

The Effect of Crosslinking on the Mechanical Properties of Polylactic Acid/Polycaprolactone Blends

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ABSTRACT: The improvement of the brittle behavior of Polylactic acid (PLA) resin was studied by blending it with Polycaprolactone (PCL) resin. These materials were fabricated into the compressed films and injection moldings. The values of tensile modulus and strength were appropriate, judging from the rule of mixtures. However, the ultimate tensile strain was very small. Dicumyl peroxide (DCP) was added to this blend system to improve its ultimate tensile strain. It was found that the value of ultimate tensile strain peaked at low DCP concentration. The samples at low DCP contents show yield point and ductile behavior under tensile test. The impact strength of the optimum composition was 2.5 times superior to neat PLA, and ductile behavior such as

plastic deformation was observed at its fracture surface. It was found that the carbonyl groups of the blend material with DCP were altered by using FTIR spectroscopy. Dynamic mechanical analysis data revealed the dual phase nature of PLA/PCL blend albeit with good interfacial adhesion, and the DCP enhanced the viscous property in PCL phase, which agreed with tensile ductility and impact strength. The mechanical properties of this blend are comparable to those of general purpose HIPS and ABS. © 2006 Wiley Periodicals, Inc. *J Appl Polym Sci* 101: 1816–1825, 2006

Key words: polyactic acid; polycaprolactone; peroxide

INTRODUCTION

Polylactic acid (PLA) being a biodegradable resin is a suitable candidate for addressing the current environmental issues. PLA is a “bio-based polymer,” since it could be manufactured from biomass materials, such as corn, potato, beet, etc.^{1,2} However, the processing characteristics, heat resistance, and mechanical properties need further improvements. For example, the processing properties of PLA for blow molding are not so good because the melt tension is very low. Therefore, the melt elongational viscosity could be adjusted by peroxide, isocyanate, and other additives, which can form crosslinked structures.³ Nanosize clay is an effective filler for high heat distortion temperature of PLA, as it has already been used in various fields.⁴ The serious issues of its mechanical properties are brittle behavior and low impact strength. Recently, synthetic rubbers were even-blended with PLA to improve impact strength while bearing in mind the restriction that only a limited quantity of petroleum based materials could be added to retain its biodegradable nature.⁵ Lately, the authors attempted to create materials that

could withstand practical application while their biodegradation properties are maintained.^{6,7}

This study attempts to improve the brittle behavior of PLA by blending it with polycaprolactone (PCL) resin. The PLA/PCL blend material could be biodegraded in the natural environment and compost. However, it is predicted that the mechanical properties of PLA/PCL binary blend may not possess adequate properties.

On the other hand, there are many studies on the addition of peroxide to polymer blend systems, in particular nonpolar polymers are frequently modified with maleic anhydride to improve compatibility with polar polymers.^{8,9} Recently, biodegradable polymers, i.e., PLA and PCL, were modified by maleic anhydride and peroxide.^{10,11} These modified materials must be compatible with other polar polymers, and they described the scheme of free radical generation via hydrogen abstraction from PLA and PCL molecules. In this study, peroxide was added to PLA/PCL binary blend to induce chemical crosslinking, to generate a high performance material.

EXPERIMENTAL

Materials and interfacial tension

The materials used in this study were PLA (Lacea H100, melt index = 8.0 g/10 min; Mitsui Chemicals,

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TABLE I
Sample Formulations Used for Making Compressive Films and Injection Moldings

PLA/PCL (wt %)	DCP (p hr)						
	0	0.1	0.2	0.3	0.5	1.0	2.0
100/0	⊙	⊙	⊙	○	○	○	○
90/10	○	○	○	○	-	-	-
80/20	○	○	○	○	-	-	-
70/30	⊙	⊙	⊙	⊙	○	○	○
50/50	○	○	○	○	-	-	-
30/70	⊙	⊙	○	○	-	-	-
0/100	⊙	⊙	○	○	○	○	○

⊙: Compressive films and injection moldings.

○: Compressive films.

Tokyo, Japan), PCL (Cel green PH7, melt index = 2.3 g/10 min; Daicel Chemical Industries, Osaka, Japan), and dicumyl peroxide (DCP) (half-life at 175°C is 1 min; NOF, Tokyo, Japan).

Melting interfacial tension data is important because polymer mixing is carried out in the molten state. The melting interfacial tension of PLA/PCL was measured by using sessile and pendant drop method. The detailed method can be found in a previous publication.¹²

Compounding with internal mixer and fabrication of films

The materials were compounded with an internal mixer (Labo Plastomill 100C100; Toyoseikiseisaku-sho, Tokyo, Japan; with a chamber volume of 30 cc) at 180°C. The compounding procedures consisted of two stages. The first stage was the compounding of PLA and PCL, and the second was the crosslinking reaction in the presence of DCP. PLA and PCL were added into mixing chamber at 10 rpm. After the addition of these materials, screw rotation was increased to 30 rpm until a stabilizing torque was attained. At the second stage, screw revolution was 60 rpm. To prevent clustering of DCP, the granulated material was added into chamber little by little. Blending was continued for 10 min after the addition of DCP.

Samples were compression molded with a hot press machine (NF-50; Shinto Metal Industries, Osaka, Japan; max load = 50 tf) and fabricated into thin films of 200 μ m thickness. The processing temperature was 180°C. The list of samples evaluated is shown in Table I. The blend ratios of PLA/PCL studied were 100/0 (neat PLA), 90/10, 80/20, 70/30, 50/50, 30/70, and 0/100 (neat PCL) by weight. The DCP contents investigated were 0, 0.1, 0.2, and 0.3 phr. To assess the effect of excess DCP addition on mechanical properties, the concentrations of 0.5, 1.0, and 2.0 phr were further added into the 100/0, 70/30, and 0/100 compositions. The cooling of samples was effected under pressure by running water through the cooling chamber of the

compression machine. This fabrication of varying materials composition facilitated the determination of optimum blend ratio and DCP concentration.

