한국염색가공학회지
pISSN 1229-0033, eISSN 2234-036X
Research Paper
https://doi.org/10.5764/TCF.2017.29.4.181

Biodegradability of Polylactic Acid Fabrics by Enzyme Hydrolysis and Soil Degradation

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Received_November 16, 2017
Revised_December 15, 2017
Accepted_December 18, 2017

Abstract The biodegradability of polylactic acid(PLA) fabrics was evaluated by two methods: enzyme and soil degradation. Three different enzymes were selected to evaluate. Degradation times were measured at optimal enzyme treatment conditions. Biodegradation by enzymatic hydrolysis was compared with soil degradation. As a result, biodegradation created cracks on the fiber surface, which led to fiber thickening and shortening. In addition, new peak was observed at 18.5° by degradation. Moreover, cracks indicating biofragmentation were confirmed by enzyme and soil degradation. By enzyme and soil degradation, the weight loss of PLA fabrics was occurred, there through, the tensile strength decreased about 25% by enzyme hydrolysis when 21 days after, and 21.67% by soil degradation when 60 days after. Furthermore, the biodegradability of PLA fabrics by enzymatic and soil degradation was investigated and enzymatic degradation was found to be superior to soil degradation of PLA fabrics. Among the three enzymes evaluated for enzymatic degradation, alcalase was the most efficient enzymes. This study established the mechanism of biodegradation of PLA nonwovens, which might prove useful in the textile industry.

Keywords *polylactic acid(PLA), fabric, biodegradation, enzyme hydrolysis, soil-burial*

Textile Coloration and Finishing
TCF 29-4/2017-12/181-194

1. Introduction

Sustainable materials within environmental friendly perspective are a philosophy[1)] introduced in the 21st century and applied to various industries. Biodegradable polymers can be considered as alternative materials from the perspective of ecological concerns and are predicted to be key factors in important future bio- and environmental industries. Polylactic acid (PLA) received a considerable amount of attention as a biomass material. It is linear aliphatic thermoplastic polyester made up of lactic acid(2-hydroxy propionic acid) building blocks, and it is derived from 100 % renewable sources such as corn[2-4)]. In particular, PLA is hydrolyzed into CO_2 and H_2O by microorganisms present in the environment[5,6)]. Therefore, PLA fibers have the potential to replace conventional petrochemical-based polymers in the textile industry[7)]. In addition, various types of PLA fibers, such as nonwoven, woven, and knit fabrics, have been developed and manufactured in the textile industry for clothing materials or household care products[2,3,8-11)].

For the application of PLA fibers in the textile industry, understanding the characteristics of PLA is important/required[12)]. Since PLA fibers have good self-extinguishing characteristics, garment made from PLA fibers have flame-resistant properties[3,13)]. Moreover, unlike other synthetic fibers, PLA fibers do not absorb light in the visible region of the spectrum, so they have very low strength loss when exposed to ultraviolet light compared to petroleum-based fibers[3,13)]. Furthermore, garments made from 100% PLA or

blends of PLA with wool and cotton feel more comfortable. The lower modulus leads to better drape and hand-feel, while the elastic recovery and crimp retention properties lead to excellent shape retention and create resistance[13].

However, PLA has some inherent disadvantages that limit its use for textile applications[14,15]. The tensile strength of PLA is lower than that of PET even though elongation is similar[13]. In addition, as PLA is linear aliphatic polyester, its resistance to hydrolysis is poorer than synthetic fibers. Moreover, enzymatic hydrolysis within a long time, PLA fibers can be degraded since enzyme cleaves the polymer chain even though some properties could be improved by enzymatic hydrolysis in a short time[7,10]. That is, properties of PLA fibers including the inherent disadvantages have to be understood and improved[14,16-18] to expand the usage of PLA fibers as textile materials and its high value applications.

Among enzymes, lipases, esterases, and proteases are hydrolysable enzymes of ester bonds on PLA fibers. Lipases(EC. 3.1.1.3) can degrade polymer chain of various aliphatic polyesters randomly[19,20]. Esterases (EC. 3.1.1.1) are carboxyl esterase and cleave ester bonds of aliphatic and aromatic polyester[21]. Proteases are used as catalysts for ester bonds when they catalyze the ester hydrolysis such as amino acid. By enzymes, degradation of PLA fibers is catalyzed by carboxyl and groups formed by chain cleavage and that amorphous regions are preferentially degraded[22-25].

Biodegradation of PLA fibers occurs in three stages: biodeterioration, biofragmentation, and assimilation[26,27]. First, biodeterioration occurs on the surface of fibers by the activation of microorganisms. The microbial species adhere to the surface of fibers. The polymer chains are weakened and the pore structure or the size can change, leading to moisture retention. Second, biofragmentation begins as microorganisms cleave the polymer chains, thereby changing the structure. Finally, biomass from the polymer is assimilated into the environment. Generally, factors that affect biodegradability are divided into two groups: physical properties and environmental conditions. Physical properties of the polymer include molecular structure and conformation, molecular weight, the shape of the polymer chain, and crystallinity. Environmental conditions include the types of microorganisms, temperature, relative humidity, and pH. These conditions determine the degree of biodeterioration and biofragmentation[28].

Therefore, studies on biodegradation processing of PLA fibers are needed considering the disuse of products. Especially, to establish whole processing of PLA fabrics in the textile industry, the effects of short time hydrolysis on PLA fibers when soil degradation have to be concerned since enzymatic treatment has been adapted to the textile finishing[7,10]. Moreover, degradation of PLA fibers has to be studied for the correlation between enzymatic degradation and soil degradation. However, there are no comprehensive studies on the mechanism of biodegradation of PLA fabric with or without enzymatic treatment.

