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Effect Of Partial Replacement Of Natural Coarse Aggregate With Recycled Aggregate On Compressive Strength And Workability Of Concrete

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Abstract: This study investigates the effect of partial replacement of natural coarse aggregate with recycled coarse aggregate (RCA) on the compressive strength and workability of concrete. With the increasing demand for sustainable construction materials, the utilization of construction and demolition waste has become a critical strategy for reducing the environmental footprint of the construction industry. In this experimental research, RCA was used to replace natural aggregate at three levels: 10%, 20%, and 30%, by weight. Additionally, silica fume was incorporated at a fixed dosage of 10% by weight of cement to enhance the pozzolanic activity and improve overall concrete performance.

Concrete mixes were prepared using a fixed mix ratio of 1:2:4 (cement: sand: aggregate) with a constant water-cement ratio. For each replacement level, mixes were prepared with and without silica fume, resulting in eight different mix combinations. Standard 150 mm concrete cubes were cast, cured for 28 days, and tested as per IS 516:1959 for compressive strength. Slump tests were also conducted to assess the workability of the mixes.

Results showed that compressive strength decreased with increasing RCA content in the absence of silica fume. However, mixes containing silica fume showed a significant improvement in strength, recovering up to 90% of the control mix's compressive performance. Workability slightly declined with RCA content but improved with silica fume addition. The study concludes that up to 30% RCA replacement, especially when combined with silica fume, can be effectively used in structural concrete, promoting sustainable practices without significantly compromising strength or workability.

Index Terms **– Recycled aggregate, concrete, OPC, Silica Fumes, Compressive strength**

I. Introduction

Concrete, as the most widely used construction material in the world, owes much of its strength and durability to Ordinary Portland Cement (OPC). However, the extensive use of OPC concrete has raised several environmental and technical concerns. The production of OPC is an energy-intensive process that contributes significantly to global greenhouse gas emissions—accounting for approximately 7–8% of total CO_2 emissions worldwide. Additionally, the extraction of raw materials such as limestone and clay leads to land degradation, dust pollution, and ecosystem disruption. From a sustainability standpoint, the conventional OPC concrete system is increasingly seen as unsustainable in the face of global environmental goals [1].

Apart from environmental concerns, OPC-based concrete also faces critical performance and durability issues, especially in aggressive environments. Its high heat of hydration can lead to thermal cracking in mass concrete applications, and the material is susceptible to chemical attacks such as sulfate and chloride ingress, leading to reinforcement corrosion. These vulnerabilities not only reduce the service life of concrete structures but also escalate long-term maintenance costs. In regions experiencing rapid urbanization, the over-reliance on OPC concrete exacerbates the demand for non-renewable natural resources like river sand and crushed stone aggregates, contributing to resource depletion [2].

In this context, the integration of recycled aggregates (RA) into concrete mixtures emerges as a promising alternative to conventional materials. Recycled aggregates, typically derived from construction and demolition waste, can substantially reduce the environmental footprint of concrete production. By minimizing the extraction of virgin aggregates and diverting waste from landfills, RA use supports circular economy principles and aligns with green construction standards such as LEED and BREEAM. Moreover, incorporating RA reduces energy consumption and CO_2 emissions associated with transporting natural aggregates, especially in urban settings where demolition waste is abundantly available [3].

In terms of material performance, while early applications of RA in concrete were met with concerns over strength and durability, recent advances in mix design and processing techniques have significantly improved its structural reliability. Through appropriate treatment, grading, and incorporation of supplementary cementitious materials (e.g., fly ash, GGBS), recycled aggregate concrete (RAC) can meet structural-grade performance standards. Additionally, RAC exhibits favorable properties such as improved thermal insulation and acoustic performance in some applications. Thus, transitioning from traditional OPC concrete to RA-integrated concrete represents a viable pathway toward more sustainable, economical, and responsible construction practices in the 21st century [4].

II. LITERATURE REVIEW

The increasing demand for sustainable construction materials has led to substantial interest in utilizing recycled aggregates (RA) as a substitute for natural aggregates in concrete. Numerous studies have shown that RA, derived from construction and demolition waste, offers both environmental and economic benefits by reducing landfill use and conserving natural resources. However, its impact on mechanical properties, particularly compressive strength, varies with the replacement percentage and mix design techniques [5].