Compounding with twin-screw extruder and fabrication of injection moldings

The 100/0, 70/30, and 0/100 blends containing 0, 0.1, 0.2, and 0.3 phr of DCP blend were compounded with a twin-screw extruder (KZW15-60MG-KIK; Technovel, Osaka, Japan; Φ 15, L/D = 60). The list of samples compounded is shown in Table I. The PLA containing 0.3 phr of DCP and the PCL containing 0.2 and 0.3 phr of DCP could not be blended owing to the high torque resulting from increased viscosity. Compounding was done at a cylinder temperature of 180°C and screw revolution of 80 rpm. These blended pellets were fabricated into injection moldings (Ti30F6; Toyo Machinery and Metal, Hyougo, Japan; maximum cavity pressure, 5 ton) of 4 mm thickness. The cylinder and cavity temperature were 180 and 25°C, respectively.

Tensile and Izod impact test

Tensile test of compressive films and injection moldings were carried out by using a universal testing machine. Tensile speed of both samples were 50 mm/min, gauge length of compressive films and injection moldings were 30 and 25 mm.

Two types Izod impact test were carried out for injection moldings. One was normal Izod impact test in which the crack propagated from the tip of notch. The second was reverse Izod impact test in which the crack propagated from opposite side against notch. The former method can evaluate the impact strength taking into account the notch sensitivity. Later method can evaluate it taking into account products in use without crack.

Observation of internal structure and fracture surface

To observe the deformation of dispersed PCL phase, the center area of the cross section before and after tensile test was observed by using atomic force microscope (AFM) (Nanoscope IIIa; Digital Instruments, CA). The compressive films were employed as observation samples. For the cross section after tensile test, a spot as close as possible to the tensile fracture surface was observed. The cross-sectional area was adjusted to a flat surface by using a microtome equipped with a glass knife. The tapping mode, which is a commonly used observation method in AFM was applied to the cross-sectional area, and the phase images were taken. Observation of the fracture surface of injection moldings after tensile test was carried out to evaluate the dropout traces, which could be used to judge interfacial adhesion.

FTIR spectroscopy

Attenuated total reflectance (ATR) spectra in the 4000–600 cm^{-1} region were measured with a FTIR spectrometer (system2000 FTIR; Perkin–Elmer, Wellestley, MA; detector: TGS, resolution: 4 cm^{-1}) to evaluate the effect of peroxide on chemical structure. ATR measurements were carried out by placing the cross sections directly on the diamond internal reflectance element that is the square window of 2 mm.

Dynamic mechanical properties

Dynamic mechanical analysis (DMA) (ARES; TA Instruments, New Castle, DE) gives much beneficial information on interfacial profile, such as the restriction of boundary and compatibility, etc. The dynamic temperature ramp test was employed for 100/0, 70/30, and 0/100 blend systems. Measurement was done at temperature ranging from -100 to 200°C , at a ramp speed of $3^\circ\text{C}/\text{min}$, 0.1% strain, and frequency of 6.28 rad/s.

RESULTS AND DISCUSSION

Determination of optimum composition by evaluation of compressive film

Effect of peroxide on melt viscosity

The torque data of neat PLA (a), neat PCL (b) and 70/30 blend systems (c) were monitored during compounding by means of an internal mixer as shown in Figure 1. The torque values increased remarkably at 450 s, which was the starting time of DCP addition, and the peak values were dependent on the DCP contents. As time passed, the torque value gradually stabilized. The torque values for the 70/30 blend rang-

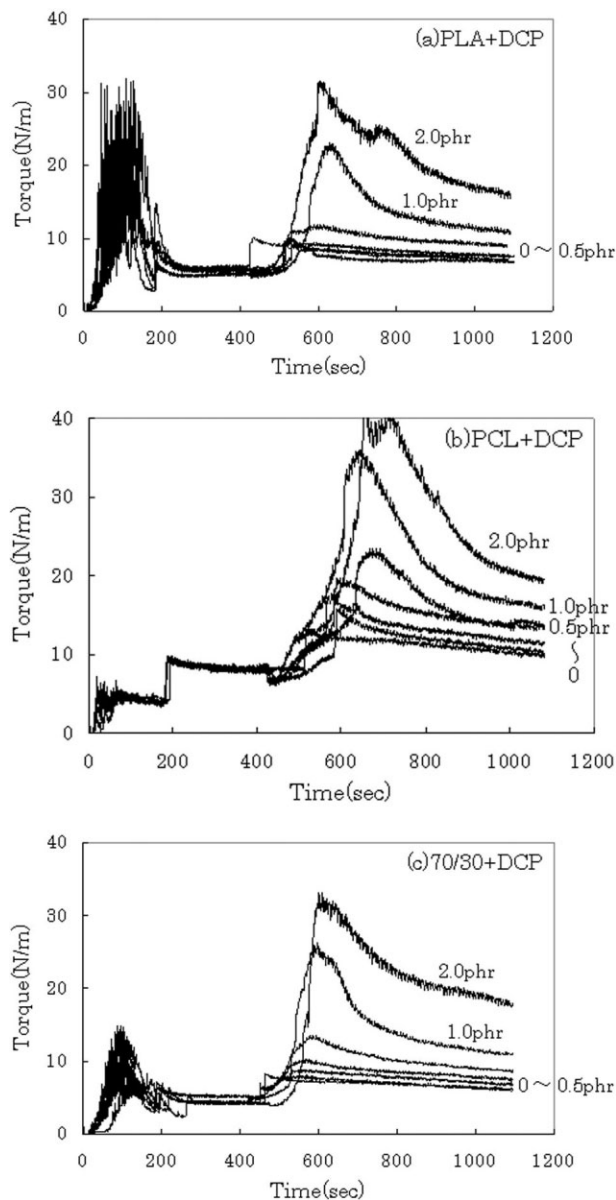


Figure 1 Torque data monitored during compounding with an internal mixer. (a) PLA + DCP; (b) PCL + DCP; (c) 70/30 + DCP.

ing from 0.3 to 2.0 phr of DCP at the end of blending were intermediate between those of neat PLA and PCL, while those of 70/30 blend ranging from 0 to 0.2 phr of DCP were similar to neat PLA. Thus, higher amount of DCP induced intense crosslinking within the bulk and through the interface between PLA and PCL.