In this study, we evaluated the enzyme and soil degradation of PLA fabrics. Enzymatic degradation was evaluated with lipase from Candida cylindracea, esterase from Porcine liver, and alcalase from Bacillus licheniformis, which are the three enzymes reported to be effective for the hydrolysis of PLA fibers in a previous study. At optimal enzyme treatment conditions, the time dependence of biodegradation was measured. Biodegradation by enzymatic hydrolysis was compared with that by soil. In addition, the effects of enzymatic hydrolysis on soil degradation were evaluated. Moreover, the effects of enzymatic hydrolysis in short time for soil degradation of PLA fabrics were also evaluated. Biodeterioration and biofragmentation were used to evaluate biodegradation over short time periods. The biodegradability was measured by weight loss, length, and thickness, along with SEM that could determine the tensile strength and estimate

Table 1. Characteristics of fabric

Fabric (%)	Yarn Count (Denier/filament)	Fabric Count (yarn/inch)	Weight (g/m^2)	Thickness (mm)
PLA 100	75/72	90 × 68	56.83	0.132

the degree of biodeterioration, and XRD patterns that could estimate the degree of biofragmentation. The results established the biodegradation mechanism of PLA nonwovens, which will be useful in the textile industry.

2. Experimental

2.1 Materials

One hundred percent polylactic acid(PLA) yarn, 75 denier and 72 filament of DTY type filament, were supplied from Huvis. PLA fabrics were weaved with conditions for the experiment(Table 1). Lipase(EC 3.1.1.3) from Candida cylindracea, esterase(EC 3.1.1.1) from Porcine liver, and alcalase(EC 3.4.21.62) from Bacillus licheniformis were used for this study(Table 2).

These enzymes were used without further purification. Tris (hydroxymethyl) amino methane (pKa = 8.06 at 20°C, Sigma Chemical Co., USA) and phosphate buffer saline(PBS) were used as buffers for enzyme degradation. Sodium azide(Junsei Chemicals, Japan) was used as antifungal agent. Calcium chloride(Junsei Chemicals, Japan) and L-cysteine(Yakuri Pure Chemicals Co. Ltd., Japan) were used as activators of enzyme degradation. 70% of Ethyl alcohol(Duksan Pure Chemicals, Korea) was used for inactivation of microbial of samples.

2.2 Enzymatic degradation

Enzymatic degradation of PLA fabrics was evaluated with lipase, esterase, and alcalase. PLA fabrics were prepared(5×15 cm, approximately 0.5g). According to the previous research[10,28], samples for lipase and esterase degradation were placed in separate erlenmeyer flasks containing 25 mL of TRIS buffer, pH 8.0, 40°C with 10%(owf) enzyme concentration, and 10mM calcium chloride which is the optimum conditions for enzymatic hydrolysis. Samples for alcalase degradation were immersed in 25mL of TRIS buffer, pH 9.5, 60°C with 50%(owf) enzyme concentration which is the optimum conditions for enzymatic hydrolysis, and 3mM L-cysteine. Sodium azide(0.05 wt%) was added to all treated solutions. Biodegradation of PLA fabrics was evaluated on day 0, 3, 7, 14 and 21.

2.3 Soil degradation

Soil degradation was carried out according to KS K ISO 11721-1. Leaf mold for re-potting, trademark registration number 0014163 was used as soil. Four PLA fabrics with different conditions-untreated, lipase treated, esterase treated and alcalase treated-were prepared. PLA fabrics were cut to approximately

Table 2. Properties of enzymes

Enzyme	Source	Activity	Form	Manufacturer
Lipase(EC 3.1.1.3)	*Candida cylindracea*	2U*/mg	Powder	Fluka
Esterase(EC 3.1.1.1)	*Porcine liver*	15U**/mg	Crude	Sigma
Alcalase(EC 3.4.21.62)	*Bacillus licheniformis*	2.4AU/g	Liquid	Novozymes

* One unit will hydrolyze 1.0 μmole of oleic acid to butyric acid and ethanol per min at pH 8.0 at 25℃
** One unit will hydrolyze 1.0 μmole of ethyl butyrate to butyric acid and ethanol per min at pH 8.0 at 40℃

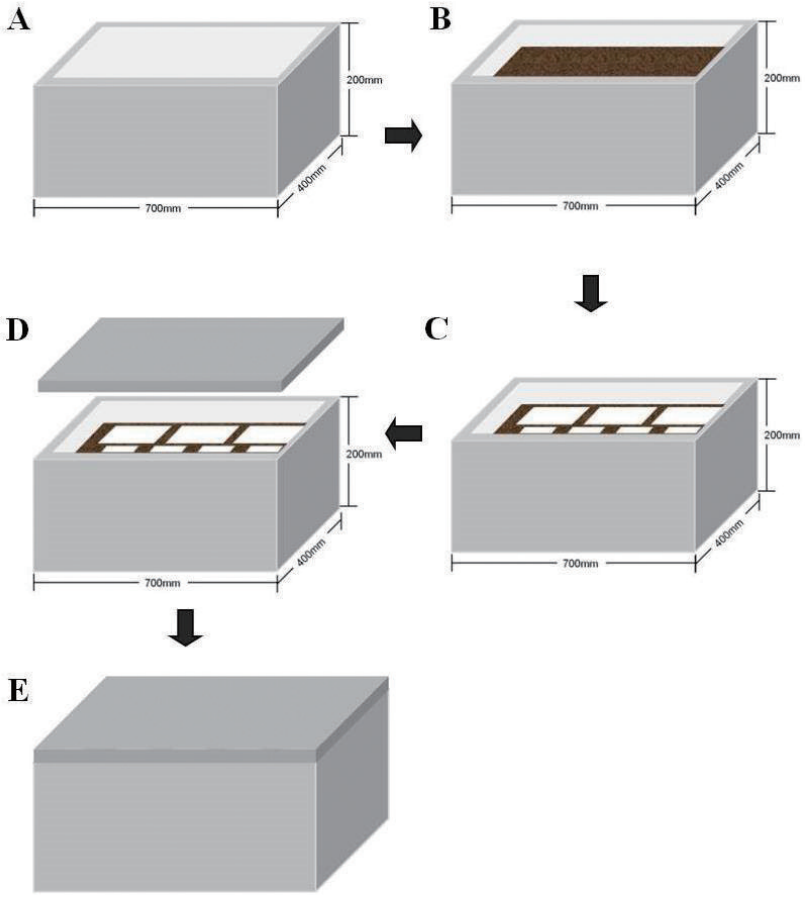

Figure 1. Preparation of the soil degradation.

