ISSN (Print) : 2337-9030 ISSN (Online) : 2685-2608
PILLAR OF PHYSICS
JURNAL BERKALA ILMIAH FISIKA
Vol. 17 (1), 2024, page. 47-54
DOI : 10.24036/15279171074

MECHANICAL CHARACTERISTICS OF ORGANIC WASTE-BASED BIODEGRADABLE PLASTICS WITH VARIATIONS IN CELLULOSE CONCENTRATION AND SYNTHESIS TEMPERATURE

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ABSTRACT

Biodegradable plastic is an innovative plastic material that is environmentally friendly because it has the property of being easily decomposed naturally by the activity of microorganisms. Biodegradable plastics are generally made from starch and cellulose which are natural polymer materials that are easily decomposed in nature. Some organic wastes contain a lot of starch and cellulose, one of which is cassava peel and corn cob waste. In this study, starch from cassava peels was used as raw material in the manufacture of biodegradable plastics and cellulose from corn cobs which functioned as filler. The purpose of this study are to determine the effect of corn cob cellulose concentration and synthesis temperature on the mechanical properties and biodegradability of biodegradable plastics. In this study, the method used to make biodegradable plastic is by using the material mixing method. There are two treatment factors, namely variations in corn cob cellulose concentration of 0%, 1%, and 2% and synthesis temperature with variations of 70˚C, 80˚C, and 90˚C. The results showed the best characteristics for the tensile strength test at the addition of 2% of cellulose concentration and 90˚C synthesis temperature of 2.31 MPa. While the best elongation value is at 0% cellulose concentration and 90˚C synthesis temperature of 21%. The best biodegradation results were obtained from the addition of a cellulose concentration of 2% and synthesis temperature of 70˚C which decomposed perfectly in the soil for 8 days.

Keywords : *Biodegradable Plastic; Starch; Cassava Peel; cellulose; Corn Cob*

I. INTRODUCTION

In recent years, plastic bag waste has become one of the most alarming environmental pollution problems in Indonesia [1]. The main reason is that the use of plastic bags as packaging is increasing and accompanied by the habit of people who often throw plastic waste carelessly. It is estimated that every day Indonesia produces 176,000 tons of waste or 64 million tons/year and about 3.2 million tons of them are plastic waste. Most of the discarded plastic waste comes from synthetic polymer materials that are not easily decomposed by microorganisms [2].

Several efforts have been made to reduce environmental damage, one of which is the development of technology towards alternative environmentally friendly plastics that can be biodegraded naturally, namely biodegradable plastics. Indonesia as a country rich in natural products, has the potential to produce various natural polymer materials so biodegradable plastic packaging technology has good prospects [3]. One of the natural polymer materials in making biodegradable plastics is starch. Starch is a biopolymer whose properties are close to ideal polymers, one of which is easily degraded in nature. Starch can be obtained in plant parts such as seeds and tubers [4].

Various studies have been conducted to explore various potentials related to the use of starch as an ingredient in biodegradable plastic composites, such as the manufacture of biodegradable plastics from cassava starch, potato starch, corn starch, and sago starch [5]. However, this material is less effective if used as a raw material for the process of making biodegradable plastics because in some areas this material is still used as an alternative to staple food. Therefore, it is necessary to utilize starch from organic waste materials, one of the organic wastes whose starch utilization is still lacking is cassava peel waste. Cassava peels contain a starch content of 44-59%.[6].

Biodegradable plastics from starch-based materials generally still have weaknesses, namely the plastic produced later is not resistant to water, is rigid, and easily brittle. Therefore, to improve these weaknesses, a combination of starch with fillers is carried out. The use of fillers in the manufacture of biodegradable plastics can improve mechanical properties in the form of tensile strength and water resistance of plastics [7]. The filler material that can be used is cellulose derived from agricultural organic waste [8]. According to Nur et al., (2020), the addition of cellulose as a filler in starch-based biodegradable plastics can reduce pore space and increase the density of intermolecular bonds so that the resulting plastic is stronger and resistant to pilling [9].

Based on research conducted by Budianto et al. (2019) on the characteristics of cassava peel starch-based biodegradable plastics using peanut shell cellulose reinforcement, shows that the addition of cellulose can affect the mechanical properties of biodegradable plastics. However, the use of peanut shell cellulose still produces weak tensile strength [10].

