Water absorption and soil burial degradation of Poly (lactic) acid (PLA)/Oil palm fibres (OPF) composite.

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Abstract: This research investigated the biodegradation of cellulose based PLA with oil palm composites on two sizes of fibre (0.25mm and 1.0mm). Poly (lactic acid) (PLA) was blended with oil palm fibre using twin screw extrusion technique. The use of oil palm can enhance the biodegradability of PLA since it is compostable under soil burial and easier absorb by water before disintegration for a few weeks. PLA was found to be biodegradable but rather slow in compostability unless at high temperature and humidity. In this study, the biodegradation rate was tested using soil burial and water absorption test. The samples were buried in soil and tested in aqueous water for specific duration at different pH. The higher the fibre content of 25%, the higher the weight loss and water absorption through soil burial and water absorption testing respectively. For soil burial testing, sample PLA OPF 25% higher weight loss of 3.7% were found for sample fiber size 1.0mm as compared to 1.6% (0.25mm). While for water absorption testing, sample has different behaviour at pH 5.5, 7 and 8. The higher the fibre content, the higher water and soil burial weight loss. For bigger fibre sizes of 1.0 mm, higher water absorption and mass loss reading were observed.

1. Introduction

Petroleum-based plastic production has risen drastically, reaching around 350 million tonnes per year (Garside, 2019). There are also billions tons of plastic waste accumulated due to inappropriate usage and disposal of plastic. This will lead to terrestrial and marine ecosystem pollution due to most of the plastic waste goes to river and oceans. In order to overcome this problem, biodegradable polymer were introduced besides to replace conventional petroleum-based polymer and to reduce environmental pollution. Biodegradable is the tendency of objects to disintegrate (decompose) by the action of microorganisms such as bacteria or biological fungi (with or without oxygen) while being assimilated into the natural environment. The biodegradable polymers that synthesised from bio-based polymer have been studied was Poly (lactic Acid) (PLA).

PLA has good mechanical properties and biodegradability compared to polystyrene (Martin & Averous, 2001). Semi-crystalline polymer is chosen for properties that require strong mechanical properties and toughness. PLA is, however, much more costly than conventional plastics, and the rate of degradation is still slow (Ramsay, Langlade, Carreau, & Ramsay, 1993).
To address the low degradation rate of PLA, blending with other natural polymers that have a higher degradation rate is recommended. Natural fibres that are completely degradable when combined with thermoplastic material are used to minimise manufacturing costs and adverse environmental effects. Today, the use of natural fibre namely oil palm fibers available abundant in Malaysia are of great importance in composite research and industry. Composites using natural fibre act as replacement for synthetic fibre in composites such as recyclability, renewability, biodegradability, abundant, resistance to corrosion, non-toxicity, high flexibility, competitive mechanical properties, low density, less energy consumption, minimum abrasive resistance to processing equipment and waste disposal problems[6]. Properties of composites were extensively studied [10, 14, 15].

Testa et al done an experiment on biodegradability of oil palm with poly (lactic acid (PLA) using garbage-processing machine shows that after composting for 30 days, PLA/Oil Palm's biodegradability decreases by 38%. The tensile strength decreases rapidly during the first 5 and 10 days. After 30 days, due to the degradation of cellulose in the oil palm fibres, the tensile strength still showed a significant decrease of 10%. At the beginning of the 14 days, the percentage of weight loss result are same but after 30 days the percentage of weight loss increase drastically about 40%. These indicates that the enzymatic degradation in the cellulose polymer chains degrades fibre strength. Decreasing strength of fibre and polymer shows that the polymer is degrade into carbon dioxide and water. Before composting, surface of the specimen is been cover by the biodegradable resin. According to Ochi, S. 2008, the exposure of the fibre is obtained due to the resin on the sample surface is degrade.

In studies on effects of Kenaf and Rice Husk on Water Absorption and Flexural Properties of Kenaf/CaCO3/HDPE and Rice Husk/CaCO3/HDPE Hybrid Composites By NAZuhaira, RM etal (2015), the effects of natural fiber for both rice husk and kenaf had been investigated [13] ; water absorption increased with the presence of kenaf and rice husk fillers. Natural fibers in composite significantly influence water absorption properties due to natural characters of fibers which contain cellulose, hemicellulose and lignin structures.

2. Experimental Analysis

2.1 Raw materials

Materials that were used in this study is Poly (lactic Acid) (PLA) of extrusion grade resin with Melt Index MI of 2, while Oil Palm Fibres (OPF) as reinforced fibre were incorporated to modify the mechanical properties which also acts as fillers.

2.2 Methodology

2.2.1 Chemical treatment of Oil Palm Fibre. Before every process, the sample need to be dried to eliminate moisture in the oven or vacuum. The cleaned oil palm sample need to be treated with 6% Sodium Hydroxide (NaOH) solution for 24 hours and then washed and dried in an oven at 40°C for 24 hours.

