WATER ABSORPTION AND TENSILE PROPERTIES OF KENAF BAST FIBER- PLASTICIZED POLY(LACTIC ACID) BIOCOMPOSITES

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Abstract - Increasing awareness on the environmental safety coupled with new rules and regulations has forced manufacturers to consider biodegradable materials for their products.The aim of this work was to investigate tensile properties and water absorption behavior of biocomposites from kenaf bast fiber and poly(lactic acid).The composites were prepared by Haake internal mixer and compression molding. Composites containing fiber loading up to 40 wt% were prepared. PLA is brittle and would result in composites with poor impact properties. Because of this, PLA was plasticized with polyethylene glycol (PEG) at 10 wt%, evaluated as the polymer matrix and referred to as p-PLA. p-PLA/KBF composites exhibited good tensile properties than unfilled p-PLA. The tensile strength and modulus of the composites increased with increasing fiber content due to high fiber-matrix compatibility. Reinforcing effect of KBF was observed when the fiber content exceeded 10 wt%. Scanning electron microscopy (SEM) of the tensile fractured surfaces revealed a very good adhesion between KBF and p-PLA matrix. In addition to fiber pullout, failure by fiber cell wall fibrillation was also observed. Water absorption behavior of p-PLA/KBF composites were studied by immersion in distilled water at room temperature for 60 days. All composites as well as unfilled p-PLA were found to exhibit non-Fickian behavior. The deviation from Fickian water uptake behavior was attributed to the development of microcracks on the surface and inside the composites. In addition to microcracks that occurred along the fiber length, water absorption too caused fiber-matrix debonding. Both were revealed via SEM examination on the surfaces of p-PLA/KBF composites. SEM examination too showed microcracks on the surface of p-PLA. Results suggested that KBF is a potential reinforcement for plasticized poly(lactic acid) composites but possible applications should avoid high humidity environment.

Introduction

Conventional and traditional fiber reinforced composites are composed of carbon fibers, glass fibers, which are incorporated into unsaturated polyesters or epoxy or other thermoplastic polymers like polypropylene and polyamide [1]. These composites have been used for a variety of applications from structural to non-structural such as those used in consumer products for casing, packaging, etc. With increasing numbers of applications and mass volume uses in part due to increasing number of world population, disposal of composites after their intended life has become a problem. Since both the fiber and matrix are made using non-degradable materials, composites do not degrade under normal environmental conditions, resulting in various forms of environmental pollution particularly during incineration [2]. In addition to composite recycling, an alternative to alleviate the disposal problem of composites is to develop composites that are environmentally friendly and fully biodegradable. This can be achieved with the use of natural fibers as reinforcing materials (or fillers) for biodegradable polymers [1, 3] to form biocomposites. Biocomposites may be used effectively in many applications such as mass-produced consumer products with short life cycles or products intended for one-time or short-term use before disposal [3]. At the end of their life, bio-composite products can be easily disposed of or composted without harming the environment [3]. Natural fibers have long been realized as potential reinforcing materials or fillers in thermoplastics as well as thermosets. This is evident from the number of publications and patents that can be dated back to as early as 1960s. Natural fibers are of interest because they exhibit low density, non-abrasiveness during processing, high specific mechanical properties and more importantly biodegradability [1]. Now the use of natural fibers has established in thermoplastic industry. As an example Trex Company, Inc, USA, is producing wood-plastic composite products for landscaping and decking market [4]. There are a variety of natural and synthetic biodegradable polymers that can be combined with natural fibers to produce biocomposites. Some of these biodegradable polymers are commercially available. Polylactic acid (PLA) for example is produced by Cargill Dow LLC in North America [5]. The polymer has been used in such established applications as medical implants, sutures, and drug-delivery systems [6]. PLA degrades by hydrolysis to lactic acid, which is metabolised by micro-organisms to water and carbon monoxide [7]. By composting together with other biomass the degradation occurs within two weeks and PLA will fully disappeared within 3-4 weeks [7]. PLA can be melt-processed with standard processing equipment such as extrusion and injection molding at temperatures below those at which natural fibers start to degrade [8]. These open possibilities of producing biocomposites from natural fibers and PLA.