In this study, the cellulose used comes from corn cob waste which has a high cellulose content of 44.9%, so it has the potential to be utilized as a filler material in the manufacture of biodegradable plastics [11]. According to Chong et al. (2021), the use of corn cob cellulose as a filler with a weight percentage of 12% can increase the tensile strength of plastic by 108% and can reduce elongation by 10% when compared to biodegradable plastics from corn starch [12].

In addition, an important factor that needs to be considered in the process of making starch-based biodegradable plastics is the synthesis temperature or mixing temperature, because if the synthesis temperature used is too low or too high it can damage the molecular structure of the biodegradable plastic which results in a decrease in the quality of the biodegradable plastic produced [13]. Based on the description above, a study was conducted to analyze the mechanical characteristics of organic waste-based biodegradable plastics with variations in cellulose concentration and synthesis temperature. In this study, the biodegradable plastic produced will be tested for mechanical properties including tensile strength test, elongation test, and biodegradation test carried out by burying the sample in the soil for 8 days to determine the ability of biodegradable plastic to decompose.

II. METHOD

Experimental research was conducted to examine the cause and effect of treatment on the object of research to determine the effect caused. The research was conducted at the West Sumatra Region X LLDIKTI Laboratory. The tools used in the research were blender, analytical scales, magnetic stirrer, sieve, oven, beaker glass, filter paper, measuring cup, petri dish, watch glass, dropper pipette, funnel, mold, and UTM (Universal Testing Machine). The materials used in this research are starch made from cassava peel, corn cob cellulose as filler, NaOH 5%, NaOCl 2%, glycerol as a plasticizer, chitosan, and 1% acetic acid as solvent.

The research was divided into three stages, namely the first stage of making starch, the second stage of cellulose isolation and the third stage of making biodegradable plastic [14]. The first stage of this research began with the preparation of starch from cassava peel waste. The first step is to wash the cassava peels that have been separated from the tubers until they are clean, then cut into small pieces. After being cut, the cassava peels were mashed by blending and filtered using a filter cloth until starch water was obtained. Furthermore, the starch water was precipitated for 24 hours, the resulting starch sediment was then oven-dried at 80˚C, the results are shown in Figure 1.

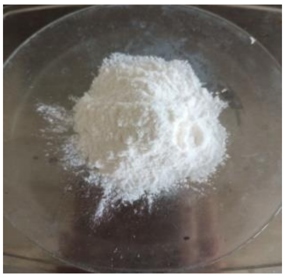

Fig. 1. Cassava peel starch

The starch obtained from cassava peel waste has a white color like starch in general as seen in Figure 1. To get starch that has finer grains, the starch is mashed again and sieved with a 200-mesh sieve to obtain fine starch.

The second stage is the corn cob cellulose isolation stage. Cellulose isolation from corn cobs is carried out by first washing the corn cobs that have been separated from the seeds and drying them in the sun. The dried corn cobs were pulverized into powder and then sieved using a 100-mesh sieve. There are three main components in corn cobs, namely cellulose, hemicellulose and lignin. To get cellulose from corn cobs, it is necessary to separate cellulose from hemicellulose and lignin. The difference between cellulose powder and pure corn cob powder is shown in Figure 2.

(a) (b)

Fig. 2. (a) Corn cob powder and (b) Corn cob cellulose powder

Figure 2 shows that the pure corn cob powder is still brown while the cellulose powder obtained from the corn cob is white, indicating that the powder no longer contains hemicellulose and lignin. To be able to separate cellulose from hemicellulose and lignin, 200ml of 5% NaOH was added to 10gr of corn cob powder, then stirred and heated at 100˚C for 1 hour with a magnetic stirrer. After that, it was filtered to get the residue, and then the residue from the filtration was dried at 80˚C. After drying the solid, 250ml of 2% NaOCl was added, and the solution was reheated and stirred for 1 hour, followed by filtration, washing with distilled water, and drying at 80˚C. Then mashed and sieved with a sieve to obtain white cellulose powder.

