# Biodegradation of Plastics: Key Issues and Advances Postprint

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## Abstract

Between 2005 and 2017, global annual plastic production increased from 230 million tons to 400 million tons, and is projected to reach 3.4 billion tons by 2050 [1]. Of the large amount of plastic waste generated from plastic consumption, only 9% is recycled, 12% is incinerated, and 79% is landfilled or directly discarded into the environment [2]. Due to their stable material properties, plastic waste degrades very slowly under natural conditions, and it is estimated that by 2050, plastic waste in landfills and the natural environment will reach 12 billion tons [2]. The long-term and large-scale accumulation of plastic waste in the environment has caused severe pollution and threats to ecological systems, becoming a global environmental issue [3].

With the discovery of plastic-degrading microorganisms and enzymes, the development of biotechnologies for environmental remediation of plastic pollution utilizing the degradative capabilities of microorganisms or enzymes has gradually been recognized as a novel approach to address plastic waste [4-6]. However, to achieve efficient biodegradation and environmental remediation of plastic pollution, two key issues must be resolved: 1) The source of plastic-degrading microorganisms or enzymes. Since the 1940s, plastics have been artificially synthesized and gradually applied to production and daily life, with a history of less than 80 years. Such a short period is considered insufficient for the natural evolution of widespread plastic-degrading microorganisms or enzymes. Exploring and utilizing plastic-degrading microorganisms and enzyme systems from natural sources represents important foundational research for developing bioremediation technologies for plastic-contaminated environments. 2) The rate of plastic biodegradation. The inert chemical structural units of polymer long chains, the high molecular weight of polymer chains, and the aggregated state structures of polymer chains are important factors that hinder and affect the efficiency of microbial or enzymatic plastic degradation.

To address these two issues, the authors conducted interdisciplinary research at the interface of bioengineering and polymer physics, achieving several advances. 1) Revealing that insects and their gut microorganisms represent an important source of plastic-degrading microorganisms. Inspired by the natural phenomenon of grain pests gnawing on plastic packaging bags, and employing isotopic tracing and multiple physicochemical analysis techniques, we systematically demonstrated for the first time that mealworms can depolymerize PS long-chain molecules and decompose them into CO2; we also elucidated that gut microbial populations play a decisive role in the plastic degradation process. Bacteria capable of degrading polystyrene (PS), polyethylene (PE), polyurethane (PUR), and polyethylene terephthalate (PET) were isolated from the guts of mealworms and waxworms [4-5]. 2) Discovering that the crystallinity of crystalline polymers (such as PE, PP, and PET) is the key factor affecting biodegradation rates. During the decomposition of crystalline polymers, microorganisms or enzymes preferentially degrade the amorphous regions of the polymer, while degrading the crystalline regions very slowly or even not at all [6]. The dense structure formed by molecular packing in crystalline regions hinders the capture of molecular chains by enzyme residues. Based on the principles of polymer crystallization thermodynamics, we proposed a decrystallization method that transforms crystalline polymers into amorphous states without altering their molecular structure, which increased the biodegradation rate of crystalline polymers by 100-fold [7].

## Full Text

## Preamble

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Between 2005 and 2017, global annual plastic production increased from 230 million to 400 million tons, with projections reaching 3.4 billion tons by 2050 [1]. Of the massive plastic waste generated, only 9% is recycled, 12% incinerated, and 79% landfilled or directly discarded into the environment [2]. Due to their stable material properties, plastic wastes degrade extremely slowly under natural conditions, with estimates suggesting that plastic waste in landfills and the natural environment will accumulate to 12 billion tons by 2050 [2].

The long-term accumulation of plastic waste poses severe threats to ecosystems and has become a global environmental challenge [3]. The discovery of plastic-degrading microorganisms and enzymes has gradually established biotechnological approaches for environmental remediation as a promising solution to plastic pollution [4-6]. However, achieving efficient biodegradation requires addressing two critical challenges: (1) the source of plastic-degrading microorganisms or enzymes. Since plastics were first synthesized in the 1840s and gradually integrated into production and daily life, their history spans less than 80 years—considered insufficient for the natural evolution of widespread plastic-degrading microorganisms or enzymes. Exploring and utilizing naturally sourced plastic-degrading microbial and enzyme systems represents crucial foundational research for bioremediation technology development. (2) the rate of plastic biodegradation. The inert chemical structures of polymer chains, high molecular weight, and aggregated chain structures are key factors limiting the efficiency of microbial or enzymatic degradation.

To address these challenges, the author conducted interdisciplinary research at the interface of bioengineering and polymer physics, achieving significant progress. First, insects and their gut microorganisms were revealed as an important source of plastic-degrading microbes. Inspired by grain pests gnawing on plastic packaging, isotopic tracing and multiple physicochemical analytical techniques were employed to systematically demonstrate for the first time that mealworms can depolymerize PS long-chain molecules and mineralize them into CO , while elucidating the decisive role of gut microbial communities in plastic degradation. Bacteria capable of degrading polystyrene (PS), polyethylene (PE), polyurethane (PUR), and polyethylene terephthalate (PET) were isolated from the guts of mealworms and wax worms [4-5]. Second, crystallinity was identified as a key factor affecting the biodegradation rate of crystalline polymers (such as PE, PP, and PET). Microorganisms or enzymes preferentially attack amorphous regions while degrading crystalline regions extremely slowly or not at all [6]. The dense molecular packing in crystalline regions obstructs enzyme active sites from accessing polymer chains. Based on polymer crystallization thermodynamics, a decrystallization method was proposed to transform crystalline polymers into amorphous states without altering their molecular structure, increasing the biodegradation rate by 100-fold [7].

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### Author Biography

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