Decomposition Characteristics of Biodegradable Plastics Made from Sago Starch-Extraction Residue

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ABSTRACT: Biodegradable plastics were synthesized for the effective use of sago starch-extraction residue, which has been discarded as a waste. Two types of esterified sago starch-extraction residue, P-SP and L-SP, were obtained. It had black color for P-SP$_{160}$ (esterified by palm oil) to light yellow color for L-SP$_{80}$ (esterified by lauric acid) and showed high carbon content, ranging from 399.3 to 537.1 g kg^{-1}. Biodegradable plastics from the residue, which had high esterification degree showed thermoplasticity and slower decomposition in Andisols in Japan and Inceptisols in Philippines. The esterification degrees of P-SP$_{160}$ and L-SP were 3.23 and 2.95 to 5.18 mmol g^{-1}, respectively. In addition, L-SP$_{80}$ exhibited the most appropriate thermal softening behavior by heating. The cumulative decomposition of P-SP$_{160}$ in Andisols and Inceptisols showed 16.7 and 32.8% of total carbon during 31 day of the incubation. On the other hand, the decomposition rates of L-SP$_{80}$ in Andisols and Inceptisols were less than 10% of total carbon during 31 day of the incubation. The addition of triacetin as plasticizer to P-SP$_{160}$ and L-SP$_{80}$ remarkably influenced the decomposition rate of both molded P-SP$_{160}$ and L-SP$_{80}$. © 2010 Wiley Periodicals, Inc. J Appl Polym Sci 119: 3145–3151, 2011

Key words: biodegradable; esterification; plastics; thermoplastics

INTRODUCTION

The sago palm, *Metroxylon sagu*, grows in lowland in Southeast Asia and Pacific Ocean within 10 degrees north and south from the equator.[1] It can accumulate starch in its trunk, which has been estimated to be more than 200 kg of starch per palm as a staple food. The residue is produced in the sago starch-extraction process and partly used for the medium of mushroom, compost and feeding materials for cattle.[2] However, there is no suitable way to utilize until now. On the other hand, palm oil also produced in Southeast Asia. The amount of production of palm oil was increasing year by year in Malaysia and Indonesia. The amount of palm oil production in Malaysia and Indonesia was 1.65 million ton and 1.69 million ton in 2007, respectively.[3] Palm oil, the ester of glycerol and several fatty acids, can be used for food, detergent, and plasticization.

Funakoshi et al.,[4] Kiguchi,[5] Shiraishi,[6] and Hassan et al.[7] have made biodegradable plastics from woody materials and bagasse fiber. Watanabe et al.[8] started the study on production of biodegradable plastics by esterification of sago starch-extraction residue using palm oil. Sasaki et al.[9,10] and Okazaki et al.[11] developed the biodegradable plastics production from the sago starch-extraction residue by several kinds of esterification. Recently Igura et al.[12] estimated the tensile strength of biodegradable plastics made from sago starch-extraction residue.

There are several methods to evaluate the decomposition of plastics such as ISO 14,851, 14,852, 14,855, and 17,556. For example, ISO 17,556 suggested the evaluation of carbon dioxide emission from soils. EU and USA also proposed the evaluation methods for biodegradation of plastics using carbon dioxide emission.

The objective of this study is to evaluate biodegradation of two types of plastics made from the sago starch-extraction residue from the view point of carbon dioxide emission. Biodegradable plastics, which produced by esterification using palm oil (Palm oil-sago plastics, P-SP) and lauroyl chloride (lauroyl chloride-sago plastics, L-SP) were used.

MATERIALS AND METHODS

Production of biodegradable plastic (P-SP) by esterification using palm oil

In previous research, in which the production of biodegradable plastic using commercialized palm oil

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produced in Malaysia was performed.[12] The sago starch-extraction residue was cut into small fragments by a grinder. To remove lipid, the residue was refluxed in the mixture of ethanol and benzene (1: 2) with a Soxhlet's extractor for 24 h. Ten grams of the lipid removed residue (hereafter this is called the Unesterified) was esterified by 120 g of palm oil with 7.5 mL of 1.0 mol l^{-1} hydrochloric acid (HCl) using oil bath at 160°C for 2 h, and then unreacted oil was removed by the mixture of ethanol and hexane (9 : 1).[10] This sago biodegradable plastic obtained by this procedure was called P-SP$_{160}$.

