Jurnal
Teknologi

Full Paper

DEVELOPMENT OF ECOFRIENDLY PLASTIC BAGS FROM BIOTHERMOPLASTIC COMPOSITE OF MODIFIED CASSAVA STARCH–GLUCOMANNAN-POLYVINYL ALCOHOL-POLYCAPROLACTONE

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Article history
Received
6 March 2023
Received in revised form
11 September 2023
Accepted
28 November 2023
Published Online
18 February 2024

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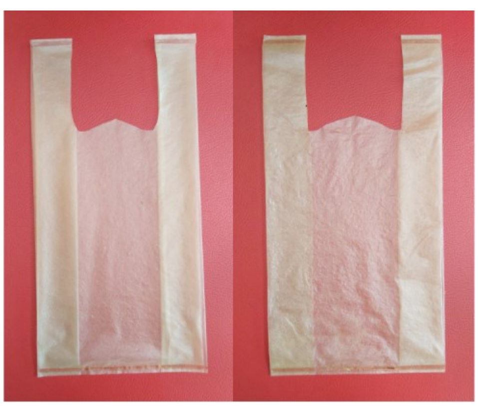
Graphical abstract



(a) (b)

a. Using teflon moulds; b. Using acrylic moulds

Abstract

The purpose of the study was to determine the type of molding material and the sealing temperature in the formation of ecofriendly plastic bags made from a Modified Starch – Glucomannan – Polyvinyl Alcohol – Polycaprolactone (MSGPVAPCL) biothermoplastic composites. The study used a factorial randomized block design experiment. Factor 1: the type of molding material consists of Teflon and acrylic while factoring 2: the sealing temperature with levels of 90, 95, 100, 105, and 110 °C. Mechanical, physical, biological and chemical characteristics were observed. The research results show that the type of teflon molding material and the sealing temperature of 105°C gave the best characteristics of ecofriendly plastic bags with a tensile strength value of 28.62 MPa, elongation at break of 8.68%, Young's modulus 449.44 MPa, a heat seal tensile strength on the bag handle of 6.10 N, a heat seal tensile strength on the bag bottom of 4.10 N, tear strength direction longitudinally of 3.61 N, transverse tear strength of 1.78 N, WVTR of 91.23 g/m^2/day, swelling of 5.31% and biodegradation time of 7.00 days, the maximum evaporation temperature of 72.43 °C, degradation temperature of 220.97 °C and a weight loss of 30.07%, a crystalline degree of 20.71% and an amorphous degree of 79.29%, a smooth longitudinal surface profile with slight waves and a transverse surface profile showing the presence of waves and fine fibers, containing functional groups O-H alcohol, C=O, C=C, C-O and $(CH_2)n$ and no heavy metals were detected. The characteristics of ecofriendly plastic bags in this research meet SNI 7818:2014 and some do not meet international standards.

Keywords: Ecofriendly plastic bags; MSGPVAPCL; type of molding material; the sealing temperature

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1.0 INTRODUCTION

Single-use plastic shopping bags will be immediately disposed of as trash after use [1]. According to Patton and Li [2], 10 billion pieces of plastic bags are wasted on the environment per year, or 85,000 tons. Meanwhile, according to Aprindo [3], 100 outlets of Aprindo members a year produce 10.95 million pieces of plastic bag waste, which is equivalent to 65.7 hectares of plastic bags. This is supported by data from Patton and Li [2] which explains that Asian people use single-use plastic bags up to 20 kg/person/year, Western Europe and North America use plastic bags of 100 kg/person/year, with an amount of 43% wasted in landfills. Thus, plastic bags become a very potential environmental pollutant because it is difficult to degrade. Thus, to overcome this, it is necessary to develop ecofriendly plastic bags made from natural and easily renewable materials such as biological materials, plants, animals, and microorganisms. One of the potential raw materials for developing ecofriendly plastic bags is starch from cassava. According to the OECD/FAO [4], world cassava production reaches 247 billion tonnes (dry matter), thus cassava starch production is also very large (190.19 billion tones).

