Biodegradable PLA-Kenaf Fibre Biocomposite for Cleaner Environment

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Abstract

This project was undertaken to study the biodegradability of PLA-KF biocomposite in different conditions; soil burial and immersion in water. The samples were buried in soil for 40 days to investigate the degradability of biocomposites. As for water absorption tests, the samples were immersed in three different types of water which were river water (pH 6), tap water (pH 7) and sea water (pH 7.5). The amount of water intake was weighed for every three days for 27 days. This is done to determine the rate of water absorption and the effect on the physical properties of biocomposites. From the soil burial tests, it was found that longer time of soil burial and higher reinforcement of kenaf fibre has increases the weight loss of PLA biocomposite. Further, it was predicted that biodegradability may be increased up to 34.5% by prolong the burial of reinforced PLA biocomposite in the soil up to 80 days.

Keywords: Biodegradable, biocomposite, kenaf fibre, polylactic acid, soil burial test, water absorption.

Introduction

In this age of high oil prices and mounting concern over carbon emissions, bioplastics offer tremendous benefits over conventional materials-social, economic and environmental. Today, thanks to the fast pace of technological innovation, bioplastics are on the verge of leaving the niche areas they have till now occupied, and competing in mainstream markets-especially in applications such as packaging, electronics, automobiles and agriculture. The chemical and plastics industries have already invested heavily in these new technologies, and have high expectations of the new generations of bioplastics which are now competing successfully with the conventional petroleum-based plastics.

The substitution from glass fibre to natural fibre is considered because of its natural properties [1]. Its density usually in the range of 1.1–1.5 g/cm^3, but its volume fraction and matrix determine the density of the composites. Natural fibres such as flax, hemp, kenaf, and sisal are abundant, cheap, renewable, and easily recycled. Other advantages include low density, high toughness, comparable specific strength properties, reduction in tool wear, ease of separation, decreased energy of fabrication, and CO_2 neutrality. Among the natural fibres mentioned above, the bast fibre exhibits a superior flexural strength and modulus of elasticity (MOE), but the leaf fibres show superior impact properties [2].

Previous studies have shown that the PLA matrix provides good mechanical behavior, but somehow PLA alone is not good enough to produce a good product [3]. Polylactic acid (PLA) has the advantage of being not only biodegradable but also renewable since the raw material, lactic acid, can be generated from microbial fermentation of biomass. Natural fiber such as kenaf fibre can be incorporated into biopolymer to achieve the desired properties and better texture in the resulting biocomposites. Thus, polylactic acid and kenaf fibers were chosen because of their good mechanical properties and biodegradability. Besides, the kenaf fiber was used as reinforcement in the polymer composites because of disintegration and hydrophilic properties. This paper reported on the biodegradability properties of PLA-KF biocomposite. The biocomposite were tested in two major conditions; burial in soil and immersion in water.

Experimental Method

Materials

Poly(lactic) acid or PLA type 3051D in the pellet form was bought from NatureWorks®. The polymer has a specific gravity of 1.24g/cm^3. Kenaf (Hibiscus cannabinus, L) bast fibers (KF) were supplied by local company, Kenaf Natural Fiber Industries Sdn. Bhd., Kelantan and has density of 1.13 g/cm^3 [4]. The fiber was ground using the Roll Mill, Fritsch Pulverisette 14. The soil used in this research is an organic soil.

Preparation of Biocomposite

The content of KF was varied from 5% to 20% by weight. Details of the composition prepared are tabulated in Table 1. KF and PLA pellets were fed into a Haake twin screw extruder at a uniform temperature of 180ºC and the screw speed was set at 150 rpm. After the compounding process, the sample was palletized for injection molding.

Characterization

Biodegradability – soil burial test

Biodegradability of composites was measured using soil burial test method as described by Behjat [5]. The sample which is in the form of rectangular sheets has been buried in the soil by random pattern as shown in Figure 1. The pot containing soil and samples are incubated at almost constant temperature of 26 ºC for more than a month. The moisture content maintained at 40-50% of the soil maximum water holding capacity. This humidity is optimal for microbial activity [6]. The pots were covered with plastic film to avoid water evaporation from the soil surface.

Biodegradation has been estimated by monitoring changes in weight as a function of burial time. The samples were removed from the soil for every 5 days. The debris on the specimens was removed by washing with water. The samples were then dried in an oven at 70-90 °C for 2 hours. After drying, the weighed of the samples were taken.

Water Absorption

The purpose of water absorption test was to observe the influence of kenaf fibre on the degree of water absorption of the samples. The sample test bars were immersed into three different aqueous environments, which were tap water (pH 7) and river water (pH 6) 18 days at room temperature. Water absorption was determined according to ASTM D570. The water absorption at any time, M_t was calculated from the following equation:

$$M_t = \frac{W_w - W_d}{W_d}$$
(8)

where, W_d and W_w are the initial dry weight and weight after immersion in water, respectively.