Production of biodegradable plastic (L-SP) by esterification using lauroyl chloride

After the removal of lipid from the Unesterified, the mixture of ethanol and benzene (1: 2) was refluxed in a Soxhlet's extractor for 24 h. According to the production methods of Ohmi et al.,[13] 10 g of the Unesterified was esterified by 300 mL of lauroyl chloride (CH$_3$(CH$_2$)$_{10}$COCl) with 150 mL of pyridine (C$_5$H$_5$N) and 150 mL of N,N-dimethylformamide (C$_3$H$_7$NO) using a water bath at 40, 60, and 80°C for 2 h. The lauric acid is one of the fatty acids, which are contained in the palm oil, coconut oil, and palm kernel oil. Then, unreacted lauroyl chloride and organic solvent were removed by the mixture of ethanol and hexane (9 : 1). These sago biodegradable plastics esterified by lauroyl chloride at 40, 60, and 80°C were called L-SP$_{40}$, L-SP$_{60}$, and L-SP$_{80}$, respectively.

Evaluation of the plastic characteristics of P-SP and L-SP samples

Infrared microspectrometric analysis

Fourier transform infrared (FTIR) analysis was carried out for the confirmation of ester carbonyl group in esterified samples using the infrared microspectrometric apparatus (FT/IR-4100 type A and IRT-3000, JASCO Co.,). In this analysis, the Unesterified, P-SP$_{160}$ and L-SP$_{80}$ were used. The circular KBr plate (1 cm in diameter) of each sample was prepared for infrared microspectrometric analysis. The measurement range of wavenumber was 600 to 4000 cm^{-1}.

Measurement of esterification degree (Ed)

Although the esterification degree (ester value) has been provided for chemical products by Japan Industrial Standard (JIS K0070),[14] the method of Sasaki was suitably used for plant residue derivatives. In this study, the esterification degree was determined according to the methods of Sasaki, which modified the methods of Browning.[15,16]

The mixture of 0.3 g of the plastic sample and 25 mL of 0.5 mol L^{-1} KOH in ethanol was refluxed at 60°C in a water bath for 1 h. After cooling, 25 mL of 0.5 mol L^{-1} HCl and several drops of phenolphthalein were added to the flask. The amount of fatty acids that were generated by saponification were determined by titration using 0.5 mol L^{-1} NaOH.[12]

The esterification degree (Ed) was calculated using the formula:

$$Ed = 0.5 \times f \times (N_1 - N_0)/W$$

where Ed, esterification degree (mol g^{-1}); N_0, mL of 0.5 N NaOH for titration of the blank; N_1, mL of 0.5 N NaOH for titration of the sample; W, mass of sample (g).

Thermogravimetry (TG)

The thermogravimetric (TG) behavior of the Unesterified, P-SP$_{160}$ and L-SP$_{80}$ were evaluated from room temperature to 600°C using a thermogravimetric analyzer (Shimadzu TG-20). The samples were first dried in a vacuum drying oven at 60°C for 24 h. After sieving through a 60 mesh sieve, about 10 mg of each sample was used for TG analysis. The test was performed under a helium atmosphere (50 mL min^{-1}), with the temperature increasing at 10°C min^{-1}. A TG curve was obtained for each sample. The thermal degradation point was obtained from the intersection of the baseline and the tangent of the curve.

Thermal softening point

The thermal softening point (Ts) of the Unesterified, P-SP$_{160}$ and L-SP$_{80}$ were investigated using a penetration test in a thermomechanical analyser.[16] Each sample was dried in a vacuum drying oven for 24 h at 60°C. After sieving through a 60 mesh sieve, the sample was filled into a 7 mm diameter glass tube in the mantle heater. The glass pin of 4 mm in diameter was placed on the sample, and the penetration of the pin was measured on a dial gauge.[12] The measurement was performed in air, at atmospheric pressure, with the temperature increasing at a rate of 3°C min^{-1}. From the thermal softening curves of each sample obtained, the thermal softening point was calculated from the intersection of the baseline and the tangent of the thermal softening curve. The percent penetration was calculated using the formula:

$$Penetration(\%) = P/h \times 100$$

where P, the distance that the pin penetrated; h, the height of the sample in the glass tube.

	pH	EC (mS m^{-1})	Total carbon (g kg^{-1})	Total nitrogen (g kg^{-1})	MWHC[a] (g g^{-1})	CO$_2$ emission (g kg^{-1})
Andisols	6.30	6.39	35.6	3.2	1.03	1.40
Inceptisols	5.96	4.89	10.3	1.2	1.17	1.23

