA), with a molecular weight (M_w) of approximately 74,000 g/mol and a density of 1.25 g/mol, was supplied by TT Biotechnologies Sdn. Bhd., Malaysia. The melting temperature (T_m) and the glass transition temperature (T_g), as given by the supplier, were 150 to 170°C and 55 to 60°C, respectively. Oil Palm Empty Fruit Bunch (OPEFB) fiber which ranges from 0.25 to 0.5 mm was purchased from Poly Region (M) Sdn. Bhd., Malaysia. NPK fertilizer granular 0.25 mm supplied from Diversatech Fertilizer (M) Sdn. Bhd., Malaysia.

Preparation of Bioplastic Fertilizer (BpF) Composites

Bioplastic fertilizer (BpF) composites were fabricated by using different formulation (Table 1). Oil palm empty fruit bunch (EFB) fibers were dried in an oven under vacuum at 80°C for 24 h; the moisture content of fiber was 2 to 5%. Then BpF compound will be press in mould of about 150 × 150 × 1 mm³ using compression hot press at temperature of 170°C for 10 min then cooling for 3 min.

CHARACTERIZATION

Thermogravimetric Analysis (TGA)

Thermogravimetric analysis is performing using a TGA Q500 V20. Universal V3.9A TA Instruments. The weight of the samples use is about 10 mg and was heated from 30°C to 600°C at the heating rate of 10°C/min. The analysis is carried out in nitrogen atmosphere with
TABLE 2. TGA characterization of neat PLA, PLA/NPK, and PLA/NPK/EFB composites.

<table>
<thead>
<tr>
<th>Composites</th>
<th>Degradation temperature(°C)</th>
<th>Residual (%) (at 550°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( T_{\text{IDT}} )</td>
<td>( T_{\text{FDT}} )</td>
</tr>
<tr>
<td>PLA (neat)</td>
<td>315</td>
<td>375</td>
</tr>
<tr>
<td>NPK</td>
<td>78</td>
<td>340</td>
</tr>
<tr>
<td>EFB</td>
<td>38</td>
<td>325</td>
</tr>
<tr>
<td>PLA25/NPK15 (0)</td>
<td>280</td>
<td>350</td>
</tr>
<tr>
<td>PLA25/NPK15 (2)</td>
<td>315</td>
<td>365</td>
</tr>
<tr>
<td>PLA25/NPK15 (4)</td>
<td>315</td>
<td>365</td>
</tr>
<tr>
<td>PLA25/NPK15 (8)</td>
<td>315</td>
<td>365</td>
</tr>
<tr>
<td>PLA10/NPK15/EFB15 (0)</td>
<td>310</td>
<td>360</td>
</tr>
<tr>
<td>PLA10/NPK15/EFB15 (2)</td>
<td>260</td>
<td>355</td>
</tr>
<tr>
<td>PLA10/NPK15/EFB15 (4)</td>
<td>276</td>
<td>355</td>
</tr>
<tr>
<td>PLA10/NPK15/EFB15 (8)</td>
<td>275</td>
<td>360</td>
</tr>
</tbody>
</table>

Values within parenthesis indicate weeks. \( T_{\text{IDT}} \): initial decomposition temperature, \( T_{\text{FDT}} \): final decomposition temperature, PLA: polylactic acid, NPK: fertilizer, EFB: empty fruit bunch.

Differential Scanning Calorimetry (DSC) Analysis

DSC analysis is carried out using a DSC Q20 V24. Universal V3.9A TA Instruments. The specimen put in an argon atmosphere with a heating rate of 5°C/min. A static argon flow of 50 mL/min and an aluminum sample pan are use. Specimens of approximately 10 mg are scan over a temperature range of 25 to 200°C.