10×20cm. Incubation baths were made from a Styrofoam box, 70cm in width, 40cm in length, and 20cm in height. Up to 7cm of soil was put into the incubation baths, and specimens were placed on top of the soil. The samples were covered with 5.5cm of soil.

Figure 1 shows the preparation process. The soil was covered with aluminum foil to retain moisture.

The humidity and the temperature were maintained about 99%, and 30°C, respectively. Biodegradation of all samples was evaluated on day 0, 3, 7, 14, 21, 30, and 60. For evaluation, specimens were washed in four steps. First, impurities were removed with tap water. Samples were washed with 70% ethyl alcohol for 30 minutes and then with tap water for 30minutes. Finally, all samples were cleaned with an ultrasonic cleaner(UC-20, Jeio-Tech., Korea). After washing, the samples were dried at 50°C.

2.4 Change in appearance

Changes in appearance of enzyme- and soil-degraded fabrics were determined by the length and the thickness. Changes in the length(%) of biodegraded and non-biodegraded fabrics were compared. Changes in the thickness were measured using a textile thickness gauge(2046F, Mitutoyo, Japan).

2.5 Weight loss

The weight loss of enzyme- and soil-biodegraded fabrics was evaluated by measuring the dry weight of the samples. The samples were dried in a conventional drying oven at 105°C for 90min, cooled in an automatic desiccator, and then weighed in a closed weighing bottle. The percentage of the weight loss was calculated as follows(1):

$$\text{Weight loss (\%)} = (W_1 - W_2)/W_1 \times 100 \quad \cdots\cdots\cdots (1)$$

Where W1 and W2 are the dry weights of the samples before and after biodegradation, respectively.

2.6 Tensile strength

The tensile strength of enzyme- and soil-biodegraded fabrics was determined using a Universal Testing Machine(H 100KS, Hounsfield Test Equipment LTD., UK) by the strip method according to KS K 0521 and KS K ISO 9073-3. An average of five test runs was reported.

2.7 X-ray diffraction(XRD)

The crystallinity of enzyme- and soil-biodegraded fabrics was measured using X-ray diffractometer, (XRD) (X'pert APD, Philips, USA) under the following operating conditions: 40kV and 30mA at λ 1.5406A. The relative intensity was recorded in the scattering range(2θ) of 5-45° in steps of 0.03°. The degree of crystallinity was calculated from the extent ratios of the crystalline area and the amorphous area to the integral extent. Mechanical background was removed from the low data, divided by the crystal peak and the amorphous peak, and fit with the Pearson VII function.

2.8 Scanning electron microscopy(SEM)

The surface of the enzyme- and soil-biodegraded fabrics was analyzed using a scanning electron microscope(SEM, S-4800, Hitachi, Japan) after the samples were plated with osmium.

3. Results and discussion

3.1 Characteristics

Figure 2 shows the change in the length and the thickness of PLA fabrics with enzymatic degradation time. As shown in Figure 2, by enzyme degradation, the length of PLA fabrics decreased, and the thickness of PLA fabrics increased when 3 days after. Generally, the fiver was expanded as the fiber width[29] it could be used to explain the thickening of the thickness. There through, the length of the fiber decreased since the amorphous region of the fiber shrank. In Figure 2(a), the length decreased about 10% within 3days, and the thickness(Figure 2(b)) was expanded. Especially, the thickness is lessened by enzymatic degradation after 21days. PLA fabrics had been thickened drastically until 3days and showed the maximum thickness at 7days. After 7days, it decreased by lipase and alcalase hydrolysis, and showed plateau by esterase hydrolysis. Especially, PLA fabrics by lipase hydrolysis decreased rapidly after 7days, and then showed 122% increase when 21days after. PLA fabrics by alcalase hydrolysis had similar increase with lipase initially; however, it decreased rapidly after 14days and then showed 124% increase when 21days after. PLA fabrics by esterase hydrolysis showed plateau line

Table 3. Abbreviations of samples by two methods depending on degradation time

Enzyme degradation		0 day	3 day	7 day	14 day	21 day		
PLA fabric	Lipase	LFE00	LFE03	LFE07	LFE14	LFE21		
	Esterase	EFE00	EFE03	EFE07	EFE14	EFE21		
	Alcalase	AFE00	AFE03	AFE07	AFE14	AFE21		
Soil degradation		**0 day**	**3 day**	**7 day**	**14 day**	**21 day**	**30 day**	**60 day**
PLA fabric	None	FS00	FS03	FS07	FS14	FS21	FS30	FS60
	Lipase	LFS00	LFS03	LFS07	LFS14	LFS21	LFS30	LFS60
	Esterase	EFS00	EFS03	EFS07	EFS14	EFS21	EFS30	EFS60
	Alcalase	AFS00	AFS03	AFS07	AFS14	AFS21	AFS30	AFS60

