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Effect of Polyvinyl Alcohol (PVA) Concentration and Stirring Time on The Mechanical Properties of Biodegradable Plastic from Kepok Banana Peel Starch

Monica Anatasya Doni[1], Riri Jonuarti[2], Ratna Wulan[3], Fadhila Ulfa Jhora[4]
[1,2,3,4] Department of Physics, Universitas Negeri Padang, Indonesia
*Corresponding Author: anatasyadonimonica@gmail.com

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ABSTRACT

One solution is to use bioplastics, which can replace synthetic plastics that are difficult to decompose. Starch is one of the materials used in the manufacture of bioplastics because it is naturally degradable. However, bioplastics made from starch tend to be brittle and easily damaged, so additional materials are needed to overcome this problem. Polyvinyl alcohol (PVA) is one of the materials used in the manufacture of bioplastics because it has properties that can be degraded naturally, is non-toxic, and is able to form good quality plastic films. This study aims to examine the effect of PVA concentration and stirring time on the mechanical properties of biodegradable plastic derived from kepok banana peels. This study used a completely randomized design with three variations of PVA concentration (3%, 4%, and 5%) and three variations of stirring time (25 minutes, 35 minutes, and 45 minutes). The results showed that at a PVA concentration of 5% with a stirring time of 45 minutes, bioplastics showed the best quality with a tensile strength value of 2.25 MPa, the best elongation at break was 416%, and the best elasticity was 0.541. In biodegradation, all samples were completely degraded within 7 days. It can be included that the addition of PVA concentration and the length of stirring effecth the mechanical properties of bioplastics but not on the biodegradation test.

Keywords: *Poluvinyl Alcohol; Kepok Banana Peel; Stirring Time; Bioplastics; Mechanical Properties*

INTRODUCTION

The use of plastic is an important necessity in everyday life as a support for various activities. However, the use of plastic also brings negative impacts with the increasing amount of plastic waste that can cause serious environmental problems. Therefore, to reduce the impact of this problem, alternative solutions are needed in the form of plastics that are safe and do not cause damage to the environment [1].

Biodegradable plastic is a type of plastic that is environmentally friendly, and able to decompose by microorganism activity or weather into water (H2O) and carbon dioxide (CO2) after use and disposal in the environment. The use of biodegradable plastics provides an alternative to the use of synthetic plastics as the ingredients come from natural sources that are not harmful to the environment.

The utilization of environmentally friendly materials derived from natural materials continues to be researched to obtain plastics with standard characteristics that do not damage the environment [2]. Starch is a material that is often used in bioplastic production. Some commonly used natural sources of starch are corn, cassava, sweet potato, potato, rice, sago, and various other materials derived from tubers, grains, vegetables, and fruits. However, the use of starch from these natural sources is considered less efficient because these materials are also staple foods for the community. Therefore, other alternatives are needed, such as unused waste that contains starch, as a solution to replace starch from the main food sources in making bioplastics.

The innovation that will be developed in this research is using starch from kepok banana peel waste. The kepok banana peel has the potential as a source of starch because it contains about 0.98% starch. The chemical composition of kepok banana peel includes moisture content of 11.09%, ash content of 4.82%, fat of 16.47%, protein of 5.99%, crude fiber of 20.96%, carbohydrate 40.74%, cellulose 17.04%, and lignin 15.36%. By utilizing kapok banana peel as a starch source, it is expected to produce environmentally friendly biodegradable plastic.

Biodegradable plastics made from starch generally have less robust mechanical properties. To overcome these limitations, it is necessary to combine starch, plasticizers, and additional synthetic polymers. Plasticizers are compounds that increase the elasticity of plastics, preventing them from becoming brittle and stiff. One plasticizer that has high elasticity is glycerol. Glycerol acts as a polyol that reduces internal hydrogen bonds, thereby increasing the distance between molecules. Of the various synthetic polymers available, polyvinyl alcohol (PVA) was chosen as one of the best choices because it is soluble in water, easily degrades naturally (biodegradability), and is compatible with starch materials. The addition of polyvinyl alcohol (PVA) serves as a reinforcement to improve the mechanical properties of starch-based biodegradable plastics. By increasing the concentration of polyvinyl alcohol (PVA), the mechanical properties of the resulting biodegradable plastic can likely be improved [3].

