Chapter 5
Poly (Lactic Acid) Generated for Advanced Materials

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ABSTRACT
The consumption of plastic products from petrochemical feedstock has increased sharply resulting in plastic waste problems while raw materials from fossil fuels tend to decrease rapidly. Researchers and the plastic industry have since proposed a sustainable solution through the development of bioplastics. Ideally, bioplastics which are synthesized from renewable bioresources normally render biodegradability in appropriate conditions. Polyester, one of the most diversely used synthetic polymers today, is an ideal choice for biodegradable polymers due to the relative ease of breaking ester linkages. Poly(lactic acid) or polylactide or PLA which is a thermoplastic polyester with many advantageous properties, for instance, environmentally friendly, biocompatibility, processability, and high chemical resistance is now available in the plastic market as a promising bioplastics. However, the cost of PLA is still much higher than that of general commodity plastics. In order to make PLA commercially competitive, advanced and innovative applications should thus be explored. In this chapter, technological background of PLA production as well as its economic situation is firstly reviewed. Then, the enhancement of PLA properties to suit advanced applications is illustrated. Some polymers used for blending with PLA along with some fillers utilized for the production of PLA composites are described. The chapter concludes with the degradation mechanism of PLA and the standard test methods.

INTRODUCTION
For the last century, plastic materials have been emerged as a key contributor to material industry development. Plastic products have been used as a common material in everyday life due to its competitive cost and acceptable performances comparing with ceramics or metals. Several new plastics have been researched and industrialized as materials for advanced applications, for example, biomedical devices, electronic parts, or construction materials. As a consequence, the plastic wastes, with the composition in municipal solid waste around 15 percent (SPI Bioplastics Council, 2012), lead to far more serious...
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environmental problems although several strategies have been implemented as solutions. Researchers thus try to develop a new class of plastics which can be degraded spontaneously in the natural condition by biological process. The use of these biodegradable plastics increases steadily, especially in packaging applications as a result of changing modern lifestyle.

Most of current commodity and engineering plastics nowadays were produced from petrochemical feedstock. Meanwhile, the depletion of fossil fuel has been recognized as a future challenge. The production process of petroleum-based plastics also generates greenhouse gas which creates critical environmental problems. The new environmental rules and regulations as well as the fluctuation in raw materials cost force the plastic industry to find a new starting block for the plastic production. Bioplastics are now a material of choices for the plastic industry as well as environmentally concerned consumers. As defined by IUPAC, bioplastics are bio-based polymers derived from the biomass or polymerized from monomer derived from the biomass. In 2012, bioplastics represent only around 0.4% of total plastics consumption as the price is 4-6 folds than that of petroleum based plastics. However, due to rapidly improved technologies, its cost is lower thus its demand growth is expected to exceed a compound annual growth rate of 25% for the period of 2012 to 2017. (Messenger, 2013) Global production of bioplastics is forecast to quadruple by 2017.

Second only to starch-based thermoplastics, poly(lactic acid) or polylactide (PLA) currently shares most of the bioplastic market. Carothers and colleagues at DuPont invented PLA in 1932, however, the process was too expensive and not until 1952 that DuPont patented the process in 1952. Due to its high production cost, it was initially produced only for biomedical applications, with the approval of the US Food and Drug Administration (FDA), such as sutures, implants, and controlled drug release. The advanced technology in lactic acid production has lowered the cost of PLA production and significantly increased interest in PLA for other applications as its claim to be a bioplastic with low carbon footprint. Similar to other bioplastics, PLA has a narrower processing window than that of other common plastics. Although several new grades of PLA are now commercially available but the processability of PLA is still a challenge. Furthermore, its brittleness is the major setback of PLA, thus several researchers have currently focused on enhancing its mechanical performance through polymer blending and polymer composite techniques.

BACKGROUND

A New Promising Bioplastics

PLA is a biodegradable thermoplastic aliphatic polyester synthesis from lactic acid which is derived from renewable biomass resources, such as corn starch, tapioca roots, or sugarcane. Its repeating unit is shown in Figure 1. Lactic acid has two optical isomers, i.e. L-lactic acid and D-lactic acid. A mixture of the two isomers is called DL-lactic acid. The polymerization of optically pure L- and D-lactic acids gives isotactic homopolymers of PLLA and PDLA, respectively. PLLA and PDLA are crystalline polymers with a melting temperature ($T_m$) around 180°C. The polymerization of DL-lactic acid leads to the formation of poly(DL-lactic acid) of which the degree of crystallinity is controlled by the ratio of D to L enantiomers used.