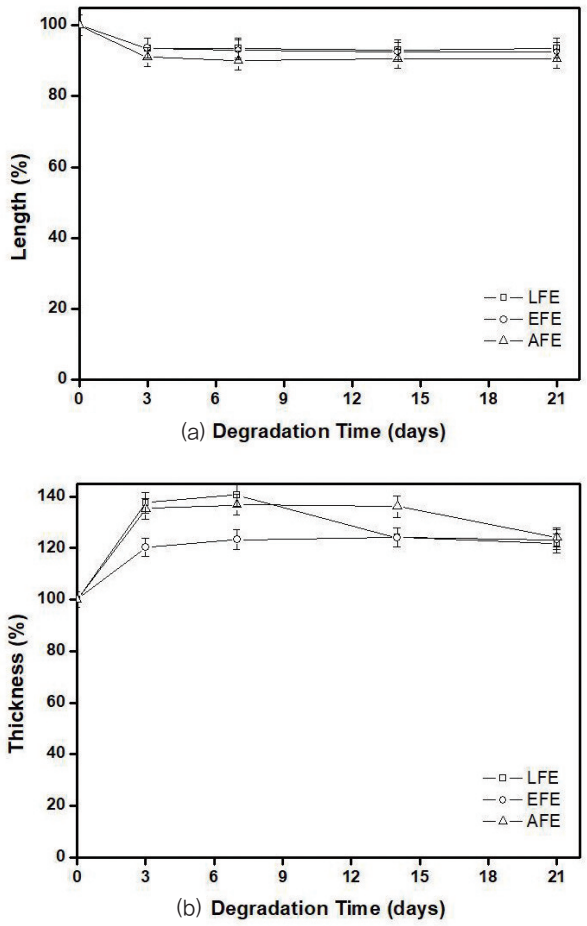

Figure 2. Length (a) and thickness (b) changes of PLA fabrics depending on enzymatic degradation time.

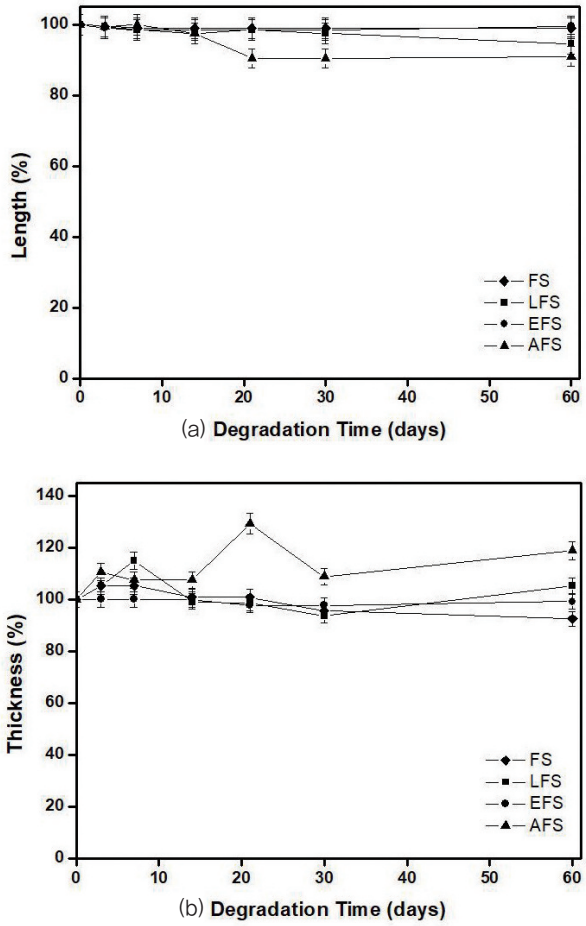

Figure 3. Length (a) and thickness (b) changes of fabrics depending on soil degradation time.

after 7days and showed 123% increase when 21days after. Therefore, three enzyme-hydrolysis PLA fabrics showed the same rate of increase in thickness when 21days after. Compared to the changes in length, at the initial degradation, the length was shortened and the thickness was thickened; however, since that point, no change in length was observed, and the thickness was thinned. Through this, it could be expected that the fiber be thickened as amorphous of the fiber was degraded, and the fiber be thinned as crystalline of the fiber was degraded since biodegradation was continued. That is, the fiber volume dwindles away by enzymatic hydrolysis, fiber can be degraded, and consequently, fiber can be expanded.

Figure 3 shows the changes in the length and the thickness of fabrics degraded in soil over time. The length of PLA fabrics degraded by soil did not changesignificantly depending on the degradation time. However, the length of lipase-treated PLA fabrics and alcalase-treated PLA fabrics decreased about 5 to 10% 21days later. As shown in Figure 3(b), the samples were thickened at initial degradations, and as degradation progressed, it showed different aspect. The thickness of PLA fabrics which were degraded by soil, and the thickness of esterase-treated PLA fabrics did not decrease significantly, whereas the thickness of lipase-treated fabrics increased until 7days, and then, decreased slightly. In addition, the thickness was increased slightly by alcalase treatment and showed the maximum thickness at 21days. Moreover, it decreased slightly 30days after. The increase in thickness was related with the decrease in length. By alcalase treat-

