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Biodegradation Study of LDPE/PCL Polyblend Plastic Film by Using the Fungus Aspergillus niger

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Abstract. Low density polyethylene (LDPE) is a polymer material that is difficult to degrade in nature and causes waste to accumulate so that it can damage the environment. To overcome this, it is necessary to blend LDPE with poly(*ε*-caprolactone) (PCL), which is easily degraded. The PCL used in this research was obtained from ROP *ε*-CL using a bis(dibzm)$_2$Zr catalyst. Meanwhile, the composition ratio of LDPE and PCL polyblend used is 10/4 (%w/w). Furthermore, the resulting LDPE/PCL polyblend plastic film was tested for biodegradation by using the fungus Aspergillus niger for 28 days. Aspergillus niger is a type of fungus that is able to decompose plastic waste. In general, the results of the biodegradation test showed that LDPE/PCL polyblend plastic films were more easily degraded compared to pure LDPE.

INTRODUCTION

Environmental pollution by plastic waste on land, sea and air continues to increase every year. Currently, plastic production has reached 300 million tons which are used for various uses [1]. LDPE, which is part of a synthetic polymer, has been widely used for packaging, household appliances, cables, flexible toys, and pipes. However, the waste produced is still difficult to overcome and needs serious handling so that the natural beauty of the environment can be preserved [2]. In an effort to overcome this problem, researchers have synthesized biodegradable plastics and biodegraded plastics using microbes [3].

Generally, there are several methods used to synthesize biodegradable plastics. These methods include biosynthesis, copolymerization, and blending [4]. The first method is biosynthesis. Biosynthesis is a method for producing polymers by means of fermentation. The resulting polymers will be biodegradable, such as poly(*ε*-caprolactone) [5–7], poly(*δ*-valerolactone), polyhydroxybutyrate, poly(lactic acid), and poly(glycolic acid) [3]. However, the yield of the resulting product is very low, so it is not economical to use it as packaging. Currently, these polymers are widely used in medical fields such as artificial organs, sources of chiral compounds for drugs, drug release control, skin structure improvement in plastic surgery, and surgical sutures.

The second method is copolymerization by combining two different monomers to produce a polymer [8], [9]. However, the process of synthesis and purification is very complicated so that it is not efficient. The third method is the blending method. This method is a combination of two or more polymers. The material used as a mixture can also be sourced from natural sources[10], [11], including cellulose, which is abundantly available in Indonesia [4].

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While the microbes that are commonly used to degrade plastic are fungi, bacteria, and algae. Some of the fungi commonly used to degrade plastic are *A. niger, A. clavatus, Curvularia senegalensis, Fusarium solani, Aureobasidium pullulans sp,* and *R. delemar* [12]. Plastic biodegradation is a degradation process that is easier to do than other methods. The biodegradation process occurs through depolymerization and mineralization processes. In this method, microbes will use synthetic polymers as a carbon source that produces microbial biomass so that it can be biodegraded in nature [13].

In this publication, we will report the research results of LDPE/PCL polyblend plastic which can be biodegraded using A. niger fungus. The plastic obtained is also presumed to have better mechanical properties than pure LDPE.

MATERIALS AND METHODS

The PCL utilized was generated via *e*-caprolactone polymerization with a bis Zr(dibenzoylmethane) complex [14], [15]. The other materials are LDPE, xylene, 70% alcohol, distilled water, A. Niger fungus, PDA media, and analytical balance. Furthermore, a mechanical properties testing is used to characterize the LDPE and plastic specimen of LDPE/PCL.

Films Preparation of LDPE/PCL Blend

The composition of the blend of LDPE with PCL is 10:4. LDPE/PCL polyblend is produced by blending the two polymers using xylene as a solvent. The solution was then stirred until homogeneous and refluxed. The resulting blend is then dried in the oven. The resulting polyblend was characterized using a mechanical properties test [4].

Utilization of A. niger Fungus in LDPE/PCL Biodegradation

After the work area is sterilized, the plastic specimen is weighed. The specimen size is 3 x 3 cm^2. After that, the plastic specimen was soaked with 70% alcohol and then rinsed with distilled water. Each immersion lasts ten minutes. This treatment was repeated 3 times with the aim of sterilizing it. Next, the fungus A. niger was inoculated across the full surface of potato dextrose agar (PDA) media. The plastic specimen was then placed in the center of the PDA medium and slightly pressed. The degradation process lasted for 28 days at 37ºC. On days 10, 20, and 28 samples were taken and their dry weight was weighed.