Mechanical properties of compressive film

The mechanical properties, which are of importance to this study, were evaluated via tensile testing. Figure 2 shows the stress–strain curves of neat PLA, neat PCL, and 70/30 blended compressive films containing

varying amounts of DCP. The modulus and strength of neat PLA was high, but the ultimate strain was very low (3.60%). On the other hand, neat PCL showed low modulus and strength, but the ultimate strain was very high.^{13,14} The ultimate strain of the 70/30 blend without DCP was only 15%, thus PCL on its own does not impart sufficient ductility on PLA. Therefore, DCP was added to achieve further improvement of tensile strain. With the addition of a little amount of DCP, the samples showed yield stress and necking. Further addition of DCP beyond the optimum amount had the opposite effect on tensile ultimate strain as embrittlement sets in.

Figure 3 shows the tensile modulus (a), strength (b), and ultimate strain (c) of all compressive films. Tensile modulus and strength of all blend specimens were positioned between those of PLA and PCL samples. The ultimate strain, except from 100/0 (neat PLA) to 80/20 and 0/100 (neat PCL) blends, showed peculiar behavior with a peak at 0.1 and 0.2 phr. The tensile properties of compressive films containing 0.2 phr of DCP were compared to the rule of mixture in Figure 4. The tensile modulus (a) of 100/0, 90/10, and 80/20 fitted the line of rule of mixture, while others fell short of the line indicating miscibility at low concentrations of PCL but the two phases separate at higher concentrations. Tensile strength yielded a similar pattern and from both properties, compatibility could be deduced at higher concentrations of PCL in spite of phase separation. This could be attributed to strong interfacial interaction as both materials are polyesters. On the other hand, peculiar plots were obtained for ultimate strain (c). At low PCL content (90/10 and 80/20), PCL addition had little influence on ultimate strain. The strain was remarkably improved at 70/30, but then dropped suddenly at 50/50 blend ratio, after which it increased with increasing PCL content. The interfacial tension of PLA/PCL at 180°C, calculated by sessile and pendant drop measurements, was 0.33 mN/m,

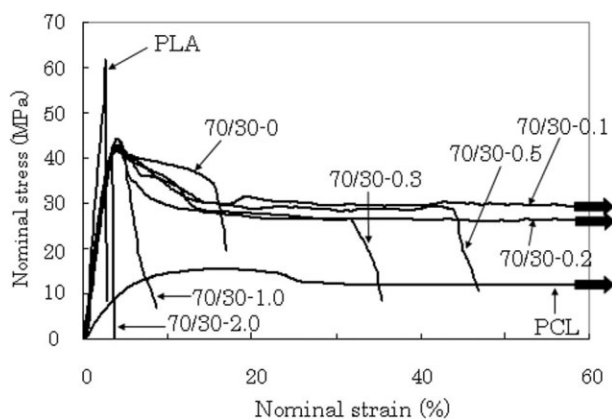


Figure 2 Tensile stress–strain curve of neat PLA, neat PCL, and 70/30 blend containing different amounts of DCP for compressive films.

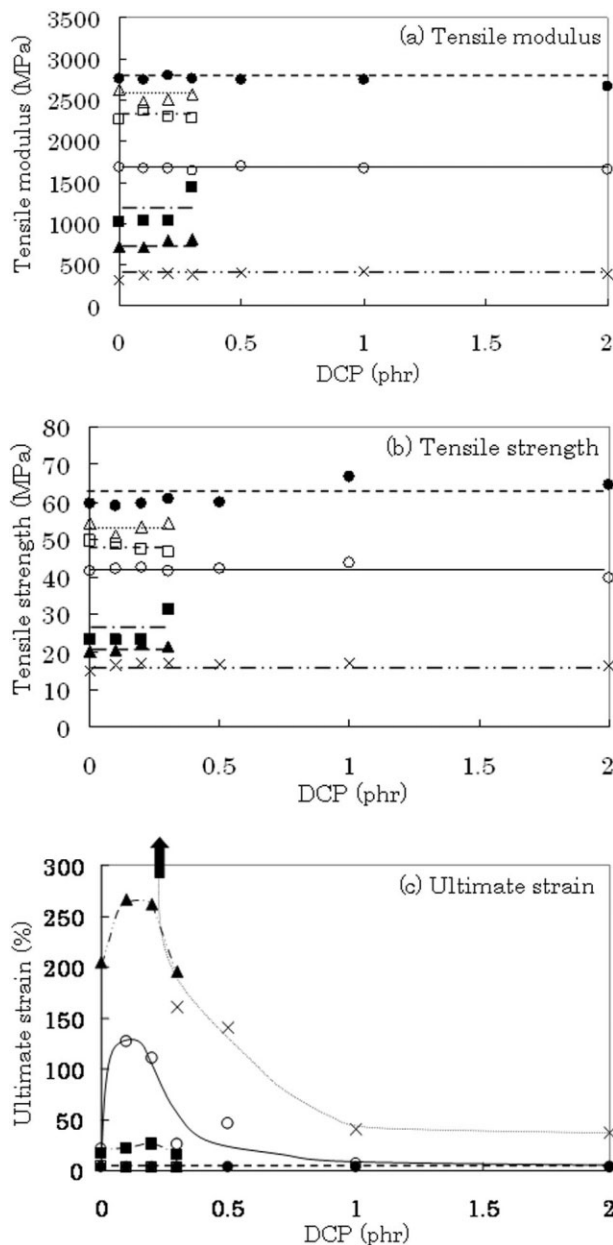


Figure 3 Tensile modulus, strength, and ultimate strain of compressive films. (a) Tensile modulus; (b) tensile strength; (c) ultimate strain; ●neat PLA; △90/10; □80/20; ○70/30; ■50/50; ▲30/70; ×Neat PCL.

which generally could be considered a compatible blend. The closeness of the values of tensile modulus and strength to those of the rule of mixture indicate compatibility and the observed mechanical properties were therefore in good agreement with interfacial tension results.

