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High-performance compostable polymer biocomposites

Clement Higginbotham

Blending modified polylactic acid with hemp or jute fibers using hot melt extrusion improves its mechanical properties and compostability.

Over the last 50 years, the production of plastic has reached very high levels. Approximately 40 billion kilograms is produced worldwide every year, which equates to about 20kg of plastic per person per year. Between 30 and 42% of this plastic is used for packaging, and mainly as a response to this level of packaging waste, there has been a strengthening of European Union legislation regarding packaging materials.[1] Current end-of-life options for plastic packaging include recycling and landfill, but diverting waste from landfill is a key element in EU policy.[2,3] As a result, interest in natural biodegradable polymers has increased.[4–6]

Polylactic acid (PLA) is a compostable polymer derived from 100% renewable resources, mostly starch and sugar. Lactic acid is one of the most widely occurring carboxylic acids in nature.[7] It was first discovered in 1780 as a component of sour milk and has been produced commercially since 1881. The biodegradation of PLA is a two-stage process, the first stage of which involves hydrolysis of ester linkages. This process can occur at high temperatures and in conditions of high humidity, with no micro-organisms necessary. As this hydrolysis occurs, the molecular weight of the biopolymer diminishes, and the second stage begins. Micro-organisms present in the soil easily digest the new low-molecular-weight lactic acid oligomers, producing carbon dioxide and water. PLA biodegrades fully and rapidly in composting conditions above 60°C.

However, for tensile strength, flexural strength, and impact strength, PLA is outperformed by commodity resins such as high-density polyethylene and polypropylene. PLA has previously been reinforced by many different types of fibers and fillers, but strength, brittleness, and cost limit PLA and its composites to low-performance applications such as plastic bags, packaging for food, and disposable cutlery and cups.

Extrusion is the process of converting a raw material into a product of uniform shape and density by forcing it through a die under controlled conditions. Screw extrusion consists of a rotating screw or set of screws inside a barrel and is a well-established manufacturing method. Biocomposites consist of natural fibers incorporated into polymer systems during processing to reinforce and reduce the final product cost.[7–14]

Figure 1. *Left: Hemp fiber. Right: Jute fiber.*

Hemp and jute are natural short-hair fibers that are cheap, readily available, and easy to produce. Hemp has been produced for thousands of years as a source of extremely durable fiber for textiles, clothing, canvas, rope, cordage, paper, and construction materials. It is easy to produce hemp organically, obviating many of the ecological problems in chemical farming of other fibers. Jute fiber is used in sacking, handbags, carpet, and packaging.

I examined the processability and performance of PLA reinforced with hemp or jute. I produced a compatibilized PLA blend using reactive twin screw extrusion and compounded it with virgin PLA and either fiber to examine the relationship between increased interfacial adhesion and the mechanical properties of the PLA composites.[15] Results showed that adding maleic anhydride to the PLA backbone can increase the hydrophilicity of the polymer and subsequently improve interfacial adhesion between PLA and the hemp or jute. I examined the compostability of the biocomposites produced using a home composting system capable of achieving the temperatures used in industrial composting facilities. (This test technique had not previously been used to analyze such materials.)

The mechanical properties of the composites produced by this method in many cases surpassed those of similar composites reported in other work. Optimizing processing conditions and determining the optimal weight percent (wt%) loading of compatibilizers yielded PLA

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composites reinforced with short fibers that exhibited considerable improvement in mechanical properties such as tensile strength, flexural strength, flexural modulus, and impact strength when compared with virgin PLA. In fact one sample, containing 40% PLA, 50% jute, and 10% PLA grafted with maleic acid (PLA-g-MA) showed increases in tensile strength and flexural strength of almost 24% (from 70 to 87MPa) and 165% (from 54 to 143MPa), respectively.

Currently, 70% of PLA produced is used in packaging applications. The composites produced in this study have the ability to replace virgin PLA as low-cost packaging alternatives. At levels above 10wt% PLA-g-MA, the composites form strong bonds that limit moisture absorption and also the biodegradation rate of the material. Wu found that biodegradation is enhanced by water diffusing into the sample when fiber is added.[16]

In addition, compared with unreinforced PLA, our samples show improved tensile strength, flexural strength, and impact strength. These enhancements are useful for low-cost production of high-modulus automotive parts from PLA. Similarly, profile-extruded building materials with high stiffness and increased impact strength could be produced. By 2020, PLA is expected to be used in a much broader array of applications. Packaging will account for only 20% of its production, areas such as transportation and textiles will account for 70%, and PLA will also be used in construction.[17] In future work, colleagues and I will produce biodegradable nanocomposites of PLA and polyhydroxybutyrate and examine the effects of processing conditions and nanoparticle loading on their mechanical properties and compostability.

Author Information

Clement Higginbotham
Athlone Institute of Technology
Athlone, Ireland

Clement Higginbotham is director of the Materials Research Institute and lecturer in chemistry and biomedical materials at Athlone Institute of Technology. He has published more than 70 papers in peer-reviewed journals and holds four patents. His research interests include organic chemistry, biomedical materials, drug delivery, polymer composites, and hydrogel development.

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