Blends of Aliphatic Polyesters. VIII. Effects of Poly(L-lactide-*co*-ε-caprolactone) on Enzymatic Hydrolysis of Poly(L-lactide), Poly(ε-caprolactone), and Their Blend Films

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ABSTRACT: Poly(L-lactide), that is, poly(L-lactic acid) (PLLA), poly(ε-caprolactone) (PCL), and their blend (50/50) films containing different amounts of poly(L-lactide-*co*-ε-caprolactone) (PLLA-CL), were prepared by solution casting. The effects of added PLLA-CL on the enzymatic hydrolysis of the films were investigated in the presence of proteinase K and *Rhizopus arrhizus* lipase by use of gravimetry. The addition of PLLA-CL decreased the proteinase K–catalyzed hydrolyzabilities of the PLLA and PLLA/PCL (50/50) films as well as the *Rhizopus arrhizus* lipase-catalyzed hydrolyzability of the PCL and PLLA/PCL (50/50) films. The decreased enzymatic hydrolyzabilities of the PLLA and PCL films upon addition of PLLA-CL are attributable to the fact that the PLLA-CL is miscible with PLLA and PCL and the dissolved PLLA-CL must disturb the adsorption and/or scission processes of the enzymes. In addition to this effect, the decreased enzymatic hydrolyzabilities of the PLLA/PCL (50/50) films upon addition of PLLA-CL can be explained by the enhanced compatibility between the PLLA-rich and PCL-rich phases arising from the dissolved PLLA-CL. These effects result in decreased hydrolyzable interfacial area for PLLA/PCL films. The decrement in proteinase K–catalyzed hydrolyzability of the PLLA film upon addition of PLLA-CL, which is miscible with PLLA, was in marked contrast with the enhanced proteinase K–catalyzed hydrolyzability of the PLLA film upon addition of PCL, which is immiscible with PLLA. This confirms that the miscibility of the second polymer is crucial to determine the proteinase K–catalyzed hydrolyzabilities of the PLLA-based blend films. © 2002 Wiley Periodicals, Inc. J Appl Polym Sci 87: 412–419, 2003

Key words: biodegradable; biomaterials; degradation; enzymes; compatibility

INTRODUCTION

Investigating enzymatic hydrolysis of biodegradable polymers is crucial to foresee their degradation behavior and mechanisms under both experimental and environmental conditions. Of the biodegradable polymers, aliphatic polyesters such as poly(L-lactide) [i.e., poly(L-lactic acid) (PLLA)] and poly(ε-caprolactone) (PCL) are a matter of concern because they are commercially available thermoplastics that have different mechanical properties and environmental biodegradabilities. In this series, we have investigated the morphology, phase structure, highly ordered structures (crystallization), physical properties, enzymatic hydrolysis, and environmental biodegradation of blends of PLLA and PCL as model biodegradable polymer blends.[1–3]

Proteinase K is a well-known enzyme to catalyze hydrolysis of PLLA[4] and the effects of second polymers on its proteinase K–catalyzed hydrolysis has been studied through the use of hydrophilic polymers such as poly(ethylene oxide),[5] cellulose,[6] poly(vinyl alcohol),[7] and hydrophobic polymers such as PCL[8–10] and poly(vinyl acetate),[11] and as well as through the use of polylactides [i.e., poly(lactic acid)s (PLAs)] having different L-lactide contents.[12] It was found that the phase structure of the blends rather than the hydrophilicity of the second component is critical to determine the proteinase K–catalyzed hydrolyzability of PLLA. In contrast, hydrolysis of PCL is catalyzed by numerous lipases such as *Rhizopus arrhizus* and *Pseudomonas*. Similar to the proteinase K–catalyzed hydrolysis of PLLA, the effects of second polymers on the lipase-catalyzed hydrolyzability have been studied by use of PLLA,[8,13] poly(DL-lactide) [i.e., poly(DL-lactic acid) (PDLLA)],[14] and starches.[15] It was revealed that the second polymers in the blends disturb the lipase-catalyzed hydrolysis, irrespective of the kind of lipases and the second polymers. The enzymatic hydrolysis and biodegradation in soil of the PLLA/PCL blends resulted in the formation of microspheres of PLLA-rich or PCL-rich phase or of pores on the blend

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surfaces, depending on the polymer mixing ratio.[3,9,10,13,15] We proved that this selective hydrolysis and removal of one component from the blends can be used to prepare porous biodegradable materials[10] and to visualize their phase structures.[13]

On the other hand, copolymers prepared by one-step ring-opening copolymerization of L-lactide and ϵ-caprolactone (PLLA-CL) have been reported to have a blocklike structure[16–19] and therefore can be used as a compatibilizer of PLLA and PCL.[3,20,21] Hijanen-Vainio et al. studied the effects of the addition of PLLA-CL on nonenzymatic hydrolysis and found that the effects of the added PLLA-CL were negligibly small.[20] In contrast, Wang et al. studied the effects of reactive compatibilization of PLLA/PCL blends on proteinase K–catalyzed hydrolysis and showed that their hydrolysis rate can be altered by the reactive compatibilization procedure.[8] Nonetheless, hitherto, there has been no work on the effects of addition of PLLA-CL on the enzymatic hydrolysis of PLLA/PCL blend specimens as well as PLLA and PCL specimens.