[a] MWHC, Maximum water holding capacity

Soil burial test of P-SP$_{160}$ and L-SP samples

The decomposition rate of the Unesterified, P-SP$_{160}$ and L-SP$_{80}$ samples were evaluated by a soil burial test. In addition, the soil burial tests of the molded P-SP$_{160}$ or L-SP$_{80}$ were also performed for the evaluation of the influence of plasticizer. According to the molding methods of Igura et al.,[17] P-SP$_{160}$ or L-SP$_{80}$ were used to mold small seedling pots in a hot press at 140°C, 215 kPa for 1 h with 50 percent (w/w) of 1,2,3-propanetriol triacetate (triacetin) as a plasticizer.[17] Both plastic pots were ground into powder and these were called P-SP$_{160}$-T and L-SP$_{80}$-T, respectively. P-SP$_{160}$-T and L-SP$_{80}$-T were also used for decomposition test.

The soil samples were collected from Hachioji, Japan for Andisols and Leyte, Philippine for Inceptisols. The pH of the soil samples was 6.30 for Andisols in Japan and 5.96 for Inceptisols in Philippines (Table I). Carbon content in Andisol and Inceptisol used in this study was 35.6 to 10.3 g kg^{-1} (Table I).

The Unesterified, P-SP$_{160}$ and L-SP$_{80}$ samples were buried in soils in the laboratory, and each sample was evaluated the biodegradation. Ten grams of air-dried soil was put into a glass bottle (volume: 140 mL) and the moisture was maintained in 55% of the maximum water holding capacity of each soil. Then each plastic sample was ground by a mortar and a pestle. These powdered samples were added to soil and mixed well in the glass bottle, and duplicate settings were prepared.

The glass bottle was sealed with a cap after the each sample was added and the gas of inside was collected by a syringe immediately after sealing. The carbon dioxide concentration in these gas phases was determined by a gas chromatograph (Shimadzu GC-8A) with thermal conductivity detector (TCD). After 3 h, the gas of inside glass bottle was collected by a syringe again and measured the carbon dioxide concentration of these gases. The determination of carbon dioxide concentration was continued at 25°C for 31 days later. The carbon dioxide concentration was determined using the standard gas of carbon dioxide (99.9%) and the obtained carbon dioxide concentration was designated as m^3 m^{-3}. The carbon dioxide emission rate was calculated using the difference of carbon dioxide concentration between

initial time and 3 h later. The carbon dioxide emission rate (g kg^{-1} h^{-1}) was calculated as follows:

$$P = p \times \Delta C/\Delta t \times V/M \times 273/(273 + T) \times 1000$$

where P, CO$_2$ emission rate (g kg^{-1} hr^{-1}); p, The density of CO$_2$ in 273 K (kg m^{-3}) = 44/22.4 = 1.96; $\Delta C/\Delta t$, The rate of change in the concentration of CO$_2$ in glass bottle (m^3 m^{-3} hr^{-1}); V, Internal capacity of glass bottle used for the cultivation (m^3); M, The dry weight of soil used for the cultivation (kg); T, Temperature (°C).

The net carbon dioxide emission rate was given from the difference between carbon dioxide emission rates of the sample-added glass bottle and glass bottle without plastics sample (control).

The total amount of carbon dioxide emission (mg kg^{-1}) was calculated from net carbon dioxide emission rate. Decomposition rate (D), which is the rate of carbon released as CO$_2$ in the total carbon of the sample,[18] was calculated as follows.

$$D = 100 \times [(CO_2)s - (CO_2)c]/(CO_2)_{Th}$$

where D, Decomposition rate (%); $(CO_2)s$, The amount of CO$_2$ emission in glass bottle with sample (mg kg^{-1}); $(CO_2)c$, The amount of CO$_2$ emission in glass bottle without sample (mg kg^{-1}); $(CO_2)_{Th}$, The amount of theoretical CO$_2$ emission (mg kg^{-1}).

The amount of theoretical carbon dioxide emission was calculated as follows:

$$(CO_2)_{Th} = M \times C \times (44/12)/S$$

where M, The sample weight that was added to glass bottle (mg); C, The rate of total carbon weight to sample weight; 44, The molecular weight of carbon dioxide (g mol^{-1}); 12, The atomic weight of carbon (g mol^{-1}); S, The weight of soil that was added to glass bottle (kg)

RESULTS AND DISCUSSION

Appearance of P-SP$_{160}$ and L-SP samples

The color of the original sago starch-extraction residue consisting of starch, cellulose, hemicellulose,

