Integrated Evaluation of Recycled Aggregates and Plastic Fibers in Low-Carbon Cement Reinforced Concrete: A Technical Feasibility Study

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Abstract

The present research adopts a triple circularity and sustainability approach, integrating: (i) recycled aggregates sourced from construction and demolition waste (CDW), (ii) recycled multilayer plastics from a packaging food company valorised as reinforcing fibres, and (iii) the use of low-carbon cement to reduce the overall environmental footprint of the composite. Through this combined strategy, the study promotes resource efficiency, waste valorisation, and the development of more sustainable reinforced concrete solutions. In that sense, multilayer plastic waste from the food-packaging industry is difficult to treat due to its laminated structure, composed of combinations of polymers (PET, PA, PVC and PE) that make it incompatible with conventional recycling processes. As a result, a significant proportion of this waste is discarded, even though its mechanical properties remain intact. This study assesses the feasibility of reincorporating it by transforming it into polymeric macrofibres for use in reinforcing eco-friendly concrete. In addition, recycled aggregates derived from production waste from a precast concrete manufacturing plant have also been incorporated as aggregate, allowing for the combined recovery of waste in a single building material system. The inclusion of the third sustainability factor—low-carbon cement—ensures that these strategies are effectively combined, resulting in a high-performance reinforced concrete with a reduced environmental footprint.

Introduction

The construction industry is one of the largest consumers of raw materials and energy globally. To mitigate its environmental impact, current research focuses on the "circularity" of construction materials, specifically through the reintegration of industrial by-products into cementitious matrices. While the use of recycled concrete aggregates (RA) is an established practice for reducing natural stone extraction, these materials often exhibit a decreased in concrete compressive strength and heterogeneous compositions. As consequence double validation is required: ensuring structural integrity and verifying that the recycled mineral fraction does not release hazardous substances (such as heavy metals or sulphates) under environmental exposure (Galvín et al., 2014). Simultaneously, the management of plastic waste remains a critical challenge. Within this stream, multilayer films from the food industry are particularly problematic. These materials consist of thin, bonded layers of different polymers (e.g., PET, PE, PA or Aluminium). Because these components have different melting points and chemical properties, they cannot be processed through conventional mechanical recycling, which typically requires single-polymer purity. Consequently, these high-performance materials are usually discarded or landfilled. In addition, the use of low-carbon cement reduces CO_2 emissions by partially replacing clinker with supplementary materials like fly ash, slag, pozzolans, or calcined clays. Thus, alternative binders and carbon-capturing technologies further lower the footprint while maintaining the mechanical performance and durability of concrete, making it a sustainable option for structural applications.

With this framework, the study adopts a **triple sustainability approach**, integrating recycled aggregates, recycled polymeric fibres, and low-carbon cement, to produce high-performance reinforced concrete with a significantly reduced environmental footprint. The study proposes a mechanical upcycling alternative: transforming these multilayer rejects into macrofibres for fibre-reinforced concrete. By combining these macrofibres with recycled aggregates from precast concrete rejects, this research aims to develop a "double-recycled" eco-concrete. The focus is to determine if the interaction between these two waste streams affects the long-term mechanical strength or the environmental safety of the material during its service life and subsequent end-of-life disposal.

Materials and Methodology

The experimental program followed a four-stage valorisation pathway, is showed in Fig 1:

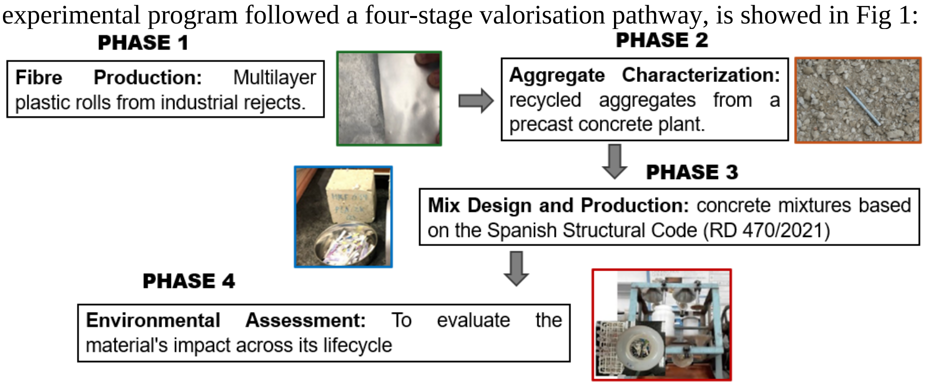


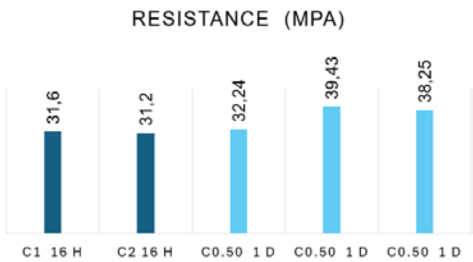
Figure 1. Materials and experimental methodology developed.

The study evaluated multilayer plastic rolls from industrial rejects, which were mechanically processed into macrofibres. To ensure compliance with EN 14889-2 standards, the films were cut to a controlled length of 50 mm and a width of 5 mm. Their tensile strength and elastic modulus were determined through direct tension tests. Recycled aggregates, sourced from rejects of a precast concrete plant, were physically characterized following EN standards: composition analysis (EN 933-11), particle size distribution (EN 933-1), and water absorption and density tests (EN 1097-6). Concrete mixtures were then formulated according to the Spanish Structural Code (RD 470/2021) targeting a compressive strength of 25 MPa. Finally, to assess the material's environmental performance throughout its lifecycle, leaching tests were conducted at different scales to simulate scenarios ensuring that the encapsulated plastics and recycled minerals do not compromise groundwater safety.

Results and Discussion

Although the study is still in progress, the following preliminary results can be summarized in Figure 2 and Table 1. The data also include mixes prepared with a water-to-cement ratio of 0.5, using a low-carbon cement (CEM III/A). Since the concrete's intended technical application is for the planned precast elements, the requirement for early demoulding necessitated measuring strength before 24 hours; therefore, Table 1 presents data at 16 and 24 hours.

	Age	MPa
REF A/C 0.50	0,66	31,7
REF A/C 0.50	0,66	37,8
REF A/C 0.50	24	39,08
REF A/C 0.50	24	35,9
REF A/C 0.50	24	39,91



Conclusions

Although the study is still in progress due to the project's development, based on previous experiences, as for its feasibility, upcycling multilayer packaging and precast waste into a single material system is a viable circular economy strategy for the construction sector. The material is recommended for non-structural precast elements where crack control and sustainability are key requirements.

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