Results and Discussion

Soil Burial Test

Figure 2 illustrates the effect of kenaf fibre content on the biodegradability of PLA-KF biocomposite. As described in Section 2.3.1, a soil burial test has been carried out on a laboratory scale to examine the biodegradability properties of PLA-KF biocomposite. The dispersion of integrity and breakup of samples was observed at about 40 days and increased during the burial time. It can be seen that the higher kenaf fibre content in PLA has leading to higher degradation of biocomposite. The highest weight loss was observed for PLA-20KF where the weight loss is about 3.65% after 40 days buried in soil. It can be predicted that by prolong the time of burial in soil up to 80 days, almost 34.5% of PLA-20KF biocomposite may be degraded. A good linear regression with a high correlation coefficient ($r^2 \geq 90\%$) is achieved between the weight loss and burial time. Comparing to the same days of burial up to 40 days, unreinforced PLA only suffers 0.70% weight loss. By predicting the degradation of unreinforced PLA at 80 days, about 5.5% only will be degraded with linear regression confidence limits $r^2 \geq 97\%$. Hence, this could suggest that kenaf fibre has favoured the biodegradability properties and promotes faster degradation of PLA biocomposite.

Photomicrographs of PLA-KF biocomposite before and after 40 days in soil burial tests are shown in Figures 3-4. By comparing Figure 3 and Figure 4, the unreinforced PLA in Figure 4 is slightly discoloured then before which is transparent. As for the reinforced PLA-KF biocomposite, physically the fiber can be seen on the surface of composite. Higher the kenaf fibre, more fiber is clearly seen and exposed on the surface of the biocomposite. This could suggest that the decomposition and degradation of PLA-KF biocomposite has taken place. Physically it can be seen the degradation has taken place in PLA-KF biocomposite due to biocomposite has been exposed to the natural microbial consortium during indoor soil experiments. Previous studies on soil burial test for sisal fibre/Mater Bi-Y biocomposites found that the soil microflora constituted a mixed microbial population which including bacteria, actinomycetes and fungi, these microorganisms act synergistically during degradation and reproduce under naturally occurring conditions [7].

It was highlited by Karlsson and Albertsson [8] that biodegradable polymers whether natural or synthetic materials may susceptible to microbial and/or enzymatic degradation. However, the rate of this biodegradation is correlated with the type of repetitive unit, morphology (e.g. crystallinity. size of spherulites), hydrophilicity, surface area and the present of additives.

Water Absorption

Figures 5-7 illustrate the water absorption of PLA-KF biocomposite. As illustrated in these figures, the water absorption of the natural fibre composites mainly depends on the fibre content in the composite. The higher the fibre content and the longer the immersion time, the higher water absorbed by the composites. Generally the three types of water studied were not significantly affected the percentage of water absorbed by the PLA-KF biocomposite. However, it is noted that the water intake of the biocomposite in the tap water was slightly higher than in the river and sea water.

The higher water absorption for reinforced polylactic acid with kenaf fibre content and immersion time is as expected. This is due to the fact that nature of cellulose and hemicelluloses in the kenaf fibre are responsible for the high water uptake of natural fibres, since they contain easy accessible hydroxyl groups, which give strong hydrophilic character to fibres [9]. Apart from that, as observed under scanning electron micrograph (SEM) as shown in Figure 8 (before immersion in water), there were voids and gap present between the kenaf fibre and polylactic acid matrix. This condition has worsened the water uptake behaviour. The number of micro voids caused the larger amount of poor bonded area between the fibre and the matrix.

The potential strength and toughness of natural fibres are usually affected by the moisture and poor wettability with polymeric materials. Due to the present of hydroxyl group and polar groups in various constituents of fibre, moisture absorption of fibre is very high which leads to poor interfacial bonding with the matrices. Surface modification is therefore necessary to improve fibre-matrix adhesion to achieve better performance of the resulting composites.

Conclusion

PLA-KF biocomposite is a green biocomposite and easily degradable. However, period of studies should be extended to monitor the biodegradability as well as percentage of water absorbed by the PLA-KF biocomposite. In future studies should also compare the degradation products before and after degradation by using Fourier transform infrared (FTIR). Therefore, it can be concluded that the use of these bio-composites will reduce the environmental problems associated with waste pollution and the findings support the predicted application of bio-composites as ‘‘green-composites’’ or ‘‘eco-composites’’.

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Table

Table 1 Compositions of PLA-KF biocomposites prepared

Sample	PLA matrix (% wt)	Kenaf fibre (% wt)
PLA	100	0
PLA-5KF	95	5
PLA-10KF	90	10
PLA-15KF	85	15
PLA-20KF	80	20

Note: PLA = polylactic acid, KF = kenaf fibre.

Figures

Figure 1 Part of specimens before filling with soil.