The purpose of this study is to investigate the effects of the addition of PLLA-CL on the enzymatic hydrolysis of PLLA/PCL films as well as PLLA and PCL films. For this purpose, PLLA/PCL, PLLA, and PCL films containing different amounts of PLLA-CL were prepared by solution-casting, and their enzymatic hydrolysis was investigated in the presence of two enzymes, proteinase K and *Rhizopus arrhizus* lipase.

EXPERIMENTAL

Materials

PCL was synthesized by a previously reported procedure (140°C for 240 h, stannous octoate 0.015 wt %).[1,22] The synthesized PCL was purified by precipitation by use of chloroform and methanol as solvent and nonsolvent, respectively, followed by drying in vacuum for 1 week. PLLA and PLLA-CL were kindly supplied by Gunze Ltd. (Kyoto, Japan) and used after purification and drying by the same procedure for PCL. Films of about 25 and 100 μm thickness were prepared by casting 1 g/dL mixed solution of purified PLLA, PCL, and PLLA-CL under different mixing ratios by use of methylene chloride as a solvent, followed by slow solvent evaporation at room temperature (25°C) for about 1 week, as reported previously.[1,22] The period of time for the solvent evaporation was 1 week to complete the phase separation between the polymers during slow solvent evaporation, assuming that it occurs.[1,22] The as-cast films were dried in vacuum for another week and stored at room temperature for at least 1 month to reach the equilibrium state before physical measurements and enzymatic hydrolysis.

Enzymatic hydrolysis

The proteinase K–catalyzed hydrolysis of the films (10 mm $\times$ 10 mm $\times$ 100 μm) was performed according to the procedure reported by Reeve et al.[24] and modified in our laboratory.[10] Briefly, the film was placed in a vial filled with 10 mL of 0.05*M* Tris–HCl buffered solution (pH 8.6) containing 1.0 mg of sodium azide (Nacalai Tesque Inc., Kyoto, Japan). Air on the surfaces of the films and the interfaces between PLLA-rich and PCL-rich phases in the films was removed under reduced pressure for 5 min. Then the film was moved to a vial filled with 5 mL of Tris–HCl buffered solution containing 1.0 mg of proteinase K (lyophilized powder, 80% protein; Sigma, St. Louis, MO) and 1.0 mg of sodium azide.

The *Rhizopus arrhizus* lipase-catalyzed hydrolysis of the films (10 mm $\times$ 10 mm $\times$ 100 μm) was performed according to the above-mentioned procedure under the conditions reported by Pranamuda et al.[15] Briefly, each of the films was placed in a vial filled with 10 mL of 0.02*M* phosphate-buffered solution (pH 7.0) containing 0.005 wt % of the surfactant Plysurf A210G (Dai-Ichi Kogyo Seiyaku Co. Ltd., Japan). After the removal of air at the surface of the films and interfaces between the two polymer phases, each of the films was moved to a vial filled with 20 mL of 0.02*M* phosphate-buffered solution (pH 7.0) containing 2000 units of lipase [Type XI, *Rhizopus arrhizus*, suspension in 3.2*M* $(NH_4)_2SO_4$/10 m*M* potassium phosphate solution; Sigma] and 0.005 wt % of Plysurf A210G, which stabilizes the suspended state of the lipase.

The proteinase K– and lipase-catalyzed hydrolysis of the films was performed at 37 and 30°C, respectively, in a rotary shaker for up to 15 days and the hydrolysis media was changed every 24 h to maintain enzymatic activity. The hydrolyzed films were washed thoroughly with distilled water at 4°C to stop further enzymatic hydrolysis, followed by drying under reduced pressure for at least 2 weeks. The distilled water used for preparation of the Tris–HCl and phosphate-buffered solution and film washing was of HPLC grade (Nacalai Tesque).