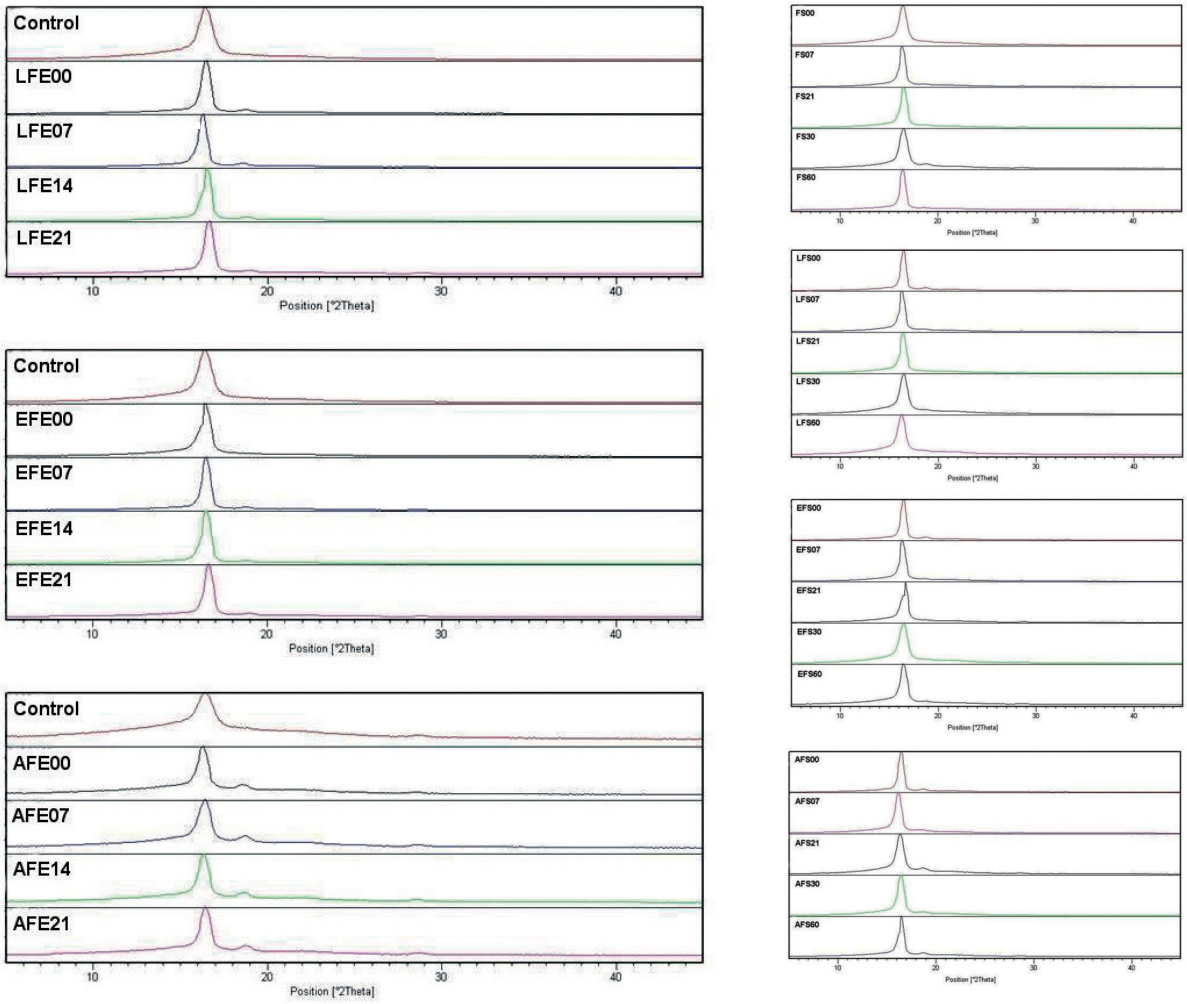

Figure 4. XRD spectra of PLA fabrics depending on degradation time; (a) enzyme degradation, (b) soil degradation.

ment, the length was decreased about 10% when 21days after, which means, there was some shrinkage of the fiber, which brought increase in the thickness.

3.2 Crystallinity

Figure 4 shows the time dependence of the XRD patterns of PLA fabrics. As shown in Figure 4(a), overall, the XRD patterns of enzyme hydrolysis PLA fabrics had sharper peak than untreated PLA fabric. The crystal peak of untreated sample was localized at 2θ=16°, and 28°. By enzyme hydrolysis, a third peak at 18.5° appeared. As the previous study[10], this new peak indicated a morphological change; invisible peak, hidden by amorphous region, starts to detect the degradation of amorphous region[12]. According to Gonzalez[30], the presence of new peaks could be attributed to oligomeric stereo complex crystal formation, so the XRD patterns changed upon degradation. In addition, the peak size of lipase and alcalase was the highest of the esterase hydrolysis fabrics. Moreover, by alcalase hydrolysis, the third peak had a high intensity since alcalase hydrolysis was performed on PLA at its glass transition temperature(Tg, 60°C) so crystallization of PLA was affected[22] Through this, lipase and alcalase hydrolysis could affect the crystalline structure more than esterase hydrolysis. As shown in Figure 4(b), the crystal peak of PLA fabrics started to degrade in soil 30days later. In addition, all

enzymatic treated samples had the third peak at 18.5°. Moreover, the third peak of alcalase-treated PLA fabrics had the largest values; it means, by alcalase, PLA fabrics could degrade in soil better than lipase and esterase. That is, with alcalase treatment on PLA fabrics, the fiber was already affected by crystallization at around 60°C, which causes more degradation by soil than enzymatic treatment. Compared to Figure 4(a) and (b), there through, PLA fabric became slightly crystalline after enzyme- and soil degradation.

3.3 Visual observations

Figure 5 shows SEM images of enzyme-degraded PLA fabrics. There was no significant difference by lipase treatment until 7days; however, the surface of the fabrics degraded a little when 14days after, and then, the outer part of the fiber was separated from the surface when 21days after. These were similar with the results of the weight loss(Figure 7(a)). In case of esterase, differences between 0day and 21days after were not observed. By alcalase treatment, no differences were observed until 7days; however, after 14days, the surface of the fiber split. Moreover, 21days after, the fiber shape was deformed since the amorphous region degraded. These results are in agree-