Soil Burial Degradation

Biodegradation tests were performed using the simple soil burial test in order to simulate the natural biodegradation of composites. All samples were buried in the top soil (Serdang type). The soil without any enzyme activity or any composting materials and located outside natural environment with an average temperature of around 30°C and 80% relative humidity. The samples were recovered from the soil at different stages of degradation (0, 2, 4, and 8 weeks). After the testing time is completed, the samples materials were washed by using running water in order to remove the soil from the surface of the samples, and then all samples were dried in the oven at a temperature of 80°C until the samples reaches a constant weight. The biodegradability was assessed and evaluated by measuring weight loss before and after testing. The weight loss of burial samples was calculated and evaluated using the Eq. 1:

\[
\text{Weight loss} \, (\%) = \left( \frac{W_0 - W_1}{W_0} \right) \times 100
\]

where \( W_0 \) and \( W_1 \) are sample weights before and after the burial test, respectively. Also the surface appearance of the burial samples test was evaluated for visual comparison by using scanning electron microscope.

Fungi Degradation

Malt extract agar was used at a concentration of 48 g/L as the culture medium. Purified white rot (Trametes versicolor) fungi were used in this study as the biological degradation agents. The purified white-rot was transferred to petri dishes containing malt extract agar using sterile pincers. The dishes were kept at 25°C for 1 week until the culture medium was fully covered by fungi. The culture fungi were transferred into petri dishes containing the culture medium that is incubating for 8 weeks at 25°C. The petri dishes containing fungi and BpF specimens were stored in an incubator for 0, 2, 4, and 8 weeks at 25°C and 75% relative humidity. Dry weights of the specimens were measured after 24 h at 103 + 2°C and weight losses were calculated same as Eq. 1.

Scanning Electron Microscopy (SEM)

The samples (soil buried samples) was evaluated and analysed using a scanning electron microscope (Hitachi, Japan. S-3400N). The acceleration voltage at the cathode was 15 kV. The samples are sputter coated with gold to avoid electrostatic charging during sample examination using an Emitech, K550X coater (600 s, 35 mA) and a pressure of 2 \times 10^{-1} \text{ bar}. The image results were analyzed to investigate distribution of EFB fibers and NPK in the polymer matrix and their interaction.

RESULTS AND DISCUSSION

Thermogravimetric Analysis (TGA)

The thermal stability of the neat PLA, PLA/NPK, and PLA/NPK/EFB composites were investigated by TGA. Table 2 and Fig. 1a and b shows that the most significant amount of weight loss in the PLA composites occurred as a single step between 315 and 375°C. NPK has been seen to multiple degradation at temperatures from 78°C, and next step temperatures 172°C, 247°C, 286°C, and final step around 339°C (Fig. 1a). The residual content of NPK is about 57.5% at 550°C. NPK when combined with PLA, the degradation temperature is lower and below the neat PLA temperature. Under certain condition (local heating, high environmental temperature, close storage room with insufficient heat exchange, etc.), complex mineral fertilizers containing ammonium nitrate are capable of decomposing spontaneously with evolution of exothermic heat [16]. In the close system, this leads to overheating of the whole mass of the substance and the decomposition reaction accelerates. As a result, thermal explosion may occur and the products of reaction (N_2O, N_2, NO_2, H_2O, Cl, NH_2Cl, etc.) escape into the gaseous phase [17]. Decomposition of the fertilizer takes place.
only when the temperature of the system is higher than certain value for particular conditions.

Figure 1b also show that the EFB fiber content overall weight loss in the composite below 350°C due to the moisture contained in the fiber. The degradation of EFB occurred in the multiple steps and initially at temperature about 38°C, for next step 152°C, 243°C, and final step about 325°C.

However, when these fibers are incorporated into a polymer matrix, degradation behaviors become masked into one dominant degradation peak which is governed by combustion kinetics of the composite. This is of particular concern as most of it is moisture which could cause secondary hydrolysis in the PLA during thermal processing. The EFB fiber also seems to delay the main degradation temperature (250–360°C) as EFB have a higher temperature of degradation than the neat PLA. In the final stage of degradation in the composites, the EFB fiber contents the amount of residual (23.5%) at 550°C. The onset of thermal decomposition of the biocomposites is slightly lower than neat PLA indicating that introduction of the fibers reduces the thermal stability. As can be observed in Fig. 1b, the addition of natural fibers has decreased the thermal stability of virgin PLA, since some portion of polymer (PLA) is replaced with less thermally stable material (natural fibers). This is a common trend and generally approved that addition of natural fibers will reduce thermal stability of the polymer matrix [18, 19].