Measurements and observations

The L-lactyl (half of L-lactide) unit content [x_L (mol %) and w_L (wt %)] of the purified PLLA-CL was determined from the 300 MHz ^{1}H-NMR spectrum obtained in deuterated chloroform (50 mg/mL) by use of a Varian Mercury 300 spectrometer (Varian Associates, Palo Alto, CA), with tetramethylsilane (TMS) as the internal standard. The ratio of the integrated intensity at 5.2 ppm (the methyne group of the LLA unit) to that at 4.1 ppm (the γ-methylene group of CL neighboring oxygen of ester bond)[19,25,29] was used to determine the chemical composition of the copolymer. The w_L value

TABLE I
Molecular Characteristics of Purified Polymers

Polymer	M_n (g/mol)	M_w/M_n	x_L (mol %)	w_L (wt %)	l_L	l_C
PLLA-CL	1.7×10^5	1.5	68.2	57.5	7.4	2.4
PLLA	5.0×10^5	2.2	—	—	—	—
PCL	1.2×10^5	1.7	—	—	—	—

of PLLA-CL was calculated from the following equation:

$$w_L(\text{wt \%}) = 100x_L72.1/[(100 - x_L)114.1 + x_L72.1] \quad (1)$$

The average monomer sequence lengths of L-lactate (l_L) and CL (l_C) units were determined from the 75.5 MHz ^{13}C-NMR spectrum measured in deuterated chloroform, with TMS as the internal standard. The spectrum was obtained under the conditions of 14,240 scans, 7.25-μs pulse width, 1.82-s acquisition time, and 1.19-s delay between pulses. The assignment of the sequences was performed according to the literature.[16,19,25–29] The l_L and l_C values of PLLA-CL were estimated on the basis of relationships between the average comonomer sequence lengths and the intensities of triad and dyad sequences.[16,19,25–29]

The weight- and number-average molecular weights (M_w and M_n, respectively) of the purified polymers were evaluated in chloroform at 40°C by a Tosoh GPC system (refractive index monitor: RI-8020) with TSK gel columns ($GMH_{XL} \times 2$), with polystyrene as a standard. The molecular characteristics of the purified polymers are listed in Table I.

The glass-transition, crystallization, and melting temperatures (T_g, T_c, and T_m, respectively) and enthalpies of crystallization and melting (ΔH_c and ΔH_m, respectively) of the films (100 μm thick) were determined by a Shimadzu DT-50 differential scanning calorimeter (Shimadzu, Kyoto, Japan) equipped with a cooling cover (LTC-50). The films (sample weight of $\sim$ 3 mg) were heated at a rate of 10°C/min under a nitrogen gas flow of 50 mL/min. DSC results were calibrated by use of benzophenone, indium, and tin as standards. The crystallinities of PLLA ($x_{c,PLLA}$) and PCL ($x_{c,PCL}$) in the films with different PLLA and PLLA-CL contents (X_{PLLA} and X, respectively) was calculated through use of the following equations, under the assumptions that PLLA-CL will not crystallize and the exothermic peak observed around 100°C was ascribed to crystallization of PLLA:

$$x_{c,PLLA}\ (\%) = 100(\Delta H_{m,PLLA} + \Delta H_{c,PLLA})/[(1 - X)X_{PLLA}135] \quad (2)$$

$$x_{c,PCL}\ (\%) = 100(\Delta H_{m,PCL})/[(1 - X)(1 - X_{PLLA})142] \quad (3)$$

$$X_{PLLA}\ (w/w) = W_{PLLA}/(W_{PLLA} + W_{PCL}) \quad (4)$$

$$X\ (w/w) = W_{PLLA\text{-}CL}/(W_{PLLA} + W_{PCL} + W_{PLLA\text{-}CL}) \quad (5)$$

where $\Delta H_{c,PLLA}$, $\Delta H_{m,PLLA}$, and $\Delta H_{m,PCL}$ (J/g of polymer) are ΔH_c of PLLA at around 100°C, ΔH_m of PLLA at around 180°C, and ΔH_m of PCL at around 60°C, respectively, and 135 (J/g of PLLA) and 142 (J/g of PCL) are the ΔH_m of PLLA and PCL crystals having infinite crystal thickness, respectively,[30,31] whereas W_{PLLA}, W_{PCL}, and $W_{PLLA\text{-}CL}$ are the weights of PLLA, PCL, and PLLA-CL in the films.

The morphology of the films of 25 μm thickness was studied with an Olympus polarization microscope (BX50; Olympus; Lake Success, NY).