In this study an attempt was made to produce biocomposites from kenaf bast fiber (KBF) and PLA. PLA is a brittle polymer and addition of kenaf would result in composites with poor impact properties. Because of this PLA was plasticized with polyethylene glycol (PEG) and evaluated as the polymer matrix (p-PLA). Composites were analyzed as a function of fiber content. Fracture surfaces of the composites were examined via scanning electron microscope to help in explaining the tensile properties. In addition water absorption study was also conducted.

Experimental

Materials

The matrix polymer was poly(lactic acid), Lacty®#9030 from Shimadzu Co. Ltd, Japan. The MFI for PLA is 82 g/10 min (190^{o} C, 2.16 kg). The reinforcement was chopped kenaf bast fiber of approximately 2 mm obtained from Forest Research Institute Malaysia (FRIM). Polyethylene glycol (PEG 1000) from Sigma-Aldrich was used as plasticizer for PLA.

Compounding and sample preparation

Melt compounding of PLA, PEG, and KBF was done in a Haake Internal Mixer operating at 190^{o}C and 50 rpm. The PEG content was fixed at 10 wt.% while for KBF, the fiber content varied from 10 to 40 wt.%. Films of 1 mm thickness were prepared by compression molding and cut into dumbbell shapes for tensile testing and rectangular shapes for water absorption study.

Tensile test

The tensile test for the composites was carried out according to ASTM D368 using an Instron 3366 P6606 tensile tester. All specimens were kept in a desiccator for 24 h prior to testing. The test was done at a crosshead speed of 5 mm/min.

Morphological test

The fracture surfaces of the composites and the effect of water absorption on the composite surface were examined with a SUPRA 35VP scanning electron microscope (SEM). Before the examination all specimens were coated with gold to eliminate electron charging.

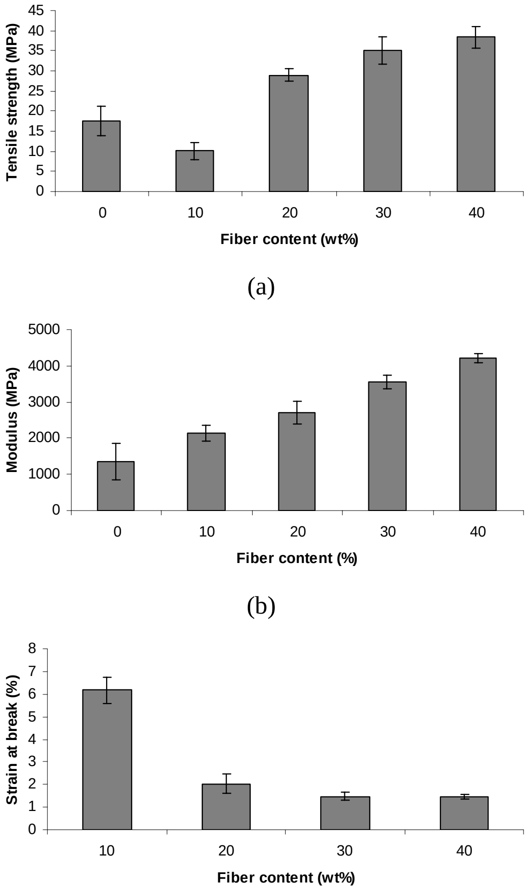
Water absorption

Water absorption was determined according to ASTM D570 on rectangular specimens. The specimens were initially dried to a constant weight and then soaked in distilled water at room temperature for 60 days. At regular time intervals, each specimen was removed from the water tank, dried and subsequently weighted. The amount of water uptake by the specimen was calculated as the weight difference and is reported as the percentage increase of the initial weight.