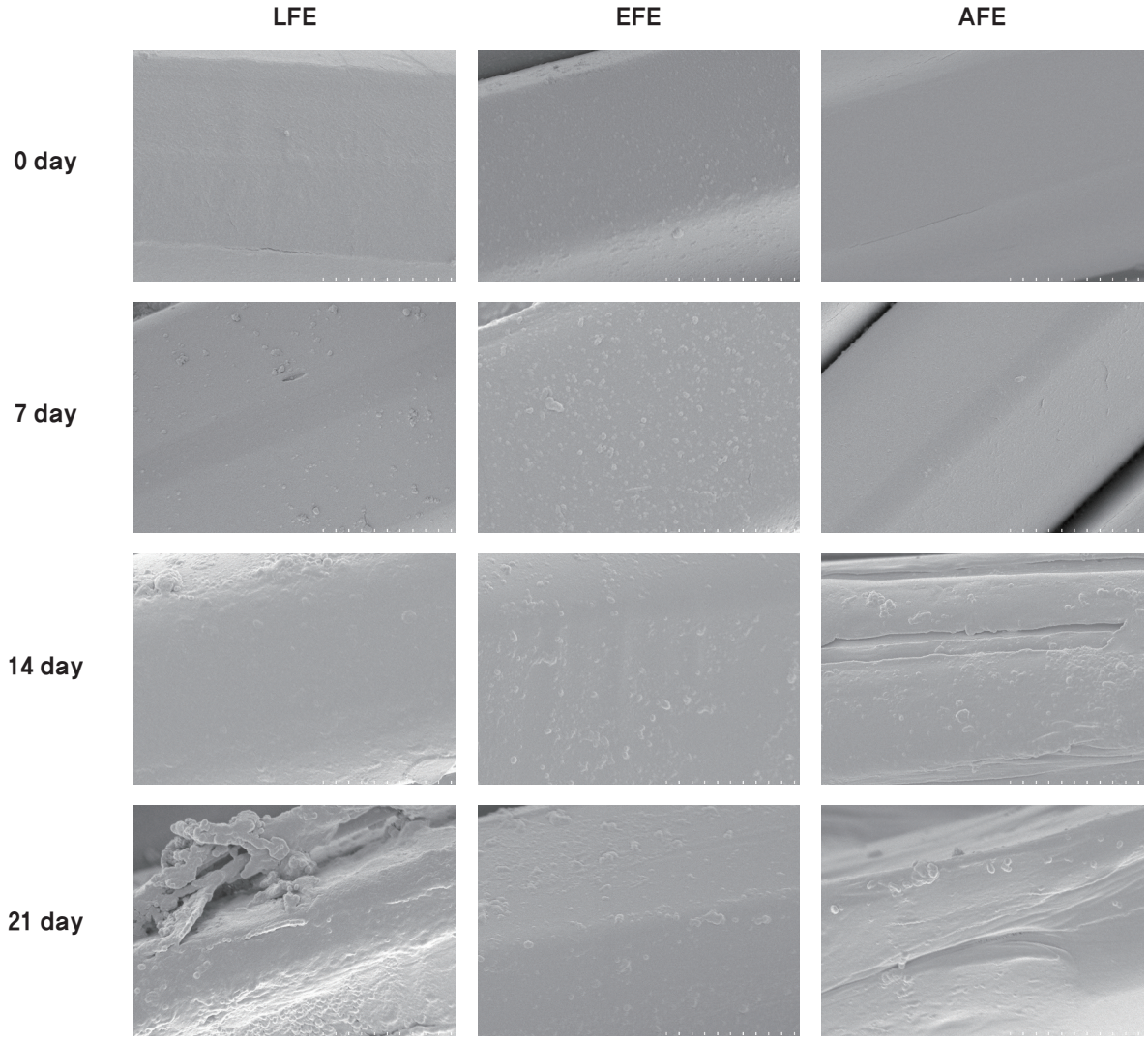

Figure 5. SEM images of enzyme hydrolyzed PLA fabrics depending on degradation time.

ment with the weight loss. From the results of SEM images, as shown in figures, some bubbles and sticky materials were observed. From Zhang et al., it showed obvious proof of erosion of PLA fabrics[31]. These could be explained by biodeterioration. Biodeterioration is mainly the result of the activity of microorganisms growing on the surface or/and inside of materials[5,32].

When biodeterioration is occurred on the surface, some microbial species can adhere, and it alters the porous structures and the size changes. As this biodeterioration is proceeded, the resistance and the durability of the fiber is weakened[26]. Thus, after 21days, biodegradation by enzyme showed biodeterioration, which is the beginning of biodegradation.

Figure 6 shows the surface morphology images of soil-degraded fabrics at various times. SEM images revealed obvious morphological changes resulting from microbial attack[33] on the PLA fibers by soil degradation. PLA fabrics have micro bubbles, which is the evidence of biodeterioration, on the surface when 30days after in soil. Especially, as a result of crystallinity, the PLA fabrics had the third peak when 30days after; however, some bubbles on the surface of the fiber did not show any significance. However,