RESULTS AND DISCUSSION

Morphology

Figure 1 shows the polarization optical photomicrographs of the PCL ($X_{PLLA} = 0$), PLLA/PCL ($X_{PLLA} = 0.5$), and PLLA ($X_{PLLA} = 1$) films containing different amounts of PLLA-CL ($X = 0$, 0.05, and 0.1). As evident from the figure, the PCL and PLLA films without PLLA-CL ($X = 0$) were covered with the spherulites with maximum radii of 200 and 10 μm, respectively; it can also be observed that the densities of the PCL and PLLA spherulites decreased with X. This shows that PLLA-CL is miscible with PCL and PLLA and that the dissolved PLLA-CL molecules disturbed formation of the nuclei of the spherulites. In contrast, a complicated phase structure was observed for the PLLA/PCL film without PLLA-CL, whereas the PLLA and PCL spherulites with maximum radii below 10 μm and of about 200 μm, respectively, were noticed for the PLLA/PCL films containing PLLA-CL. The formation of these well-defined spherulites can be ascribed to the increased compatibility between the PCL-rich and PLLA-rich phases, which was caused by the dissolved PLLA-CL in the two phases. The increased compatibility between the two phases decreased the interfacial area or defects, resulting in formation of the well-defined spherulites.

Highly ordered structures

Physical properties of the films before hydrolysis are presented in Table II. Here, it can be seen that the $T_{m,PCL}$ and $T_{m,PLLA}$ were practically constant, irrespective of the X_{PLLA} and X values, implying that the