TABLE II
Color of the Unesterified Sago Starch-Extraction Residue and Sago Biodegradable Plastics Made from Sago Starch-Extraction Residue by Esterification

| Sample	Color
Unesterified[a]	Dull orange (7.5YR 7/4)
P-SP$_{160}$	Black (7.5YR 1.7/1)
L-SP$_{40}$	Pale yellow (2.5Y 8/3)
L-SP$_{60}$	Pale yellow (2.5Y 8/4)
L-SP$_{80}$	Light yellow (2.5Y 7/4)

[a] The unesterified sago starch-extraction residue

and lignin,[16] was light yellow-orange (7.5YR 8/3) to dull orange (7.5YR 7/4).[19] On the other hand, the color of P-SP$_{160}$ was black (7.5YR 1.7/1).[12] The color of L-SP$_{40}$, L-SP$_{60}$, and L-SP$_{80}$ were pale yellow (2.5Y 8/3), pale yellow (2.5Y 8/4), and light yellow (2.5Y 7/4), respectively (Table II). The addition of triacetin did not change the color of the plastics.

The color of original plastics produced is important for making various kinds of daily necessities. P-SP and L-SP were characterized by volume increase compared to the Unesterified.

Infrared microspectrometric characteristics of P-SP and L-SP

Figure 1 shows the FTIR spectra of the Unesterified, P-SP$_{160}$, L-SP$_{80}$. P-SP$_{160}$, and L-SP$_{80}$, which showed relatively high adsorption peak at 1730 cm^{-1}, which derived from the ester carbonyl group (C=O) absorption, compared with the Unesterified. The absorbance intensity (peak height) of ester linkage at 1730 cm^{-1} was the following sequence, Unesterified < P-SP$_{160}$ < L-SP$_{80}$. Therefore, the ester groups were introduced into P-SP$_{160}$ and L-SP$_{80}$ by esterification. On the other hand, L-SP$_{80}$ showed the remarkable increase of the adsorption peak in the range of 2800–3000 cm^{-1}, which derived from aliphatic C—H stretching (—CH$_2$— and —CH$_3$) adsorption. However, P-SP$_{160}$ showed a little increase in the adsorption
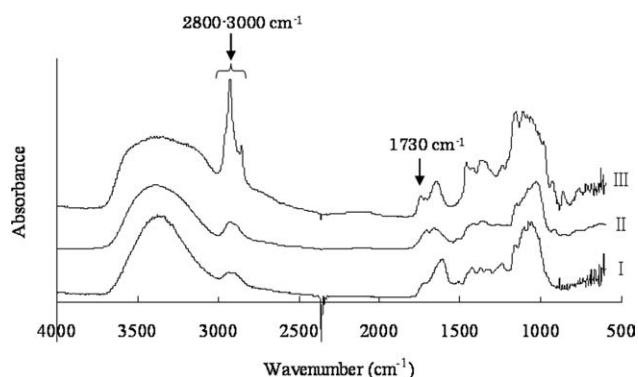
Figure 1 FTIR spectra of the unesterified sample, P-SP$_{160}$ and L-SP$_{80}$. I: the unesterified sago starch-extraction residue, II: P-SP$_{160}$, III: L-SP$_{80}$.

peak of 2800–3000 cm^{-1}. Therefore, it showed that much more fatty acid esters were formed in L-SP$_{80}$ in comparison with P-SP$_{160}$.

Esterification degree (Ed) of P-SP and L-SP

Figure 2 shows that the esterification degree (Ed) of the Unesterified was 1.84 mmol g^{-1} and esterified samples varied from 2.95 to 5.18 mmol g^{-1}. The esterification gave high Ed values to P-SP$_{160}$,[12] L-SP$_{40}$, L-SP$_{60}$ and L-SP$_{80}$, compared with the Unesterified, suggesting that the Unesterified sample originally held ester bonding. When the esterification temperature increased, the Ed of L-SP tended to increase gradually. L-SP$_{80}$, which had the highest Ed of all the L-SP samples, was used for the following further thermal analysis and soil burial test.