2.2.2 Mixing and Compounding. Oil palm fibre and PLA were blended and the mixture extruded into twin screw extruder of length/diameter ratio of 16:1 before palletized. The temperature of the extruder of the machine were set to different temperature zones ranging from 160-175°C and the rotation speed is 330 r/min. Next, the extruded will be trim using trimming machine before. Then the sample were compressed using Hot Press Machine.

3. Results and Discussions
3.1 Water Absorption

Water absorption test was conducted to determine the absorption of the sample when immersed in the different pH system. The duration of immersion was taken for 6 weeks.

3.1.1 Water absorption in different pH. PLA Virgin showed minimum water absorption value. PLA Virgin sample absorb less moisture than sample that compounded with oil palm fibres. The water absorption value for all samples that immersed in acidic (pH 5.5) water solution have been reported in Figure 1. Results clearly indicated that sample of PLA Virgin showed lowest water absorption value which is 1.06% over 16 weeks. Figure 1 showed the increasing water absorption values with addition of fibre content. According to Huner (2015), Zahari et al. (2015), and Chen et al. (2016), water absorption increased as the fibre content increase due to the hydrophilic nature of fibre that they are cellulose fibre. Upon exposure to the water absorption, the fibre initially swells. Besides, as results of swelling, micro cracks can appear in a brittle matrix and in turn can lead to larger water transport through the fibre matrix interface. Higher water absorption were exhibited by fibre size 1.0mm, this is followed by 0.25mm. This is was due to the larger fibre sizes impose less surface interaction between matrix and fibres.

The water absorption value for all samples that immersed in neutral (pH 7) were exhibited as in Figure 2. Results clearly indicated that sample of PLA Virgin showed minimum water absorption value which is 1.11% over 6 weeks. Figure 2 shows increasing in water absorption values with addition of fibre content. It can be interpret that from the fibre size 0.25mm, values of sample of PLA/3% OPF, PLA/7% OPF,PLA/15%OPF and PLA/25%OPF showed 1.6%,2.34%,2.3% and 6.48% increased water absorption respectively at room temperature. According to Huner (2015), Zahari et al. (2015), and Chen et al. (2016), water absorption increased as the fibre content increase understandably due to the hydrophilic nature of cellulose fibres. Fibre matrix interface breakdown and water are diffused into the interface and microcracks region and ingression of water could initiate degradation hotspots. For composite of fibre size 1.0mm, water absorption of PLA/3% OPF, PLA/7% OPF, PLA/15%OPF and PLA/25%OPF showed 2.59%,3.07%,3.35% and 8.46% respectively. Higher water absorption for higher loading, was imparted by the larger size of fibres having less surface interaction and for bonding between matrix and fibre.

![Figure 1: Graph of water absorption test in acidic condition PH 5.5.](image1)

![Figure 2: Graph of water absorption test in neutral condition PH 7.](image2)
Figure 3 showed increasing water absorption values with addition of fiber content. For 0.25mm, PLA/25%OPF showed highest water ~ 5.58% whilst for fiber size 1.0mm, absorption value can go up to 8.56% for highest fiber composition of 25% This is was due to the larger size of fiber which cause higher water uptake.

3.2 Soil Burial Test
Degradation of sample was measured based on dry weight loss before and after buried time. While a dry weight loss can be used to indicate biodegradation rate of sample during soil burial condition. It can be observe that, as the soil burial duration increased, the percentage of weight loss also increased and more significant increase was found when incorporate with oil palm fibre. It also can be observe that, the higher the percentage of fibre, the higher the percentage of weight loss over 10 days. And the percentage of weight loss of sample PLA/3% OPF, PLA/7% OPF, PLA/15% OPF and PLA/15% OPF are more higher compared to PLA Virgin. These results indicate that the introduction of OPF had accelerate the degradation of PLA. This is because ligno-cellulosic materials are more easily attacked by microorganisms. This occur due to the increased in water uptake of the composites which causes major deterioration. Swelling by water uptake also led to the micro cracking of the composites resulting in weight loss. The activities of microorganisms in the soil reduced the sample weights. The voids caused by the presence of moisture also permitted the colonization by microorganisms.
Figure 4 and 5 shows two size of oil palm fibre when incorporate with PLA. From this figure, different size of fibre gives different percentage of weight loss. The sample shows a progressive loss of the mechanical properties in relation to the biodegradation time. It can be observed that, the bigger size of fibre leads to higher percentage weight loss. For specimen PLA/3% OPF which the fibre size 1.0 mm has higher percentage of weight loss across 10 days which 1.8% as compared to fibre size 0.25mm was only 1.27%. The trend of this graph was similar to other percentage of fibre loading whereas the higher size of fibre shows higher percentage of weight loss. For specimen 7% of oil palm fibre loading with fibre size 1.0mm and 0.25mm, the percentage of weight loss was 2.9% and 1.2% respectively. Next, across 10 days, the percentage of weight loss for specimen 15% of oil palm fibre loading 2.6% and 1.35% according to fibre size 1.0 and 0.25mm respectively. Lastly for specimen PLA/25% OPF of 1.0 mm shows the highest percentage of weight loss than 0.25mm. At this stage, hydrophilic group on the surface of the OPF absorbed water and microorganisms leading to degradation. The increased of fibre content, accelerated the degradation of PLA. This indicate that, size of fibre 1.0 mm was the most optimum biodegradability due to the highest loss weight of the sample.