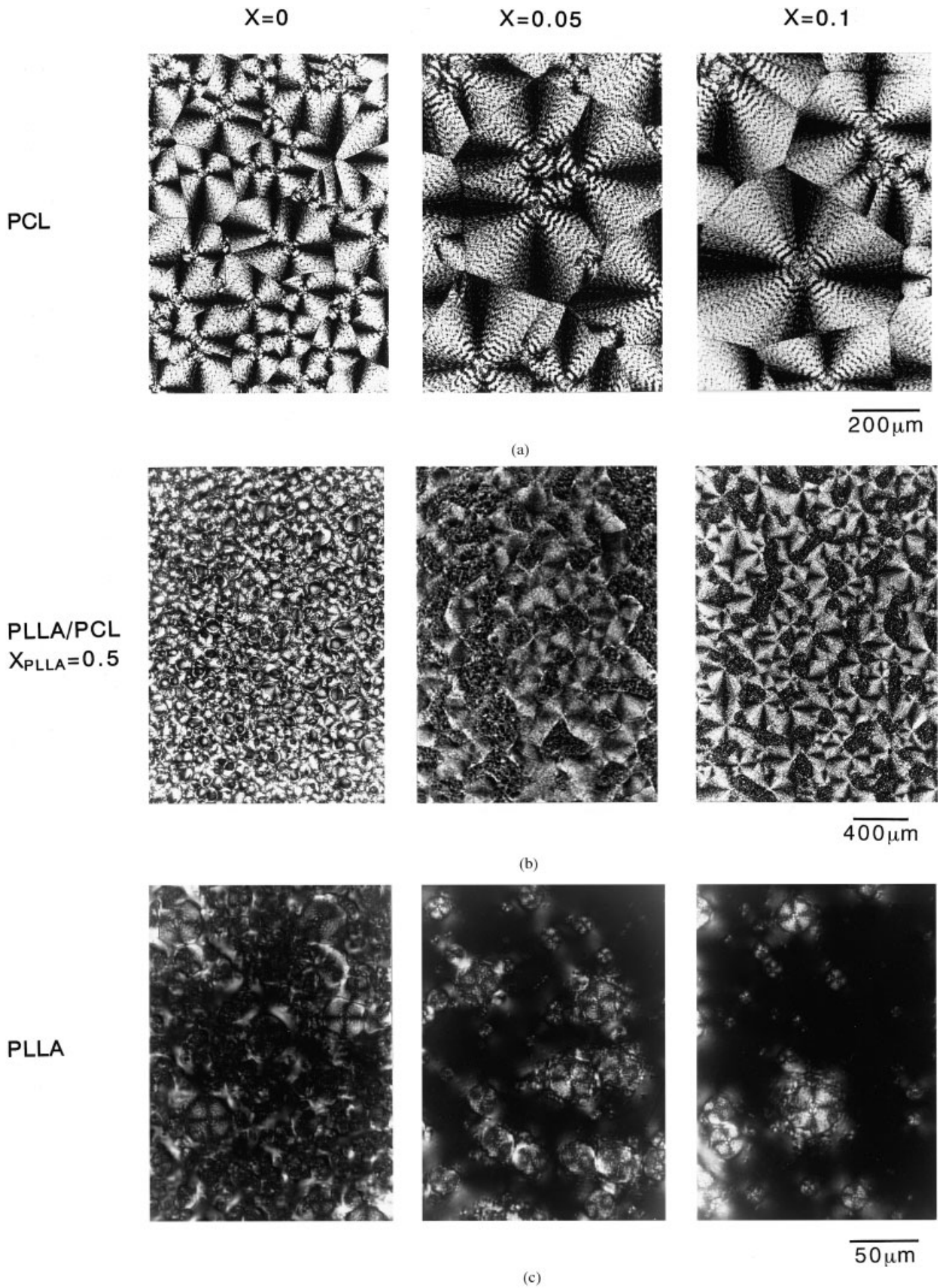

Figure 1 Polarization photomicrographs of the (a) PCL ($X_{PLLA} = 0$), (b) PLLA/PCL ($X_{PLLA} = 0.5$), and (c) PLLA ($X_{PLLA} = 1$) films with different values of X.

TABLE II
Thermal Properties of PLLA, PLLA/PCL, and PLLA Films

Film	X_{PLLA}	X	$T_{m,PCL}$ (°C)	$T_{m,PLLA}$ (°C)	$x_{c,PCL}$ (%)	$x_{c,PLLA}$ (%)
PCL	0	0	65	—	52	—
		0.05	63	—	55	—
		0.1	65	—	50	—
PLLA/PCL	0.5	0	64	178	53	24
		0.05	64	179	40	30
		0.1	63	178	57	32
PLLA	1	0	—	179	—	36
		0.05	—	179	—	29
		0.1	—	178	—	31

crystalline size remained unvaried. The $x_{c,PCL}$ and $x_{c,PLLA}$ of the films containing PLLA-CL were higher or lower than those without PLLA-CL, depending on the X_{PLLA} and X values. It is probable that the following two effects for PCL and PLLA crystallization, that is, the disturbance through dilution by the added PLLA-CL and the enhancement by high mobility of the added PLLA-CL, compete with each other and the overall effect depends on the X_{PLLA} and X values.

Proteinase K–catalyzed hydrolysis

PCL, PLLA/PCL, and PLLA films without PLLA-CL

Figure 2 gives the change in weight loss for the PCL (X_{PLLA} = 0), PLLA/PCL (X_{PLLA} = 0.5), and PLLA (X_{PLLA} = 1) films without PLLA-CL (X = 0), hydrolyzed enzymatically in the presence of proteinase K. Evidently, proteinase K has a significant catalytic effect on the hydrolysis of the pure PLLA and PLLA/PCL films, but has no significant catalytic effect on that

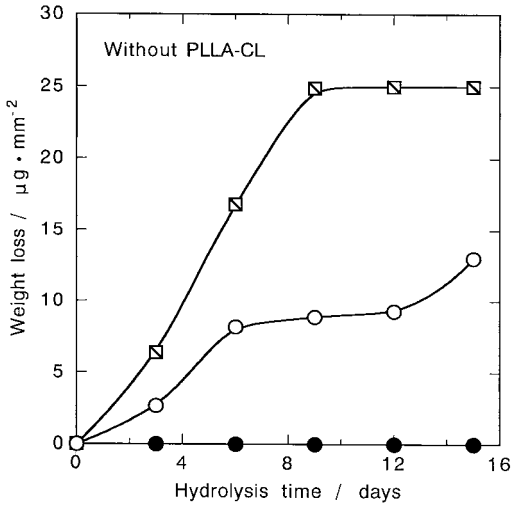

Figure 2 Weight loss per unit surface area of the PCL (●), PLLA/PCL (X_{PLLA} = 0.5) (▨), and PLLA (○), films without PLLA-CL, hydrolyzed enzymatically in the presence of proteinase K as a function of hydrolysis time.

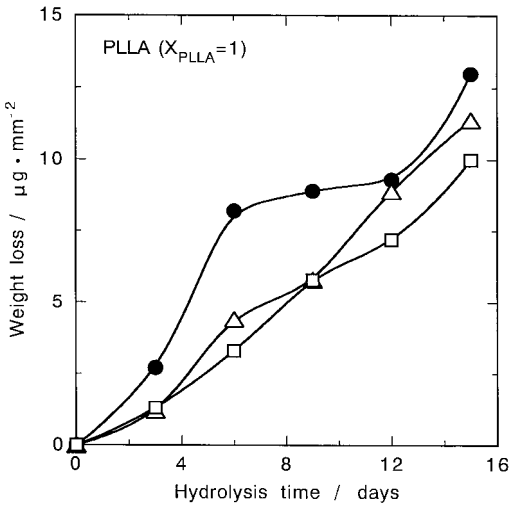

Figure 3 Weight loss per unit surface area of the PLLA films, with X = 0 (●), 0.05 (△), and 0.1 (□), hydrolyzed enzymatically in the presence of proteinase K as a function of hydrolysis time.