According to SNI 7818:2014, ecofriendly plastic bags are plastic bags that designed in such a way that their chemical structure changes significantly under certain environmental conditions which has an impact on changes in properties measured using standard methods. This means that the ecofriendly plastic bags are bioplastic made from natural raw materials and is easily biodegradable. Several studies have developed bioplastics using biothermoplastic composites as raw materials. For example, Harsojuwono *et al.* [5] have developed a biothermoplastic composite from cassava starch modified, glucomannan, and polyvinyl alcohol which has the characteristics of being able to melt and stick when heated. Meanwhile, Paoli [6] showed that biothermoplastic composites derived from natural biological materials are not resistant to heat. If heated, the texture changes from hard to soft, but when cooled again, the texture changes from soft to hard again. Park *et al.* [7] reported that isosorbide biothermoplastic composites have soluble and recyclable characteristics and have a tensile strength of 78 MPa with a melting temperature of 212°C, and a coefficient of thermal expansion of 23.8 ppm/°K. Harsojuwono *et al.* [8] have developed a Modified Starch – Glucomannan – Polyvinyl Alcohol – Polycaprolactone (MSGPVAPCL) biothermoplastic composite and used 0.5% maleic anhydrous acid as a compatibilizer. The results of the development of MSGPVAPCL bio thermoplastic composites are biothermoplastic sheets that are not yet in the form of ecofriendly plastic bags. This biothermoplastic composite has tensile strength characteristics with a ratio of 1.20 and Young's modulus with a ratio of 1.36 to commercial plastics, elongation at break of 8.01%, swelling of 4.85%, Water Vapor Transfer Rate (WVTR) of 91.12 g/m^2/day, degradation time of 7 days, crystalline degree of 20.80%, amorphous degrees of 79.20%, the maximum temperature of the evaporation process is 72.56 °C, the maximum temperature of degradation is 221.01°C and has met most of the SNI 7818:2014 and international standards (ASTM 5336), Thus, the MSGPVAPCL biothermoplastic composite has great potency to be made ecofriendly plastic bags. The problem is that making ecofriendly plastic bags from the MSGPVAPCL biothermoplastic composite is influenced by many factors, including the molding equipment material and the sealing temperature in the casting method. By knowing and obtaining the right molding equipment material and sealing temperature, it is hoped that ecofriendly plastic bags will be produced from MSGPVAPCL biothermoplastic composites that meet SNI 7818:2014 and ASTM 5336.

According to Judawisastra *et al.* [9], the wrong type of molding equipment material in the casting process causes failure to form a biothermoplastic composite sheet, such as the sheet being sticky and cannot be separated from the molding tool. According to Harsojuwono *et al*. [10], teflon sheets can be used to mold glucomannan-modified cassava starch bioplastic composite sheets and have complied with the SNI 7818:2014 and ASTM 5336. Meanwhile, Ikhwanudin *et al*. [11] succeeded in using acrylic plates in molding bioplastic composites based on *batu* banana leaf powder and Carboxylmethyl Celulose (CMC) reinforced with Arabic gum.

In addition to the molding materials mentioned above, the sealing temperature also has an effect on the formation of ecofriendly plastic bags. The sealing temperature is basically related to the melting temperature of the biothermoplastic composite. A sealing temperature that is too low will cause the biothermoplastic composite sheet to not melt, causing sealing failure. Meanwhile, a temperature that is too high will burn the biothermoplastic composite sheet which will also result in sealing failure [12]. According to Setiawan *et al.* [13], bioplastic based on cassava peel starch with rice husk nano-silica can be sealed at a temperature between 91.43–139.22°C depending on the concentration of nano-silica used. Sari *et al*. [14] showed that the biothermoplastic composite of galactomannan and polyvinyl alcohol had a sealing temperature of 120°C. Meanwhile, Maghfirah *et al*. [15] showed a bioplastic composite of starch and ceratin which has a melting temperature of 95°C which is also the sealing temperature. The description above shows that the type of molding equipment material and sealing temperature are only suitable for certain biothermoplastic composite materials, while the information about the type of molding equipment material and sealing temperature in making ecofriendly plastic bags made from MSGPVAPCL biothermoplastic composite material is not yet known. Therefore, it is necessary to conduct research on the type of molding equipment material and sealing temperature in order to produce ecofriendly plastic bags from MSGPVAPCL biothermoplastic composites that meet SNI 7818:2014 and international standards (ASTM 5336). The aim of this research is to determine the type of molding equipment material and the correct sealing temperature so that ecofriendly plastic bag characteristics are produced from MSGPVAPCL biothermoplastic composites that meet SNI 7818:2014, and international standards (ASTM 5336).

2.0 METHODOLOGY

2.1 Material

The materials used in this study included modified cassava starch and glucomannan (CV Nura Jaya), vinegar (CH_3COOH), glycerol, ZnO, and distilled water (CV Brathacem), PVA, PCL, and maleic acid (CV Sukses Makmur). The tools used were a water bath, teflon plate and acrylic plate, plastic mechanical test equipment, namely autograph-Shimadzu based on ASTM D638, Scanning Electron Microscopy (SEM), FTIR Spectrometer, Thermal Gravimetry Analyzer (TGA), X-Ray Diffractometer (XRD).

2.2 Method

2.2.1 Experimental Design

The experiment design in this study was a randomized group design in factorial experiments. Factor I was the type of molded material (M) which includes Teflon (M1) and acrylic (M2). Factor II was the sealing temperature (T) with levels of 90 (T1), 95 (T2), 100 (T3), 105 (T4), and 110 °C (T5) therefore, there were 10 combination treatments. Each treatment combination was grouped into 4 based on the processing time of making ecofriendly plastic bags from glucomannan-modified cassava starch biothermoplastic composites, so there were 40 experimental units.

