ENVIRONMENTAL DEGRADATION OF STEREOCOMPLEX-TYPE POLYLACTIC ACID FIBER

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ABSTRACT

Biodegradable polymers are gaining attention from the viewpoint of protection of the natural environment. Polylactic acid (PLA) is one of the best-known biodegradable polymers and has many good properties such as biodegradability, biocompatibility, mechanical strength and transparency. Because of enantiomeric composition of PLA, there are three types, poly-L-lactic acid (PLLA), poly-D-lactic acid (PDLA) and stereocomplex-type polylactic acid (SCPLA). In recent years, SCPLA is gaining attention in the various fields due to its melting point of 220°C, which is higher than that of pure PLLA and PDLA. Exposure of PLA to environmental agents such as water, heat, degrades its mechanical properties. This study reports the effect of water and high temperature environment on mechanical properties of SCPLA fiber, and the surface morphological changes in SCPLA fiber and PLLA fiber immersed in water have been investigated. For the SCPLA fiber immersed in water at high temperature, tensile strength drastically decreased with the hydrolysis of SCPLA. Compared to the PLLA fiber, however, SCPLA fiber had a greater resistance to hydrolysis. When SCPLA fiber and PLLA fiber were immersed in water at high temperature, regular patterns of cracks running in the vertical direction to the fiber axis was observed and finally, the fibers was partially broken.

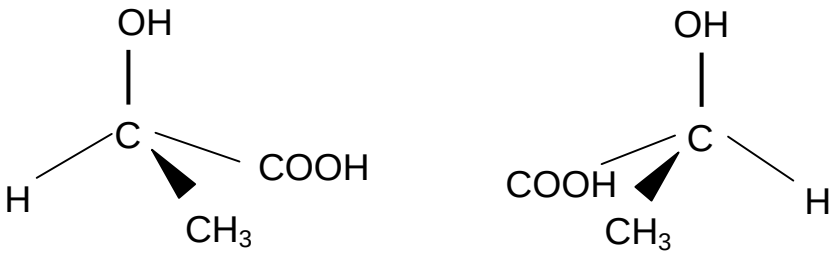
1. INTRODUCTION

Biodegradable polymers are gaining attention from the viewpoint of protection of the natural environment. Polylactic acid (PLA) is one of the best-known biodegradable polymers and has many good properties such as biodegradability, biocompatibility, mechanical strength and transparency. Because of enantiomeric composition of PLA, there are three types, poly-L-lactic acid (PLLA), poly-D-lactic acid (PDLA) and stereocomplex-type polylactic acid (SCPLA). SCPLA is made from mixture of PLLA and PDLA [1]. The melting point of SCPLA is 220°C, which is higher than that of pure PLLA and PDLA, because of its strong van der waals interactions of SCPLA.
Since PLA is biodegradable polymer, exposure of PLA to environmental agents such as water, heat and so on, degrades its mechanical properties. This study reports the effect of water and high temperature environment on mechanical properties of SCPLA fiber, and the surface morphological changes of SCPLA and PLLA fibers immersed in water have been investigated.

2. MATERIALS AND EXPERIMENTAL PROCEDURE

The polymers used in this study were PLLA (weight-average molecular weight MW = 2.2×105 g/mol) and PDLA (MW = 2.2×105 g/mol). The molecular structure of L-Lactic acid and D-Lactic acid are show in Figure.1. A blended PLLA and PDLA (1:1) was extruded with a screw extruder equipped with a single nozzle. The blend was melted at 240°C. The melt spun fiber was drawn four times at 80°C and it was drawn one and a half times at 190°C in an annealing process.

Some fibers were immersed in distilled water at 20°C (refer to as “in water (20°C)”) or 80°C (in water (80°C)) and others were kept in hot air at 80°C (in air (80°C)). Schematic drawing of a tensile test specimen is shown in Figure 2. Polyester film was used for a tab and a fiber was glued to the tab with adhesive. Tensile tests were conducted under a crosshead speed of 1.8 mm/min using a magnetic micro testing system (Shimadzu Co, MMT-101NB-2) at room temperature.
Surface morphological changes in SCPLA and PLLA fibers subjected to distilled water at 95°C were investigated. To enhance the hydrolysis, temperature of water was set to 95°C, instead of 80°C. After the fibers were immersed in water for 15 h, these fibers were observed for every 5 hours.