Next is the third stage, namely the manufacture of biodegradable plastic films. The first step was to weigh the mass of cassava peel starch and corn cob cellulose according to the treatment (mass ratio (m/m) of starch to cellulose is 2:2, 3:1, 4:0). Cassava peel starch was mixed with 80 ml of 1% acetic acid until homogeneous. Then corn cob cellulose was mixed into a glass beaker containing starch - acetic acid according to the treatment. The mixture was stirred using a magnetic stirrer at different temperature variations according to the treatment (T = 70˚C, 80˚C, 90˚C) for 30 minutes at 1100 rpm. After 5 minutes chitosan solution (5 g chitosan + 100ml acetic acid) was added to the starch-cellulose solution. The next step after 10 minutes as much as 3ml of glycerol was added to the starch - cellulose - chitosan solution and stirred again for 15 minutes. The homogeneous solution formed was poured into a mold and dried in an oven at 90˚C for 6 hours until bioplastic sheets were obtained.

III. RESULTS AND DISCUSSION

The following is the form of biodegradable plastic produced from mixing cassava peel starch, 1% acetic acid, glycerol, chitosan, corn cob cellulose as much as 0%, 1%, and 2%, with a synthesis temperature treatment of 70˚C, 80˚C, and 90˚C which produced 9 samples of plastic film as shown in Figure 3.

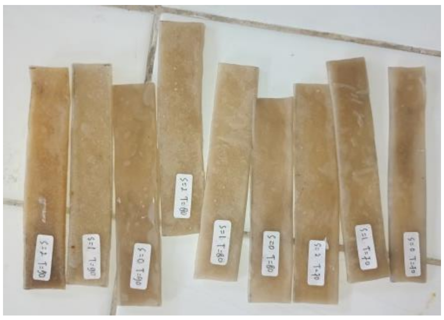

Fig. 3. Biodegradable plastic film from cassava peel starch

Figure 3 shows that the biodegradable plastic film produced has a slightly brownish color and the surface structure of the plastic film is slightly rough. In this study, the mechanical properties and biodegradability of the biodegradable plastic film produced were tested. Testing the mechanical properties of biodegradable plastic includes tensile strength tests and elongation tests. The results of testing the mechanical properties of biodegradable plastic from cassava peel starch with temperature variations and cob cellulose can be seen in Table 1.

Table 1. Mechanical properties test results of biodegradable plastic from cassava peel starch

Synthesis Temperature (˚C)	Cellulose Concentration (%)	Mechanical Properties (Standart JIS 2-1707)	
		Tensile strength (Mpa)	Elongation (%)
70	0	0,95	14,4
	1	1,35	13
	2	1,41	11,1
80	0	1,20	16,5
	1	1,73	14,2
	2	2,22	12,5
90	0	1,35	21
	1	2,13	18,3
	2	2,31	15,4

Table 1 shows that the variation of corn cob cellulose concentration and synthesis temperature used can affect the mechanical properties of biodegradable plastic from cassava peel starch. This is to the theory that the mechanical properties of biodegradable plastics are influenced by the properties of the components of the constituent materials and also (treatment during the synthesis process of biodegradable plastic films [15]

Tensile strength is a mechanical characteristic that indicates the size of the maximum stress required by a material to withstand a force before the material breaks [9]. Tensile strength measurement is done to determine the ability of biodegradable plastic to withstand the load when the plastic is stretched. The tensile strength value of biodegradable plastic from cassava peel starch with a variation of corn cob cellulose concentration and synthesis temperature is in the range of 0.96 -2.31 Mpa as shown in Figure 4.