2.2.2 Ecofriendly Plastic Bag Manufacturing

Modified cassava starch and glucomannan were prepared in a ratio of 3:1 with a total weight of 6 g plus 90 g of 1% acetic acid solution and then heated and stirred in a water bath at a temperature of 75$\pm$1 °C to form a gel. The heated gel was added with 1 g of glycerol, 0.6 g of ZnO, and 3 g of polyvinyl alcohol and then stirred for 5 min at a temperature of 75$\pm$1 °C. Furthermore, 1.2 g of polycaprolactone gel (PCL was dissolved and stirred until homogeneous in ethyl acetate at a ratio of 1:1 according to Harsojuwono *et al.* [8] and 0.21 g of maleic acid and stirred for 5 minutes. Further, it was molded on a mold plate with the type of molding material according to the treatment and continued with drying in a drying oven at a temperature of 60 °C for 5 hours. The formed biothermoplastic composite was cooled at room temperature above the mold and removed after 24 hours [16]. The biothermoplastic composite sheet was then formed into a bag with the appropriate sealing temperature according to the treatment. Ecofriendly plastic bags that are formed were tested according to quality variables based on SNI 7818: 2014 as well as international standards (ASTM 5336).

2.2.3 Observation Variable

The variables observed included tensile strength (SNI 7818:2014), elongation at break (SNI 7818:2014), Young's modulus (ISO 527/1B), the heat seal tensile strength and tear strength (SNI 7818:2014), WVTR (JIS 2-1707), swelling (EN 317), biodegradation time (ASTM 5336), surface profile (ASTM E 2015), functional group [30], thermal stability (ASTM E2550), crystallinity (ASTM F2778), and heavy metal content (ISO/IEC 17025).

2.2.4 Data Analysis

Data from measurements of tensile strength, elongation at break, Young's modulus, heat seal tensile strength, tear strength, WVTR, swelling, biodegradation time were analyzed of variance (ANOVA) using the SPSS 25 program and continued with the Duncan Multiple Range Test to see differences between treatments. Meanwhile, the surface profile data, thermal stability, crystallinity and heavy metal content were analyzed descriptively both qualitatively and quantitatively.

3.0 RESULTS AND DISCUSSION

3.1 Tensile Strength, Elongation at Break, and Young's Modulus

The analysis of variant showed that the type of molding equipment had a significant effect, meanwhile, the sealing temperature and its interactions did not significantly affect the tensile strength, elongation at break, and Young's modulus of ecofriendly plastic bags. The mean tensile strength values ranged from 26.14–28.62 MPa, elongation at break ranged from 8.61–10.67% and Young's modulus ranged from 329.63–449.44 MPa, as shown in Table 1.

Using teflon molding equipment resulted in the ecofriendly plastic bags with a higher tensile strength (28.21–28.62 MPa) than its counterpart that using acrylic molding equipment (26.16–26.67 MPa). It seems that the Teflon molding equipment has a smoother surface and greater cohesive force than the acrylic type. According to Ayoola *et al*. [17], the mold structure with a smooth surface and high cohesive force causes the molded material to be less sticky and tend to bind strongly to each particle of the material compared to surfaces that have low cohesive forces or higher adhesion forces. This also results in lower casting defects such as lower porosity thereby increasing tensile strength [18]. However, when compared with SNI 7818:2014, all ecofriendly plastic bags have met the standard with a minimum value of 13.7 MPa.

The elongation at break value of plastic bags using Teflon molding equipment is lower than those using acrylic molding equipment, with values between 8.61–8.83% and 10.38–10.67%, respectively. This is caused the cohesive force between the molding equipment surface and the material that is molded is higher than its adhesive force, resulting in a strong bond between the same particles in the material is molded [17]. The impact is that the particle dislocation motion is inhibited which reduces the elongation at break value [19]. However, when compared with the value of SNI 7818:2014 (400 – 1120 %), all ecofriendly plastic bags are not up to standard. When compared with ASTM 5336 which sets an elongation at break value of less than 500%, then all ecofriendly plastic bags have met the standard

The mean value of Young's modulus of plastic bags using Teflon molding equipment is higher than those using acrylic molding equipment, with mean values between 422.84–449.44 MPa and 329.63–388.89 MPa, respectively. The Young's modulus value is directly proportional to the tensile strength value. As explained by Ayoola *et al.* [17] and Zhang *et al*. [18], the higher cohesive force of the impression device causes the bond between the molded composite particles to be stronger. This causes low porosity and increased polymer strength so the tensile strength and Young modulus values are also high. However, when compared with ISO 527/1B which sets a minimum Young's modulus value of 6019 MPa, then all ecofriendly plastic bags do not meet the standard.