of the pure PCL film. It is interesting to note that the PLLA/PCL (X_{PLLA} = 0.5) film has a high hydrolyzability compared with that of the pure PLLA film. The $x_{c,PLLA}$ value of the PLLA/PCL (X_{PLLA} = 0.5, X = 0) film (24%) was slightly lower than that of the pure PLLA film (36%) (Table II). However, the low $x_{c,PLLA}$ value of the PLLA/PCL film cannot solely explain its enhanced proteinase K–catalyzed hydrolysis. The enhanced hydrolysis of the PLLA/PCL films can be ascribed mainly to the diffusion of proteinase K to the interfaces of PLLA-rich and PCL-rich phases as well as on the film surface, and subsequent enzymatic hydrolysis there.[10] In other words, the enzymatic hydrolyzable area is increased by the phase separation into the PLLA-rich and PCL-rich phases. Another probable reason is that a trace amount of PCL dissolved in the PLLA-rich phase enhances the adsorption and scission processes of proteinase K. The result obtained here is in good agreement with that reported for PLLA/PCL films,[9,10] but is in marked contrast with that reported for the compression-molded PLLA/PCL films having low molecular weights,[8] where the hydrolysis rate increased proportionally with X_{PLLA}. This difference may be attributed to the difference in the preparation procedure and the molecular weight of the PLLA/PCL blend. The percentage weight loss value of the PLLA/PCL film saturated around 50 wt % (53 and 54 wt % at 12 and 15 days, respectively). This coincides well with the reported result,[10] and reflects that most of the PLLA molecules were hydrolyzed and removed from the PLLA/PCL film.

PLLA films containing PLLA-CL

Figure 3 illustrates the change in weight loss for the PLLA (X_{PLLA} = 1) films containing different amounts

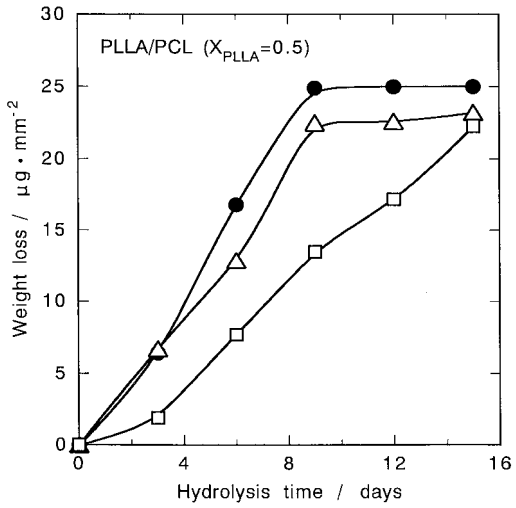

Figure 4 Weight loss per unit surface area of PLLA/PCL (X_{PLLA} = 0.5) films, with X = 0 (●), 0.05 (△), and 0.1 (□), hydrolyzed enzymatically in the presence of proteinase K as a function of hydrolysis time.

of PLLA-CL (X = 0, 0.05, and 0.1), hydrolyzed enzymatically in the presence of proteinase K. The weight loss rate of the PLLA films decreased with X (i.e., the amount of PLLA-CL added to the PLLA film), although the $x_{c,PLLA}$ values of the PLLA films containing PLLA-CL were lower than that of the pure PLLA film, as shown in Table II. The decreased hydrolyzabilities of the PLLA films containing PLLA-CL, in spite of their low $x_{c,PLLA}$ values, indicate that PLLA-CL is miscible with PLLA and therefore the PLLA-CL molecules dissolved in PLLA disturbed the adsorption of proteinase K to the film surface and/or the scission of PLLA chains by the adsorbed proteinase K. The result obtained here also confirms our assumption that the phase structure of the PLLA-based polymer blends rather than the hydrophilicity of a second polymer is crucial to determine proteinase K–catalyzed hydrolyzability[32]; that is, proteinase K–catalyzed hydrolyzabilities of the PLLA-based polymer blends increase and decrease, when the blends are phase separated and miscible, respectively.