(a) L-lactic acid (b) D-lactic acid

Figure 1: Molecular structure of lactic acid.

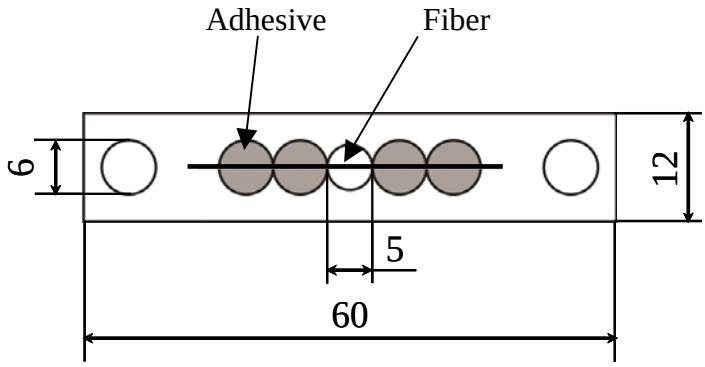


Figure 2: Schematic drawing of a tensile test specimen (All dimensions are in mm.).

3. RESULTS AND DISCUSSION

The relationship between tensile strength and environmental exposed time for SCPLA fiber is shown in Figure 3. The tensile strength of specimens in water (20°C) for 504 h is almost equal to that of the virgin specimen. The tensile strength of specimens in air (80°C) for 168 h is also almost equal to that of the virgin specimen. In contrast, the tensile strength of specimens in water (80°C) for 72 h dropped to 45% of that of the virgin specimen. For the SCPLA fiber immersed in water at high temperature, tensile

strength drastically decreased. This decrease is considered to be caused by hydrolysis of SCPLA.

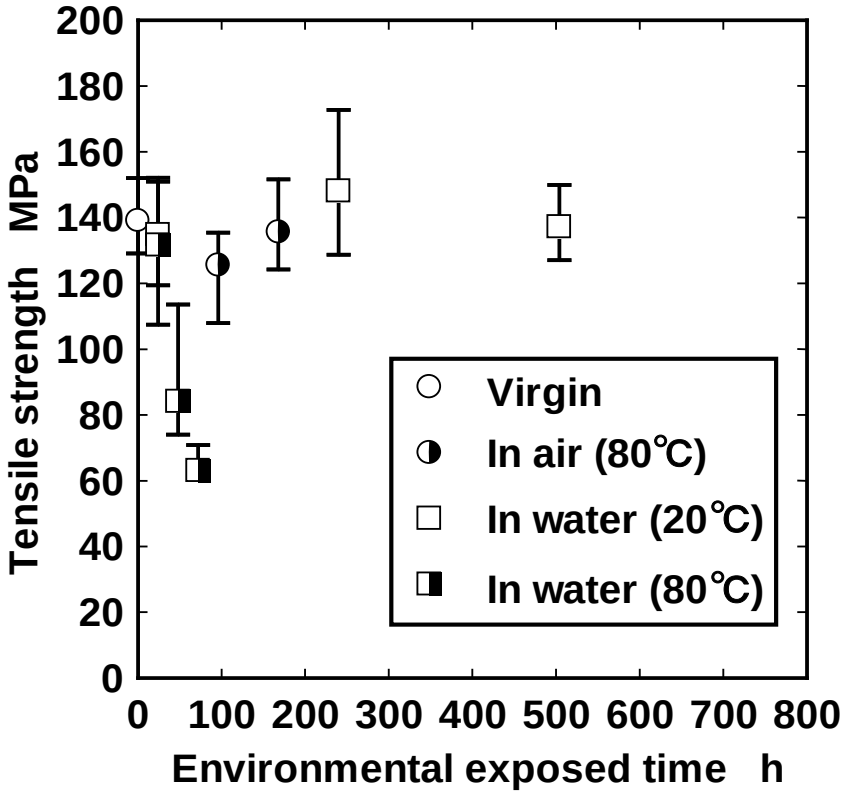
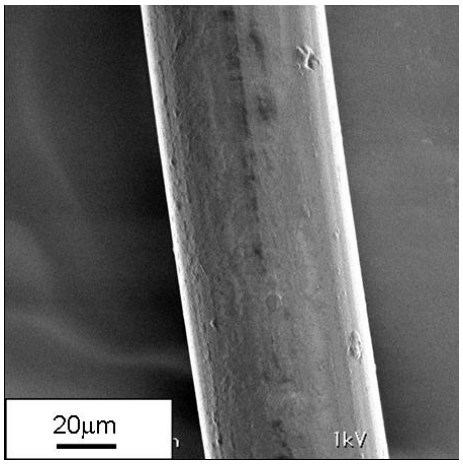