Table 1 The average of tensile strength, elongation at break, Young modulus of ecofriendly plastic bags

Treatment	tensile strength (MPa)	elongation at break (%)	Young's modulus (MPa)
Teflon, 90°C	28.21 ᵃ	8.83 ᵇ	422.84 ᵃ
Teflon, 95°C	28.26 ᵃ	8.77 ᵇ	442.22 ᵃ
Teflon,100°C	28.51 ᵃ	8.70 ᵇ	445.68 ᵃ
Teflon, 105°C	28.62 ᵃ	8.61 ᵇ	449.44 ᵃ
Teflon, 110°C	28.28 ᵃ	8.68 ᵇ	443.05 ᵃ
Acrylic, 90°C	26.16 ᵇ	10.67 ᵃ	329.63 ᵇ
Acrylic, 95°C	26.20 ᵇ	10.59 ᵃ	334.44 ᵇ
Acrylic, 100°C	26.29 ᵇ	10.47 ᵃ	351.11 ᵇ
Acrylic, 105°C	26.67 ᵇ	10.38 ᵃ	388.89 ᵇ
Acrylic, 110°C	26.24 ᵇ	10.41 ᵃ	356.04 ᵇ

Notes: Different alphabetical letters in the same column indicate a significant difference between treatment (P< 0.05)

3.2 WVTR, Swelling, Biodegradation Time

The analysis of variant showed that the type of molding material had a significant effect, meanwhile, the sealing temperature and its interactions did not significantly affect the WVTR and swelling. The type of molding equipment material, sealing temperature and their interactions have no significant effect on the biodegradation time of ecofriendly plastic bags. The mean value of WVTR ranged from 91.14–103.13 g/m²/day, swelling ranged from 5.31–6.86%, and biodegradation time ranged from 6.50–7.25 days, as shown in Table 2.

The WVTR value for ecofriendly plastic bags using Teflon printing equipment was significantly different from those using acrylic molding equipment. The WVTR value of plastic bags using Teflon molding equipment is lower than those using acrylic molding equipment, with values between 91.14–91.53 g/m²/day and 102.21–103.13 g/m²/day, respectively. This is in accordance with what was proposed by Turan [20], the difference in pore structure that causes differences in WVTR. Low porosity will reduce the ability to transport water vapor which means lowering WVTR, and vice versa [18, 20} The pore structure can also be seen on the surface profile of ecofriendly plastic bags. The pore structure of ecofriendly plastic bags that use Teflon molding is very smooth and tight compared to using acrylic. This causes the WVTR of ecofriendly plastic bags that use Teflon printing to tend to be lower than those that use acrylic. If the WVTR value of ecofriendly plastic bags is compared with the JIS 2-1707 standard which sets a maximum WVTR of 0.0292 g/m².hour, then the WVTR value does not meet the standard.

The mean value of swelling for ecofriendly plastic bags using Teflon molding equipment was significantly different from those using acrylic molding equipment. The swelling value of ecofriendly plastic bags using Teflon molding equipment is lower than those using molding equipment acrylic, with mean values between 5.31–5.61% and 6.53–6.86%, respectively. This is also related to the porosity of the material is molded. High porosity causes water molecules to be able to diffuse into the material, thereby increasing swelling [20]. If the swelling value of ecofriendly plastic bags is compared with the EN 317 standard which sets a maximum swelling value of 1.44%, then it does not meet the standard.

Table 2 The average of WVTR, swelling and biodegradation time of ecofriendly plastic bags

Treatment	WVTR (g/m²/ day)	swelling (%)	biodegrade-tion time (day)
Teflon, 90°C	91.53 ᵇ	5.62 ᵇ	7.00 ᵃ
Teflon, 95°C	91.47 ᵇ	5.56 ᵇ	7.25 ᵃ
Teflon,100°C	91.42 ᵇ	5.47 ᵇ	7.00 ᵃ
Teflon, 105°C	91.14 ᵇ	5.31 ᵇ	7.00 ᵃ
Teflon, 110°C	91.23 ᵇ	5.45 ᵇ	6.75 ᵃ
Acrylic, 90°C	103.13 ᵃ	6.86 ᵃ	6.50 ᵃ
Acrylic, 95°C	102.94 ᵃ	6.79 ᵃ	7.25 ᵃ
Acrylic, 100°C	102.74 ᵃ	6.62 ᵃ	7.00 ᵃ
Acrylic, 105°C	102.21 ᵃ	6.53 ᵃ	7.25 ᵃ
Acrylic, 110°C	102.45 ᵃ	6.64 ᵃ	6.75 ᵃ

Notes: Different alphabetical letters in the same column indicate a significant difference between treatment (P< 0.05)

The mean value of biodegradation time for ecofriendly plastic bags using Teflon molding equipment was not significantly different from those using acrylic molding equipment. The biodegradation time for ecofriendly plastic bags using the ASTM D5988 method produces values ranging from 6.50–7.25 days. This biodegradation time is similar to the degradation time of the MSGPVA biothermoplastic composite which is in the range of 6.25–6.50 days [5] and the degradation time of the MSGPVAPCL biothermoplastic composite is in the range of 7 days [8]. This biodegradation time is in accordance with international standards, namely ASTM 5336 for PLA from Japan and PCL from the UK which sets a maximum of 60 days.