4. Conclusion
PLA composite system has element of biodegradability compared to the conventional plastic polymer. This study had shown biodegradation of PLA/OPF in soil burial and their water absorption behaviour. Oil palm fibre/PLA could be biodegraded by microorganisms in the plantation soil.

The higher the percentage of fibre in composite system, the higher the percentage of water absorbed and weight loss. This experiment were done at room temperature. Hydrolysis of PLA matrix must occur for further degradation of PLA while for fibre, the higher the size of fibre the higher the percentage of water absorbed and weight loss. This had been exhibited via biodegradation rate of the larger 1.0mm as compared to reduced size (0.25mm).

References
[1] R. L. Shogren, W. M. Doane, D. Garkotta, J. W. Lawton, and J. L. Willett, “Biodegradation of starch/polylactic acid/poly(hydroxyester-ether) composite bars in soil,” Polym. Degrad. Stab., vol. 79, no. 3, pp. 405–411, 2003.
[2] M. Akrami, I. Ghasemi, H. Azizi, M. Karrabi, and M. Seyedabadi, “A new approach in compatibilization of the poly(lactic acid)/thermoplastic starch (PLA/TPS) blends,” Carbohydr. Polym., vol. 144, pp. 254–262, 2016.

[3] S. Ochi, “Mechanical properties of kenaf fibers and kenaf/PLA composites,” Mech. Mater., vol. 40, no. 4–5, pp. 446–452, 2008.

[4] Z. Xiong et al., “Preparation and characterization of poly(lactic acid)/starch composites toughened with epoxidized soybean oil,” Carbohydr. Polym., vol. 92, no. 1, pp. 810–816, 2013.

[5] M. Babaee, M. Jonoobi, Y. Hamzeh, and A. Ashori, “Biodegradability and mechanical properties of reinforced starch nanocomposites using cellulose nanofibers,” Carbohydr. Polym., vol. 132, pp. 1–8, 2015.

[6] A. M. Adole, J. M. Yatim, and S. A. Ramli, “SCIENCE & TECHNOLOGY Kenaf Fibre and Its Bio-Based Composites : A Conspectus,” vol. 27, no. 1, pp. 297–329, 2019.

[7] N. Saba, M. T. Paridah, and M. Jawaid, “Mechanical properties of kenaf fibre reinforced polymer composite: A review,” Constr. Build. Mater., vol. 76, pp. 87–96, 2015.

[8] V. Fiore, G. Di Bella, and A. Valenza, “The effect of alkaline treatment on mechanical properties of kenaf fibers and their epoxy composites,” Compos. Part B Eng., vol. 68, pp. 14–21, 2015.

[9] O. M. L. Asumani, R. G. Reid, and R. Paskaramoorthy, “The effects of alkali-silane treatment on the tensile and flexural properties of short fibre non-woven kenaf reinforced polypropylene composites,” Compos. Part A Appl. Sci. Manuf., vol. 43, no. 9, pp. 1431–1440, 2012.

[10] B. F. Yousif, A. Shalwan, C. W. Chin, and K. C. Ming, “Flexural properties of treated and untreated kenaf/epoxy composites,” Mater. Des., vol. 40, pp. 378–385, 2012.

[11] S. Lv, Y. Zhang, J. Gu, and H. Tan, “Biodegradation behavior and modelling of soil burial effect on degradation rate of PLA blended with starch and wood flour,” Colloids Surfaces B Biointerfaces, vol. 159, pp. 800–808, 2017.

[12] Ochi, S. (2008). Mechanical properties of kenaf fibers and kenaf/PLA composite. Mechanics of Materials, 40(4-5), 446-452. https://doi.org/10.1016/j.mechmat.2007.10.006

[13] Noor Zuhaira Abd Aziz, Rahmah Mohamed, Mohd Muizz Fahimi M, World Academy of Science, Engineering and Technology International Journal of Industrial and Manufacturing Engineering Vol9, No:4, 2015

[14] Mohd Nurazzi, N, Khalina, A.1.2*, Sapuan, S. M. Dayang Laila, A. H. A .1, Rahmah, M and Hanafiee, Z. A Review: Fibres, Polymer Matrices and Composites Pertanika J. Sci. & Technol. 25 (4): 1085 - 1102 (2017)

[15] R Mohamed. Physical and morphological properties of filled calcium carbonate/kenaf fibre/rice husk polypropylene hybrid composite., AIP Conference Proceedings 1985 (1), 040009