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Towards sustainable plastics recycling: assessing the integrity status of polypropylene (PP) debris to recycle marine-degraded materials

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Abstract. Polypropylene (PP) is a widely used polymer with significant environmental implications when improperly disposed. Effective recycling strategies for PP are crucial for mitigating plastic pollution and achieving sustainability goals. This investigation focuses on classifying PP debris based on their integrity status using, microscopy, Fourier Transform Infrared (FTIR) spectroscopy, and tensile testing. The debris are classified based on the above analyses in three different groups, based on the induced damage due to environmental exposure. In the present work, the classified PP debris samples are then blended with virgin PP to produce recycled specimens, aiming to enhance their properties and their overall quality. The recycled specimens undergo further evaluation through the same mechanical, chemical and morphological analysis. This assessment helps identify the integrity status group(s) with desirable properties and determines the optimal percentage of virgin PP incorporation. The research findings contribute to the development of sustainable and cost-effective recycled PP specimens, promoting circularity in PP plastics.

Keywords: Marine pollution; Plastic debris; Polypropylene; Injection moulding; Recycling

1. Introduction

Marine plastic pollution has emerged as a critical environmental issue, with Polypropylene (PP) being one of the major contributors to this global challenge (Tang et al., 2019). PP, a versatile and widely used plastic, finds its way into marine ecosystems through various sources, including improper waste management, industrial discharge, and maritime activities (Kazour et al., 2019). The persistence and accumulation of PP debris in marine environments poses significant threats to marine life, ecosystems, and human health.

Addressing the issue of marine plastic pollution requires effective recycling strategies that can minimize the environmental impact of PP waste. Recycling offers a promising solution by diverting PP waste from landfills and incineration, reducing the demand for virgin plastic production, and conserving valuable resources. Among various recycling techniques, injection moulding has gained prominence due to its ability to process a wide range of plastics, including PP, into new products with desirable properties (Gall et al., 2021). Injection moulding allows for the transformation of PP debris into reusable materials through the application of heat and pressure, resulting in the creation of new products with diverse applications (Huang and Peng, 2021). This technique enables the fabrication of various plastic products, such as containers, packaging materials, automotive components, and household items. By harnessing the capabilities of injection molding, PP waste can be transformed into valuable resources, contributing to the circular economy and reducing the reliance on virgin PP production.

Through a comprehensive analysis of the marine plastic pollution problem, the potential of recycling via injection molding, and the characterization of recycled PP products, this study strives to contribute to the development of sustainable and efficient recycling strategies for PP waste. By understanding the significance of recycling PP debris and its potential for reducing marine plastic pollution, a way towards a more environmentally conscious and resource-efficient future can be paved.

2. Theoretical Background

Polypropylene (PP) is well-known for its durability and resistance to degradation. Nevertheless, when exposed to the marine environment, PP undergoes various degradation processes influenced by factors such as ultraviolet (UV) radiation, temperature fluctuations, mechanical stresses, and exposure to seawater and marine organisms (Singh and Sharma, 2008). These factors can lead to the deterioration of PP's mechanical properties, structural integrity, and surface morphology.

UV radiation, particularly in the form of sunlight, causes photodegradation of PP by breaking down the polymer chains, resulting in reduced molecular weight and decreased mechanical strength (Sivan, 2011). Temperature variations in marine environments further accelerate this process. Additionally, the presence of seawater and marine organisms can lead to chemical degradation through hydrolysis, oxidation, and biofouling, contributing to the overall degradation of PP in the marine environment (Chamas et al., 2020).

During the recycling process, incorporating a certain percentage of virgin plastic into the recycled material is often necessary to improve the mechanical properties and overall quality of the final product. The optimal percentage of virgin plastic incorporation depends on several factors, including the health status of the PP debris and the desired properties of the recycled specimens (Hahladakis et al., 2018). By examining the degradation behavior of PP in the marine environment and understanding the recommended percentages of virgin plastic incorporation, this study aims to build upon existing knowledge and contribute to the scientific understanding of recycling PP debris into high-quality and sustainable products.

3. Experimental Procedure

To address these challenges, it is crucial to develop effective recycling strategies that not only mitigate the environmental impact but also yield sustainable and cost-effective products. In this context, understanding the health status of PP debris and formulating recycled specimens based on their properties is paramount. Initially, voluntary cleanup actions were organized throughout the year by “OZON” Non-Governmental Organization on the coastal areas of Korinthos, where the identification of the plastic debris and the separation of polypropylene took place, as depicted in Figs. 1 and 2.

Figure 1. Cleanup action in the coast of Korinthos by “OZON” NGO during the winter season 2022-2023.

Figure 2. Cleanup action in the coast of Korinthos during the summer season and on-site classification of the debris.

Since this research aims to classify PP debris regarding their structural integrity status, comprehensive testing was conducted, including microscopy, Fourier Transform Infrared (FTIR) spectroscopy, and tensile testing. Light optical microscopy allowed for a detailed examination of the microstructure to identify morphological alterations and defects. FTIR analysis provided insights into chemical changes and compositional variations, while tensile testing enabled the evaluation of mechanical properties and structural integrity.

Based on the classification obtained through these analyses, the next step was to produce tensile specimens from the debris samples and with different percentages of virgin PP. Initially the PP debris were inserted into a shredder to granulate the material (Fig. 3) for the injection moulding process. Then, different ratios of molten plastic debris to virgin material were injected into the mould to produce tensile specimens. The dimensions of the tensile specimens was according to ASTM D638 (ASTM International, 2017).

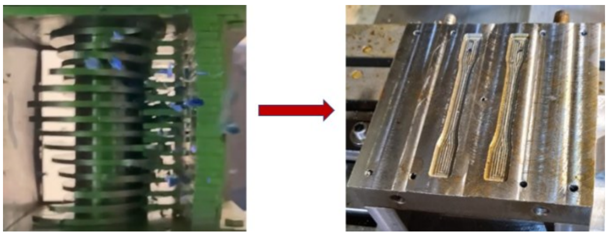

Figure 3. (left) The shredding process of plastic debris and (right) the mould used to manufacture the tensile specimens

4. Results and future aspects

The results of the mechanical, chemical and morphological analysis, gave a valuable feedback on the the structural integrity of the PP debris. As a result, the plastic debris was separated into three (3) different groups ranging from barely intact to excessively damaged properties, as depicted in Table 1, due to the exposure to marine environment.

Table 1. Status integrity of PP debris

Degradation (%) percentage of PP debris			
Healthy properties	100-70	70-40	40-5
Damage on properties	0-30	30-60	60-95

Finally, two (2) different cases of virgin PP incorporation for each status integrity group were tested. For PP debris with minimal degradation (i.e. with structural health ranging from 70 – 100 %), percentages of approximate 10 % to 30 % virgin PP incorporation were examined. For moderately degraded PP debris i.e. with structural health ranging from 40 – 70 %), incorporation of approximate 30 % to 50% of virgin PP inclusion was attempted. For the last status integrity group (heavily degraded PP debris), a higher percentage of virgin PP was necessary to achieve appreciable properties, and the blend involved approximate 60 % to 80 % virgin PP. The results showed that certain level of mechanical properties were achieved and a novel concept for recycling polymers is proposed.

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