3.3 Heat Seal Tensile Strength and Tear Strength

The analysis of variance showed that the type of molding material, the sealing temperature and their interactions had a significant effect to the tensile strength of heat seal and tear strength. The mean value of heat seal tensile strength at the handle of the bag ranges of 2.11 - 6.10 N, and at the bottom of the bag it ranges of 1.05 t - 4.10 N. The mean value of tear strength in the longitudinal direction ranges of 1.02 - 3.61 N, in the transverse direction it ranges of 0.72 - 1.78 N, as shown in Table 3.

Table 3 shows the same heat seal results as the research of Tsuji *et al* [21]. Initially, the increase in sealing temperature increases the tensile strength to its optimum point, after passing the optimum point the increase in temperature actually decreases tensile strength [21]. According to SNI 7818:2014 , the optimum temperature for sealing that does not cause scorching of the bioplastic sample is called heat seal. Therefore, the heat seal of ecofriendly plastic bags on the handle occurs at a sealing temperature of 105 °C, which results in a heat-adhesive tensile strength value of 5.60–6.10 N.

Meanwhile, SNI 7818:2014 determines the minimum value of heat seal is 4.9 N for the handle of the bag, thus the plastic bag made using Teflon and acrylic molding equipment with a sealing temperature of 105 °C has met the standard. The high mean value (4.05–4.10 N) of the heat seal tensile strength at the bottom of the bag was obtained by ecofriendly plastic bags that were molded using Teflon and acrylic at a sealing temperature of 105 °C, which was significantly different from the others. The low mean value (1.05 – 1.90 N) of the heat seal tensile strength at the bottom of the bag was found in ecofriendly plastic bags molded using Teflon and acrylic at sealing temperatures of 90 and 95 °C, which were significantly different from the others. The same explanation as that has been put forward by Tsuji *et al*. [21] for the tensile strength of heat seal at the handle of the bag.

Heat seal at the bottom of the bag occurred at a sealing temperature of 105 °C, which resulted in a heat seal tensile strength value of 4.05-4.10 N. Meanwhile, SNI 7818:2014 requires a minimum heat seal value of 2.9 N for the bottom of the bag, thus plastic bags made using Teflon and acrylic molding equipment with a sealing temperature of 105 °C have met the standard. Table 3 also shows that the high mean value (3.56–3.61 N) of tear strength in the longitudinal position is owned by ecofriendly plastic bags that are molded using Teflon and acrylic at a sealing temperature of 105 °C, which is significantly different from the others. This is because at the optimum temperature of sealing, the peak of cold crystallization occurs, thus the tear strength is maximal [21].

Table 3 The mean of heat seal tensile strength and tear strength of ecofriendly plastic bags

Treatment	Mean of heat seal tensile strength (N)		Mean of tear strength (N)	
	Pouch handle	bottom of the bag	Longi-tudinal	Trans-versal
Teflon, 90°C	2.13 c	1.10 c	1.03 b	0.76 b
Teflon, 95°C	3.73 bc	1.90 c	1.39 b	0.89 b
Teflon,100°C	4.82 ab	2.67 b	1.98 b	0.99 b
Teflon, 105°C	6.10 a	4.10 a	3.61 a	1.78 a
Teflon, 110°C	4.76 ab	2.73 b	1.94 b	0.96 b
Acrylic, 90°C	2.11 c	1.05 c	1.02 b	0.72 b
Acrylic, 95°C	3.69 bc	1.86 c	1.32 b	0.87 b
Acrylic, 100°C	4.76 ab	2.62 b	1.96 b	0.97 b
Acrylic, 105°C	5.60 a	4.05 a	3.56 a	1.74 a
Acrylic, 110°C	4.74 ab	2.71 b	1.91 b	0.89 b

Notes: Different alphabetical letters in the same column indicate a significant difference between treatment (P< 0.05

Based on SNI 7818:2014, the tear strength value in the longitudinal position is at least 2 N, meanwhile ecofriendly plastic bags made using Teflon and acrylic molding equipment with an adhesive temperature of 105 °C have a tear strength value in the longitudinal position which is higher than that set by SNI SNI 7818:2014. Therefore, environmentally friendly plastic bags are made using Teflon and acrylic molds with an adhesive temperature of 105 °C which meets tear strength standards for the longitudinal position.

The high mean value (1.74 – 1.78 N) of tear strength in the transverse position was obtained by ecofriendly plastic bags that were molded using Teflon and acrylic at a sealing temperature of 105 °C, which was significantly different from the others. These results are in accordance with the results of Nyoto *et al.* [22], who tested several product packaging.