Notably, the 70/30 PLA/PCL composition containing 0.1 and 0.2 phr of DCP had reasonable values of modulus and strength that were close to the rule of mixture, while the ultimate strain was high (130%). Moreover the blend contains a relatively high “bio-based content.” It has therefore been uncovered that

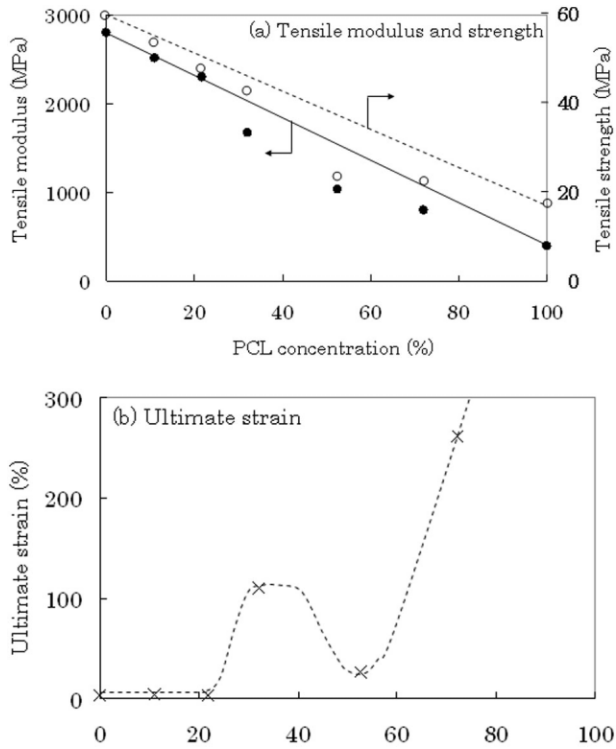


Figure 4 Comparison with rule of mixture and experimental value of compressive films containing 0.2 phr of DCP. (a) Tensile modulus and strength; (b) ultimate strain; ●tensile modulus; ○tensile strength; ×ultimate strain.

ultimate strain improved considerably, while modulus and strength were retained with the addition of small

quantities of DCP. The 70/30 blend containing 0.1 or 0.2 phr of DCP was judged to be the optimum composition.

Internal structure of compressive films

The atomic force microscopy (AFM) observation of cross sections was carried out to evaluate the internal structure of the blends. The AFM images and the schematic diagram of the 70/30 blend containing 0, 0.2, and 2.0 phr of DCP are shown in Figure 5. These micrographs were captured in the phase imaging mode in which the image contrast describes the stiffness and viscoelasticity of the materials. The internal structure was typical sea-island structure where the dark PCL islands were dispersed in the bright PLA sea. The average diameter of PCL islands was 2.7, 1.1, and 0.31 μm in the PLA/PCL blends containing 0, 0.2, and 2.0 phr, respectively. The diameters of PCL particles decreased with increasing DCP content. Thus, a fine structure could be formed by DCP addition. The addition of DCP promoted high viscosity of the melt that enhanced the formation of fine dispersions.

Figure 6 compares the variation of ultimate strain in comparison to average dispersed size at varying DCP content for the 70/30 blend. The value of ultimate strain peaked at 0.1 and 0.2 phr, while the average diameter decreased continuously with increasing DCP content. Hence, it could be inferred that ultimate strain has no direct relationship with average particle size.

Figure 7 shows the internal structure of compressive films after tensile test. The dispersions of samples

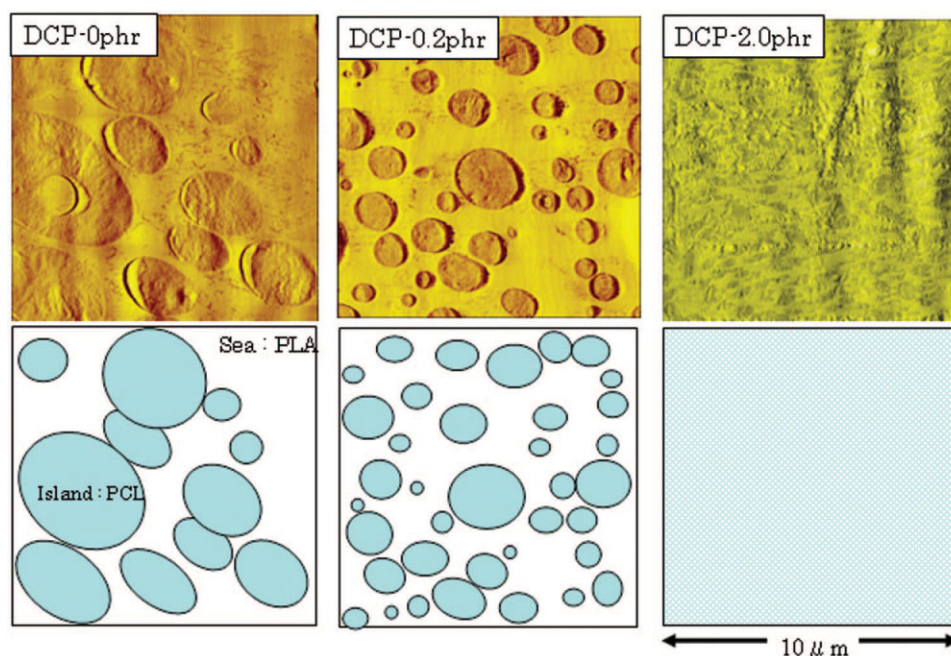


Figure 5 AFM image and the schematic diagram of 70/30 blend containing 0, 0.2, and 2.0 phr of DCP. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