Differential Scanning Calorimetry (DSC)

The crystallization and melting behavior of PLA/NPK and PLA/NPK/EFB composites were investigated by DSC analysis performed on the first heating cycle. The thermal properties such as glass transition temperature ($T_g$), crystallization temperature ($T_c$), melting temperature ($T_m$), of the Neat PLA, PLA/NPK, and PLA/NPK/EFB composites are summarized in Table 3. The DSC results indicated that the addition of the EFB fibers into PLA/NPK causes slight reduction of $T_m$ of the PLA matrix (Fig. 2). This reduction in $T_m$, for both PLA25/NPK15 and PLA10/NPK15/EFB15 composites may be associated with a lower molecular weight but this may also be offset by the rigid fibers slightly restricting the chain mobility of the PLA molecules. The overall effect of this was not significant with regards to fiber loading but is consistent with previous studies [20–22] that showed that the introduction of micro-sized cellulose fibers into a PLA matrix did not significantly affect the glass transition temperature as measured by DSC. It also shows that PLA exhibits a single endothermic melting peak at 151°C and no exothermic peak, whereas the pure PLA and most of the PLA composites showed two distinct endothermic melting peaks at 147 to 151°C and 153 to 156°C respectively, in addition to one exothermic crystallization peak at 99 to 110°C.

These changes to the thermal and crystalline behaviors of the PLA-based materials are affected by a number of factors including thermo-mechanical processing, sample composition, the nature of the filler, molecular weight of PLA matrix and time–temperature history of the sample already formed [23]. In this case, the observed two melting peaks are associated with the multi-step processing condition of the PLA and the PLA-based composites rather than the incorporation of the fibers since the dual melting peaks are already present on the DSC curve of the PLA sample. The dual melting peaks phenomenon of

![FIG. 1. (a). The thermal stability of the neat PLA and PLA/NPK composites. (b). The thermal stability of the pure EFB and PLA/NPK/EFB composites. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]](image)

<table>
<thead>
<tr>
<th>Sample</th>
<th>$T_g$ (°C)</th>
<th>$T_c$ (°C)</th>
<th>$T_m$ (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLA (neat)</td>
<td>61.6</td>
<td>121.0</td>
<td>155.2</td>
</tr>
<tr>
<td>NPK</td>
<td>ND</td>
<td>107.8</td>
<td>197.2</td>
</tr>
<tr>
<td>EFB</td>
<td>ND</td>
<td>138.3</td>
<td>177.6</td>
</tr>
<tr>
<td>PLA25/NPK15 (0)</td>
<td>61.2</td>
<td>94.7</td>
<td>151.7</td>
</tr>
<tr>
<td>PLA25/NPK15 (2)</td>
<td>61.6</td>
<td>ND</td>
<td>152.5</td>
</tr>
<tr>
<td>PLA25/NPK15 (4)</td>
<td>63.3</td>
<td>ND</td>
<td>153.9</td>
</tr>
<tr>
<td>PLA25/NPK15 (8)</td>
<td>61.5</td>
<td>ND</td>
<td>153.9</td>
</tr>
<tr>
<td>PLA10/NPK15/EFB15 (0)</td>
<td>57.6</td>
<td>90.8</td>
<td>148.9</td>
</tr>
<tr>
<td>PLA10/NPK15/EFB15 (2)</td>
<td>63.8</td>
<td>ND</td>
<td>143.4</td>
</tr>
<tr>
<td>PLA10/NPK15/EFB15 (4)</td>
<td>63.3</td>
<td>ND</td>
<td>144.2</td>
</tr>
<tr>
<td>PLA10/NPK15/EFB15 (8)</td>
<td>62.6</td>
<td>ND</td>
<td>143.6</td>
</tr>
</tbody>
</table>