Based on SNI 7818:2014, the tear strength value in the transverse position is at least 1 N. meanwhile ecofriendly plastic bags made using Teflon and acrylic molding equipment with an seal temperature of 105 °C have a tear strength value in the longitudinal position which is higher than that set by SNI 7818:2014. Therefore, ecofriendly plastic bags are made using Teflon and acrylic molding equipment with a sealing temperature of 105 °C which meets the tear strength standard of the transverse position.

3.4 Thermal Stability and Crystallinity

The thermal stability of ecofriendly plastic bags is presented in Figure 1. Figure 1a shows the relationship between temperature and weight loss rate (DTG/derivative of thermogravimetry) of ecofriendly plastic bags. Meanwhile, Figure 1b is the result of research by Harsojuwono *et al.* [5, 8] which shows the rate of weight loss for MSGPVAPCL biothermoplastic composites and MSGPVA biothermoplastic composites. There is a similarity between the rate of weight loss experienced by ecofriendly plastic bags and the rate of weight loss of the MSGPVAPCL biothermoplastic composite. Both have a higher weight loss rate than the MSGPVA biothermoplastic composite. Meanwhile, Figure 1c shows the evaporation process (phase I) which lasts up to a temperature of 100 °C and the degradation process (phase II) which lasts up to a temperature of 500 °C for ecofriendly plastic bags.

Meanwhile, Figure 1d shows the evaporation process (phase I) which lasts up to a temperature of 100 °C and the degradation process (phase II) which lasts up to a temperature of 500 °C for the MSGPVAPCL and MSGPVA biothermoplastic composites [5, 8]. In the description above, there is a similarity in the weight loss between ecofriendly plastic bags and the MSGPVAPCL biothermoplastic composite. But the MSGPVA biothermoplastic composite [5] shows a higher rate of weight loss than ecofriendly plastic bags.

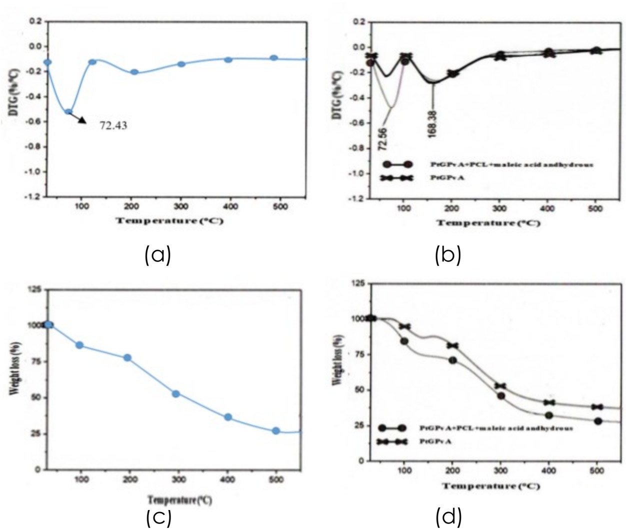


Figure 1 The relationship between temperature and DTG (a) ecofriendly plastic bags (b) biothermoplastic composite MSGPVAPCL [8] and MSGPVA [5] and the relationship between temperature and weight loss (c) ecofriendly plastic bags (d) biothermoplastic composite MSGPVAPCL [8] and MSGPVA [5]

Table 4 shows that the initial temperature of the evaporation process (phase I) of ecofriendly plastic bags and MSGPVAPCL biothermoplastic composites has almost the same temperature range, namely 37.88–37.99 °C. Eco-friendly plastic bags have a maximum evaporation temperature of 72.43 °C, while MSGPVAPCL biothermoplastic composites have a temperature of 72.56 °C. Both have the same maximum evaporation temperature. This has an impact on weight loss which is almost similar, which is around 4.71–4.73%. According to Perez *et al.* [23] the thermal stability of a material is known from the material's ability to resist evaporation (phase I) and degradation (phase 2).

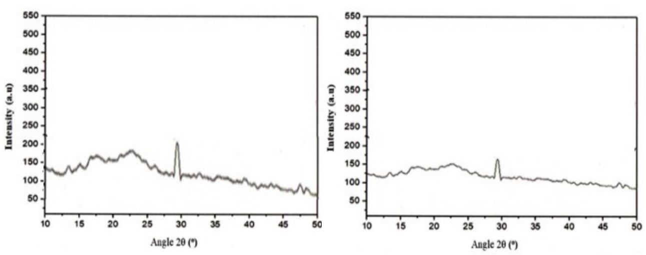
Table 4 also shows that the initial degradation of ecofriendly plastic bags occurs at a temperature of 105.56 °C which is close to the initial temperature of the degradation of MSGPVAPCL biothermoplastic composites at a temperature of 104.79 °C. This causes the degradation of ecofriendly plastic bags to occur at a maximum temperature of 220.97 °C which is close to the maximum degradation temperature of MSGPVA PCL biothermoplastic composites at 221.01 °C. As a result, both ecofriendly plastic bags and MSGPVAPCL biothermoplastic composites experienced a similar weight loss of 30.15% and 30.07%, with remaining charcoal 27.88% and 27.43%, respectively. This reduction in weight loss is the result of a complex process involving dehydration of the pyranose ring, polymerization and decomposition of glucose from starch [24].