2.1 Partial Replacement Effects (10%–30%)

Studies have consistently reported that at low levels of substitution (10%–30%), the reduction in compressive strength is relatively marginal and can be effectively mitigated using supplementary cementitious materials. Ghosh and Samanta (2024) found that concrete with up to 30% RA retained a compressive strength above 35 MPa, suitable for most structural applications, provided appropriate mix design adjustments were made. Similarly, Guendouz et al. (2025) demonstrated that partial RA replacement at 10%, 20%, and 30% maintained satisfactory mechanical performance and could be enhanced using pozzolanic additives [6].

2.2Optimization with Mineral Additives

Multiple studies explored the integration of silica fume, fly ash, and other pozzolanic materials to counter the decline in compressive strength due to RA. Nora et al. (2024) analyzed the effect of expanded perlite and RA in mortar, concluding that partial replacements (10–30%) combined with silica fume showed improved densification of the interfacial transition zone, enhancing overall strength. Another notable study by Jhakal et al. (2024) confirmed that the combination of RA and glass powder as partial replacements (up to 30%) not only maintained mechanical integrity but also improved durability characteristics such as permeability and freeze-thaw resistance [7].

2.3 Microstructural Impacts and Mix Performance

Microstructural investigations revealed that RA often contains adhered mortar, which increases porosity and water absorption. However, Kashyap et al. (2024) emphasized that controlled processing and pre-soaking of RA, along with 10–20% replacement, allowed concrete to perform comparably to conventional mixes. Their results indicated less than 10% reduction in compressive strength for 20% RA substitution when supplementary cementitious materials were included [8].

2.4 Environmental and Practical Implications

The environmental benefits of using RA have been highlighted across studies, with significant reductions in carbon footprint, raw material extraction, and waste disposal. Muthukumarasamy et al. (2024) found that a 30% replacement level strikes a practical balance between performance and sustainability, while also reducing concrete costs. Worku and Ejigu (2024) further supported this by integrating recycled aggregates with PET waste, noting satisfactory compressive performance in the 10–30% range [9].

2.5 Comparative Findings

A comparative study by Guendouz and Boukhelkhal (2025) on marble powder and RA concluded that 30% replacement maintained acceptable compressive strength, and recommended it as a practical ceiling for most applications. They also noted enhanced thermal and acoustic insulation properties in RAC. Across the board, concrete mixes with 10%–30% RA showed mechanical viability for non-load-bearing and some structural elements, especially when supported by chemical or mineral admixtures [10].

III. Material and Methodology

3.1. Materials

This study investigates the influence of partial replacement of natural coarse aggregate with recycled coarse aggregate (RA) on the compressive strength of concrete. The concrete mix consists of Ordinary Portland Cement (OPC), natural fine aggregate (sand), natural coarse aggregate (gravel), recycled coarse aggregate (RCA), potable water, and silica fume as a mineral admixture to enhance strength and durability [11-12].

3.1.1 **Cement**: Ordinary Portland Cement (OPC) 43 grade conforming to *IS 8112:2013* was used. The cement was procured in standard 50 kg bags and stored in moisture-proof conditions.

3.1.2 **Fine Aggregate (Sand)**: Natural river sand conforming to *IS 383:2016*, Zone II grading, was used. The sand was sieved and tested to meet particle size distribution and cleanliness criteria.

3.1.3 **Natural Coarse Aggregate**: Crushed granite stone from local quarries with a nominal maximum size of 20 mm was used, as per *IS 383:2016*.

3.1.4 **Recycled Coarse Aggregate (RCA)**: Sourced from construction and demolition waste, the concrete debris was manually crushed, screened, and cleaned to remove contaminants like plaster, wood, and glass. The RCA was processed to a maximum size of 20 mm and conformed to the gradation requirements of *IS 383:2016 (Annex A)* for recycled aggregate.

3.1.5 **Admixture (Silica Fume)**: Microsilica was used as a mineral admixture at a fixed dosage of 10% by weight of cement, in accordance with *IS 15388:2003*, to enhance the pozzolanic reactivity and reduce porosity.

3.1.6 **Water**: Fresh potable tap water conforming to *IS 456:2000* specifications was used for both mixing and curing..