Values within parenthesis indicate weeks. $T_g$: glass transition temperature, $T_c$: crystallization temperature, $T_m$: melting temperature, PLA: polylactic acid, NPK: fertilizer, EFB: empty fruit bunch fiber, ND: not determined.
PLA has also been observed by other researchers [23]. It attributed to rearrangement of lamellar during crystallization of PLA, resulting in formation of a fraction of thinner and/or less perfect crystals in addition to the original crystallites on the melting endotherms. The relative temperatures of $T_g$, $T_c$, and $T_m$ seem to mixed fiber content for PLA10/NPK15/EFB15 composites and this is due to the progressive hydrolysis of the PLA caused by the addition of fibers during thermal processing. Additionally, the thermal processing of neat PLA and PLA in the composites resulted in a decrease in normalized PLA crystallinity.

**Soil Burial Test**

The soil or compost degradation of PLA is reported to occur by two processes: during the initial phases of the degradation, the high molecular weight PLA chains are hydrolyzed to form lower molecular weight chains [24]. This reaction can be accelerated by acids or bases and it is also affected by both temperature and moisture [24]. During this step, some microorganisms in the compost are able to catalyze the degradation, probably by hydrolytic scission of ester groups into an acid and an alcohol, finally converting the lower molecular chains to CO$_2$, water, and humus. As far as biodegradability is concerned, it has been confirmed that PLA is naturally degraded in soil or compost [24], even if it is known that PLA is less susceptible to degradation than other aliphatic biodegradable polymers in natural environment [25]. It was reported that the resulting products of the PLA hydrolytic degradation can be totally assimilated by microorganisms such as fungi or bacteria [26, 27]. Since surface degradation usually leads to loss of degradation products, such as lactic acid for PLA in soil or compost [24]. These results suggest either that the products at this stage are adherent to the material surface and/or that the microorganisms belonging to the compost are not able to considerably assimilate them. It is also possible that the degradation mainly proceeds; at least in this period of time from the interior of the samples and that the diffusion rate of degradation products is relatively slow. It reported [28] that the hydrolytic degradation of PLA in aqueous media proceeds faster in the centre of the sample than at the surface. It suggesting that the hydrolysis products formed near the surface are dissolved in the degradation medium while in the inner part there is a high concentration of carboxylic end groups able to catalyze ester hydrolysis.

The effect of NPK fertilizer on the biodegradation of PLA/NPK/EFB blends in simulated soil under controlled temperature and humidity was accessed by weight loss, and morphological study. In the weight loss studied, the variation of sample mass is due to NPK release and polymer biodegradation. When compared with the composite with PLA/NPK/EFB was poor interfacial adhesion between the PLA matrix and EFB fiber would increase the surface area of NPK, and thereby, facilitate its degradation during exposure to microorganisms in soil. So, the EFB used as a filler in the composite would increase the degradation rate of the composite. Its also contributed potassium (K) after degradation process. The degradation of PLA25/NPK15 was slower than that of any composites. Basically, a higher EFB content resulted in a faster degradation. PLA10/NPK15/EFB15 was degraded fastest of all the samples. This result showed that decreasing PLA content, the degradation rate increased for the composites with a higher content of EFB. Figure 3 showed that PLA/NPK composites was degraded about 37.4% after 8 weeks. For control NPK gave the higher result of degradation about 84.6% after 8 weeks in soil. The phenomena NPK was absorbed in soil very faster without degradation processed. Furthermore, comparing the biodegradation of PLA and PLA/EFB composites, the higher cellulose content of EFB fibers leads to higher water adsorption which has a synergetic effect on the rate of biodegradation and as a result would increase the degradation rate of the composite. In addition to cellulose content, the amount of lignin as a hydrophobic component can reduce the rate of biodegradation.
Researchers [29] found growth of fungal mycelia on racemic PLA plates after 8 weeks in soil. PLA is completely mineralized to CO$_2$, water and a small amount of biomass after 4 to 6 weeks in compost (60°C) [30]. Urayama et al. [31] found only a 20% decrease in molecular weight of PLA (100% L) plates after 20 months in soil while a 75% decrease was noted for PLA (70% L). Ho and Pometto [32] found that about 20% of a PLA film was mineralized to CO$_2$ after 182 days in a laboratory respirometer charged with soil at 28°C. Calmon et al. [33] found that PLA films had weight losses varying from 0 to 100% after burial in soil for 2 years depending on PLA type and location. Osawa et al. [34] found that the molecular weight of PLA in PLA/starch 70/30 moldings decreased by about 60% after burial in soil for 45 days versus 10% for PLA alone. Acceleration of PLA degradation in blends with polyethylene glycol [35] was claimed.

