Pre-treatment Techniques for Enhanced Performance of Recycled Aggregates in Concrete

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Abstract - The recycled concrete aggregates (RCA) derived from the waste generated due to demolished construction structures is constrained due to presence of adhered residual mortar resulting in increased porosity. This attached mortar layer induces high water absorption, lowers the aggregate density, and establishes a weaker Interfacial Transition Zone (ITZ), which ultimately degrades the strength properties of structural concrete. This paper investigates the efficiency of distinct pre-treatment techniques on RCA and evaluates their precise impact on mechanical properties of M20 and M30 grade concrete at a 50% replacement level. Three pre-treatment methods were systematically analyzed: Mechanical Scrubbing, Acid Soaking utilizing 0.1M hydrochloric acid (HCL), and Cement-Silica Fume Slurry Coating. Experimental results established that untreated RCA reduces compressive strength by 15-20% compared to natural aggregate counterparts. Pre-treatment effectively restored this mechanical loss. For M20 grade concrete, acid soaking and slurry coating yielded compressive strength increments of 16.7% and 19.9%, respectively, over untreated RCA. Parallel trends were observed in M30 grade concrete, achieving peak improvements of 20.0% in compressive strength utilizing the slurry coating technique. The analysis demonstrates that while mechanical scrubbing offers a low-cost baseline improvement, surface coating and chemical treatments are critical for enabling structural applications of RCA in M30 grade and above.

Keywords: Recycled Concrete Aggregate; Pre-treatment techniques; Compressive strength; Attached mortar; Interfacial Transition Zone.

1. Introduction

The global construction sector consumes upward of 40 billion tonnes of natural aggregates annually, causing severe depletion of primary stone and river sand reserves [1, 2]. Concurrently, the continuous demolition of aging infrastructure generates immense volumes of Construction and Demolition (C&D) waste [3]. Recycling and reuse of this C&D waste as Recycled Concrete Aggregate (RCA) presents a sustainable solution in dual aspect, mitigating both landfill stress and raw material extraction [4]. However, RCA diverges fundamentally from Natural Aggregate (NA) due to the existence of attached mortar to the surface of the original parent rock [5, 6].

This adhered mortar is inherently porous and contains a network of micro cracks induced during the primary crushing phase in the process of recycling [7]. Consequently, untreated RCA exhibits elevated water absorption, reduced specific gravity, and inferior crushing values when compared to NA [8]. When incorporated into new concrete matrices, the old mortar forms a complex, multi-layered Interfacial Transition Zone (ITZ). This zone acts as a microstructural weak link, compromising the macroscopic structural integrity of the concrete [9, 10].

To counteract these material deficiencies, various pre-treatment protocols have been theorized to either strip the adhered mortar from the parent rock or densify it prior to mixing [11].

The main objective of this study is to enumerate the specific percentage increments in its mechanical properties (compressive and split tensile strength) with standard concrete grades (M20 and M30), utilizing practically scalable pre-treatment methodologies.

2. Literature Review

Current methodologies for RCA pre-treatment are broadly classified into two operational mechanisms: mortar removal and mortar strengthening.

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2.1 Mortar Removal Techniques
Mechanical abrasion or scrubbing depends on abrasive forces to dislodge loose mortar from the RCA surface. Investigations by Tam et al. [12], Dilbas et al. [13] confirms that this abrasion treatment effectively reduces the water absorption in concrete. However, applying excessive mechanical force risks propagating new micro-cracks within the parent aggregate itself [14].
Chemical treatments, specifically acid soaking, demonstrate superior efficiency in mortar removal. Ismail and Ramli [15] employed low-concentration hydrochloric (HCL) and sulfuric (H_2SO_4) acids to selectively dissolve calcium hydroxide $Ca(OH)_2$ and calcium silicate hydrates (C-S-H) within the old mortar matrix. Al-Bayati et al. [16] reported that immersing RCA in 0.1M (concentration of a solution defined by molarity M) HCL for 24 hours optimally reduces the adverse effect of adhered mortar without attacking the parent siliceous aggregate, resulting in a 0-15% improvement in compressive strength of resulting concrete [17, 18, 19].

