MIT Climate & Sustainability Consortium

Addressing End-of-Life Management Challenges for Hard-to-Break-Down Polymers

Project Overview

How can we make plastics easier to break down and recycle when we are done using them?

Jeremiah Johnson

Every year, industries manufacture vast amounts of plastics, used for a wide range of applications – but when these plastics reach the end of their life, they are difficult to recycle, often ending up in landfills. This project, led by MIT Professor Jeremiah Johnson (Chemistry), along with graduate student Kwangwook Ko, tackles this major waste problem by designing a special building block – called a *cleavable comonomer* (CC) – that is integrated evenly throughout plastics during production to facilitate their degradation. When triggered by a mild chemical treatment at the end of the plastic's life, this built-in mechanism breaks the plastic into smaller, manageable pieces that can be easily recycled or upcycled.

This project aligns closely with the MCSC's Circularity pathway.

Findings & Outcomes

The team found that in order for polymers to break down efficiently, the cleavable units they designed must be evenly distributed through the polymer chains. This finding led them to create a family of molecules that can incorporate into the chemical structure of plastic and help it break down into smaller pieces without losing its durability.

For the team's demonstration of how the addition of the cleavable comonomer would work, they chose polymethylmethacrylate (PMMA) – also known as acrylic or plexiglass and used in a variety of applications, including medicine, construction, and manufacturing – as a model plastic. They combined advanced computer modeling with innovative chemical synthesis to reach these findings.

Understanding how to design breakable plastics. Using computer simulations and lab experiments, the researchers discovered that for a plastic to efficiently break down into small, recyclable pieces, the *self-destruct* components must have reactivity parameters that fall within a certain range to ensure they are evenly and uniformly distributed throughout the polymer chains.

Creating new molecules (bDOTs). To achieve this ideal balance throughout the polymer chain, the team developed new molecules that are incorporated into the chemical structure of plastics, ensuring an even distribution of breakable sites. They created a family of enhanced molecules called bDOTs, among which F-p-CF_3PhDOT emerged as the best performer under conditions similar to those in industrial production.

Making and breaking the plastic. Using methods similar to those in large-scale manufacturing, the team produced high-quality PMMA with the new molecule incorporated. Tests showed that when the plastic was treated with a mild chemical trigger, it broke down into much smaller pieces (over 20 times smaller in size), without losing the clear, durable properties that make PMMA so useful.

The resulting plastic behaves just like normal PMMA during use – clear, strong, and heat-resistant – but it has the added benefit of being easy to deconstruct at the end of its life. This innovative approach can pave the way for making many other types of plastics easier to recycle.

Journal Publication: *The Journal of the American Chemical Society*

The team's findings were detailed in *The Journal of the American Chemical Society*, in an article entitled "Mechanism-Guided Discovery of Cleavable Comonomers for Backbone Deconstructable Poly(methyl methacrylate)." The article is co-authored by Kwangwook Ko, David Lundberg, Alayna Johnson, and Jeremiah Johnson. The work was presented at several conferences, including the American Chemical Society (ACS) Conference, Fall 2023.

Opportunities for Implementation

This breakthrough has significant potential for industry and the environment:

- **Seamless integration into existing production:** The new cleavable molecule works with current industrial methods used to produce PMMA. Manufacturers can adopt this technology without needing to overhaul their entire production process, making it a practical solution for reducing plastic waste.

- **Enhanced sustainability:** By making plastics easier to break down and recycle, the technology supports a circular economy where materials are reused instead of discarded, which could significantly lower environmental waste and help companies meet sustainability goals.

- **New business and collaboration opportunities:** Companies can pilot the team's method to produce "smart" plastics that retain all the benefits of traditional materials while offering easier recycling and potential cost savings in waste management. The researchers are eager to collaborate with industry partners to scale up production and further refine the technology, not only for PMMA but also for a broader range of commodity plastics.