PLLA/PCL films containing PLLA-CL

Figure 4 shows the change in weight loss for the PLLA/PCL (X_{PLLA} = 0.5) films containing different amounts of PLLA-CL (X = 0, 0.05, and 0.1), hydrolyzed enzymatically in the presence of proteinase K. The weight loss rate of the PLLA/PCL films decreased with X. The $x_{c,PLLA}$ values of the PLLA/PCL films increased monotonically from 24 to 32% by increasing the X from 0 to 0.1, as shown in Table II. However, the small $x_{c,PLLA}$ increase of the PLLA/PCL films with X cannot solely account for the decreased hydrolyzabilities of PLLA/PCL films containing PLLA-CL compared with that of PLLA/PCL film without PLLA-CL. The increased compatibility between the PLLA-rich and PCL-rich phases caused by the dissolved PLLA-CL may have decreased the hydrolyzable interfacial area between the PLLA-rich and PCL-rich phases. Another probable reason is that the PLLA-CL molecules dissolved in the PLLA-rich phase disturb the adsorption of proteinase K to the film surface and interfaces and/or the scission of PLLA chains by the adsorbed proteinase K. Even the hydrolysis rate of the PLLA/PCL film with X = 0.1 was higher than that of the pure PLLA film. This strongly suggests that the phase-separated structure remained to some extent in the PLLA/PCL film, even when X increased to 10 wt %, or the enhancement effect by the trace amount of PCL dissolved in the PLLA-rich phase cannot be compensated by the disturbance effect by the dissolved PLLA-CL. Similar to the result of the PLLA/PCL film with X = 0, the percentage weight loss value of the PLLA/PCL film with X = 0.05 approached 50 wt % at 15 days, meaning that most of the PLLA chains were hydrolyzed and removed from the film.

Lipase-catalyzed hydrolysis

PCL, PLLA/PCL, and PLLA films without PLLA-CL

Figure 5 demonstrates the change in weight loss for the PCL, PLLA/PCL (X_{PLLA} = 0.5), and PLLA films without PLLA-CL (X = 0), hydrolyzed enzymatically in the presence of *Rhizopus arrhizus* lipase. It is seen that *Rhizopus arrhizus* lipase has a significant catalytic effect on the hydrolysis of the pure PCL and PLLA/PCL films, but has no significant catalytic effect on that of the pure PLLA film. In contrast to the high proteinase K–catalyzed hydrolyzability of the PLLA/PCL

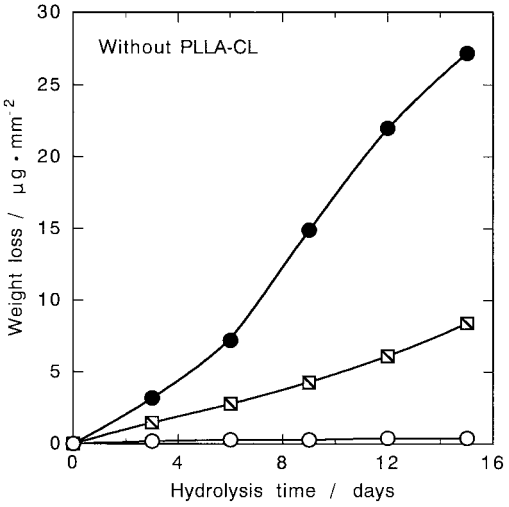

Figure 5 Weight loss per unit surface area of the PCL (●), PLLA/PCL (X_{PLLA} = 0.5) (▨), PLLA (○), films without PLLA-CL, hydrolyzed enzymatically in the presence of *Rhizopus arrhizus* lipase as a function of hydrolysis time.

film without PLLA-CL compared with that of the pure PLLA film, the lipase-catalyzed hydrolyzability of the PLLA/PCL film was lower than the value expected from those of the pure PCL and PLLA films, in spite of the similar $x_{c,PCL}$ values of the pure PCL (52%) and PLLA/PCL (53%) films (Table II). This is comparable with the reported results[9,13] and can be explained by the fact that a trace amount of PLLA molecules dissolved in the PCL-rich phase may have disturbed the adsorption of the lipase to the film surface and the interfaces between the two phases and/or the scission of PCL chains by the adsorbed lipase.

PCL films containing PLLA-CL

Figure 6 gives the change in weight loss for the PCL films containing different amounts of PLLA-CL (X = 0, 0.05, and 0.1), hydrolyzed enzymatically in the presence of *Rhizopus arrhizus* lipase. Similar to the results for the lipase-catalyzed hydrolysis of PLLA/PCL films and for the proteinase K–catalyzed hydrolysis of the PLLA/PLLA-CL films, the lipase-catalyzed hydrolyzability of PCL decreased slightly with X. The $x_{c,PCL}$ values of the PCL films with X = 0, 0.05, and 0.1 were very similar (Table II), and therefore the effects of $x_{c,PCL}$ on their hydrolyzabilities must have been very small. It is probable that PCL is miscible with PLLA-CL and the PLLA-CL molecules dissolved in the PCL-rich phase disturbed the lipase-catalyzed hydrolysis.