2.2 Mortar Strengthening Techniques
In contrast to removal strategies, surface coating techniques attempt to densify the existing porous RCA structure. Polymer impregnation treatments, such as utilizing polyvinyl alcohol (PVA) or silane coupling agents, effectively seal surface pores, drastically reducing water ab-sorption metrics [20, 21]. Despite their efficacy, polymers remain cost-prohibitive for large-scale concrete production.

Mineral admixtures provide a viable, cost-effective alternative. Coating RCA with a highly reactive slurry composed of cement and silica fume or fly ash has been documented extensively [22, 23]. The pozzolanic reaction triggered between the amorphous silica in the fume and the residual calcium hydroxide $Ca(OH)_2$ in the old mortar generates secondary C-S-H gel which enhances the strength properties in concrete. This chemical process results into significantly strengthen and densifies the ITZ [24, 25, 26].

Recent alternative advancements include accelerated carbonation curing, wherein CO_2 gas reacts with portlandite in the old mortar to precipitate stable calcium carbonate, effectively sealing micro-pores [27, 28, 29]. While highly effective, the requirement for specialized pressurized carbonation chambers restricts its in-situ application [30]. Therefore, the current study isolates scalable, field-ready methods: mechanical scrubbing, low-molarity acid soaking, and pozzolanic slurry coating, examining their exact performance increments in M20 and M30 structural grades.

3. Materials and Methodology

3.1 Constituent Materials
The experimental program utilized ordinary Portland cement (OPC) 53 grade, confirming to Indian standard specifications for high-strength requirements. Bhima basin river sand conforming to Zone II grading was selected as the fine aggregate. Crushed basalt rock with a maximum nominal size of 20mm served as the natural coarse aggregate (NA). The recycled concrete aggregate (RCA) was procured from an industrial C&D waste processing facility. Commercial-grade Silica Fume was utilized for the slurry coating procedure, and 0.1 Molarity Hydrochloric acid (HCl) was used for the chemical immersion tests.

3.2 Pre-treatment Protocols
The RCA was mechanically sieved to ensure its gradation curve precisely matched that of the NA. To establish a distinct performance delta, a 50% volume replacement of NA with RCA was maintained across all experimental batches. The aggregates were subjected to the following standardized treatments:

a. Control (URCA): Untreated RCA simply washed with water to eliminate superficial dust particulates.
b. Treatment 1 (Mech.-RCA): RCA processed via mechanical scrubbing in a Los Angeles abrasion drum (operated without abrasive steel charges) for 15 minutes to strip weakly bonded mortar, followed by water washing.
c. Treatment 2 (Acid-RCA): RCA was kept submerged in a 0.1M HCL acidic solution for a period of 24 hours at ambient room temperature (25°C). Further, post immersion, the aggregates were rigorously washed with fresh water to neutralize the pH and subsequently air-dried.
d. Treatment 3 (Coat-RCA): RCA physically coated with a reactive cement-silica fume slurry (proportioned at 10% silica fume by weight of cement, utilizing a w/c ratio of 0.4). The treated aggregates were cured under saturated burlap for 7 days to ensure adequate pozzolanic hydration prior to the main concrete mixing phase.

3.3 Mix Proportioning and Testing Setup
Concrete mix designs targeting standard structural grades M20 (target mean strength 26.6 MPa) and M30 (target mean strength 38.25 MPa) were formulated utilizing fixed water-to-cement ratios of 0.50 and 0.45, respectively. Poly-carboxylate ether-based superplasticizer dosages were adjusted to maintain a consistent workability slump of 75-100 mm across all batches. Standard 150 mm cubic specimens were cast for compressive strength evaluations at 7 and 28 days. Cylindrical specimens (150 mm diameter × 300

mm height) were prepared for 28-day split tensile testing to evaluate micro-cracking resistance.

4. Results and Discussion

4.1 Physical Properties of Treated Aggregates

The applied pre-treatments induced measurable alterations to the fundamental physical characteristics of the RCA. The baseline untreated RCA (URCA) exhibited a high water absorption rate of 6.8% and a specific gravity of 2.38. The acid immersion treatment (Acid-RCA) successfully dissolved a significant portion of the porous mortar, reducing the water absorption to 4.1% and raising the specific gravity to 2.52. The slurry coating technique (Coat-RCA) achieved the lowest water absorption at 3.5%, primarily by mechanically sealing the surface porosity rather than removing material.