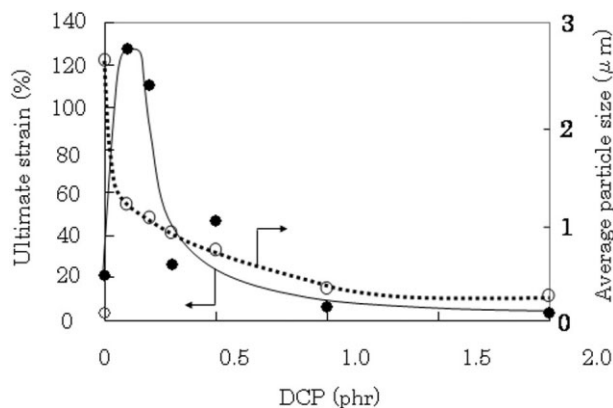


Figure 6 Relationship between ultimate strain, average dispersed size, and DCP content for 70/30 blend. ○average particle size; ●ultimate strain.

containing 0 and 2.0 phr of DCP were of spherical shape and were similar to those before tensile test, i.e., the deformation of dispersions was absolutely not observed. On the other hand, the dispersions of the samples containing 0.2 phr of DCP were elongated along the tensile direction. The PCL components respond to the deformation of the PLA matrix. This indicates that tensile stress was transmitted through the interface of PLA/PCL because of improved interfacial adhesion resulting from cocrosslink formation. This may not be obvious in the 2 phr of DCP sample because of small sizes of the dispersions.

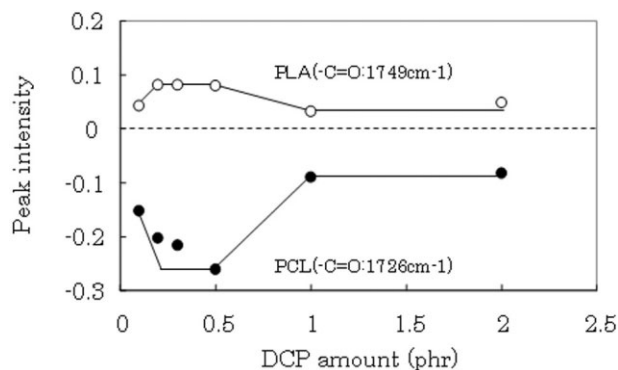


Figure 8 FTIR peak intensity change with the addition of DCP. ○carbonyl group of PLA; ●carbonyl group of PCL.

Evaluation of peroxide on chemical structure

Figure 8 shows the relationship between FTIR peak intensity and DCP content of the 70/30 blend. The peak intensity was obtained by subtracting the spectrum of PLA/PCL blend without DCP from the spectra of each sheets containing DCP. The base peak for subtraction was methyl group of PLA at 1452 cm^{-1} ,¹⁵ which is more stable than other functional groups against peroxide in both molecules. The value 0 along the ordinate indicates equal amount functional group as the PLA/PCL blend containing 0 phr of DCP. The increase or decrease of functional groups is reflected in the peak intensity. A remarkable change of peak intensity was observed for the carbonyl group. The

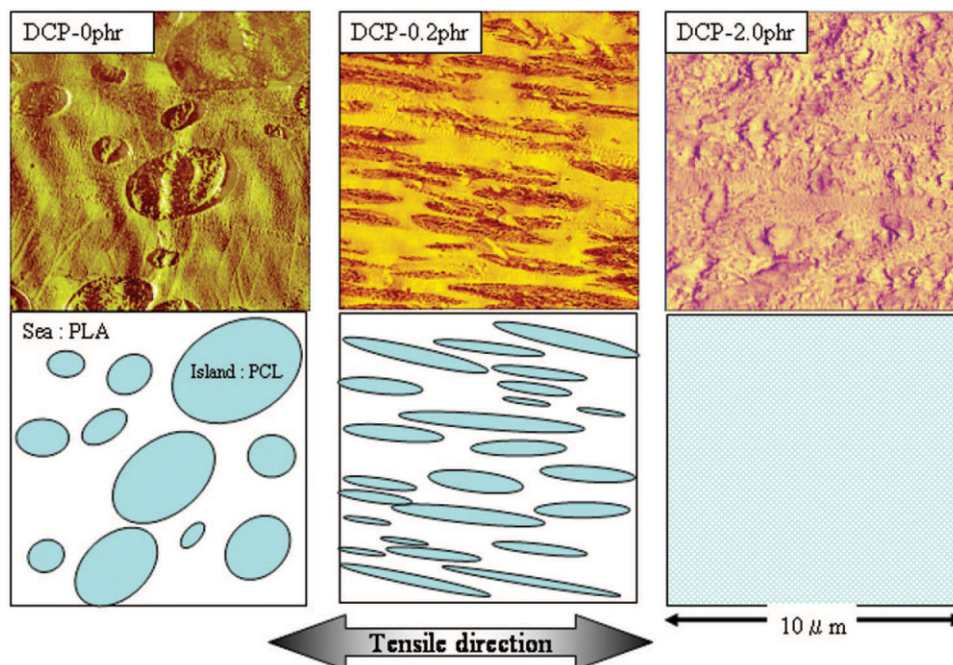


Figure 7 AFM image and the schematic diagram of the 70/30 PLA/PCL blend containing DCP 0, 0.2, and 2.0 phr after tensile test. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

carbonyl group absorption at 1749 cm^{-1} for PLA increased in the case of the addition of small quantities of DCP (0.1–0.5 phr). On the other hand, the carbonyl group at 1726 cm^{-1} of PCL distinctly showed the opposite trend. It is indicated that small amount of DCP effected some chemical reactions in both polymers.

The sequence of reactions that lead to crosslink formation are proposed in Figure 9.^{10,11} The peroxide decomposes to R^∞ radicals, which abstract hydrogen from both PLA and PCL to yield free radicals. In PCL, the free radical is next to the carbonyl group, so β -scission of PCL radical occurred to yield a primary radical. The molecular structure of PCL containing many secondary hydrogen atoms facilitates easy abstraction of hydrogen atom by peroxide than PLA molecules. The tendency of hydrogen abstraction is reflected in the changes of the carbonyl group of PCL. The primary alkyl radicals resulting from PCL scission can easily access the tertiary radicals of PLA to form cocrosslinks.