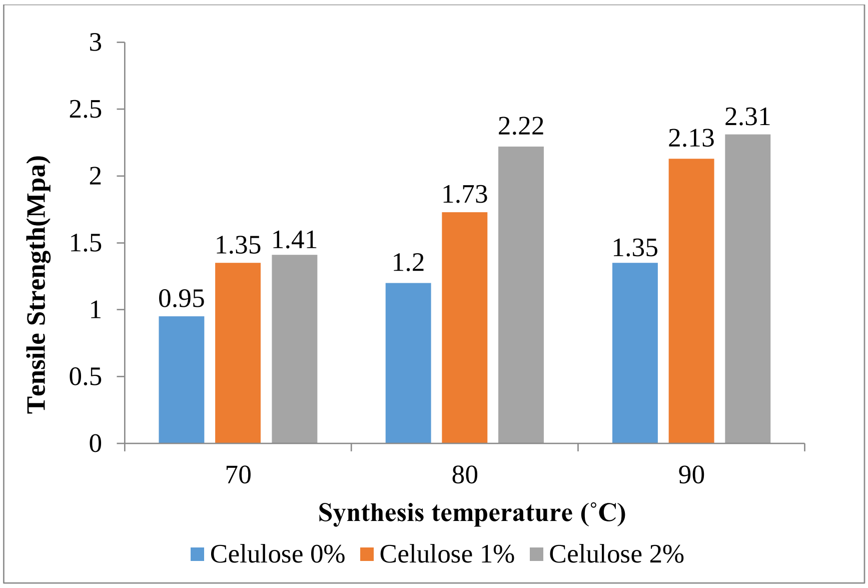

Fig. 4. Tensile strength test results of biodegradable plastics with corn cob cellulose addition and synthesis temperature

Figure 4 shows that the tensile strength value of biodegradable plastic from cassava peel starch increases as the concentration of corn cob cellulose increases and the synthesis temperature increases. The highest tensile strength value is in biodegradable plastic with corn cob cellulose concentration of 2% and a synthesis temperature of 90˚C at 2.31 MPa. This means that the corn cob cellulose concentration of 2% reacts well at a synthesis temperature of 90˚C. The higher synthesis temperature can facilitate the mixture to be more homogeneous, but at too high a synthesis temperature can result in the breakage of polymer chains in polysaccharide granules which will reduce the mechanical properties of biodegradable plastics [16].

Biodegradable plastic with the composition of corn cob cellulose addition has a greater tensile strength value compared to biodegradable plastic without the addition of corn cob cellulose. This is because cellulose as a reinforcing component has a straight and long polymer chain so that it can increase the mechanical strength of the composite material [8]. The increase in tensile strength of biodegradable plastics on the addition of cellulose is also influenced by hydroxyl groups from starch with hydroxyl and carboxyl groups from cellulose which form inter and intermolecular hydrogen bonds to form a thin layer that strengthens each other. So to be able to break the polymer chain bond between starch and cellulose, chitosan and glycerol require a lot of energy [17]

The lowest tensile strength value was obtained from biodegradable plastic with a cellulose concentration of 0% at a synthesis temperature of 70˚C, which amounted to 0.95 Mpa. The low value of tensile strength is influenced by several factors including due to the homogeneity of the plastic produced being different. The less homogeneous mixing process can result in uneven distribution of molecules in the constituent components of biodegradable plastics which causes the thickness of the resulting plastic to be uneven, so that the resulting plastic material has a decrease in tensile strength [18].

Based on the results of this study, the tensile strength values of all biodegradable plastic film samples from cassava peel starch have met the JIS (Japanese Industrial Standard) 2-1707 (1975) bioplastic standard. The minimum value for the tensile strength of bioplastics based on JIS 2-1707 (1975) is 0.392 Mpa.

Elongation is the change in length that occurs in the material when stretched or pulled, the more the distance between molecules is stretched the material increases in length until it finally breaks [19] Elongation testing aims to show the elasticity of biodegradable plastics. The greater the percent elongation, the more elastic the biodegradable plastic. The percent elongation value is obtained together with the tensile strength measurement [20]. The addition of corn cob cellulose concentration and synthesis temperature will affect the elongation value of biodegradable plastics from cassava peel starch as shown in Figure 5.