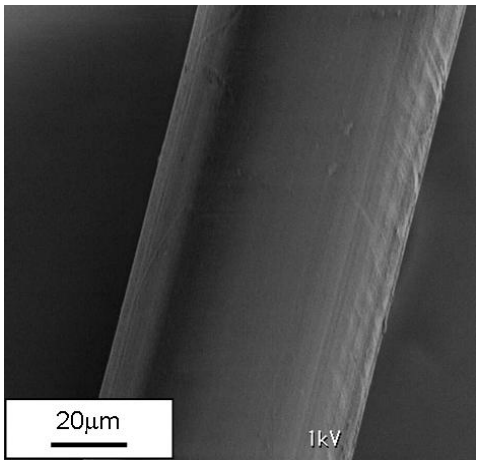
Figure 3: Relationship between tensile strength and environmental exposed time for stereocomplex-type polylactic acid fiber.

SEM images of SCPLA fibers and PLLA fibers immersed in distilled water at 95°C are shown in Figures 4 and 5. SCPLA fibers immersed in water for 15 h remained almost unchanged, however, PLLA fibers immersed in water for 15 h revealed regular patterns of cracks running in the vertical direction to the fiber axis. SCPLA fibers immersed in water for 25 h revealed regular patterns of cracks running in the vertical direction to the fiber axis. Finally, PLLA fibers immersed in water for 25 h were partially broken and SCPLA fibers immersed in water for 35 h were also partially broken.

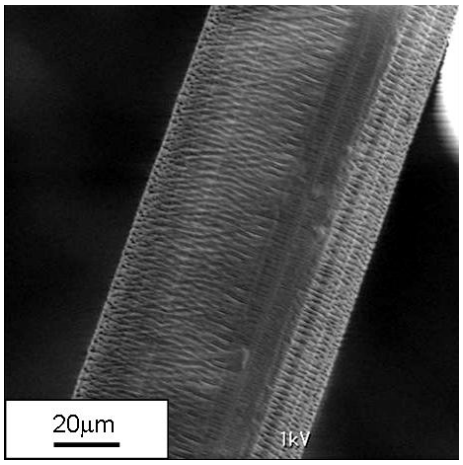
Generally, SCPLA has better durability to water than PLLA and PDLA because PLLA segment and PDLA segment have strong interactive force in both crystalline region and amorphous region [2]. In this study, compared to the PLLA fiber, SCPLA fiber had a greater resistance to hydrolysis.