Table 4 Initial temperature, maximum temperature, and weight loss during evaporation (phase I) and degradation (phase II) from ecofriendly plastic bags

Material type	Phase I			Phase II			charcoal on 500°C (%)
	$T_{initial}$ (°C)	T_{max} (°C)	Weight losses on T_{max} (%)	$T_{initial}$ (°C)	T_{max} (°C)	Weight losses on T_{max} (%)	
MSGPVAPCL [8]	37.99	72.56	4.73	104.79	221.01	30.15	27.8
Eco-friendly plastic bag	37.88	72.43	4.71	105.56	220.97	30.07	27.4

The relationship of 2θ angle with X-ray diffraction intensity on ecofriendly plastic bags is shown in Figure 2a, while the relationship of 2θ angle with X-ray diffraction intensity on MSGPVAPCL biothermoplastic composites [8] is shown in Figure 2b. Figures 2a and 2b have similar diffraction intensities between ecofriendly plastic bags and MSGPVAPCL biothermoplastic composites. Under these conditions, both have almost the same degree of crystalline and amorphous, 20.71% for the crystalline degree of ecofriendly plastic bags and 20.80% for MSGPVAPCL biothermoplastic composites. Meanwhile, the amorphous degree was 79.29% for ecofriendly plastic bags and 79.20% for MSGPVAPCL biothermoplastic composites [8] with diffraction peaks of 2θ which were close to the similarity at 13.4, 15.1, 16.7, 17.4, 22.7, and 29.30°.

Figure 2 shows that the ecofriendly plastic bag experiences a widening of intensity around the 2 theta area at angles 13.4, 15.1, 16.7, 17.4, 22.7°, while the intensity of 2 theta at an angle of 29.30° increases compared to the MSGPVAPCL biothermoplastic composite. This occurs due to the interaction of active groups from polymer components which form new crystals in ecofriendly plastic bags. of ecofriendly plastic bags and their comparison biothermoplastic composites. This is due to a decrease in intensity and a shift in the diffraction peak from the crystalline regions to the amorphous regions which is widely distributed. This condition occurs because intermolecular and intramolecular hydrogen bonds are broken during the composite formation process which results in damage to the crystal structure of the constituent polymer [25]. This is in accordance with the opinion of Zhang *et al.* [18] who explained that in the composite system there is a strong interaction of polymer-forming materials. This causes the polymer to be easily dispersed even without a solvent [26].

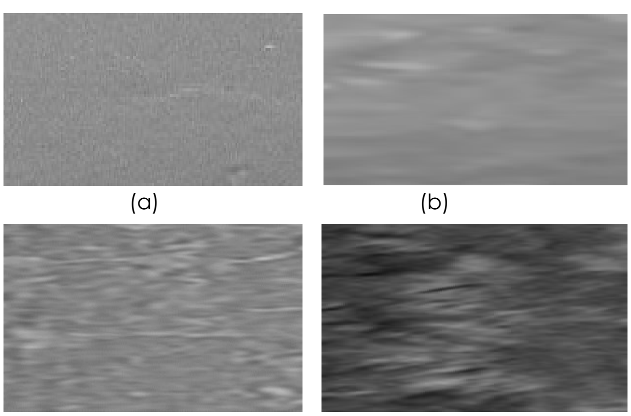


(a) (b)

Figure 2 The relationship between 2θ angle and X-ray diffraction intensity (a) ecofriendly plastic bags, (b) MSGPVAPCL biothermoplastic composites [8]

3.5 Surface Profile

Figure 3 shows that ecofriendly plastic bags have a smoother longitudinal and transverse surface profile with fewer waves than the surface profile of MSGPVAPCL biothermoplastic composites. This is due to the linear orientation of the polymer [27].

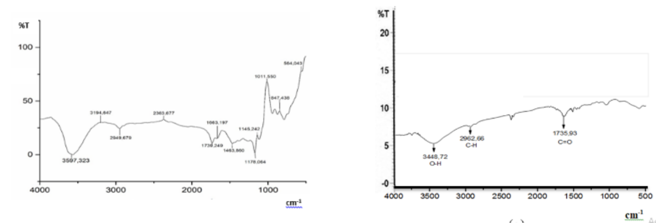


(a) (b) (c) (d)

Figure 3 Surface profile : Longitudinal view (a) ecofriendly plastic bags and (b) MSGPVAPCL bioplastic composite [8]; and transverse view of (c) ecofriendly plastic bags (d) MSGPVAPCL bioplastic composite [8]

3.6 Functional Groups

The presence of functional groups in ecofriendly plastic bags really depends on the ingredients used. Figure 4a shows the wavelength spectra of ecofriendly plastic bags, while Figure 4b is the wavelength spectra of the MSGPVAPCL biothermoplastic composite which is the comparison [8]. Meanwhile, Table 5 shows the functional groups in the wavelength shown in Figures 4a and 4b. Table 5 shows that ecofriendly plastic bags contain functional groups O-H at wavelengths of 2363,677, 2949,679, 3194,647, 3597,323 cm^{-1}, functional groups C=O at wavelengths of 1663,197, 1739,249 cm^{-1}, functional groups C=C at wavelengths of 1463,860, the C-O functional group at wavelengths of 10150, 1145.242, 1178.064 cm^{-1} and wavelengths $(CH_2)n$ at wavelengths of 564.62, 647.438 cm^{-1}.