Thermal characteristics of P-SP and L-SP

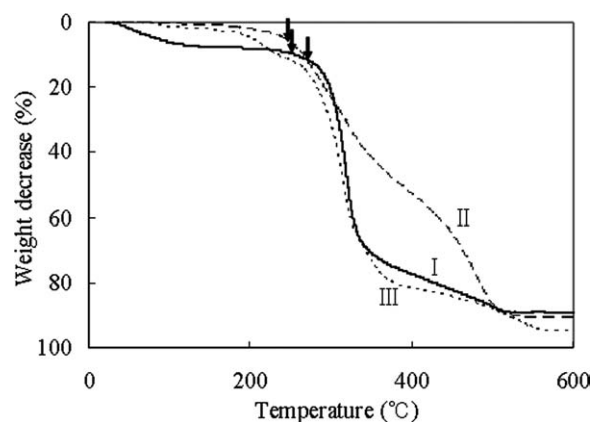#### Thermal degradation point (T_d) and thermal softening point (T_s)

Figure 3 and Table III show the thermogravimetric curves of the Unesterified, P-SP$_{160}^{12}$ and L-SP$_{80}$. The thermal degradation points (T_d) for the Unesterified, P-SP$_{160}$, and L-SP$_{80}$ were 259.6°C, 228.3°C, and 228.5°C, respectively. P-SP$_{160}$ showed almost similar T_d value to L-SP$_{80}$.

Figure 4 and Table III show the thermal softening curves of the Unesterified, P-SP$_{160}^{12}$ and L-SP$_{80}$. The thermal softening points (T_s) were 259.3, 220.1, and 115.1°C, respectively. L-SP$_{80}$ exhibited the lowest T_s in all samples. L-SP$_{80}$ exhibited the appropriate thermal softening value for the plastics in all samples. The remarkable decrease in thermal softening point suggested the thermoplastic characteristics of the material.

The thermal softening point of P-SP$_{160}$ was slightly lower than thermal degradation points. This suggests that thermal softening occurred in P-SP$_{160}$ before it was carbonized. P-SP$_{160}$ showed slight thermal softening. On the other hand, T_s and T_d of the Unesterified (259.3 and 259.6°C) occurred at much
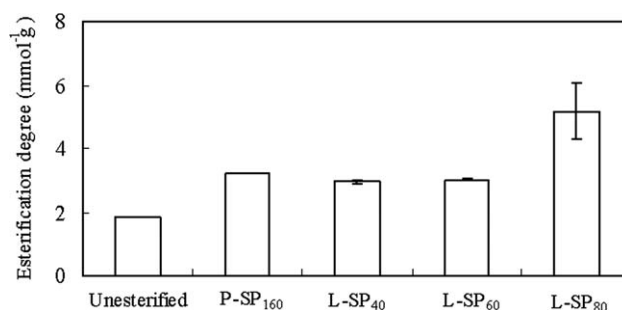
Figure 2 The esterification degree of P-SP$_{160}$ and L-SP samples.

Figure 3 Thermogravimetric curves of the unesterified residue, P-SP$_{160}$ and L-SP$_{80}$. I: the unesterified sago starch-extraction residue, II: P-SP$_{160}$, III: L-SP$_{80}$. Arrow shows thermal degradation point.

the same temperature. Thus, the residue did not exhibit thermal softening. The T_s of L-SP$_{80}$ was much lower than T_d of that. Therefore, L-SP$_{80}$ exhibited better thermal softening behavior than P-SP$_{160}$ and the Unesterified. The addition of lauric ester groups to a polymer can be expected to reduce the softening point of the material due to the long (C11) alkyl chain presented in the compound, which can act as an internal plasticizer for the polymer. The high esterification degree of the L-SP$_{80}$ by lauroyl chloride, therefore, can be expected to lower the softening point, compared to other samples, as the product has the highest degree of substitution.

Decomposition characteristics of sago biodegradable plastics

Decomposition characteristics of P-SP$_{160}$

Carbon content in Andisol and Inceptisol used in this study was 35.6 to 10.3 g kg^{-1}, which was a basic background value for carbon dioxide emission from soil. Andisol had higher carbon content compared with Inceptisol but the carbon dioxide emission in Andisols was similar to that in Inceptisols (Table I). Large amount of carbon dioxide emission from Inceptisol seemed to be derived from easily decomposable organic carbon content and the difference of microbial activities.

A-1 and B-1 in Figure 5 show the decomposition rate of P-SP$_{160}$ and the Unesterified that calculated from the CO$_2$ emission. During the period of 31 days, the decomposition rates of P-SP$_{160}$ reached 16.7% of added plastics carbon in Andisol and 32.8% in Inceptisol. P-SP$_{160}$ was decomposed much more quickly in Inceptisol than in Andisol, as shown in Figure 5.

Dřímal et al.[20] reported that the poly-β-hydroxybutyrate (PHB) as commercial biodegradable plastics reached almost 70% of decomposition rate (about 30 days) by gas chromatograph analysis. The degradation rate of P-SP$_{160}$ in Inceptisols was less than half value compared with PHB. The degradation rate of P-SP$_{160}$ in Andisol showed almost half value of P-SP$_{160}$ in Inceptisol. The degradation rates of P-SP$_{160}$ were clearly different in Andisol and Inceptisol.