The length of stirring time during the heating process also affects the mechanical properties of biodegradable plastics made from starch. If the stirring time is too short, the homogeneity of mixing the ingredients is low and causes the reactions that support the mechanical properties of biodegradable plastics to decrease. However, if the stirring time is too long, a lot of water vapor escapes and causes the biodegradable plastic to become dry and lose flexibility [4].

Therefore, this research aims to determine the effect of polyvinyl alcohol (PVA) concentration and length of stirring time in the heating process on the mechanical and biodegradation properties of biodegradable plastic made from kepok banana peel starch.

MATERIALS AND METHODS

Research Materials and Tools

The materials used consisted of kepok banana peel starch, PVA (polyvinyl alcohol), glycerol, 1% acetic acid, chitosan, and distilled water. The tools used consisted of beakers, measuring cups, Petri dishes, stirring rods, magnetic stirrer, hot pleat, 20×20 cm non-stick baking sheet, analytical balance, oven, and UTM (Universal Testing Machine).

Experimental design

This study adopted a completely randomized design (CRD). The independent variables in the study consisted of three levels of PVA (polyvinyl alcohol) concentration, namely 3%, 4%, and 5%, and three levels of stirring time, namely 25 minutes, 35 minutes, and 45 minutes (Rachman, 2018). The control variables in this study were the weight of starch, glycerol, and 1% acetic acid. Meanwhile, the dependent variables in this study include the measurement of tensile strength, elongation, young modulus, and degradation test values of the bioplastic manufacturing results.

Research Implementation

The kepok banana peel waste was first cut into smaller pieces and then washed thoroughly. The banana peel is then mashed with a blender. Then the banana peel that has been refined is filtered and water is taken only. The filtered banana peel water was then allowed to stand for 24 hours until the starch settled at the bottom. After the settling process, the starch that has settled is separated from the water and dried using an oven at 50oC for 24 hours [5].

The process of making bioplastic film begins with weighing 1 gram of kepok banana peel starch, PVA according to treatment (3%, 4%, and 5%), 1 gram of chitosan, 2 ml of glycerol, and 100 ml of 1% acetic acid solution. Next, 1% acetic acid solution, chitosan, and starch were put into a 250 ml glass beaker. All ingredients were then stirred until homogeneous using a magnetic stirrer with stirring time according to the treatment (25 minutes, 35 minutes, and 45 minutes) at 70oC[6]. After the starch was gelatinized, glycerol was added to the mixture. Next, this mixture was molded using a 20×20 cm non-stick baking pan. The samples were then dried in an oven at 50oC for 16 hours. Once dry, the samples can be released from the mold and are ready to be tested for tensile strength, elongation at break, elasticity, and biodegradation tests.

Characteristic Test

The tensile strength test is obtained by dividing the maximum stress produced by the sample by its cross-sectional area. The tensile strength testing process follows the JIS (Japanese Industrial Standard) 2-1707 standard where the tensile strength value is at least 4 KgF/cm2 or 0.3923 MPa. The calculation for the tensile strength test is done using the following equation:

$$\sigma = \frac{F_{max}}{A}$$

Description:
σ : tensile strength (MPa)
F_{max} : maximum stress (N)
A : cross-sectional area (mm^2)

The elongation at break test was conducted using the same method as in the tensile strength test. The elongation at break test results refer to the JIS (Japanese Industrial Standard) 2-1707 standard where the elongation at break value is at least 70%. Calculation of elongation at break is done with the following equation:

$$e = \frac{\Delta l}{l_0} \times 100\%$$

Keterangan :
e : strain (%)
Δl : length increment (mm)

l_0 : initial length (mm)

The elasticity test (modulus young) is obtained by calculating the quotient between the tensile strength value and the elongation at break. The elongation at break test results refer to international standards (ASTM D638) where the elasticity value is at least 200 MPa. The calculation of elongation at break is done using the following equation:

$$\text{Elasticity (MPa)} = \frac{\text{Tensile strength (MPa)}}{\text{estrangement (\%)}}$$

Information :
E : elasticity (MPa)
σ : tensile strength (MPa)
e : strain (mm)

The biodegradation test refers to the standard SNI 7188.7: 2016 where bioplastics have degraded >60% within 7 days.