Mechanical properties of injection moldings at optimum blend composition

Compounding by use of twin screw extruder

The 70/30 blend containing small amounts of DCP, which was judged as the optimum composition owing to its reasonable tensile modulus, strength, high ultimate strain, and high bio-based content, was compounded by using a twin-screw extruder, and then injection-molded parts were fabricated to evaluate tensile, impact strength, and DMA properties. The neat PLA with 0.3 phr of DCP, neat PCL with 0.2 and 0.3 phr of DCP could not be compounded because of their high of shear viscosity. On the other hand, the 70/30 with 0.1, 0.2, and 0.3 phr of DCP could be compounded. Thus, the viscosity of bulk polymer is different from those of the blend materials having interface.

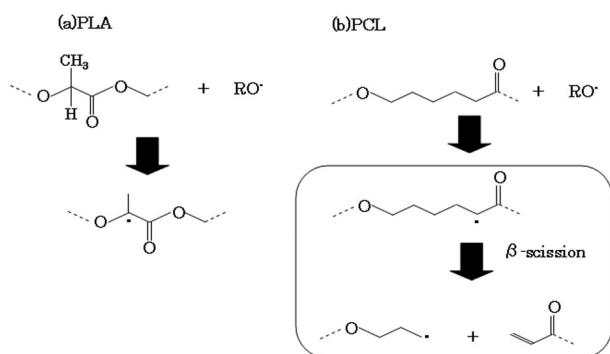


Figure 9 Predicted scheme for PLA/PCL crosslink formation. (a) PLA; (b) PCL.

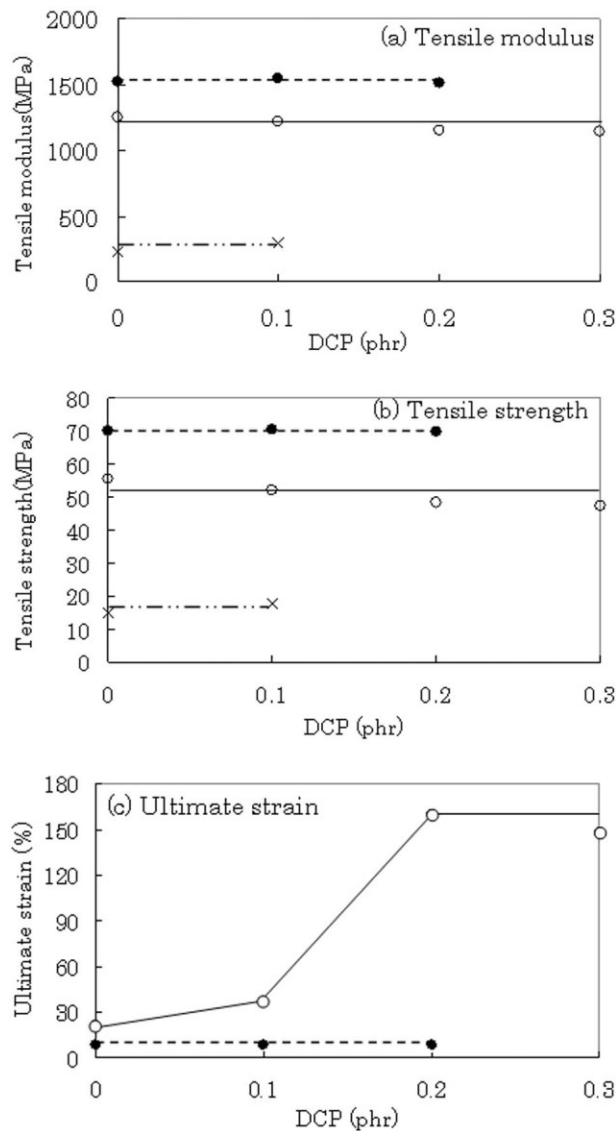


Figure 10 Tensile modulus, strength, and ultimate strain of injection moldings. (a) tensile modulus; (b) tensile strength; (c) ultimate strain; ●neat PLA; ○70/30; ×neat PCL.

Mechanical properties of optimum blend

Figure 10 shows the tensile modulus (a), strength (b), and ultimate strain (c) of injection moldings. The data showed a similar trend to those obtained for compressive films, which did not deviate too far from the rule of mixtures.

However, the absolute value of the modulus was low in contrast to the compressive films. This could be due to the different cooling methods that the samples were subjected to. In the case of compressive films, the cooling of samples was effected by the cold water running through the cavities of the cooling plates. The cooling rate was slow and took several minutes. Consequently, the crystallinity of these samples is high. On the other hand, in the case of injection moldings, the melted materials were injected into the cold cavity

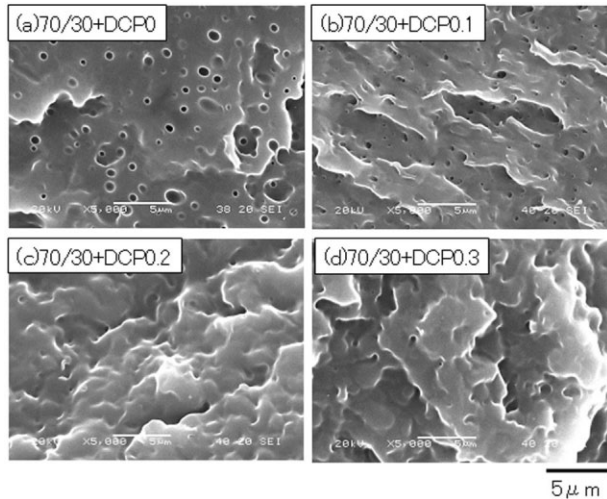


Figure 11 Tensile fracture surface of 70/30 blends. (a) DCP0; (b) DCP0.1; (c) DCP0.2; (d) DCP0.3.

of the mold, so the cooling rate was very fast. This results in the lowering of crystallinity. PLA is a crystalline material, therefore the processing conditions seriously affect mechanical properties. For example, modulus could vary from 2000 to 4600 MPa depending on the processing conditions.¹⁶

There were clear differences at the fracture surfaces obtained after tensile testing as shown in Figure 11. Many dropout traces were observed in the sample without DCP, which decreased with increasing DCP content. The dropout traces of the samples with 0.2 and 0.3 phr of DCP were very few, which is an indication of the good interfacial adhesion between PLA and PCL phases. These results were in agreement with the observed ultimate strain.