PLLA/PCL films containing PLLA-CL

Figure 7 illustrates the change in weight loss for the PLLA/PCL (X_{PLLA} = 0.5) films containing different amounts of PLLA-CL (X = 0, 0.05, and 0.1), hydrolyzed enzymatically in the presence of *Rhizopus arrhizus* lipase. The weight loss rate of the PLLA/PCL films decreased with X. The $x_{c,PCL}$ values of the PLLA/PCL films increased in the following order; 40% at X = 0.05 < 53% at X = 0 < 57% at X = 0.1 (Table II). This means that the $x_{c,PCL}$ was not a main parameter to determine their lipase-catalyzed hydrolyzabilities. Probably, the PLLA-CL molecules dissolved in the PCL-rich phase of the PLLA/PCL films disturbed the lipase-catalyzed hydrolysis and/or the increased compatibility between the PLLA-rich and PCL-rich phases caused by the dissolved PLLA-CL may have decreased the hydrolyzable interfacial area between the PLLA-rich and PCL-rich phases.

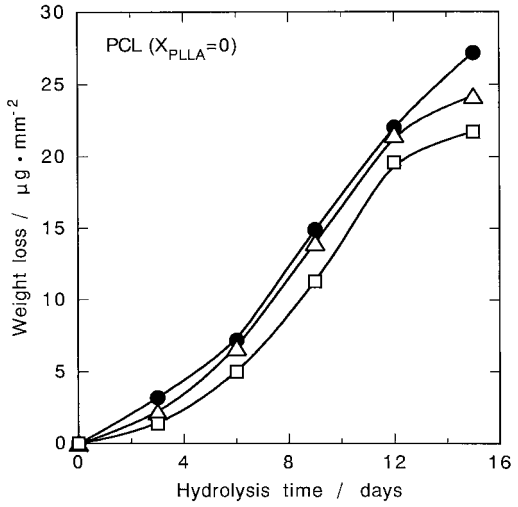

Figure 6 Weight loss per unit surface area of the PCL films, with X = 0 (●), 0.05 (△), and 0.1 (□), hydrolyzed enzymatically in the presence of *Rhizopus arrhizus* lipase as a function of hydrolysis time.

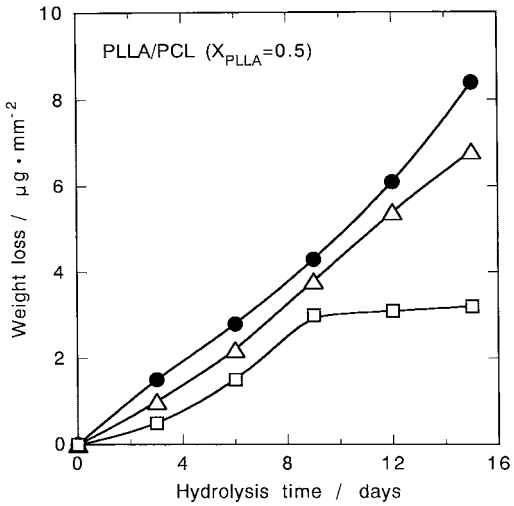

Figure 7 Weight loss per unit surface area of the PLLA/PCL (X_{PLLA} = 0.5) films, with X = 0 (●), 0.05 (△), and 0.1 (□), hydrolyzed enzymatically in the presence of *Rhizopus arrhizus* lipase as a function of hydrolysis time.

CONCLUSIONS

The addition of PLLA-CL decreased the proteinase K–catalyzed hydrolyzabilities of the PLLA and PLLA/PCL (50/50) films and the *Rhizopus arrhizus* lipase-catalyzed hydrolyzabilities of the PCL and PLLA/PCL (50/50) films. The decreased enzymatic hydrolyzabilities of the PLLA and PCL films upon addition of PLLA-CL can be attributed to the fact that PLLA-CL is miscible with PLLA and PCL and the dissolved PLLA-CL must disturb the adsorption and/or scission processes of the enzymes. In addition to this effect, the decreased enzymatic hydrolyzability of the PLLA/PCL (50/50) films upon addition of PLLA-CL can be explained in terms of the increment of the compatibility between the PLLA-rich and PCL-rich phases by the dissolved PLLA-CL, resulting in a decreased hydrolyzable interfacial area. The decreased proteinase K–catalyzed hydrolyzability of the

PLLA films upon addition of PLLA-CL, which is miscible with PLLA, is in marked contrast with the enhanced proteinase K–catalyzed hydrolyzability of the PLLA film upon addition of PCL, which is immiscible with PLLA. This confirms that the miscibility of the second polymer is crucial to determine proteinase K–catalyzed hydrolyzabilities of the PLLA-based blend films.

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