Results and Discussion

Tensile properties of composites

Figure 1 shows the tensile properties for p-PLA and p-PLA/KBF composites. It is clear from Figure 1(a) that the addition of KBF into p-PLA resulted in a significant change in its tensile properties. At 10 wt.% fiber content, the tensile strength dropped from 17 MPa to 10 MPa. At 20 to 40 wt.%, however, the property increased almost linearly with maximum improvement of 120%. The increase in the tensile strength suggests that KBF and p-PLA are compatible resulting in a good interfacial interaction between the two components. As for the tensile modulus, the property too increased with increasing fiber content. Maximum improvement of 213% was observed when p-PLA/KBF composites is filled with 40 wt.% fiber content (Figure 1(b)).



(a)

(b)

(c)

Figure 1 – (a) tensile strength, (b) tensile modulus, and (c) strain at break results of p-PLA and p-PLA/KBF composites at various fiber contents. The strain at break for p-PLA is 174%.

In contrast the addition of KBF decreased the strain at break of P-PLA/KBF composites (Figure 1(c)).

Morphological examination of the fracture surfaces

SEM micrographs of the tensile fracture surfaces of p-PLA/KBF composites were examined to aid in explaining the tensile properties. Many short fiber pull-outs were observed and they were extensively covered by the matrix, p-PLA (the SEM micrographs are not shown). Examination at higher magnification revealed that some of KBF were actually fractured with fiber cell wall fibrillation (Figure 2) during the tensile test. As seen in Figure 2, the fractured fiber too exhibits an irregular shape indicating the fiber had been stressed prior to failure. These observations confirm that there is a good interfacial adhesion between KBF and p-PLA as reflected in the tensile strength results. It is observed too that KBF is well distributed in p-PLA (The SEM micrographs are not shown). Good interfacial adhesion and KBF dispersion account for the high improvement in the tensile strength and tensile modulus of p-PLA/KBF composites.

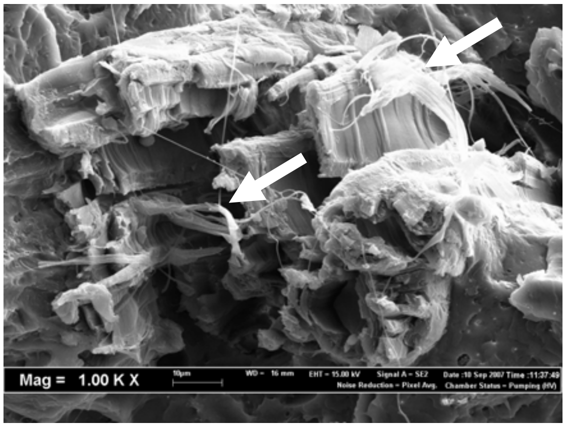


Figure 2 – A detailed SEM micrograph of the fracture surface of p-PLA/KBF composites. Fiber cell wall fibrillation are marked with arrows.

Water absorption behavior of composites

Figure 3 shows the percentage of water uptake as a function of square root of time for p-PLA and p-PLA/KBF composites. It is interesting to note that both p-PLA and p-PLA/KBF composites absorbed appreciable amount of water after 60 days of water immersion at room temperature. All materials too did not reach saturation after prolonged time suggesting non-Fickian behavior. For p-PLA/KBF composites, this behavior was obvious for composites filled with more than 10 wt.% fiber content.

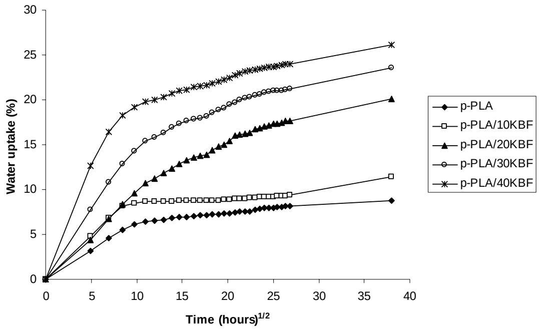


Figure 3 – Water absorption curves for p-PLA and p-PLA/KBF composites.