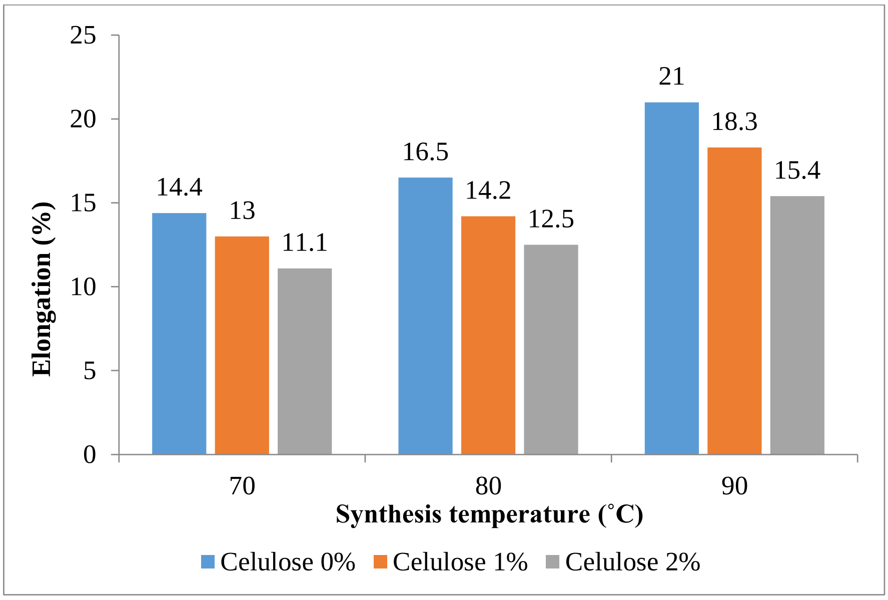

Fig. 5. Elongation test results of biodegradable plastics with corn cob cellulose addition and synthesis temperature

Based on Figure 5, it can be seen that the highest elongation value is found in biodegradable plastic treated with 0% corn cob cellulose concentration (without cellulose) with a synthesis temperature of 90˚C at 21%. On the other hand, the lowest elongation value was obtained with the addition of 2% corn cob cellulose concentration at 70˚C synthesis temperature, which amounted to 11.1%. The effect of synthesis temperature in biodegradable plastics has a relatively regular range, so it can be interpreted that the higher the blending temperature, the greater the elongation value of biodegradable plastics. The biggest influence on the elongation value of biodegradable plastics is the amount of biodegradable plastic constituent components used, namely cellulose, chitosan and glycerol as a plasticizer. The addition of glycerol as a plasticizer functions as a giver of elasticity properties in biodegradable plastics[21]. The more glycerol is added, it can make the plastic film more elastic so that its elongation will tend to increase [22].

The addition of filler in making biodegradable plastics can have an inverse effect when compared to the addition of plasticizers [23]. The addition of corncob cellulose causes the elongation value of biodegradable plastic to decrease. The decrease in elongation value occurs when the concentration of corn cob cellulose is increased by 2%. This is because cellulose has high flexibility, as a filler the addition of cellulose can also reduce the intermolecular bond distance due to the formation of more hydrogen bonds so that the resulting biodegradable plastic becomes stiff and less elastic [24].

Based on the results of this study, the elongation value of all biodegradable plastic film samples from cassava peel starch has met the JIS (Japanese Industrial Standard) 2-1707 (1975) bioplastic standard where the standard value of elongation <10% is said to be bad, the elongation value of 10% - 50% is stated to be quite good, and the elongation value >50% is stated to be good.

Biodegradation testing on biodegradable plastic films serves to determine how long it takes for plastic films to be degraded by microorganisms in an environment [25]. The biodegradation process can occur due to hydrolysis (chemical degradation), enzymes (enzymatic degradation), bacteria or fungi, and so on. Chemical degradation reactions in linear polymers can cause a decrease in molecular weight (shortening of chain length) [26]. In this study, biodegradation testing was carried out by burying plastic films in soil media. The use of soil media is because in the soil there are bacteria that can decompose plastic films so as to break polymer chains into monomers through enzymes produced by these bacteria. This process produces organic compounds in the form of lactic acid, amino acids, sugars and other organic compounds that do not pollute the environment [27].

Based on the results of the analysis, the addition of cellulose concentration and heating temperature had a significant effect on the degradation rate of biodegradable plastic from cassava peel starch. The results of the biodegradation test by burying the biodegradable plastic film in soil media for 8 days can be seen in Figure 6.