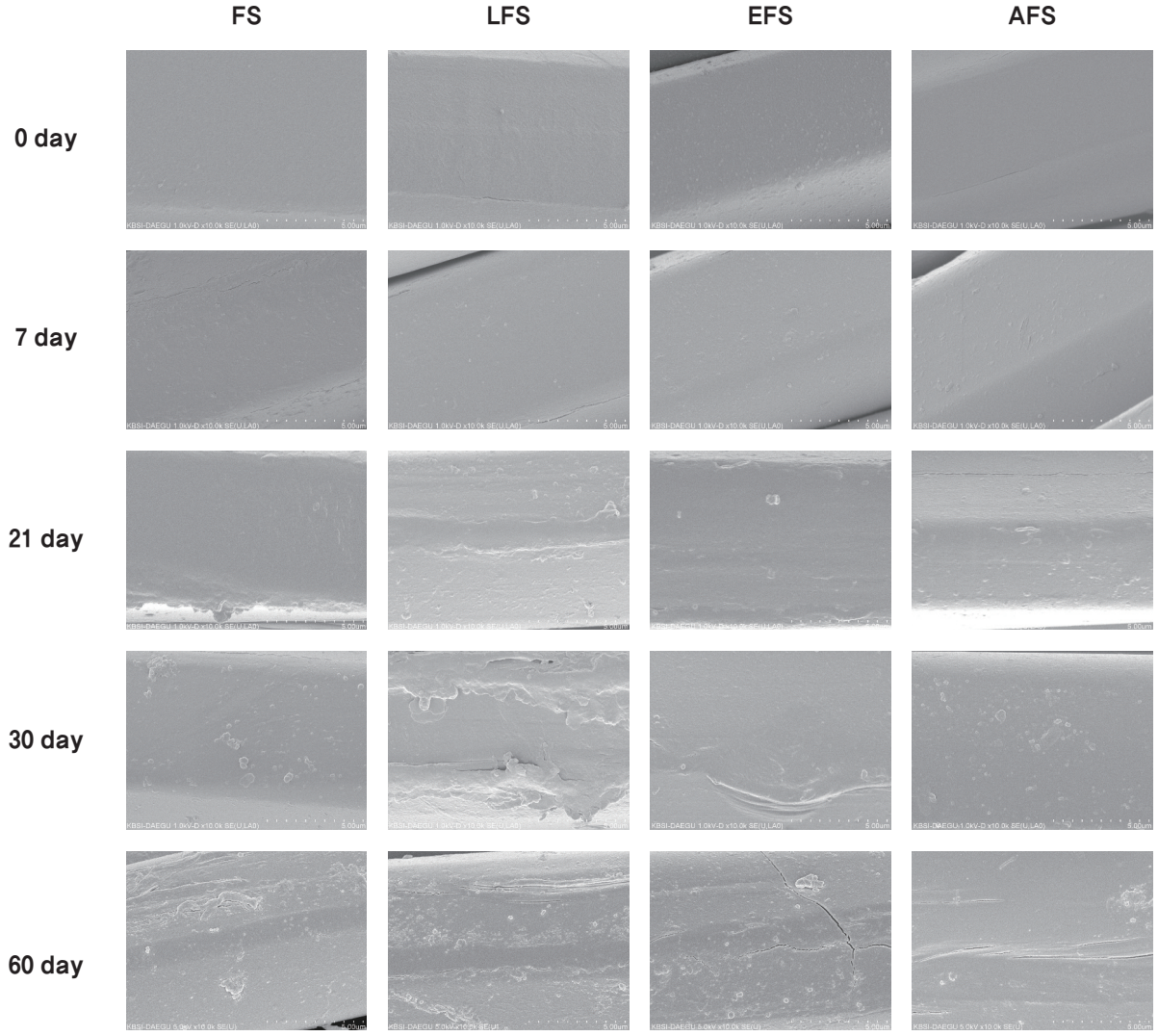

Figure 6. SEM images of soil-degraded PLA fabrics depending on degradation time.

when 60days later, some cracks, which are the evidence of biofragmentation, were observed in the PLA nonwovens. Also, more micro bubbles were observed at 60days buried PLA fabrics. As shown in the SEM images of lipase-treated PLA fabrics, compared with the unburied, the surface was degraded a little when 21days after, and some cracks were observed at the surface of the fiber. Esterase-treated PLA fabrics by soil degradation, 30days after, showed little squash at some part of the fiber surface since the amorphous region degraded and they were intensified as the buried time lasted. In the case of alcalase-treated PLA fabrics by soil degradation, micro bubbles were observed at the surface of the fiber as degradation when 21days later, and then biofragmentation such as fibrils and cracks was observed when 60days after. Through these results, biodeterioration was occurred on the PLA fabrics by soil degradation[34], and these results were related to the results of the tensile strength.

3.4 Weight loss and tensile strength

Figure 7 shows the time dependence of weight loss during biodegradation of the PLA fabrics. As shown in Figure 7(a), the weight loss of the PLA fabrics was slightly increased by lipase and esterase hydrolysis. In addition, by alcalase hydrolysis, the weight was lost by enzymatic degradation as time went by. Enzyme degradation of polymers by hydrolysis is a two-step progress; at the first step, there is an adsorption of the enzyme on the surface of the substrate through surface-binding domain, and at the second step, enzymes hydrolyze the ester bond[22,27,35]. Thus, during the initial degradation time, the PLA fiber could degrade as the degradation time went on. Moreover, among three enzymes, alcalase was shown the highest biodegradability. This is due to the treatment conditions of the three enzymes. The optimal treatment condition for alcalase was a pH of 9.5, and a temperature of 60°C, whereas those of lipase and esterase were a pH of 8.0, and a temperature of 40°C. Generally,

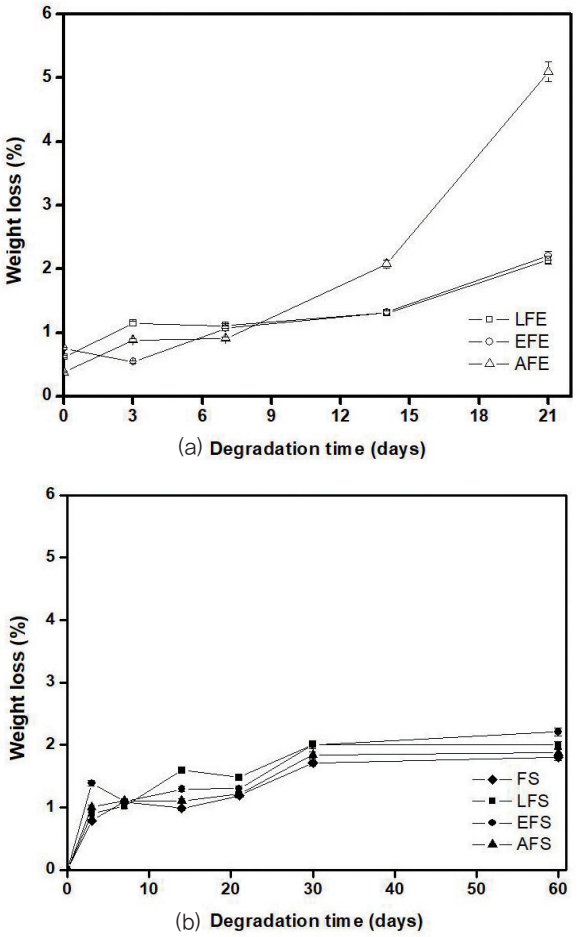

Figure 7. The weight loss of PLA fabrics depending on degradation time; (a) enzyme degradation, (b) soil degradation.