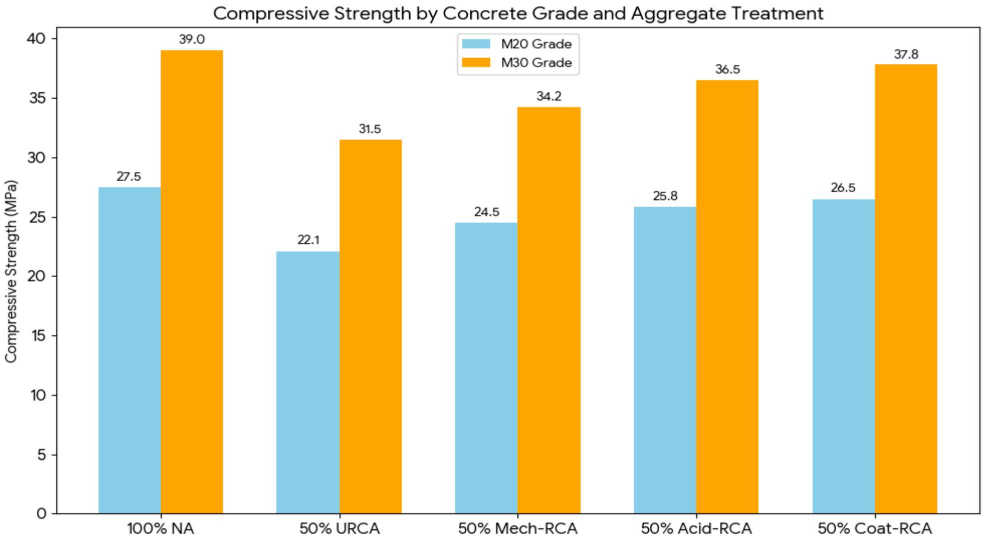
4.2 Compressive Strength Analysis

Table 1 outlines the 28-day compressive strength results. The direct substitution of 50% un-treated RCA (URCA) resulted in a baseline structural capacity drop of 19.6% and 19.2% for the M20 and M30 grades, respectively, when compared to the 100% NA reference benchmarks.

Table 1: 28-Day Compressive Strength and Percentage Increments

Concrete Grade	Aggregate Type / Treatment	Strength (MPa)	Percentage Increment (over URCA)
M20	100% NA (Reference)	27.5	-
	50% URCA (Untreated)	22.1	Baseline
	50% Mech.-RCA	24.5	+10.86%
	50% Acid-RCA	25.8	+16.74%
	50% Coat-RCA	26.5	+19.91%
M30	100% NA (Reference)	39	-
	50% URCA (Untreated)	31.5	Baseline
	50% Mech.-RCA	34.2	+8.57%
	50% Acid-RCA	36.5	+15.87%
	50% Coat-RCA	37.8	+20.00%

