Evaluation of the Technical Feasibility of Recycled Aggregates Derived from CDW for Use in Sustainable Reinforced Concrete

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Abstract

The construction industry is a key driver of the global economy, accounting for about 5.5% of the European Union's GDP. However, it faces significant environmental challenges due to its high consumption of non-renewable resources, energy-intensive processes, extensive land use, and large volumes of construction and demolition waste. Globally, the sector consumes around 63% of raw materials, including over 50 billion tons of sand and gravel annually, essential for producing concrete, cement, and glass. Demand for these materials is expected to rise sharply, with projections indicating that global use of non-metallic minerals could increase from 35 billion tons in 2011 to 82 billion tons by 2060. Addressing these challenges requires a transition to sustainable construction practices, such as the use of recyclable and reusable materials, improving energy efficiency, and adopting effective waste management throughout the building lifecycle. Research and innovation are critical to developing environmentally friendly alternatives that reduce the sector's ecological footprint while supporting sustainable growth. The present study evaluates the potential of recycled materials to replace conventional components in concrete, focusing on both their environmental impact and the rheological performance of the resulting mixtures. It aims to provide insights into the technical feasibility and environmental benefits of using these materials in concrete production. The research also assesses whether recycled materials can meet safety and performance standards, supporting sustainable construction practices within a circular economy.

Introduction

In Europe, construction still relies predominantly on virgin materials, with only 10.6% of input derived from recycled sources. Moreover, approximately 70% of these recycled materials are employed in low-value applications, rather than being incorporated into concrete for structural or non-structural uses. This underscores the need to develop strategies that enhance the use of recycled aggregates (RA) in concrete, promoting higher-value applications and advancing circular economy practices within the construction sector. Concrete production is an energy-intensive process: for raw material extraction, transportation, mixing, placing, and curing. Much of this energy comes from non-renewable sources, which significantly increases the environmental impact of concrete manufacturing, particularly its contribution to greenhouse gas emissions and the sector's overall carbon footprint. Therefore, maximizing the reuse of recycled materials in concrete production is aligned with sustainable construction criteria and can help reduce industry's environmental burden. Construction and Demolition Waste (CDW) refer to materials discarded during construction, renovation, or demolition. CDW generation differs across European countries, primarily due to variations in construction practices, material types, climate conditions, levels of economic development, and the age and location of buildings. Understanding the chemical composition of this type of waste is essential for assessing its potential for recovery and reuse in specific applications in AEC sector. In that sense, the evaluation of the use of recycled materials in concrete manufacturing has been extensively studied (Brito and Agrela, 2018). Previous experiences have been applied to concrete reinforced with plastic fibers. Vaccaro et al., 2021 investigated the incorporation of macroplastic fibers derived from food packaging waste into concrete. By varying fiber content, the effects on compressive strength, modules of elasticity, flexural strength, and toughness were evaluated. Although the fibers slightly reduced mechanical strength compared to conventional concrete, they improved post-crack resistance and toughness, demonstrating their potential to enhance the circular economy.

The present study aims to develop a concrete mix that achieves both high technical performance and reduced environmental impact through the incorporation of recycled aggregates. Specifically, it investigates the use of recycled concrete aggregates, evaluating their effects on the mechanical, physical, and environmental performance of the resulting concrete.

Results and discussion

The present research work uses CEM III/A, a low CO_2-emission cement designed and manufactured with high energy efficiency. The objective is to reduce the environmental impact of the material, specifically the carbon footprint associated, without compromising its structural performance. The study includes three concrete batches: Reference Mix (C-REF): used natural aggregates and CEM III/A; Recycled Aggregate Mix (C-RA20) with a 20% replacement of natural aggregates with recycled aggregates and Aggregate Mix with Fibers (RC-RA20) by adding 2 kg/m³ of synthetic fibers (see Fig. 1).

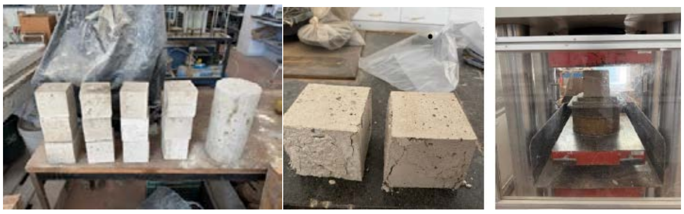

Figure 1. Evolution of compressive strength (MPa)

Table 1. Compressive strength (MPa)

	Day 1			Day 7		
C-REF	19,43	19,26	19,74	35,16	33,93	35,64
C-RA20	17,01	13,29	18,73	31,59	31,22	32,24
RC-RA20	14,01	13,92	15,04	24,5	25,34	25,63

As is shown in Table 1, after 1 day, replacing 20% of natural aggregates with recycled aggregates reduced early strength by 16%, and adding fibers caused a further decrease. Despite this, long-term performance with CEM III/A is expected to be satisfactory, though longer curing and careful demolding may be needed. At 7 days, the control mix reached 34.91 MPa, 20% recycled aggregates reduced it to 31.68 MPa, and adding fibers lowered it to 25.16 MPa. Despite these reductions, all mixes showed adequate structural performance, demonstrating the feasibility of sustainable precast concrete.

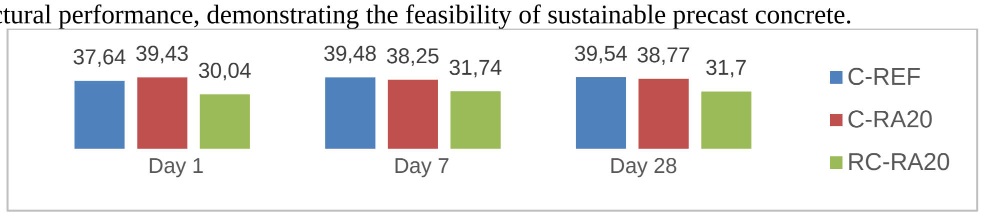

Figure 2. Evolution of compressive strength (MPa)

At 28 days, the control mix and the 20% recycled aggregate (RA) mix achieved nearly identical compressive strengths (38.89 MPa and 38.82 MPa), indicating that partial replacement with RA did not adversely affect performance. However, adding 2 kg/m³ of fibers to the 20% RA mix reduced strength to 31.16 MPa (about 20% lower than the control), likely due to reduced workability and increased void content. Despite this reduction, fibers primarily enhance ductility and crack resistance, and the mix can still be suitable for structural and non-structural applications.

Conclusions

Adding plastic fibers reduced compressive strength, but the results remained suitable for structural and non-structural uses. Although fiber slightly decreases strength, they enhance toughness, crack resistance, and post-cracking behavior, supporting their use when durability and sustainability are priorities. Overall, both RA and plastic fibers can be effectively incorporated into concrete if properly optimized. Their use addresses current environmental and construction challenges, and further research could investigate other CDW-derived aggregates, long-term leaching behavior, and different RA replacement ratios (10–30%) or higher fiber dosages (4–6 kg/m³).

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