RESULTS AND DISCUSSION

Mechanical Properties Testing

In this research, biodegradable LDPE/PCL polyblend plastic has been obtained. Tensile strength (MPa) and elongation (%) tests have been carried out mechanical properties testing, the results of which are shown in Figure 1. The tensile strength of a plastic is the highest load that a plastic can withstand when stretched before breaking. While elongation is the proportion of the increase in length that occurs compared to the initial length.

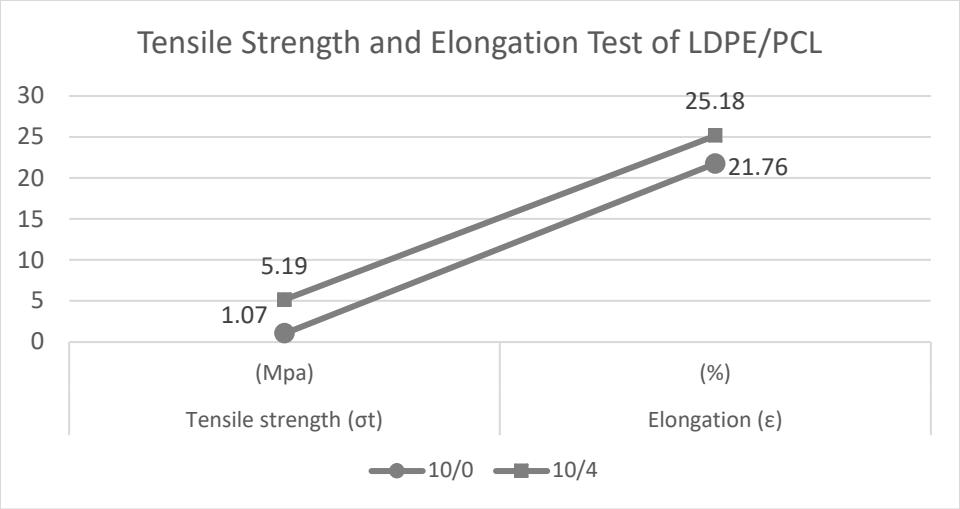
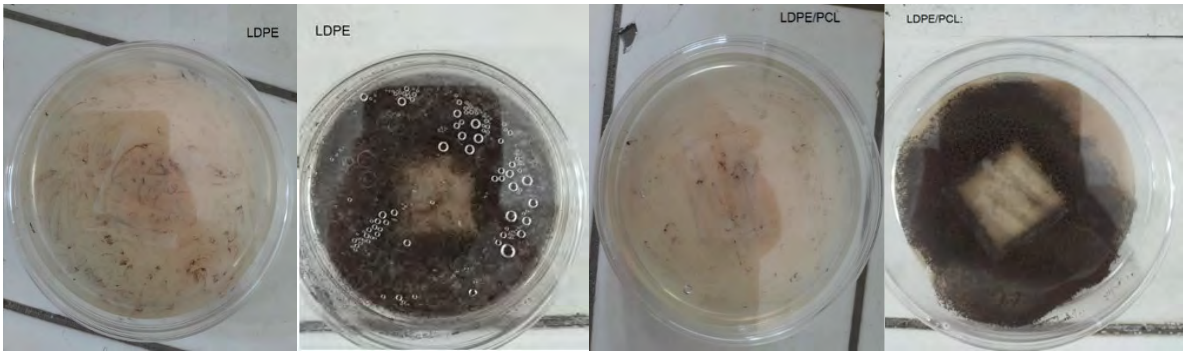


FIGURE 1. Results of the mechanical properties testing of PS/PCL Polyblend Plastic Specimens

In Figure 1, the value of mechanical properties including tensile strength and elongation is presented where the compatibility of polyblend is higher than pure LDPE. The high tensile strength of LDPE/PCL polyblend is influenced by the homogeneity of the plastic and the addition of PCL. The homogeneity of the material is influenced by the speed at which it is stirred so that the resulting mixture is evenly distributed and denser. Pure LDPE has a tensile strength of 1.07 MPa and an elongation of 21.76%. In contrast, with the addition of PCL, the tensile strength of polyblend increased to 5.19 MPa and elongation increased to 25.18%.

LDPE/PCL Biodegradation by A.niger Fungus

Biodegradation of LDPE and polyblend LDPE/PCL by a Aspergillus niger for 28 days is presented in Figure 2.