Palm oil consisted of esters with glycerol and several saturated fatty acids; lauric acid (C$_{11}$H$_{23}$COOH, 0.1–1.0 %), myristic acid (C$_{13}$H$_{27}$COOH, 0.9–1.5 %), palmitic acid (C$_{15}$H$_{31}$COOH, 41.8–46.8 %), stearic acid (C$_{17}$H$_{35}$COOH, 4.2–5.1 %), arachidic acid (C$_{19}$H$_{39}$COOH, 0.2–0.7 %), and unsaturated fatty acids; Oleic acid (C$_{17}$H$_{33}$COOH; 37.3–40.8 %), linoleic acid (C$_{17}$H$_{31}$COOH; 9.1–11.0 %), linolenic acid (C$_{17}$H$_{29}$COOH, 4.2–5.1 %).[21] Therefore, P-SP$_{160}$ was composed of starch, cellulose, hemicellulose, and lignin esterified by several fatty acids.

Most of fungi can decompose biodegradable plastics made by the esterification.[9,22] Esterified cellulose is a major component of these plastics,[16] and is possible to be degraded by bacteria and Actinomyces,[23]

TABLE III
Physical and Chemical Properties of the Unesterified Sago Starch-Extraction Residue, P-SP$_{160}$ and L-SP$_{80}$

| Sample	Symbol	Esterification temperature (°C)	Esterification degree (mmol g^{-1})	Molding temperature (°C)	Total carbon (g kg^{-1})	Total nitrogen (g kg^{-1})	T_d[d] (°C)	T_s[e] (°C)
Unesterified	Unesterified [a]	–	1.84	–	379.6	3.3	259.6	259.3
Esterified	P-SP$_{160}$	160	3.23	–	399.3	3.3	228.3	220.1
	L-SP$_{40}$	40	2.95	–	467.9	2.6	226.4	183.3
	L-SP$_{60}$	60	3.03	–	510.3	2.8	227.7	149.3
	L-SP$_{80}$	80	5.18	–	537.1	2.5	228.5	115.1
Molded	P-SP$_{160}$-T [b]	–	–	140	449.2	3.4	–	–
	L-SP$_{80}$-T [c]	–	–	140	545.3	3.1	–	–

[a] Thermal degradation point.
[b] Thermal softening point.
[c] The unesterified sago starch-extraction residue.
[d] P-SP$_{160}$-T: the molded P-SP$_{160}$ which contain triacetin as plasticizer.
[e] L-SP$_{80}$-T: the molded L-SP$_{80}$ which contain triacetin as plasticizer.
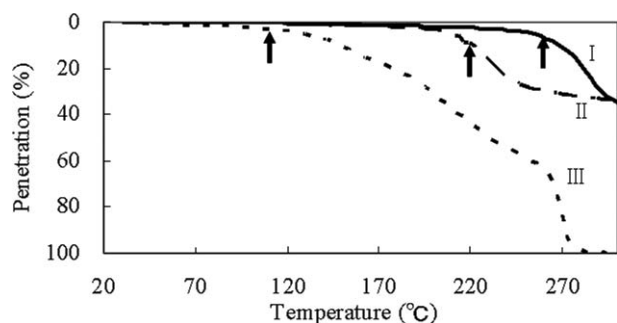
Figure 4 Thermal softening curves of the unesterified residue, P-SP$_{160}$ and L-SP$_{80}$. I: the unesterified sago starch-extraction residue, II: P-SP$_{160}$, III: L-SP$_{80}$. Arrow shows thermal softening point.

and so on. Therefore, the difference of decomposition rate in each soil rate seemed to be based on the different microbial communities.

Decomposition characteristics of L-SP$_{80}$

A-2 and B-2 in Figure 5 show the decomposition rate of L-SP$_{80}$ and the Unesterified that calculated from the CO$_2$ emission. During the period of 31 days, the decomposition rates of L-SP$_{80}$ reached 6.7% in Andisol and 9.3% in Inceptisol. The decom-

position rate of L-PS$_{80}$ during 31 days of soil burial test showed lower decomposition rate than P-SP$_{160}$ and provided the similar decomposition rate in Andisols and Inceptisols. The errors of the results of carbon dioxide emission of L-SP$_{80}$ were smaller than that of P-SP$_{160}$ and their standard deviation ranged from 0.4 to 0.6. A part of L-SP$_{80}$ seemed to be decomposed by microorganisms during the test period. Therefore, it is expected that L-SP$_{80}$ can be applied for plant seedling pots for wood, which can decompose in relatively long time.

