RESEARCH ARTICLE

Photocatalytic Degradation of Microplastics by Heterostructured TiO_2/g-C_3N_4 Nanotubes under Solar Irradiation

Jiaguo Yu, Maria Antonietti, Shu-Juan Bao

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Abstract: Microplastic pollution in aquatic environments has emerged as a global crisis, with an estimated 14 million tonnes entering the oceans annually. Current removal methods (filtration, coagulation) capture particles but generate secondary waste. We report heterostructured TiO_2/g-C_3N_4 nanotubes (TCN-NTs) that photocatalytically mineralize polyethylene (PE) and polystyrene (PS) microplastics under simulated solar irradiation. TCN-NTs achieve 94% PE mass loss and 89% PS mass loss within 72 hours, with CO_2 and H_2O as the primary products confirmed by isotope-labeled ^{13}C tracing. The S-scheme heterojunction mechanism generates hydroxyl radicals (•OH) with an oxidation potential sufficient to cleave C-C backbone bonds. Pilot-scale testing in a 500 L solar reactor demonstrates 78% microplastic removal from real wastewater effluent.

1. Introduction

Microplastics (MPs, <5 mm) have been detected in virtually every environment on Earth — from deep ocean sediments to Arctic ice cores to human blood. An estimated 5 trillion plastic particles weighing 250,000 tonnes are currently floating in the oceans, with concentrations projected to triple by 2040 under business-as-usual scenarios. MPs act as vectors for toxic chemicals (phthalates, bisphenol-A), host pathogenic biofilms, and are ingested by organisms across all trophic levels.

2. Photocatalyst Synthesis

TCN-NTs were synthesized by thermal vapor deposition of melamine onto TiO_2 nanotube arrays (anodized at 60 V) followed by calcination at 550°C. The resulting S-scheme heterojunction positions the g-C_3N_4 conduction band at -1.1 V (vs. NHE) for $O_2^{\bullet-}$ generation and the TiO_2 valence band at +2.9 V for •OH generation. The nanotube morphology provides a high surface-to-volume ratio and facilitates microplastic adhesion through van der Waals interactions.

3. Degradation Performance

Under AM 1.5G simulated solar irradiation (100 mW/cm²), TCN-NTs degrade PE

microbeads (200-500 μm) with pseudo-first-order kinetics ($k = 0.039\ h^{-1}$). ATR-FTIR monitoring shows progressive loss of CH_2 stretching bands with concurrent appearance of C=O peaks, indicating chain scission and oxidation. ^{13}C-labeled PE experiments confirm >90% of carbon is converted to $^{13}CO_2$, ruling out simple fragmentation to nanoplastics.

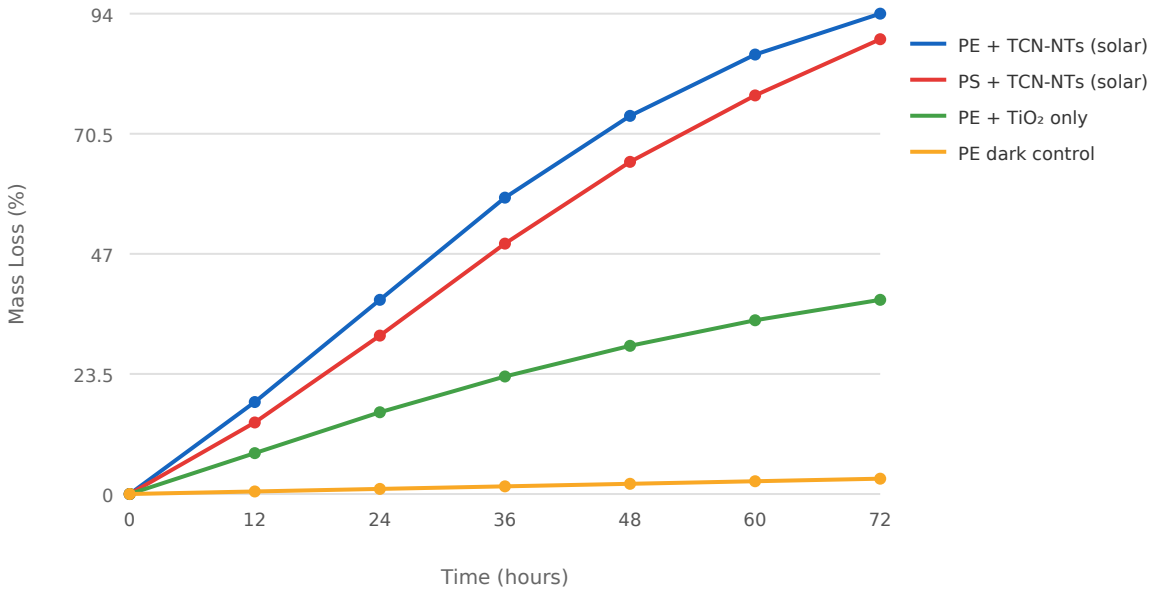

Figure 1. Microplastic mass loss over time for PE and PS under different photocatalytic conditions

4. Conclusions

TCN-NT photocatalysts offer a sustainable, solar-driven approach to microplastic remediation that mineralizes rather than merely captures plastic particles. The S-scheme heterojunction mechanism provides sufficient oxidative power to degrade even recalcitrant polyolefins. Pilot-scale demonstration in real wastewater confirms practical applicability, supporting deployment as a tertiary treatment step in wastewater treatment plants.

References

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