the PLA fiber was weak at alkaline solution at high temperature above 60°C. Especially, alkaline protease originated from Bacillus showed appreciable degrading activity of the PLA fibers[20,35]. In addition, amorphous PLA was degraded by annealing[22] since alcalase treatment occurred at the glass transition temperature around 60°C. Therefore, alcalase shows higher activity than lipase and esterase for biodegradation of the PLA fabrics. As shown in Figure 7(b), the weight loss of soil degradation after enzyme-treated PLA fabrics was increased about 1.47 folds by lipase and esterase treatment, and 1.07 folds by alcalase treatment compared to untreated PLA fabrics; however, the increase range of all PLA fabrics was low which is related to the previous work[21]. After 60days,

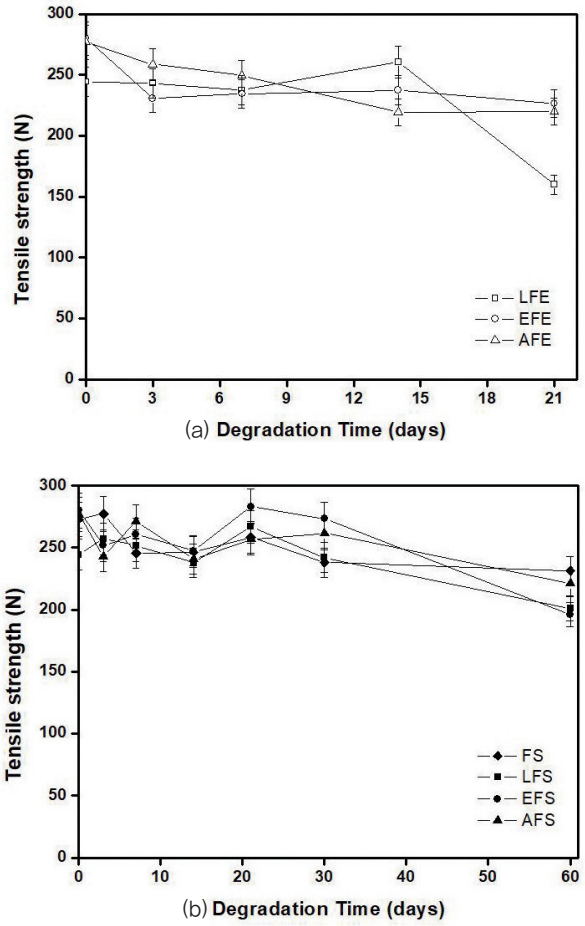

Figure 8. The tensile strength of PLA fabrics depending on degradation time; (a) enzyme degradation, (b) soil degradation.

enzyme-treated PLA fabrics had 2% weight loss, increased about 2 folds compared with the initial degradation having 1% weight loss. Generally, cotton and PLA fiber are known as degradable polymer that affects the degradation by molecular weight, tacticity, and crystallinity[36-42]. However, the PLA fibers have difficulties in degrading compared to the cellulose fiber[43] since cellulose fiber is well-degraded entirely within 90days[28]. Therefore, by soil degradation, the degradation rate of PLA fabrics was slower than enzyme degradation.

Figure 8 shows the tensile strength of the PLA fabrics depending on the degradation time. As shown in Figure 8(a), the tensile strength decreased slightly over time. The tensile strength of the PLA fabrics decreased about 35% by lipase treatment, 19% by esterase treatment, and 21% by alcalase treatment when 21days after. The tensile strength of the lipase hydrolyzed PLA fabrics showed the largest decrease, whereas the weight loss of alcalase hydrolyzed PLA fabrics had the largest value. Figure 8(b) shows that the tensile strength of soil-degraded PLA fabric samples did not decrease significantly with increasing degradation time. Moreover, as shown in Figure 8(b), the tensile strength of enzyme-treated PLA fabrics did not decrease until 21days buried, but they increased and decreased continually since polymer was formed with crystalline; and amorphous regions, the tensile strength may be increased and decreased[44]. However, after 30days, the tensile strength of the lipase, esterase, and alcalase-treated PLA fabrics was decreased linearly. Therefore, the tensile strength when soil degradation after enzyme-treated PLA fabrics started to decrease after 30days buried. Consequently, based on the result of the weight loss, the tendency of tensile strength is opposite to that of weight loss. That is, more weight loss causes the decrease in tensile strength.

4. Conclusions

In this study, biodegradability by enzyme and soil of PLA fabrics was evaluated to establish the bio-refinery processing of the PLA fabrics. By biodegradation, the PLA fiber was inflated as width way, therefore, the length of the PLA fabrics shortened, and the thickness of the PLA fabrics was increased. That is, biodegradation created cracks on the fiber surface, which led to fiber thickening. As a result, the degree of crystallinity of the PLA fabrics increased as degradation time went on compared with un-degraded fabrics. In addition, a new peak was observed at 18.5° by degradation. Bubbles and slits were observed on the surface of the fibers hydrolyzed by three enzymes and soil degradation indicating biode-

terioration. Furthermore, the cracks indicating biofragmentation were confirmed by enzyme and soil degradation. Alcalase hydrolyzed PLA fabrics were degraded more than lipase or esterase hydrolyzed PLA fabrics, as demonstrated by the enormous loss of the weight and the tensile strength. After 21days of treatment, the weight loss of the PLA fabrics degraded by alcalase increased about 2.5 fold compared with lipase or esterase. The tensile strength of the PLA fabrics decreased about 1.3 fold with enzymes after 21days of hydrolysis. Moreover, after 60days of buried time, the loss of weight of the PLA fabrics increased about 1.3 fold and the tensile strength of the PLA fabrics decreased about 1.3 fold. This study investigated the biodegradability of the PLA fabrics by enzymatic and soil degradation, and it was found that enzymatic degradation is superior to soil degradation of PLA fabrics. Moreover, among the three enzymes evaluated for enzymatic degradation, alcalase was the most efficient enzymes.

Acknowledgement

This work was supported by the fund of research promotion program, Gyeongsang National University, 2017.

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