Polycaprolactone and Its Use as a Biodegradable Trash Bag

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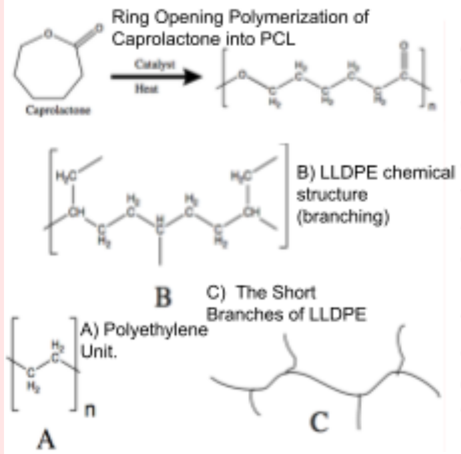
ABSTRACT

The Earth is choking from the pollution of man made plastic and the environment is in desperate need of a solution that will aid in the fight against climate change. The emerging research and production of biodegradable polymers offers hope of an environmentally safe alternative that will be able to be used in place of standard plastic. This study aims to strategize a substitute for the linear low-density polyethylene (LLDPE) trash bag using polycaprolactone (PCL), a biodegradable polyester. Specifically, it investigates PCL's manufacturing capabilities and molecular effectiveness as a LLDPE replacement. There is a probable need for a modification of PCL in order for it to be a feasible LLDPE replacement and multiple solutions including polymerization synthesis to add branching and polyester blends are reviewed.

To explore PCL as a LLDPE substitute, this research study details the molecular properties and material characteristics of both materials, as well as trash bag manufacturing methods to determine the ability for PCL to be a LLDPE replacement. These investigations will bring into question PCL's capability to be used as a trash bag and feasible modifications of PCL will be theorized to mimic the molecular properties that make LLDPE. The theory of this eco-friendly alternative presents possible and adequate results as a LLDPE substitute.

COMPARING PCL & LLDPE

PCL Characteristics:
-synthetic aliphatic polyester
-synthesized by a ring opening polymerization of caprolactone
-m.p. = 57-60 °C -solid at room temp (20,000 g/mol)
-13.9 ± 0.4 MPa at 0.4–0.5 mm thickness.
-Able to be decomposed by enzymes secreted by organisms (i.e *Streptomyces thermonitrifican* & *Bacillus licheniformis)*



LLDPE Characteristics:
-Affordable, flexible, lightweight and strong.
-synthetic thermoplastic polymer
-M.p = 105-115 °C
-tensile strength: 12.7 MPa at 0.034 mm thickness
-doesn't degrade quickly at high temperatures.

Issues with LLDPE:
-Long polymers chains with extremely strong carbon-carbon bonds that cannot be consumed by microorganisms
-only degrade by UV rays and that require centuries to break down
-commonly melted down which in turn releases toxic fumes such as dioxins and polychlorinated biphenyls (BCPs) into the atmosphere that threaten the health of humans, animals and vegetation. These hazardous chemicals are known to produce cancer and introduce reproductive anomalies

STANDARD TRASH BAG CREATION

In order for PCL to be able to replace LLDPE in standard issued trash bags, it should be able to undergo similar manufacturing techniques.

How Trash Bags are Made:
polyethylene pellets are sent through an extruder where these pellets are melted to make them more pliable and moldable. This melted plastic is then placed in a die and is cut into a ring shape where air can be forced through it so it can be formed into a thin strong bubble. When the air is removed from the bubble, the material is very thin and can be easily cut into sheets that can be melted together at the seams to give the shape of the trash bag.

TESTING THE ABILITY OF PCL

Melt Strength: Melt strength has to do with the melted plastics ability to undergo tension and on the polymer's ability to resist untangling under strain, in this case of trash bag manufacturing. In order for PCL to be manufactured in a similar way to LLDPE it must be able to be melted down in order to create the thin sheets required to make the trash bag. PCL has a low melting point and at high temperatures, particularly in the presence of moisture, PCL degrades very quickly. LLDPE with a higher melting point and lower rate of decomposition, is more optimal. PCL requires less heat and therefore is more environmentally friendly. Despite that positive attribute, it is not this clear cut. It is important that PCL has the melt strength to undergo this form of manufacturing. PCL should be tested to see if the extensional viscosity to undergo these manufacturing techniques. To see if it has a high enough melt strength an extensional rheometer could be used test the maximum tension that both the melts of LLDPE and PCL can be subjected to without breaking.

