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Valorisation of Marine Polypropylene Waste: Integrity Assessment and Recycling Performance

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Abstract. Marine plastic pollution represents a persistent global environmental challenge, with polypropylene (PP) being a prevalent component among marine litter. Building on CEST 2023, this study advances PP debris classification and recyclability assessment, introducing a systematic approach for assessing the recyclability prospects of marine-degraded PP. This study establishes a refined integrity categorization of PP debris using Ultraviolet (UV) spectroscopy, tensile testing, and morphological assessment. Subsequently, a comprehensive analysis of mechanical performance was performed by blending different categories of PP debris with virgin PP, applying controlled injection moulding processes. Results confirmed that blending ratios significantly impact the mechanical properties of the final products. Specifically, blends incorporating 50 % lightly damaged PP (LDPP50-VPP50) and 30 % moderately damaged PP (MDPP30-VPP70) yielded the most efficient performance, maintaining mechanical properties within acceptable thresholds for practical applications. This methodology highlights the importance of debris integrity assessment as a decision-making tool in recycling strategies, promoting the valorisation of marine plastic waste and contributing to circular economy models.

Keywords: Marine pollution; Plastic debris; Polypropylene; Mechanical recycling

1. Introduction

Marine plastic pollution poses a major global threat, with millions of tons entering oceans annually, impacting marine life, ecosystems, and human health (Zhao and Zhu, 2025). Among the most prevalent polymers found in marine debris is PP, widely used due to its versatility, durability, and resistance to chemicals and moisture. However, these same properties that make PP useful also contribute to its persistence in the environment, where it can degrade into microplastics over extended periods.

Addressing the environmental threat posed by PP debris requires not only efficient collection and recycling practices, but also advanced approaches that account for the altered properties of materials subjected to harsh marine conditions. Building upon previous preliminary investigations presented at CEST 2023, the present study advances the scientific understanding of PP degradation and recycling by introducing a refined methodology that evaluates both the integrity status and mechanical performance of marine-degraded PP debris.

2. Theoretical Background

PP, despite its inherent durability, undergoes various degradation processes when exposed to marine environments, including photodegradation, thermo-oxidation, hydrolysis, and mechanical erosion. These processes cause polymer chain scission, oxidation, and surface embrittlement, leading to a progressive decline in mechanical and functional properties (Lourmpas et al., 2024). Degradation is often accelerated by UV, temperature shifts, and biofouling, making the prediction of the material's performance challenging.

Traditional recycling processes, such as mechanical recycling and injection moulding, generally assume predictable material properties; however, the unpredictable nature of marine-degraded plastics often results in poor-quality recycled products (Syberg et al., 2022). Thus, incorporating an integrity-based assessment prior to recycling becomes essential to determine the suitability of marine plastic waste for reuse. Previous work has suggested that blending marine-degraded PP with virgin material can improve the mechanical properties of the resulting products; however, without systematic classification of the debris integrity status, the effectiveness and consistency of such blends remain uncertain.

The present research addresses this gap by applying a combined methodology of UV spectroscopy, tensile testing, and morphological assessment to classify PP debris according to their integrity status. This classification forms the basis for optimized blending ratios with virgin PP, ensuring that the mechanical performance of recycled products meets the necessary standards for practical applications.

3. Experimental Procedure

PP debris was collected from coastal cleanup activities in Korinthos, Greece. After visual sorting and preliminary washing, debris was further cleaned, dried, and mechanically shredded.

To assess the degradation level, selected samples analysed through UV spectrophotometry, tensile testing, and morphological evaluation. Based on these analyses, debris was categorized into three degradation tiers: lightly, moderately, and heavily damaged.

Recycled specimens were then produced by blending each debris damage group with virgin PP at different mixing ratios (Figure 1), using industrial injection moulding under controlled parameters (210 °C, 5 MPa). Blends were injection-moulded into ASTM D638 tensile specimens and tested for ultimate tensile strength (σ_{UTS}) and Young's modulus. The mechanical results were analysed comparatively to identify optimal blending strategies for practical recycling applications.

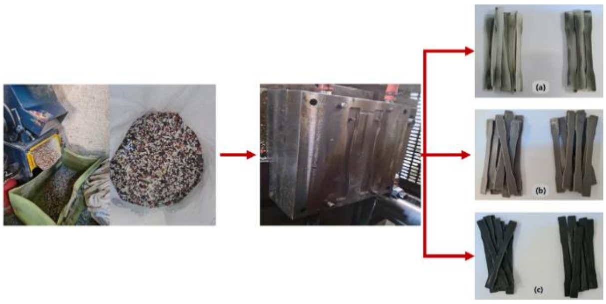

Figure 1. Injection-molded PP specimens produced by blending shredded debris with virgin PP at: a) low, b) medium, and c) high debris content.

4. Results and discussion

The classification process confirmed substantial variability in the degradation of PP debris, significantly affecting their mechanical performance. Specifically, LDPP50-VPP50 and MDPP30-VPP70 blends, yielded the most efficient performance, with reductions below 10 % for σ_{UTS} (Figure 2). Conversely, high-damage debris blends, even with high virgin PP content, resulted in unacceptable mechanical properties, indicating limited recyclability potential. The results underline the necessity of integrating an integrity-based classification methodology in recycling schemes, enabling efficient utilization of marine plastic waste while ensuring product reliability.

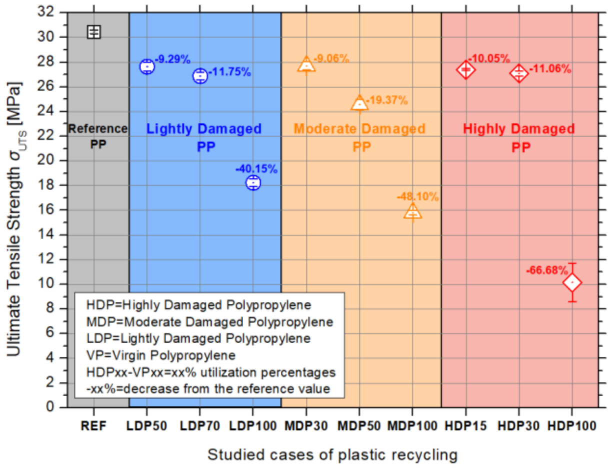

Figure 2. Average σ_{UTS} values of recycled PP blends, compared to average value of reference PP

5. Conclusions

This research advances the initial findings presented in CEST 2023, proposing a mature methodology for the valorisation of PP marine waste. Integrity assessment is crucial for recycling pathways balancing efficiency and performance. Future perspectives include expanding the methodology to other polymer types and evaluating real-life product applications of the proposed blends, contributing to broader marine plastic waste management strategies.

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