RESULTS AND DISCUSSION

Tensile Strength

The results of the variation analysis showed that the concentration of PVA and the length of stirring time affected the tensile strength value of bioplastics made from kepok banana peel starch. From this study, it was found that the tensile strength value of bioplastics was in the range of 0.96 - 2.21 Mpa with details that can be seen in Table 1.

Table 1: Tensile strength values (Mpa) of kepok banana peel starch biodegradable plastics

Concentration PVA (%)	Stirring Time (Minutes)			Standar	
	25	35	45		
3	0,96	1,01	1,07	Minimal 4KgF/cm^2 or 0,3923 Mpa	JIS 2-1707
4	1,54	1,57	1,94		
5	1,58	1,61	2,25		

Tensile strength is a measure of the maximum stress required by the sample to be able to withstand the force before it is finally cut off. Based on Table 1, the results show that bioplastics with a PVA concentration of 5% and a stirring time of 45 minutes have the highest tensile strength value, which is 2.21 MPa. In contrast, bioplastics with a PVA concentration of 3% and a stirring time of 3 minutes showed the lowest tensile strength value, which was 0.95 MPa.

The increase in tensile strength value is influenced by the increase in PVA concentration because PVA can form flexible and high-quality plastic films [4]. The hydroxyl group on PVA plays a role in forming hydrogen bonds when interacting with starch, resulting in synergy between starch and PVA. The presence of many hydrogen bonds in the composite leads to higher tensile strength values because these chemical bonds require higher energy to break [7].

In addition, the length of stirring time also affects the tensile strength value, where the longer the stirring time results in a higher tensile strength value. This is because the stirring process helps to create homogeneity and good compatibility in the mixture. In addition, the water vapor released during the stirring process also plays a role in making the molecular structure in the composite tighter and stronger.

The research results of all plastic film samples meet the JIS (Japanese Industrial Standard) 2-1707 bioplastic standard, which sets a minimum value for tensile strength of 0.3923 MPa as an indicator that the bioplastic is considered good.

Elongation at Break

The results of the variation analysis showed that the concentration of PVA and the length of stirring time had a significant influence on the elongation at break value of the biodegradable plastics produced. From this study, it was found that the elongation at break values was in the range of 275% to 416%, and the details can be seen in Table 2.

Table 2: Elongation at break values (%) of kepok banana peel starch biodegradable plastics

Concentration PVA (%)	Stirring Time (Minutes)			Standar	
	25	35	45		
3	275	283	292	Minimal 70%	JIS 2-1707
4	342	350	375		
5	350	375	416		

Elongation at break is the maximum change in length of the sample before it is finally cut off in the tensile test. The purpose of this test is to compare the elongation or length increase of the sample before and after the tensile test. Table 2 shows that the highest elongation at break value is obtained from bioplastics with 5% PVA concentration and 45 minutes stirring time, which is 416%. The lowest elongation at break value is obtained from biodegradable plastic with 3% PVA concentration and 35 minutes stirring time, which is 275%.

The concentration of polyvinyl alcohol (PVA) plays an important role in forming the structure and mechanical properties of biodegradable plastics. The higher the concentration of PVA, the more likely it will produce bioplastics with higher elongation at the break because PVA can form flexible and strong plastic films. In addition, the length of stirring time also affects the mechanical properties of bioplastics. A longer stirring process can help create a more organized and homogeneous molecular structure, which contributes to the increased elasticity and flexibility of bioplastics.

The results of this study meet the JIS (Japanese Industrial Standard) 2-1707 bioplastic standard, where the standard sets the minimum value for elongation at break at 70% as an indicator that the bioplastic is considered good.