Influence of the presence of plasticizer for decomposition rate

The decomposition rate of P-SP$_{160}$-T in Andisols and Inceptisols showed 26.5 and 40.6% of total carbon during 31 days of the incubation, respectively (Fig. 5). P-SP$_{160}$-T consisting of 1 : 1 mixture of P-SP$_{160}$ and triacetin (1,2,3-propanetriol triacetate), which was one of the most important component in the early stages of decomposition, was made by a hot press at 140 degree. On the other hand, the decomposition rate of L-SP$_{80}$-T in Andisols and Inceptisols showed 15.6 and 29.1% of total carbon during 31 days of the incubation, respectively. The addition of
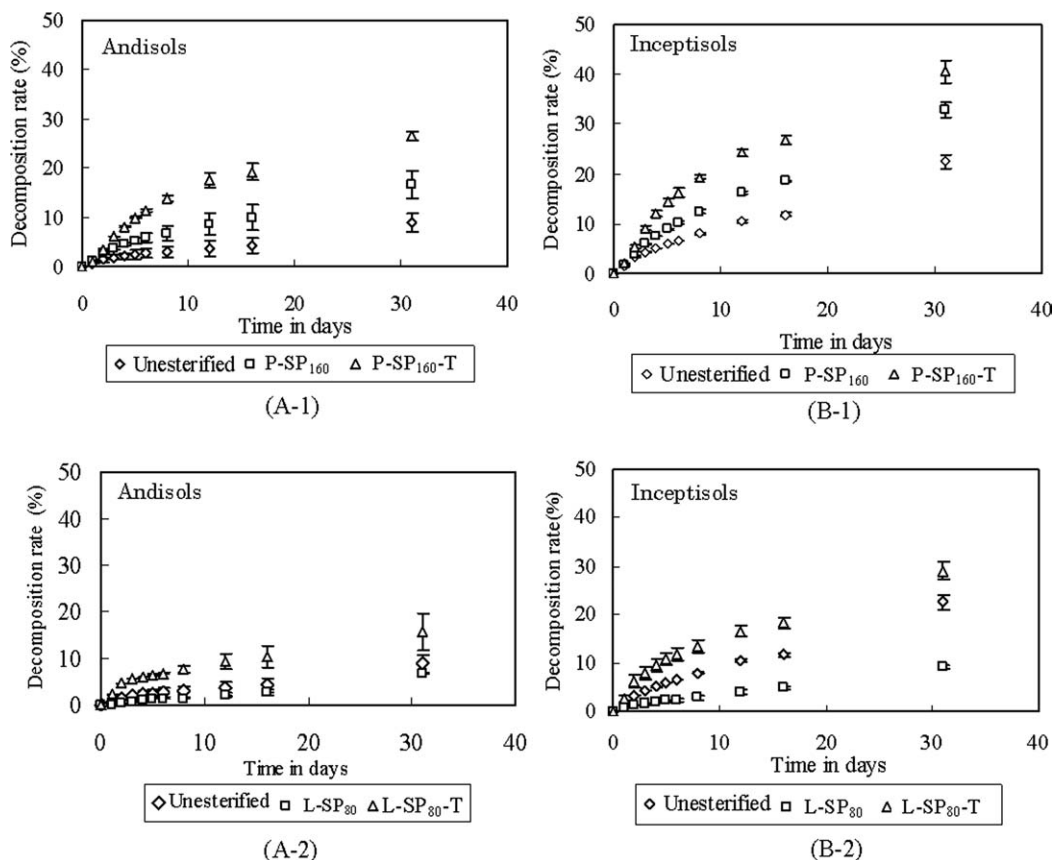
Figure 5 Decomposition rate of the unesterified sago starch-extraction residue, P-SP$_{160}$ and L-SP$_{80}$ in soil. A-1, A-2: Decomposition rate in Andisol B-1, B-2: Decomposition rate in Inceptisol P-SP$_{160}$-T, L-SP$_{80}$-T: the molded P-SP$_{160}$ and L-SP$_{80}$ which contain triacetin as plasticizer.

triacetin (50% (w/w)) remarkably accelerated the decomposition rate of the biodegradable plastics, P-SP$_{160}$ and L-SP$_{80}$ during the study. However, L-SP$_{80}$-T revealed lower decomposition rate than P-SP$_{160}$ in both Andisols and Inceptisols. Therefore, it seemed that the decomposition rate of the mixture of plastic and triacetin could be controlled by the amount of the added triacetin.