**Scanning Electron Microscopy (SEM)**

The voids, which can be seen between natural fibers and PLA matrix, clearly indicate the poor interaction between them. After composting for soil burial test, the surface of composite samples, particularly PLA10/NPK15/EFB15 have trace of shrinkage and roughness, slightly generating the exposure of natural fiber bundles. Figure 4a–d shows SEM micrographs of PLA10/NPK15/EFB15 composite after 0 to 8 weeks of burial tests, respectively. It can be seen from Fig. 4a that the PLA10/NPK15/EFB15 sheet remained unchanged, without any change in the original shape, whereas all the composites collapsed as degradation proceeded. However, there are differences in the degree of degradation between the 4 weeks and 8 weeks. The loss of shape occurred slower in the composites with EFB fibers. In the SEM micrographs (Fig. 4d) shown that more content of EFB fibers were degraded and forming cracks and holes on the surface. These cracks and holes were produced by the degradation of EFB fibers. There were more cracks and holes in the composite after 8 weeks in soil burial test.
A multitude of methods are available to test for fungal degradation of wood and plastics, however, there is no laboratory standard currently available for testing the fungal durability of wood plastic composites (WPC). At present, in North America, the soil-block test for wood [36, 37] has been adopted for fungal durability tests of WPC in which weight loss serves as an indicator of decay. Specific adjustments will have to be made to existing wood durability standards so that they can be appropriately used in WPC fungal decay testing. The results indicated that fungus exposure times (8 weeks) showed PLA15/NPK15/EFB10 is higher value of degradation about 35% weight loss compared with sample PLA25/NPK15 without EFB fiber for 25% weight loss (Fig. 5). White rot fungi (T. versicolor) deplete all components of wood/fiber cell wall during decay but some white rot fungi can degrade the lignin in the wood preferentially to cellulose. It can say that the removal of lignin as a hydrophobic component and the preservation much of the cellulose as a hydrophilic component tend to favor increased water absorption. Weight loss of an extruded WPC formulation with 70% wood filler and incubated with T. versicolor was twice as high as that of redwood in a modified agar-block test (6% vs. 3%), however, only 1% weight loss was obtained when the formulation contained 49% wood filler [38]. These results indicate that WPC can be designed to provide high fungal durability by controlling the material composition of the formulation. Generally, reported weight losses of WPC obtained in laboratory testing are below 10%. Researches [39] determined that weight loss in WPC due to fungal decay increased as the wood particle size increased, probably due to a more effective encapsulation of smaller wood particles by the polymer matrix.

CONCLUSIONS

The effect of fertilizer on the degradation and decomposition of PLA based materials was studied. Biodegradation was evaluated by soil burial and fungal testing. It was found that degradation rates of PLA, PLA/NPK, and PLA/NPK/EFB blends BpF composites were lower decomposition than neat PLA. The biodegradation rate was increased when the EFB fibers content was increased from 10.26 to 12.87% after 8 weeks. On the other hand, both NPK and EFB accelerated the thermal decomposition of PLA. When the EFB fiber content increased from 5, 10, and 15 by weight the decomposition peak of PLA decreased from about 397 to 352°C. The lower decomposition temperature of NPK (322°C) compared with the EFB fibers (355°C). Particularly PLA10/NPK15/EFB15 has trace of shrinkage and roughness, slightly generating the exposure of natural fiber bundles. PLA10/NPK15/EFB15 was degraded fastest of all the samples. This result showed that decreasing PLA content, the degradation rate increased for the composites with a higher content of EFB. PLA15/NPK15/EFB10 is higher value of degradation about 35% weight loss compared with sample PLA25/NPK15 without EFB fiber.

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