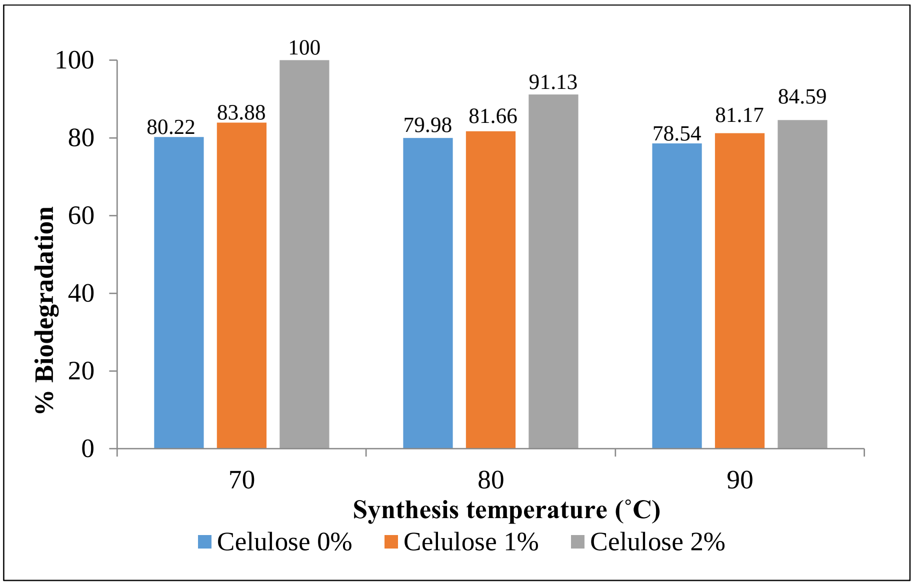

Fig. 6. Biodegradation test results of biodegradable plastics with corn cob cellulose addition and synthesis temperature

Based on Figure 6, it can be seen that for 8 days the biodegradable plastic film with a cellulose concentration of 2% lost weight faster than the plastic film with a cellulose concentration of 0% and 1%. This is because the concentration of corn cob cellulose used can absorb more water which will accelerate the degradation process [28]. Cellulose contains hydroxyl groups and carboxyl groups so that it can bind and absorb water molecules contained in the soil. This causes the humidity of biodegradable plastics to increase, thus accelerating the development of microorganisms such as bacteria and fungi that can decompose biodegradable plastics when buried in the soil [29]. In addition, the increase in the percentage of biodegradation in biodegradable plastics occurs because the plastic film is made from starch, where starch contains hydroxyl groups and is hydrophilic which can bind water from the soil [30].

Conversely, increasing the synthesis temperature can prolong the degradation process of biodegradable plastics [31]. It can be seen in Figure 6 that the degradation process of biodegradable plastic films with 90˚C synthesis temperature treatment is slower in losing weight than plastic films with 70˚C and 80˚C synthesis temperature treatment. This occurs because the increase in heating temperature in the synthesis of biodegradable plastics results in many plastic particles undergoing physico-chemical changes, where the molecular structure of the plastic is increasingly homogeneous and tight, The increase in blending temperature also results in reduced water content in biodegradable plastics, causing the process to take longer to decompose [32].

Based on Indonesian standards (ASTM 5336), the duration of biodegradable plastic film degradation for PLA plastic from Japan and PLC from the UK takes as long as 60 days to degrade completely (100%) [33]. In the results of this study, the duration of the plastic degraded almost completely (above 75%) for 8 days. This proves that all plastic film samples have met the criteria of biodegradable plastics that are easily degraded based on ASTM 5336.

IV. CONCLUSION

The addition of corn cob cellulose concentration and the increase of synthesis temperature affect the mechanical properties and biodegradation of biodegradable plastics from cassava peel starch. The higher the concentration of cellulose added to the biodegradable plastic, the higher the tensile strength value, but the elongation value will decrease. Meanwhile, the higher the use of synthesis temperature, the higher the tensile strength and elongation values. The highest tensile strength value was obtained from the addition of 2% cellulose concentration and a 90˚C synthesis temperature of 2.31 Mpa, while the best elongation value was at 0% cellulose concentration and 90˚C synthesis temperature of 21%. The addition of cellulose concentration can make the biodegradable plastic decomposition process take place faster, on the other hand, the increase in synthesis temperature which is higher results in the biodegradable plastic experiencing a slower decomposition process. The best percent weight loss of biodegradable plastic was obtained from the addition of 2% cellulose concentration and 70˚C synthesis temperature which decomposed completely in the soil for 8 days.

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