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Sustainable Concrete Production Using Locally Sourced Recycled Aggregates

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Abstract

This study investigates the feasibility of producing sustainable M25 grade concrete using locally sourced recycled concrete aggregates (RCA) from ten sites in Marathwada, India. Due to adhered mortar, RCA showed lower specific gravity and higher water absorption than natural aggregates. A practical mortar-removal method and tailored mix design were developed. Testing specimens at 0%, 50%, 60%, and 100% replacement levels revealed that 60% substitution of 20 mm RCA achieved target compressive strength. The findings confirm that processed RCA, with appropriate proportioning, offers a viable sustainable alternative to natural aggregates, effectively reducing construction and demolition waste and environmental burden while meeting structural performance criteria.

Keywords: Concrete, Compressive strength, Strength, RCA

1. Introduction

The global construction sector serves as a dual-edged force: it is both a primary driver of economic growth and a major contributor to environmental degradation through excessive natural resource consumption and massive waste generation. Construction and demolition (C&D) activities produce vast quantities of debris, with concrete rubble constituting a significant portion that is typically landfilled, creating pressing ecological and land-use challenges. Recycled concrete aggregates (RCA) present a promising alternative to natural aggregate quarrying, fostering circular economy principles by reducing landfill burden and conserving virgin materials. However, RCA inherently differs from natural aggregates due to adhered mortar, which lowers specific gravity, increases water absorption, and weakens the interfacial transition zone, often compromising concrete strength and durability. This study addresses these challenges by procuring RCA from ten locations across the Marathwada region (India) and implementing a practical mortar-removal processing method. A systematic mix design methodology tailored for recycled aggregates was developed and validated through

extensive experimentation involving 186 specimens at 0%, 50%, 60%, and 100% replacement levels. The research specifically targets M25 grade concrete and demonstrates that with appropriate processing and proportioning—particularly at a 60% substitution level of 20 mm maximum-size RCA—the target compressive strength can be reliably achieved. By establishing a regionally validated approach, this study aims to demonstrate that locally sourced, processed RCA can serve as a sustainable, technically feasible alternative to natural aggregates, significantly mitigating C&D waste while meeting structural performance requirements for mainstream construction applications.

2. Literature Review

The pursuit of sustainable construction has globally stimulated research into recycled concrete aggregate (RCA) derived from construction and demolition (C&D) waste. Extensive studies confirm that RCA's inherent adhered mortar reduces its density and increases water absorption relative to natural aggregates (NA), directly impairing mechanical properties such as compressive strength, tensile strength, and modulus of elasticity as replacement ratios increase [1,2]. A critical gap identified in literature is the absence of a standardized mix design procedure for RCA concrete; most existing approaches merely adapt codes like IS 10262:2019 or ACI 211.1, which fail to accommodate RCA's high absorption capacity, often resulting in unpredictable performance [3]. Achieving higher strength grades with 100% RCA typically necessitates significant modifications, including reduced water-cement ratios or supplementary cementitious materials.

Various processing techniques—including mechanical abrasion, heat treatment, and acid soaking—have demonstrated potential for removing or strengthening adhered mortar, thereby enhancing aggregate properties [4]. However, many of these methods remain energy-intensive or impractical for large-scale applications, underscoring the need for simple, cost-effective solutions. While conservative replacement levels (30–50%) are widely recommended to preserve properties, such approaches limit environmental benefits [5]. Recent reviews have synthesized mix design strategies and performance understanding for recycled aggregate concrete, providing a valuable foundation [6]. Nevertheless, significant knowledge gaps persist regarding the interactive effects of mix design parameters—particularly fly ash substitution, aggregate-binder ratio, and fiber dosage—on the mechanical behavior of high-volume fly ash (HVFA) concrete. Moreover, optimal fiber volume fractions for specific fly ash contents remain undefined, and the influence of fibers on long-term strength development in HVFA mixes with high replacement levels warrants further investigation [7]. This study addresses these gaps by developing a practical, validated mix design methodology enabling higher RCA incorporation rates (up to 60%) while reliably achieving M25 structural grade strength, using locally sourced and processed aggregates from the Marathwada region.