Puncture Resistance: LLDPE is used for trash bags because of its ability to stretch. Therefore, in order for PCL to be used, it must have similar strength and flexibility. Puncture strength relies on the materials breaking strength and the penetration distance. The puncture resistance can be organized on a graph with the load and deflection being analyzed and PCL and LLDPE compared. The average trash bag weighs 22lbs, and this should be taken into account during testing. It's important to see how they compare, it also must be noted what puncture resistance is needed for an effective trash bag. This can be done by using the two bags with the same amount of weight inside and seeing how sharp objects affect the bag.

Tensile Strength: To test how the bags compare to one another, tensile tests could be performed. These tests test the strength of the polymer and its resistance to breaking under tension. The pull exerted on the polymer, the force and speed that these materials break, is valuable to this calculation.

CONS OF USING PCL

In regards to PCL, there is a strong possibility based on past experiments and research of its molecular properties, that it cannot compete with LLDPE. The melt strength of PCL is much lower. One way to combat this is modifying the formula to help increase these

POSSIBLE MODIFICATIONS TO OPTIMIZE PCL

SOLUTION: Adding side chains
-branches would be added via a chemical polymerization synthesis
-branches can get caught within one another, making the molecules less able to slide past each other and this theoretically would have positive effects on PCL's melt strength
-ex) an alpha hydrogen on the polycaprolactone chain can be substituted by a longer side chain
ISSUES: May weaken the tensile strength and/or increase its brittleness

SOLUTION: Starch Blends
-high biodegradability and low price point
-PCL/starch/glycerol trash bags have already been made in Korea
-overall branched starch increases the melt strength of PCL
ISSUES: starch has a high sensitivity to moist, many starch blend research doesn't use proper plasticisers

SOLUTION: Polymer Blends
Polylactic Acid (PLA)
-PLA is rigid and has a high tensile strength
-past research indicates Melt strength slightly increased and lowered the tensile strength. (done with plasticizer Pluronic)
ISSUES: The melt strength from past experiments didn't increase enough to allow this blend to be used as a trash bag. In the future, different plasticizer could be tested with PLA/PCL blends to see if this helps the melt strength more.
Polypropylene (PP)
-PP has a high melt strength
-past research shows PP increases the melt strength and reduces the brittleness significantly
ISSUES: PP has a slow rate of biodegradation and negatively affects the rate of decomposition. This could be a bonas, as PCL does degrade very quickly. The blend has a higher m.p than PCL alone, which means more energy is required in manufacturing.

PLASTICIZERS

Many company funded research into the creation of bioplastics has led to the unethical choices in their means of production. One of these is making blends of biodegradable and non biodegradable plastic, which only partially degrade. Another is using plasticisers that have negative effects on health and biodegradability.
-Gycerol: generally environmentally friendly and non toxic, but does have negative effects on biodegradability, due to its antibacterial and antimicrobial properties.
-Urea: (commonly found in urine) Can cause algae to produce domoic acid, a deadly toxin that has been linked to mass animal deaths. It is chemically treated before being released into water bodies, but if used in polymers and disposed of as most plastics are, it cannot be used without these adverse effects on the environment.
-Formaldehyde: highly biodegradable, but is broken down into formic acid and carbon monoxide, which are highly toxic to aquatic life, animals and humans.
-Pluronic: A less frequently used plasticizer and should be researched and implemented more often due to its non toxic and high biodegradability.

PCL AS A BIOPLASTIC: THE FUTURE

The uses of polyesters like PCL offer hope for sustainable polymer substitutes for LLDPE. PCL and modified PCL will undergo melt strength, tensile strength and puncture resistance testing to see how it compares to LLDPE. Manufacturing trials of PCL will be conducted in order to see if it can undergo standard hopper/extruder methods currently used to create standard trash bags.The creations of these products must be done ethically and transparently. Those who aren't educated in chemistry and environmental science may believe that biodegradable products using dangerous chemicals are eco friendly. To combat this, there must be government regulation on what can be considered biodegradable.Currently most biodegradability research is done in simulated experiments and due to the complexity of nature, biodegradability needs to be tested in multiple natural environments including oceans and landfills. The experimentation of PCL as a trash bag is just a small sect of the future of biodegradable plastics and offers hope. Humans must internationally agree to increase research and regulation in biodegradable alternatives to plastic to help save the world from its certain demise.

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