Figure 12 shows the relationship between normal (a) and reverse (b) Izod impact strength. The impact strength of PLA maintained a constant value at all DCP contents in both tests. On the other hand, the impact strength of PLA/PCL (70/30) showed a higher value, which increased with increasing DCP content at low DCP concentrations. In the case of the normal Izod impact test, the PLA/PCL containing 0.3 phr of DCP showed a value that was 2.5 times the value of the PLA. In the case of the reverse Izod impact test, the impact strength of both samples showed similar values from 0 to 0.2 phr of DCP contents. On the other hand, PLA/PCL blend containing 0.3 phr showed a higher value that was 2.5 times those of the other materials. Based on those observations, it is obvious that DCP addition significantly alters the impact properties of this blend system.

Pronounced differences were observed between the fracture surfaces of the samples that showed low and high impact strength. Figure 13 shows the fracture surface of the reverse Izod samples of neat PLA and 70/30 blend containing 0 and 0.3 phr of DCP. There

were many bumpy lines in the neat PLA system and the 70/30 blend containing 0 phr of DCP. On the other hand, the bumpy lines disappeared in the 70/30 blend containing 0.3 phr of DCP while whitening phenomenon, which is an indication of ductile fracture, was observed.

Interaction between PLA and PCL phases

The DMA analysis was carried out to evaluate the compatibility and the effects of DCP addition. The DMA curves of neat PLA (a), neat PCL (b) and the 70/30 blend (c) with 0 phr of DCP are as shown in Figure 14. In all cases, storage modulus (G') reduced gradually as temperature increased. However, G' of neat PLA and 70/30 blend increased at 75°C as a result of crystallization of PLA. This was indicated by the transparent neat PLA becoming cloudy after DMA test. The sharp reduction of the G' of neat PCL at -55°C was due to T_g of PCL, however, that of the 70/30 blend at this temperature was not so sharp indicating some degree of compatibility between PLA and PCL. This blend system without DCP although phase-separated and therefore not a miscible system, it could be considered as compatible blend based on

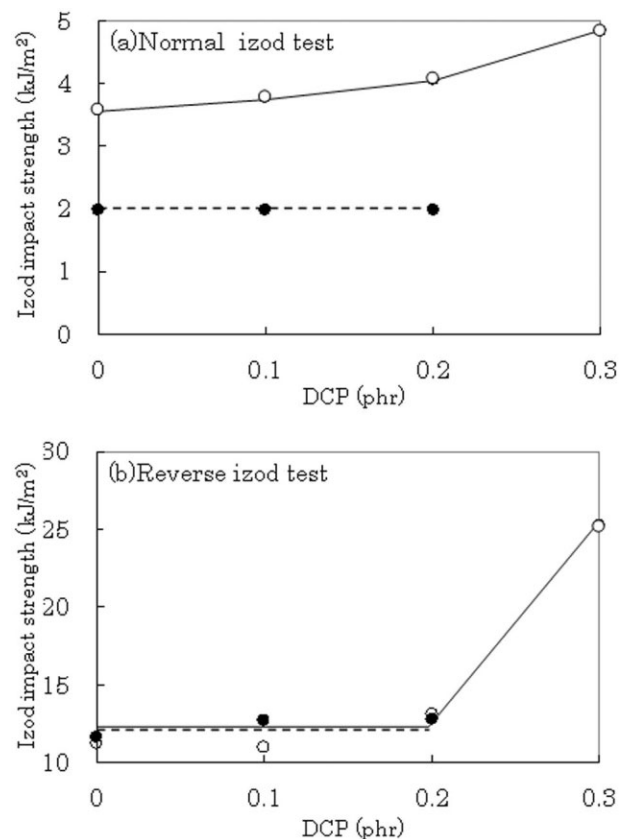


Figure 12 Relationship between Izod impact strength and DCP content. (a) Normal Izod test; (b) reverse Izod test; ●Neat PLA; ○70/30; ×Neat PCL.

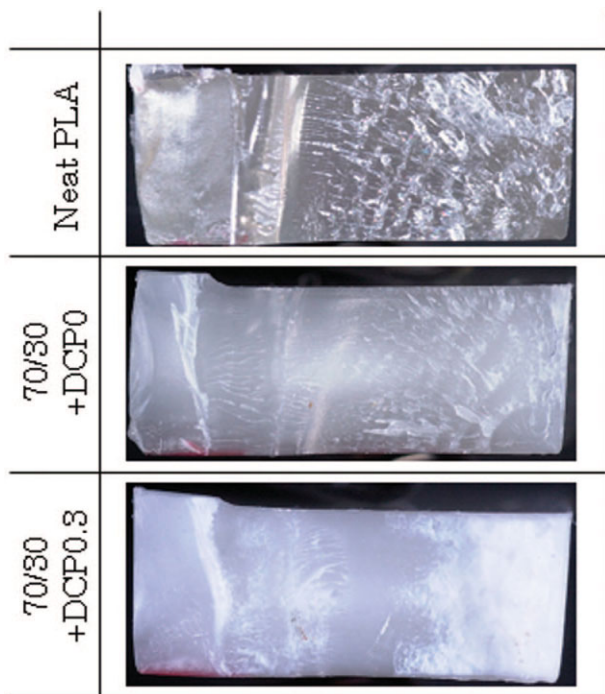


Figure 13 Fracture surface of reverse Izod samples. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

this DMA result, melting interfacial tension, tensile modulus, and strength. Compatibility arises from the common functional group, which accounts for strong interfacial interactions.