SEM micrographs in Figure 4 show the effect of water absorption on the surfaces of p-PLA and p-PLA/KBF composites. It is clear from Figure 4(a) that micro-cracks were formed on the surface of p-PLA. PEG is a water soluble material. The material, which is low in molecular weight, might have leached out from p-PLA.

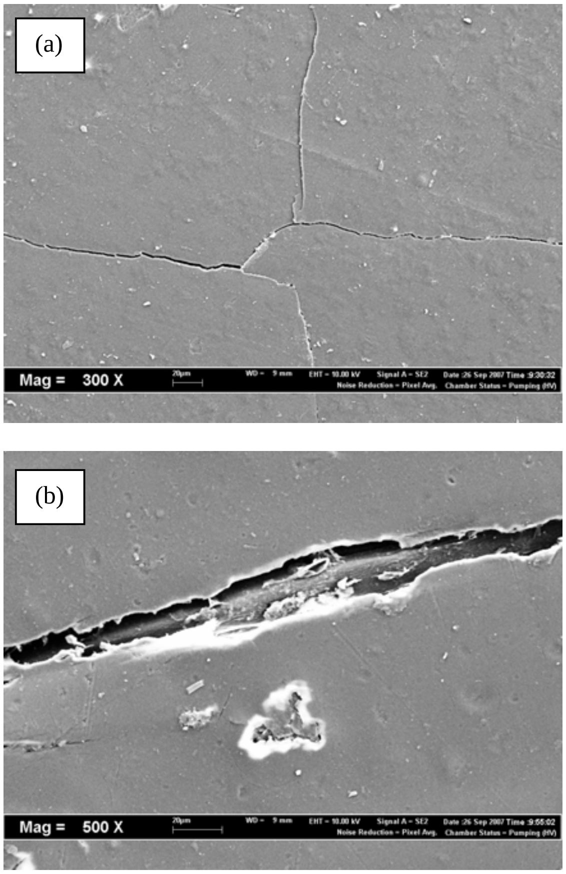


Figure 4 – SEM micrographs showing of (a) surface cracking p-PLA, and (b) matrix cracking along the fiber length and fiber-matrix debonding of p-PLA/KBF composites (40 wt.% fiber loading) due to water absorption.

This would develop internal stresses that lead to micro-cracking of p-PLA. KBF is hydrophilic and readily absorbs water that results in fiber swelling. Fiber swelling can generate microcracks in the adjacent matrix, specifically along the fiber length as observed in Figure 4(b). Continuous penetration of water molecules via capillary action through the microcraks, makes it impossible for p-PLA and p-PLA/KBF composites to reach saturation after 60 days of water immersion. This explains the non-Fickian water diffusional process of these materials. Other severe effect of water absorption is fiber-matrix debonding as shown in Figure 4(b). Matrix microcracking and fiber-matrix debonding are the two main factors that responsible for poor composite properties in wet.

Conclusions

The results of this study could be summarized as follows:

1. The incorporation of KBF into p-PLA increased both the tensile strength and tensile modulus of the resulted composites except the strain at break.
2. Reinforcing effect of KBF was observed when the fiber content exceeded 10 wt.%.
3. SEM examination on composite fracture surfaces revealed a good interfacial adhesion between KBF and p-PLA. Too KBF was observed to disperse uniformly within the polymer matrix.
4. Both p-PLA and p-PLA/KBF composites absorbed water and exhibited non-Fickian water diffusional process.
5. p-PLA exhibited microcracking due to water absorption. As for p-PLA/KBF composites microcracking was obvious along the fiber length. Other severe effect was fiber-matrix debonding.

The results of this work suggest that KBF is a potential reinforcement for p-PLA but possible applications should avoid high humidity environments.

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