3.2. Mix Design and Proportions

A nominal mix of M20 concrete was adopted, with a cement:sand:coarse aggregate ratio of **1:2:4 by volume**, in line with *IS 456:2000* recommendations for general-purpose concrete. The total coarse aggregate content remained constant, with RCA replacing natural coarse aggregate in incremental steps [13-14]:

- **Mix A (Control)**: 0% RCA, 100% natural coarse aggregate
- **Mix B**: 10% RCA, 90% natural coarse aggregate
- **Mix C**: 20% RCA, 80% natural coarse aggregate
- **Mix D**: 30% RCA, 70% natural coarse aggregate

Each mix configuration was prepared both with and without silica fume, resulting in eight concrete batches (A1 to D2). The **water-cement ratio** was maintained at **0.50** for all batches. Mix proportions were kept uniform, and workability was adjusted using water and thorough mixing.

3.3. Specimen Preparation

Concrete cube specimens of size 150 mm × 150 mm × 150 mm were cast for each mix type, as specified in *IS 516:1959*. The concrete was mixed in a tilting drum mixer. Placement was done in three layers, each compacted using a tamping rod to ensure homogeneity and void minimization.

After demoulding at 24 hours, specimens were cured in clean water at a temperature of 27±2°C for **28 days** as per *IS 9013:1978*. Each mix had **three replicate specimens**, and average compressive strength was computed for comparison.

3.4. Testing Procedure

After curing, specimens were subjected to compressive strength testing using a calibrated compression testing machine (CTM) with a capacity of 3000 kN, conforming to *IS 14858:2000*. The loading rate was maintained at 140 kg/cm² per minute (equivalent to 0.25 MPa/s), in line with *IS 516:1959*.

Additionally, slump tests were carried out for each mix using the standard slump cone as per *IS 1199:1959* to determine workability. Observations were also recorded on setting times, appearance, and consistency.

All experimental data were statistically analyzed to evaluate the influence of recycled aggregate percentage and silica fume addition on compressive strength and fresh concrete properties.

IV. RESULT AND DISCUSSION

The methodology section outline the plan and method that how the study is conducted. This includes Universe of the study, sample of the study,Data and Sources of Data, study's variables and analytical framework. The detailsare as follows;

4.1 Compressive Strength Results

The compressive strength of concrete cubes was tested after 28 days of curing. The results are presented in Table 1 and graphically illustrated in Figures 1 and 2. The trend indicates that as the percentage of recycled aggregate increased from 0% to 30%, there was a gradual reduction in compressive strength. However, mixes containing 10% silica fume exhibited a significant improvement in compressive strength compared to their non-admixed counterparts

4.2 Effect of Recycled Aggregate on Compressive Strength

Concrete mixes with increasing RCA content showed a progressive decline in compressive strength. This is attributed to the porous nature and weaker interfacial bond of RCA compared to natural aggregates. At 30% replacement, the reduction in strength reached approximately 20% relative to the control mix (A1). The loss is primarily due to the adhered mortar on RCA, which introduces more voids and micro-cracks into the matrix.

Table 4.1: Compressive Strength of Concrete Cubes at 28 Days

Mix ID	% RCA	Silica Fume (%)	Avg. Compressive Strength (MPa)
A1	0	0	30.9
A2	0	10	33.2
B1	10	0	28.5
B2	10	10	31.4
C1	20	0	26.7
C2	20	10	29.3
D1	30	0	24.6
D2	30	10	27.8

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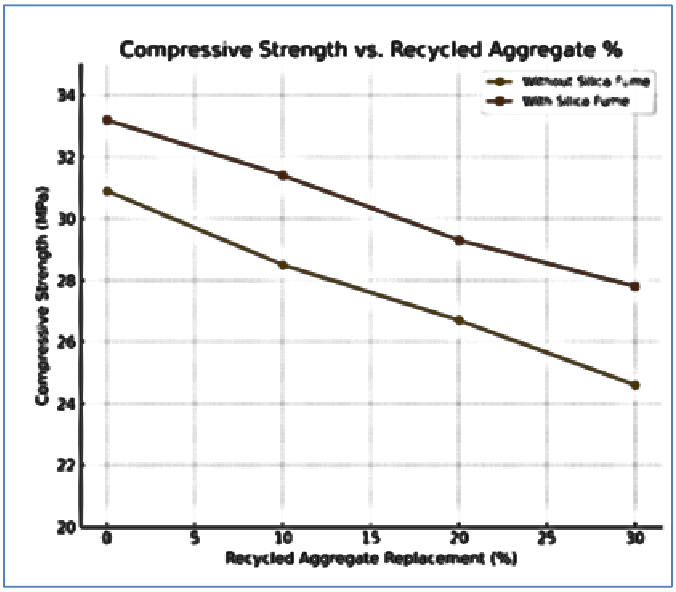