(a) (b)

Figure 4 Wavenumber spectra (a) ecofriendly plastic bags, (b) biothermoplastic composites MSGPVAPCL [8]

Table 5 Comparison of wavelengths and functional groups of ecofriendly plastic bags with MSGPVAPCL biothermoplastic compositebags

Standard wavelength area (cm^{-1}) [30]	Standard functional group [30]	Wavelength on environ-mentally friendly plastic bags (cm^{-1})	Functional groups in environmentally friendly plastic bags	Wavelength of MSGPVA-PCL biothermo plastic composites (cm^{-1}) 8]	Functional groups in MSGPVA-PCL biothermo plastic composites [8]
2000-3600	O-H	2363.677, 2949.679, 3194.647, 3597.323	O-H	2962.66, 3448.72	O-H
1690-1760	C=O	1739.249	C=O	1735,93	C=O
1460-1480	C=C	1463.860	C=C		
1080-1300	C-O	10150, 1145.242, 1178.064	C-O		
650 – 1000	C-H	564.62,			
< 722	$(CH_2)_n$	647.438	$(CH_2)_n$		

This condition is different from the MSGPVAPCL [8] biothermoplastic composite which has fewer functional groups consisting of O-H at a wavelength of 2962.66, 3448.72 $cm^{-1}$and C=O at a wavelength of 1735.93 cm^{-1}. This indicates a change in the functional group and a shift in wavenumber. Changes in intensity and shift in wavenumber showed good biocompatibility between biopolymers [23, 28]. According to Zarzo [29], although organic compounds have the same basic elements in the form of carbon chains, they have very different properties from each other due to differences in inherent functional groups.

3.6 Heavy Metal Content

Ecofriendly plastic bags should not contain hazardous components, because the presence of hazardous components can cause migration from ecofriendly plastic bags to packaged products. This is in accordance with the opinion of Bhunia *et al.* [31], who explained that the chemical components of packaging made from polymers can migrate from the packaging to the packaged material during storage, microwave, or conventional heating treatment.

SNI requires that hazardous heavy metals are not allowed to be in ecofriendly packaging or plastic bags. The results of testing for heavy metals from ecofriendly plastic bags are shown in Table 6. Heavy metals such as Cd, Pb, Hg, and Cr^{3+} were not detected in ecofriendly plastic bags, so these ecofriendly plastic bags have complied with SNI.

Table 6 Heavy metal content in ecofriendly plastic bags

Heavy metal content	Test result
Cd	Not detected
PB	Not detected
Hg	Not detected
$C3^{3+}$	Not detected

4.0 CONCLUSION

The Teflon molding material type and pressing temperature of 105°C provide the best ecofriendly plastic bag quality with characteristics : a tensile strength value of 28.62 MPa, elongation at break 8.68%, Young's modulus 449.44 MPa, WVTR 91.23 g/m^2/day, swelling 5.31%, biodegradation time 7.00 days, tensile strength of the bag handle 6.10 N, tensile strength of the bottom of the bag 4.10 N, tear strength in the longitudinal direction 3.61 N, tear strength in the transverse direction 1.78 N.

Ecofriendly plastic bags have a maximum temperature of the evaporation process of 72.43°C, a maximum temperature of degradation of 220.97°C and experience weight loss of 30.07%, have a crystalline degree of 20.71% and an amorphous degree of 79.29%. Surface profile of ecofriendly plastic bag on the longitudinal posision show a smooth surface with few waves, while a transverse surface profile show a smooth waves and fibers. Ecofriendly plastic bag contain the functional groups O-H alcohol, C=O, C=C, C-O and (CH2)n and no heavy metals were detected.

The characteristics of tensile strength, elongation at break, biodegradation time, tensile strength of the bag handle, tensile strength of the bottom of the bag, tear strength in the longitudinal direction and tear strength in the transverse direction meet the standards of SNI 7818:2014 and ASTM 5336, while Young's modulus, WVTR and swelling do not meet other international standards.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

Acknowledgement

We would like to thank Udayana University for providing research grant funding from DIPA PNBP Udayana University TA-2022, No: B/78.15/UN14.4.A/PT.01.03/2022, April 19 2022 and facilitating the research and publication.

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