Fig. 1



Comparative 28-Day Compressive Strength

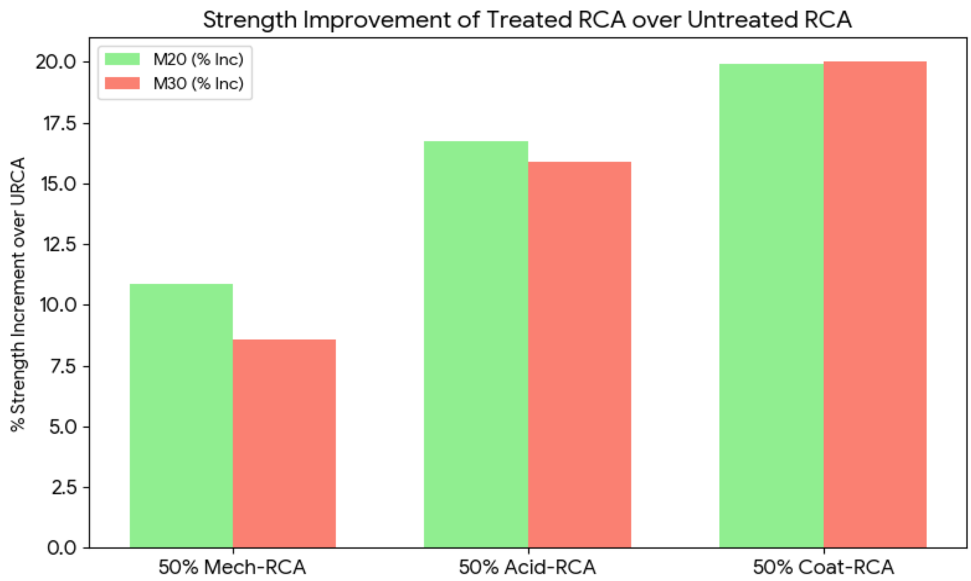


Fig. 2 % Increment (over URCA)

Mechanical scrubbing (Mech.-RCA) eliminated the weakest exterior stratum of adhered mortar, yielding a moderate structural improvement of 8-10%. The chemical acid treatment (Acid-RCA) dissolved a higher volume of the detrimental paste, allowing superior mechanical inter-locking between the parent rock and the new cementitious matrix, which translated to an approximate 16% strength increment.

The Coat-RCA protocol exhibited the highest efficacy, enhancing compressive strength by approximately 20% across both concrete grades. The integration of silica fume in the coating engaged in a localized pozzolanic reaction with the residual portlandite. This chemical inter-action heavily densified the Interfacial Transition Zone (ITZ), bridging the microstructural gap between the old aggregate and the new cement paste. Crucially, the Coat-RCA mix in the M20 series achieved 26.50 MPa, restoring the structural capacity to 96% of the benchmark natural aggregate concrete.

4.3 Split Tensile Strength Analysis

Tensile strength metrics are notoriously sensitive to the microstructural quality of the ITZ. As detailed in Table 2, untreated RCA severely compromised tensile performance. Failure patterns indicated rapid crack propagation directly through the structurally deficient old mortar layers.

The surface coating technique (Coat-RCA) provided exceptional crack-arresting capabilities in this testing phase. By reinforcing the ITZ, the coating improved tensile strength by 24.65% in M20 and 23.08% in M30. The densified layer effectively restricted micro-crack initiation and altered the failure plane to force crack propagation through the tougher parent aggregate rather than the interface.

Table 2: 28-Day Split Tensile Strength and Percentage Increments

Concrete Grade	Aggregate Type / Treatment	Strength (MPa)	Percentage Increment (over URCA)
M20	50% URCA (Untreated)	2.15	Baseline
	50% Mech-RCA	2.38	+10.70%
	50% Acid-RCA	2.55	+18.60%
	50% Coat-RCA	2.68	+24.65%
M30	50% URCA (Untreated)	2.6	Baseline
	50% Mech-RCA	2.82	+8.46%
	50% Acid-RCA	3.05	+17.31%
	50% Coat-RCA	3.2	+23.08%

5. Conclusion

This experimental investigation analyzed the impact of scalable pre-treatment methodologies for Recycled Concrete Aggregates (RCA) and quantified their specific mechanical influence on M20 and M30 grade concrete. The key findings are summarized below:

1. The direct implementation of untreated RCA at a 50% substitution level reduces the compressive and tensile capacities of the concrete by approximately 20%. This substantial drop relegates untreated RCA primarily to non-structural applications.
2. Mechanical scrubbing yields a moderate performance recovery (8-10%) by stripping the loosest surface mortar. However, it remains inadequate for fully restoring the parameters required for structural integrity.
3. Low-molarity acid soaking (0.1M HCL) successfully dissolves the adhered mortar, yielding a consistent 15-17% increment in compressive strength. Despite its efficacy, the logistical requirements for acidic wastewater neutralization limit its viability for continuous field application.
4. Cement-silica fume slurry coating emerged as the superior technique. By chemically strengthening the old mortar rather than removing it, the process densified the ITZ. This resulted
5. in a 20% increment in compressive strength and up to a 24.6% increment in split tensile strength.
6. For standard construction projects utilizing M20 and M30 grades, slurry-coated RCA can safely replace up to 50% of natural coarse aggregate while successfully maintaining 95-97% of the original design strength associated with natural aggregate concrete.

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