(a) LDPE 0d (b) LDPE 28d (c) LDPE/PCL 0d (d) LDPE/PCL 28d

FIGURE 2. Growth of A. niger on LDPE and LDPE/PCL using PDA media

The growth of A. niger fungus looks like granules which is an indication that fungal spores have grown. In Figure 2, there has been a change in color to black after the sample was biodegraded for 28 days.

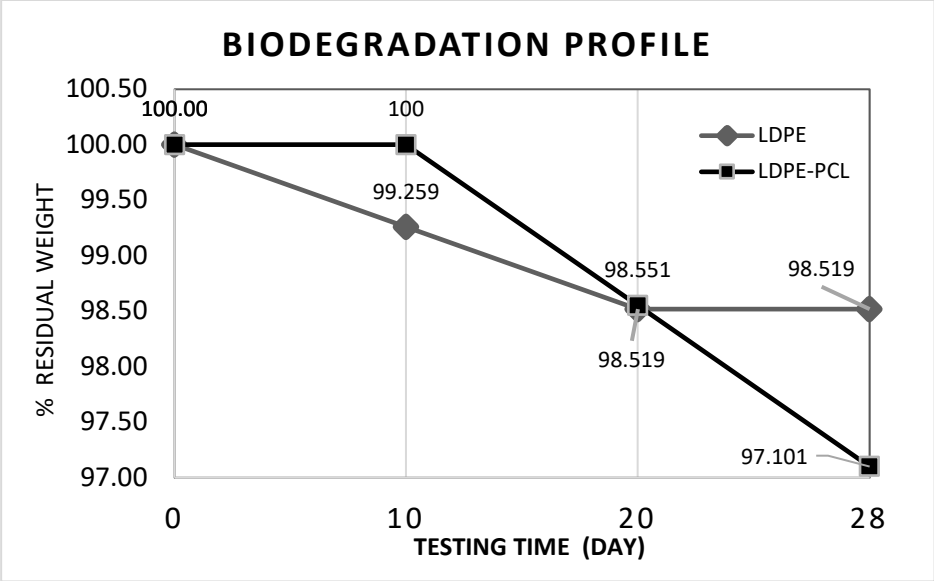


FIGURE 3. LDPE/PCL biodegradation by A.niger fungus

In Figure 3, the results of the LDPE/PCL polyblend biodegradation test using A. niger fungus are shown. Biodegradation was carried out for 28 days where LDPE/PCL polyblend had a higher degradation rate than pure LDPE. After 10 days of biodegradation, the fungal degradation activity of LDPE/PCL polyblend was 0.75%. In contrast, the activity of pure LDPE is 0%. On day 20, the fungal degradation activity of LDPE and LDPE/PCL polyblend was the same, namely 1.5%. On day 28, the fungal degradation activity of LDPE/PCL polyblend was 2.9% and the percentage by weight was reduced to 97.1%. In contrast, the fungal activity in LDPE was only 1.5% and the weight percentage was reduced to 98.5%.

The molecular structure of LDPE does not have a carbonyl functional group, so it is more difficult to degrade by fungi. In addition, LDPE also has a long carbon chain, is derived from petroleum derivatives, has high molecular weight, good thermal resistance, has high resistance to extreme environments, and has strong bonds between atoms. This factor makes it difficult for the fungus to break it down into simpler molecules. Naturally, LDPE can still be degraded, but it takes a very long time because of its hydrophobic nature. Factors that can affect the degradation of LDPE are solar radiation, humidity, heat and pressure [16].

The active interaction between fungus and plastic is the first step for biodegradation mechanism. The next step is the formation of the intermediate polymer. These compounds already have functional groups such as esters, carboxylates, hydrocarbons, and ketones with more hydrophilic properties. Furthermore, the polymer will be more easily attached by microorganisms to carry out the biodegradation process by way of enzymatic activity. As a result, the polymer will break down more easily into oligomers, dimers, monomers, biomass, CO_2, CH_4, and H_2O. Finally, the weight of the degraded polymer will decrease so that it will be more easily decomposed by the fungus A. niger [17], [18].

CONCLUSION

Aspergillus niger has been used to degrade LDPE plastic and LDPE/PCL polyblend for 28 days. As a result, LDPE/PCL polyblend was degraded by 2.9% while pure LDPE was only 1.5%. Meanwhile, the final weight percentage of polyblend is 97.1% while LDPE is only 98.5%. Fungal biodegradation activity obtained in this study is still relatively low. Therefore, in further research, it is necessary to use variations in the use of fungi, variations in degradation time and variations in biodegradation methods to increase the activity of fungal biodegradation.

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