POLYLACTIC ACID as a BIODEGRADABLE COMPOSITE

A Review

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Polylactic acid (PLA) is an environmentally friendly plastic polymer that is made from entirely renewable sources. Its production, however, is costly and intensive. PLA is derived from lactic acid, which can be synthesized either industrially under conditions of extreme heat and pressure, or biologically by microorganisms. The biodegradation of PLA is continually being improved through the addition of modifiers such as chitosan. Research is also underway to identify more economical methods of PLA production and decomposition.

Introduction

The mass-production of processed foods in the United States has caused a significant upsurge in the amount of plastic that is used for packaging. Plastics and polymers are commonly used for food storage because they are low-cost and sanitary. With the rapid growth of domestic landfills and the unfortunate expansion of the Great Pacific Garbage Patch, it is vital that more biodegradable and sustainable polymers are used for packaging of all kinds. Polylactic acid (PLA) is a plastic derived from entirely "renewable resources such as sugar, corn, potatoes," and other plants (Vasile et al. 2018), which has become desirable because it is durable, rigid, and easily processed. Its applications range from food packaging to biomedical usage (Spiridon et al. 2018). This review will discuss the methods of PLA production and biodegradation, as well as how the composite can be used to improve the sustainability of plastic production.

Catalytic Synthesis of PLA from Lactide

Producing PLA directly from natural plant sources is often difficult and inefficient. Catalytic synthesis of PLA is a commercial process by which the cyclic dimer of lactic acid, lactide, undergoes a ring-opening process using a tin catalyst. The reaction that converts pure lactic acid to lactide is a dehydration reaction under equilibrium, meaning that the lactide produced must also be removed in order for its production to continue. There are multiple experimental methods that can accomplish this, including prepolymerization and continuous synthesis. Batch prepolymerization uses high pressures and temperatures to dehydrate "the lactic acid to a prepolymer" of lactide. In continuous synthesis, a prepolymer is continually fed to a reactor under high temperatures with a tin catalyst, producing lactide.

After production, the crude lactide will require purification. One method is distillation, but the process is intense and requires at least two distillation tubes at low pressures and temperatures ranging from 200-300°C. Other methods include crystallization of lactide, which allows it to be removed from the lactic acid and its oligomers. More traditional methods like "absorption or membrane separation" can also be employed (Groot et al. 2010).

Biosynthesis of Lactic Acid

Because industrially produced lactic acid is often contaminated, microorganisms are responsible for the majority of lactic acid production in biotechnology. Their products are often the most pure and, under the right conditions, the process is very efficient. These bacteria, yeast, and fungi perform glycolysis and alcoholic fermentation under anaerobic conditions, during which the enzyme lactic dehydrogenase converts pyruvate into lactate, which becomes lactic acid when in a water solution (Groot et al. 2010).

The use of these microorganisms, however, can be costly. Thus, it has become increasingly popular to use "residual biomass from agriculture" to produce the lactic acid that is used for sustainable PLA production (Tan et al. 2017). The direct condensation of lactic acid is the most commonly used lab method for the isolation of pure product. However, this process can often leave behind residual water molecules and yield lower molecular weight polymers. Mitsui Toatsu Chemicals in Japan, has recently patented a method in which high temperatures are used "to drive the removal of water in the direct esterification process to obtain high-molecular weight PLA," which is more durable (Elsawy et al. 2017).

Degradation of PLA

The primary reason to use PLA over other polymers is to improve the ecological footprint of industrial plastic production. It has become imperative that scientific researchers study the reaction mechanisms and rates of PLA polymer biodegradation. The reaction that recycles PLA back to its simpler components occurs through "random hydrolytic scission of ester bonds" coupled with the "diffusion of water in to the amorphous regions" of the semicrystalline PLA. This step is then followed by hydrolytic attack and degradation of the crystalline amorphous regions of the molecules (Elsawy et al. 2017). The degradation of the polymer is influenced by a variety of factors. A recent PLA study concluded that along with the addition of chitosan (discussed below), a long period of soil burial and access to greater than average amounts of ground water is needed in order to significantly increase degradation rates (Mitelut et al., 2018).

To achieve complete decomposition, PLA must be degraded into lactic acid and then further into carbon dioxide and water. Elsawy et al. (2017) researched this process and found that the hydrolytic degradation rate was dependent on molecular weight, temperature, and pH. When studied at extreme pH levels, degradation was more rapid. Rapid degeneration of PLA into its substituents and regeneration into new PLA is key to this polymer's sustainability. Avoiding the use of raw materials in the production of PLA is both cost and energy efficient, making this substance more renewable and recyclable.

"Improving plastic polymers is key to a more sustainable planet."

Modification Strategies

Material scientists all over the world recognize that the natural degradation of PLA is too slow to be as sustainable as is necessary. It is also too brittle to be more trustworthy in packaging than traditional plastic polymers. Scientific development is currently underway to improve the overall performance of this material. One promising method is plasticizing, in which other chemicals are added to the mixture in order to improve elongation of polymers, impact resistance, and rigidity.

Increasingly common is the method of improving PLA's structure by blending in "various synthetic and biopolymers" (Elsawy et al. 2017). Most often, a fiber called chitosan is used as a blending agent, which, although very difficult to effectively incorporate into the PLA mixture, has the ability to improve the biocompatibility and mechanical properties of the plastic. The addition of chitosan was observed to improve the hydrolytic degradation rate of PLA due to the fiber's hydrophilic character. When chitosan is mixed into the PLA, complete degradation no longer requires a long soil burial period (Vasile et al. 2018).

Conclusion

Improving plastic polymers is key to a more sustainable planet. The production of PLA, though costly and intensive, provides an eco-friendly alternative to traditional polymers. As global climate change becomes increasingly drastic, the pursuit of more environmentally viable production methods becomes more important. Targeting specific biodegradation methods and modifying the composites are both viable options. Modifications using chitosan appear to be the most promising, but plasticizing has also improved PLA quality. With additional modifications, PLA has the potential to become an economical source of renewable and biodegradable packaging material.

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