3. Materials and Method

Ordinary Portland Cement (OPC) of 53-grade conforming to IS: 12269-1987 was used as the primary binder, supplemented with Class C fly ash. Natural river sand served as fine aggregate, characterized for bulk specific gravity and water absorption as per IS: 2386 (Part III). Crushed granite of nominal 20 mm maximum size, retained on a 12.5 mm sieve, constituted the natural coarse aggregate (NCA). Processed recycled concrete aggregates (RCA) were procured from ten C&D waste sites across the Marathwada region and prepared using a practical mortar-removal technique. Potable water was used for mixing and curing, and polypropylene fibers were incorporated in selected mixes to enhance mechanical performance. A systematic mix design methodology specifically tailored for recycled aggregates was developed, modifying the conventional approach to account for RCA's high water absorption. The RCA was pre-saturated by adding extra water equivalent to its 24-hour water absorption capacity during initial mixing. This ensured that the effective water-to-cement (w/c)

ratio remained constant and workability was preserved. Natural coarse aggregate was replaced with processed RCA at four volumetric ratios: 0% (Control), 50%, 60%, and 100%. A total of 186 specimens were cast across all mixes. All specimens were demolded after 24 hours and transferred to a water-curing tank maintained at $27^{\circ}\pm 2^{\circ}\text{C}$ until testing. Curing was conducted for 7 and 28 days in accordance with standard practices.

4. Result

The compressive strength results for concrete mixtures incorporating 100% recycled concrete aggregates (RCA) are presented and analyzed in this section. Three different mix design approaches—IS 10262:2019, ACI 211.1, and DOE (Department of Environment) method—were evaluated for their effectiveness in producing M25 grade concrete with fully recycled aggregates. The experimental results revealed a significant variation in compressive strength across the three mix design methodologies. At 7 days of curing, both the IS and ACI methods yielded identical compressive strengths of 14.45 N/mm^2 , while the DOE approach produced notably lower strength values. This disparity became more pronounced at 28 days, where the IS method delivered the highest compressive strength of 25.18 N/mm^2 , followed by the ACI method, with the DOE approach yielding the lowest strength values.

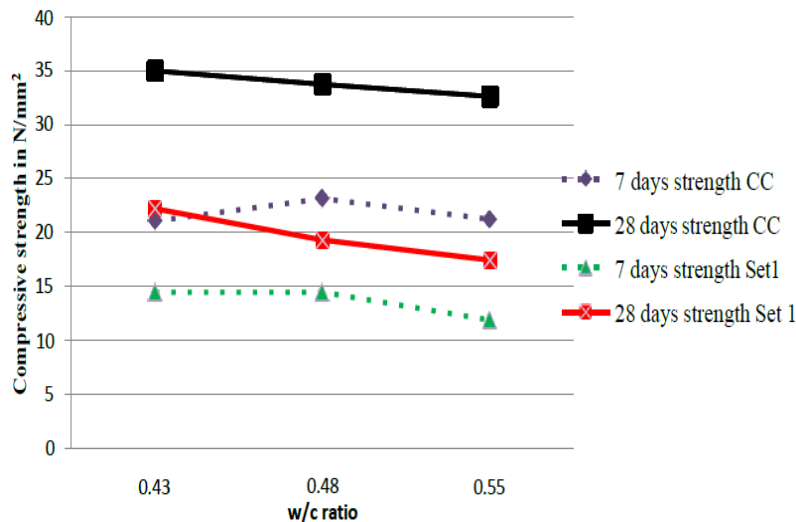


Fig. 1 - Compressive Strength of Set 1 with Controlled Concrete

5. Conclusion

The compressive strength results for concrete mixtures incorporating 100% recycled concrete aggregates (RCA) revealed significant variation across three mix design methodologies—IS 10262:2019, ACI 211.1, and DOE (Department of Environment) method. At 7 days of curing, both the IS and ACI methods yielded identical compressive strengths of 14.45 N/mm^2 , while the DOE approach produced notably lower values. At 28 days, the IS method delivered the highest compressive strength of 25.18 N/mm^2 , corresponding to the maximum cement content of 447 kg/m^3 . In contrast, the DOE method utilized the lowest cement content (373 kg/m^3) and produced the weakest concrete. Compared to conventional concrete, all 100% RCA mixtures exhibited substantial strength reductions ranging from 36% to 46% at 28 days. For M25 grade concrete, partial replacement of natural aggregates with RCA at proportions of 40–60% resulted in compressive strength reductions of 15–35% at 28 days. This range indicates that moderate RCA incorporation can yield acceptable structural performance with appropriate mix design adjustments.

The primary cause of the reduction is the adhering mortar that covers the recycled aggregates, which causes their water absorption to be 5–10% higher than that of the regular aggregates. Using recycled aggregates in proportions of 40 to 60 percent has been found to reduce the compressive strength of M25 grade concrete by 15 to 35 percent at 28 days. It has been discovered that adding 10 mm recycled aggregates to concrete combined with coarse recycled aggregates of 20 mm will further lower the concrete's compressive strength by up to 46%. Concrete costs are directly reduced when recycled aggregate concrete is used instead of regular aggregate concrete

Declaration of Conflicting Interests

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