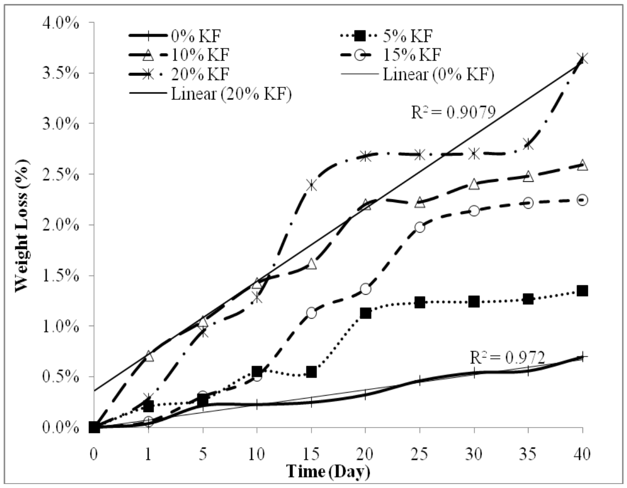

Figure 2 The effect of kenaf fibre content on the biodegradability of PLA-KF biocomposite.

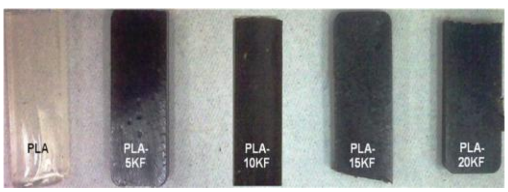

Figure 3 Photomicrographs of PLA-KF biocomposite before soil burial test.

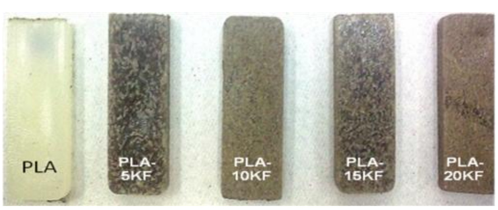

Figure 4 Photomicrographs of the PLA-KF biocomposite after burial for 40 days.

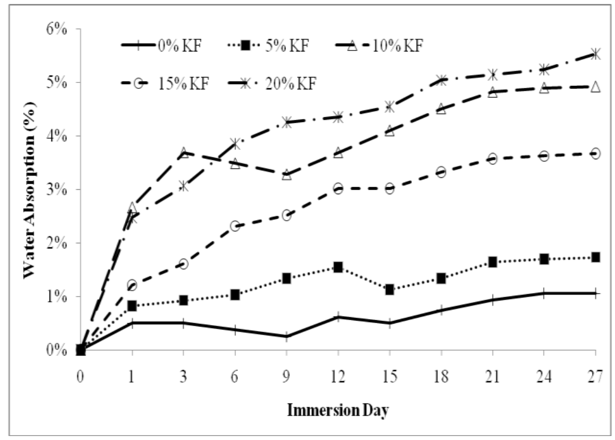

Figure 5 Water absorption of PLA-KF biocomposite in tap water as a function immersion time.

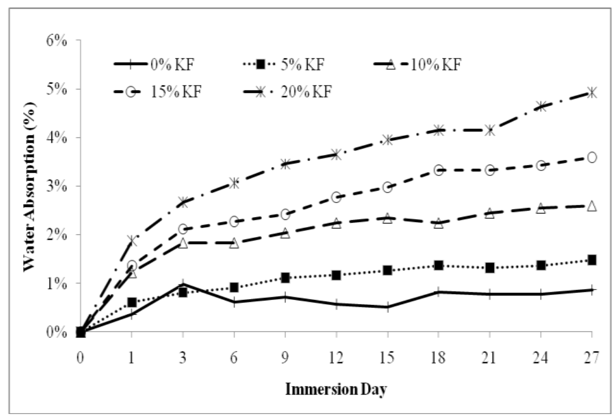

Figure 6 Water absorption of PLA-KF biocomposite in river water as a function immersion time.

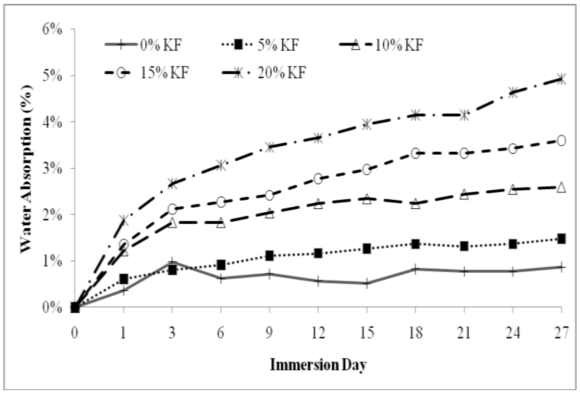

Figure 7 Water absorption of PLA-KF biocomposite in sea water as a function immersion time.

Figure 8 Scanning electron micrograph of PLA-10KF biocomposite at 100x magnification.