The two relaxation peaks of the loss modulus (G'') and $\tan \delta$ curve at -50 and 60°C , indicating the glass transition temperature (T_g) of both components, were evident in the 70/30 blend indicating phase separation. It could be seen that the peak shapes and height of G'' at -50°C were different, as shown in Figure 15, which reflects the effect of DCP addition on G'' . The PCL peak was sharper than that of the 70/30 blend. In the case of 70/30 blend, the peak shape of the samples with greater DCP contents were broader than those containing less amount of DCP. The height of G'' also increased with increasing DCP content. Thus, it could be inferred that DCP addition enhanced the viscous nature of the 70/30 blend, which is consistent with the high ultimate tensile strain and impact strength.

PLA and PCL are both polyesters in which the monomers are linked by the same ester functional group ($-\text{COOC}-$). It is therefore expected that this combination should yield a miscible system. Our studies involving mechanical properties as a function of composition revealed that this is indeed true at low concentrations of PCL but phase separation might occur at higher concentrations, indicated by deviation from the rule of mixture. In the 70/30 PLA/PCL blend, it is revealed by DMA and AFM that both PCL and PLA exist mostly in separate phases perhaps due

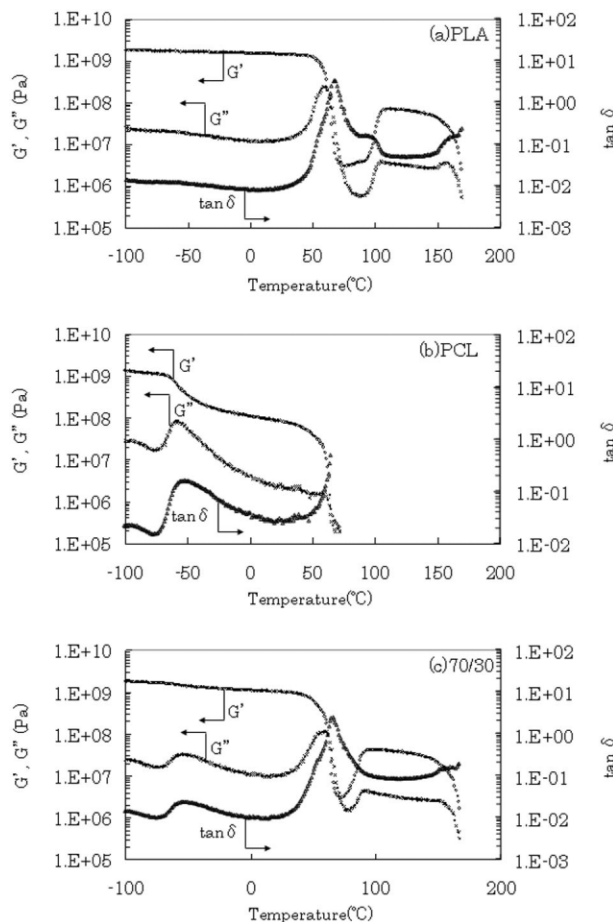


Figure 14 Storage modulus, loss modulus, and $\tan \delta$ curves. (a) PLA; (b) PCL; (c) 70/30; $\circ G'$; $\times G''$; $\triangle \tan \delta$.

to the highly crystalline nature of both polymers. However, a reasonable level of compatibility could be judged from tensile modulus, strength, and DMA property due to strong interfacial interactions by the $-\text{COOC}-$ of both polymers. Therefore, this blend could be considered a compatible blend. In the case of

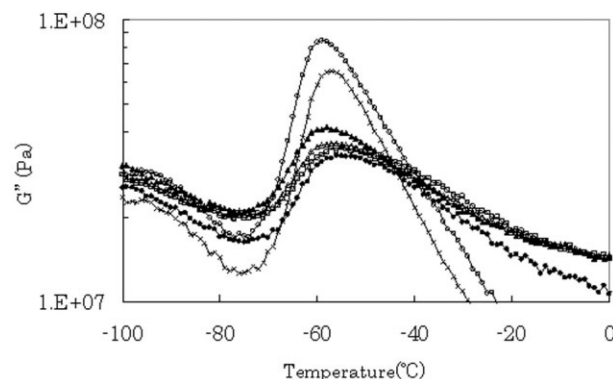


Figure 15 Loss modulus (G'') curve of PCL and 70/30 blend. \circ neat PCL; \times PCL + DCP0.1; \bullet 70/30; \square 70/30 + DCP0.1; \triangle 70/30 + DCP0.2 phr; \blacktriangle 70/30 + DCP0.3 phr.

the blend containing DCP, the PCL phases are also independently dispersed in PLA matrix as similar to the blend without DCP, i.e., this blend is also not miscible. However, it showed better ultimate tensile strain and impact strength maintaining the high tensile modulus and strength. These results showed that this blend is more compatible than the blend without DCP. Improved compatibility would arise from the formation of crosslinks initiated by the peroxide in addition to the interactions of the ester groups. Therefore, the crosslinked system is a highly compatible blend system, which utilize the individual material property of PLA and PCL phases through improved interfacial adhesion. Of particular interest is the mechanical properties of PLA/PCL blend (70/30) containing 0.3 phr of DCP that are comparable to those of popular plastics such as ABS and HIPS.

CONCLUSIONS

1. It has been shown that PLA/PCL blend could be considered to be a compatible blend system based on the results of the melting interfacial tension, DMA, and tensile test. Furthermore, the PLA/PCL containing little amount of DCP blend shows higher compatible behavior.
2. The optimum blend ratio of PLA/PCL blend was determined as 70/30. The values of tensile modulus and strength were intermediate between those of neat PLA and neat PCL, thus obeying the rule of mixture. The ultimate strain showed peculiar behavior by yielding highly ductile blends at low DCP concentrations. The 70/30 PLA/PCL blend showed mechanical properties that were comparable or surpassed those of some common plastics.
3. The dispersed PCL particles were extended along the tensile direction when tensile load was applied to the samples. It is presumed that the extended PCL particles follow the deformation of PLA matrix, and this delay failure during tensile test.
4. Dropout traces and stress whitening phenomenon were observed in the tensile and impact fracture surfaces, which indicate improved interfacial adhesion resulting from DCP addition, thus DCP is a good compatibilizer for PLA/PCL blend.

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