CONCLUSION

Sago starch-extraction residue can be used as a raw material for biodegradable plastics, which is one of the effective uses. P-SP$_{160}$ showed slight thermal softening behavior and relatively high decomposition rate. P-SP$_{160}$ can be applied for agricultural pots which can decompose in a short time. L-SP$_{80}$ could be expected the better thermal softening behavior than the other samples as the products has highest degree of substitution. L-SP$_{80}$ could be expected to have better thermal softening behavior than the other samples because of the highest degree of substitution. Furthermore, L-SP$_{80}$ was characterized by lower decomposition rate compared with P-SP$_{160}$. It is suggested that the thermal characteristics of L-SP$_{80}$ were similar to the commercial plastics. Then, it is concluded that L-SP$_{80}$ can be applied for wood plant seedling pots which can be decomposed in relatively long period of time.

References

1. Flach, M.; Kraalingen, D. W. G. V.; Simbardjo, G. In Sago-'85 the Third International Sago Symposium; Noboru, Y. and Kenji, K., The Sago Palm Research Fund, Tokyo, 1986; 86.
2. Haska, N. New Frontiers of Sago Palm Studies; Universal Academy Press: Tokyo, Japan, 2002.
3. Food and Agriculture Organization, http://faostat.fao.org/, 2008.
4. Funakoshi, H.; Shiraishi, N.; Norimoto, M.; Aoki, T.; Hayashi, H.; Yokota, T. Holzforschung 1979, 33, 159.
5. Kiguchi, M. Mokuzai Gakkaishi 1990, 36, 651.
6. Shiraishi, N. Sen-1 Gakkash 1983, 39, 95.
7. Hassan, M. L.; Rowell, R. M.; Fadl, N. A.; Yacoub, S. F.; Christainsen, A. W. J Appl Polym Sci 2000, 76, 561.
8. Watanabe, T.; Ohmi, M. Sago Palm 1997, 5, 10.
9. Sasaki, S.; Ohmi, M.; Tominaga, H.; Fukuda, K. Sago Palm 2002, 10, 1.
10. Sasaki, S.; Yamaguchi, C.; Tanaka, H.; Ohmi, M.; Tominaga, H. Sago Palm 1999, 7, 1.
11. Okazaki, M.; Tadenuma, S.; Ohmi, M. Presented at Proceedings of the 8th International Sago Symposium, Sago Palm Development and utilization, Indonesia, 2005.
12. Igura, M.; Okazaki, M.; Kimura, S. D.; Toyota, K.; Ohmi, M.; Kuwabara, T.; Syuno, M. Sago Palm 2007, 15, 1.
13. Ohmi, M.; Inomata, H.; Sasaki, S.; Tominaga, H.; Fukuda, K. Sago Palm 2003, 11, 1.
14. Test methods for acid value, saponification value, ester value, iodine value, hydroxyl value and unsaponifiable matter of chemical products, JAS, Japanese Industrial Standard K 0070, Japanese Standard Association, Tokyo, Japan, 1992.
15. Browning, B. L. Methods of Wood Chemistry; Interscience Publishers: New York, 1967; Vol 2.
16. Sasaki, S. Characteristics and thermoplasticity of sago starch extraction residue as wood biomass, United Graduate School of Agricultural Science, Tokyo University of Agriculture and Technology, Tokyo, Japan, 2003, 131.
17. Igura, M.; Okazaki, M.; Ohmi, M. Presented at the Proceedings of the 9th International Sago Symposium, Ormoc City, Philippines, July 19–21, 2007.
18. Szaraz, L.; Beczner, J. Int Biodeterior Biodegradation 2003, 52, 93.
19. Oyama, M.; Takehara, H. Revised Standard Soil Color Charts; Fujihira kogyo Co., Ltd: Tokyo, Japan, 2001.
20. Drimal, P.; Hrncirik, J.; Hoffmann, J. J Polym Environ 2006, 14, 309.
21. Fujita, S. Food Fat and Oil, and Their Applications; Saiwai Shobo: Tokyo, Japan, 2000.
22. Hirano, T.; Tanaka, H.; Enoki, A. Holzforschung 1997, 51, 389.
23. Omiya, K. In Encyclopaedia of cellulose; The Cellulose Society of Japan, Asakura Shoten: Tokyo, Japan, 2000.