Figure 4.1: Compressive Strength vs. Recycled Aggregate (%)

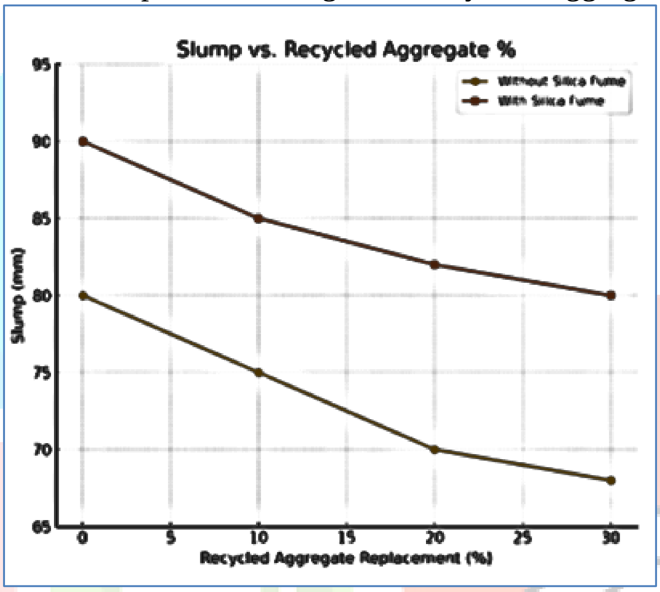

Figure 4.2: Slump vs. Recycled Aggregate (%)

4.3 Effect of Silica Fume on Strength Recovery

The addition of 10% silica fume significantly enhanced the compressive strength across all mixes. Mixes with silica fume consistently exhibited 2.5–3.5 MPa higher strength than those without. This improvement is due to the pozzolanic reaction between silica fume and calcium hydroxide (CH), resulting in the formation of additional C-S-H gel, which densifies the matrix and strengthens the interfacial transition zone (ITZ).

For example, while mix D1 (30% RCA without silica fume) had a compressive strength of 24.6 MPa, the strength improved to 27.8 MPa in D2 (30% RCA with silica fume), recovering nearly 90% of the control mix's performance. This suggests that silica fume can effectively mitigate the negative effects of RCA at moderate replacement levels

4.4 Workability Observations

The slump values decreased slightly with the increase in RCA due to its higher water absorption and rough texture. However, mixes with silica fume showed better cohesion and slight improvement in slump due to finer particle packing and better dispersion. None of the mixes experienced segregation or bleeding, and all maintained acceptable workability for manual casting.

V. CONCLUSION

The study demonstrates that partial replacement of natural coarse aggregate with recycled aggregate (RCA) in concrete significantly affects compressive strength and workability. A consistent reduction in strength was observed with increasing RCA content due to its porous nature and the presence of adhered mortar. However, even at 30% RCA replacement, the compressive strength remained within acceptable limits for structural applications when supported by proper mix design. The observed decrease in slump with increasing RCA content reflects the higher water absorption and rough texture of recycled aggregates, but the values were still suitable for manual placement and compaction.

The incorporation of 10% silica fume markedly improved the mechanical performance of concrete mixes with RCA. Its pozzolanic reactivity not only enhanced the interfacial transition zone (ITZ) but also compensated for the strength loss typically associated with RCA. Concrete mixes with 10–20% RCA and silica fume exhibited compressive strengths comparable to the control mix, validating the feasibility of using recycled aggregate in moderate proportions. This approach supports sustainable construction practices by minimizing the use of natural aggregates and promoting the reuse of construction and demolition waste without significantly compromising structural integrity

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