Modulus Young

Based on the variation analysis conducted, the results obtained show that the concentration of PVA and the length of stirring time affect the value of young's modulus. From this study, it was found that the elongation at the break value of bioplastics was in the range of 0.349 MPa to 0.541 Mpa, and the details can be seen in Table 3.

Table 3: Elasticity values (Mpa) of kepok banana peel starch biodegradable plastics

Concentration PVA (%)	Waktu Pengadukan (Menit)			Standar	
	25	35	45		
3	0,349	0,356	0,366	Minimal 200 Mpa	ASTM D638
4	0,450	0,448	0,517		
5	0,451	0,429	0,541		

Elasticity, also known as Young's modulus, is a measure of the stiffness of a material. The stiffer the material, the higher the elasticity value [8]. From Table 3, it can be seen that bioplastics with 5% PVA concentration and 45 minutes of stirring time have the highest elasticity value of 0.541 MPa. Meanwhile, bioplastics with 3% PVA concentration and a stirring time of 3 minutes have the lowest elasticity value of 0.349 MPa.

The results of the variation analysis obtained are the higher the concentration of PVA and the longer the stirring time, the higher the elasticity value obtained. This is because elasticity is directly proportional to the tensile strength value [4]. These results indicate that the combination of PVA concentration and stirring time affects the elasticity and flexibility of bioplastics. The higher the concentration of PVA and the longer the stirring time, tends to increase the value of elongation at break, indicating that these conditions produce bioplastics with more elastic and flexible properties. This can be important information in choosing a combination of materials and bioplastic manufacturing processes for certain applications that require a special level of elasticity and flexibility.

The elasticity value in this study has not yet obtained results that meet the standards. The best elasticity value obtained from this study was 0.541 at 5% PVA concentration with a stirring time of 45 minutes. According to international standards (ASTM D638) the elasticity value of bioplastics is at least 200 MPa.

Biodegradation

The purpose of biodegradation testing is to understand the extent to which biodegradable plastics can withstand the influence of degrading microorganisms, moisture, temperature, and physicochemical factors present in the soil.

Figure 1. Biodegradation testing

The results of the variation analysis showed that the observed variables, namely the concentration of Polyvinyl Alcohol (PVA) and the length of stirring time, did not have a significant effect on biodegradability. The biodegradable plastic produced in this study has properties that are easily decomposed because PVA is a material that easily interacts with water and microorganisms found in soil. Biodegradable plastic can be completely degraded for 7 days. It can be seen in Figure 2 that the plastic melts and merges with the soil.

Figure 2. Biodegradable plastic at 7 days burial

The degradation of biodegradable plastics is greatly influenced by the starch content in them. The higher the starch concentration, the more microorganisms play a role in the degradation process. These microorganisms use enzymes to break the polymer bonds and convert them into monomers[9]. Biodegradable plastics also contain hydroxyl (O-H), carbonyl (C=O), and carboxyl (C-O) ester functional groups that are hydrophilic, thus facilitating the penetration of water molecules and allowing microorganisms to enter the structure of biodegradable plastics for the degradation process.

The biodegradability of all these biodegradable plastics has met the quality standards of bioplastics. According to SNI 7188.7:2016, bioplastics must degrade >60% within 7 days, and all biodegradable plastics have been completely degraded within 7 days.

CONCLUSION

Polyvinyl alcohol (PVA) concentration and stirring time have a significant influence on mechanical properties. The results showed that at a PVA concentration of 5% with a stirring time of 45 minutes, bioplastics showed the best quality with a tensile strength value of 2.25 Mpa, the best elongation of 416%, and the best young modulus of 0.541. However, it is interesting to note that PVA concentration and stirring time had no significant effect on the degradation rate of biodegradable plastics. All plastic samples were fully degraded and integrated into the soil within 7 days. This indicates that the bioplastics produced at various PVA concentrations and stirring times have an equivalent ability to undergo natural, environmentally friendly degradation.

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