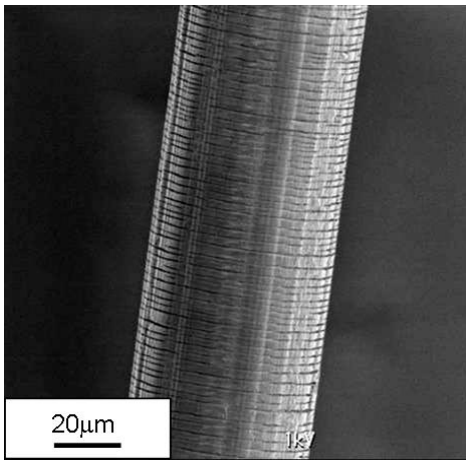
0 h



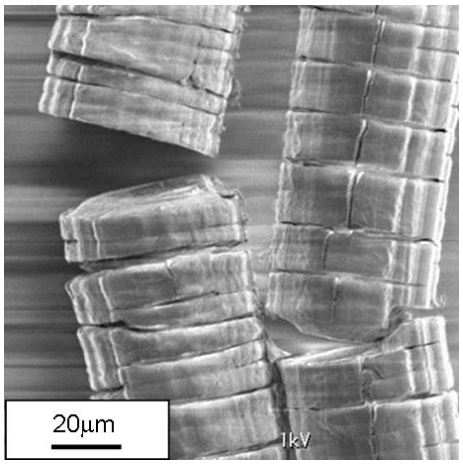
15 h



20 h

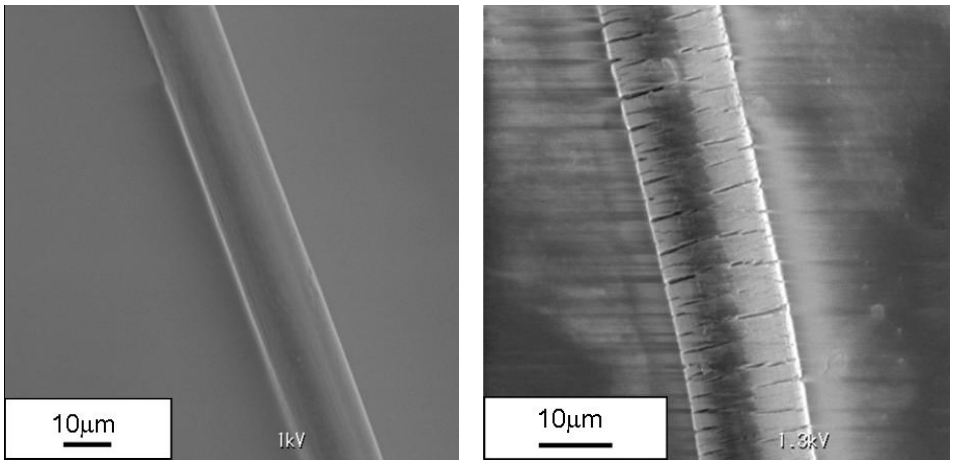


25 h

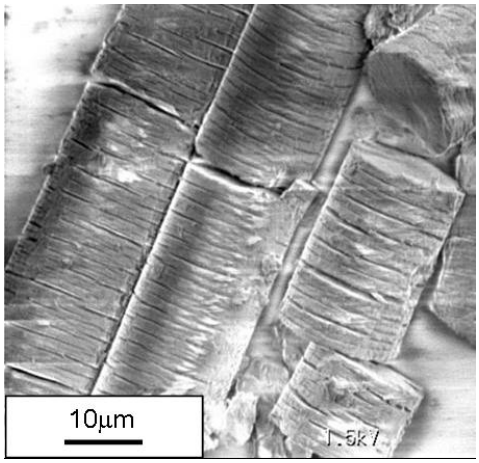


35 h

Figure 4: SEM images of SCPLA fibers immersed in distilled water at 95°C.



0 h 15 h



25 h

Figure 5: SEM images of PLLA fibers immersed in distilled water at 95°C.

4. CONCLUSIONS

The effect of water and high temperature environment on mechanical properties of SCPLA fiber, and the surface morphological changes of SCPLA and PLLA fibers immersed in water have been investigated in this paper. The investigation yielded the following conclusions:

(1) For the SCPLA fiber immersed in water at high temperature, tensile strength drastically decreased with the hydrolysis of SCPLA.
(2) Compared to the PLLA fiber, SCPLA fiber had a greater resistance to hydrolysis. When PLA fibers were immersed in water at high temperature, regular patterns of cracks runs in the vertical direction to the fiber.

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