Water Absorption and Resource use in Concrete with Recycled Coarse Aggregate, Marble Powder and Waste-Glass Powder: Implications for Decentralized Water Infrastructure

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Abstract: *Reducing primary aggregate demand and avoiding landfill disposal of construction waste may support more sustainable construction of small water and sanitation facilities. However, mixtures that use recycled aggregate must be assessed for moisture uptake before they are considered for water-exposed service. This study re-examines an existing four-mixture M30 concrete programme with emphasis on water absorption, batch-water demand and material circularity. Recycled coarse aggregate (RCA) increased from 0% to 60%, while combined marble dust (MD) and recycled glass dust (GD) replaced 0% to 20% of cement by mass. The reported 24-hour water absorption increased from 2.10% (control) to 4.35%, 4.65% and 5.10% as recycled content rose, although 28-day compressive strength increased from 28.43 to 35.40 MPa. The tabulated batch-water quantity also increased from 197.6 to 226.4 L/m³, a 14.6% rise; because RCA was reportedly preconditioned to saturated surface-dry state, this water accounting requires confirmation. The results demonstrate a strength–absorption trade-off rather than proven water-tightness. Replacing 20% of cement reduces the listed cement mass by 82.15 kg/m³, but a net life-cycle or potable-water saving has not been quantified. The findings supply a preliminary screening dataset for non-liquid-retaining components around decentralized water facilities and identify essential pressure-penetration, sorptivity, leaching and crack-control tests before use in tanks, channels or treatment units.*

Keywords: *Recycled Aggregate Concrete; Water Absorption; Water*

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Infrastructure; Construction Waste; Mixing-Water Demand; Environmental Sustainability

Introduction

Concrete is widely used in community water infrastructure, including pump-house foundations, drainage works, access paths, valve chambers and water treatment facilities. The environmental consequences of these works extend beyond cement manufacture: extraction of virgin aggregate alters landscapes, demolition debris occupies disposal land, and water is consumed during aggregate washing, concrete mixing and curing. In the design of facilities that manage water, a material choice should therefore be evaluated against both the resource demand of construction and the moisture-related performance expected in service.

Recycled coarse aggregate recovered from demolished concrete can substitute for part of the natural aggregate, thereby keeping mineral resources in use. Its attached old mortar, however, creates a more porous composite particle than conventional crushed granite. Greater aggregate water uptake can interfere with workability and effective water-to-binder ratio, while pores at old- and new-paste interfaces may alter the water-accessible pore system in hardened concrete. These effects are well documented as recurring concerns in recycled aggregate research [1–3]. The mechanical behaviour of recycled aggregate concrete has also been reviewed extensively [4], and recent work combining laboratory testing with machine learning has examined how recycled-aggregate concrete performs across different strength regimes [5].

Marble processing and post-consumer glass generate two additional mineral waste streams. They join a wider group of industrial and agricultural by-products being evaluated as partial binder substitutes, including steel slag in paving-grade concrete [6] and agro-residue-derived pozzolans in low-carbon concrete [7]. Fine marble powder may contribute particle filling, whereas suitably ground soda–lime glass may supply reactive silica in a cementitious environment. Neither mechanism automatically guarantees low water permeability: replacement can dilute cement, recycled aggregate adds absorption capacity, and different test procedures characterise different aspects of transport. A 24-hour mass-absorption measurement identifies accessible water uptake under the reported laboratory procedure; it is not interchangeable with sorptivity, hydraulic conductivity, pressurised water penetration or leakage under sustained head [8]. For this reason, mechanical and

transport properties are best evaluated together when alternative aggregates or binders are introduced [9].

This distinction is particularly important for water and sanitation applications. Liquid-containing environmental structures are designed for stringent crack-control and liquid-tightness requirements, as illustrated by IS 3370 (Part 2):2021 [10] and ACI 350-20 [11]. Mechanical strength alone cannot establish suitability for a reservoir wall, tank base, wet well, sewer or treated-water chamber. Conversely, non-retaining ancillary components exposed only intermittently to rain or washing may permit a different combination of material performance and resource efficiency, subject to the governing exposure and design requirements.

The present paper therefore changes the *interpretive question*, not the measurements, of a completed laboratory study. It asks (i) how absorption responds across four reported combined RCA–MD–GD mixtures; (ii) what the reported mixing-water schedule implies about batch-water accounting; (iii) whether reduced cement and virgin aggregate quantities offer a measurable resource substitution; and (iv) what additional evidence would be required to apply the material in water-service infrastructure. No drinking-water-quality sampling, wastewater treatment test, field leakage measurement or verified life-cycle assessment was part of the source programme.

Materials and methods

2.1 Source programme and constituents

The source investigation used OPC 53-grade cement (reported specific gravity 3.04), Zone II natural river sand (2.60) and natural crushed-granite coarse aggregate (2.78). Demolition-derived coarse RCA was jaw-crushed, graded to a nominal 20 mm particle size, washed and reportedly brought to saturated surface-dry (SSD) condition before batching. The 24-hour aggregate absorption figures were 0.8% for natural coarse aggregate and 5.4% for RCA, a difference of 4.6 percentage points. The lower RCA specific gravity, 2.42, is consistent with residual adhered mortar. These values are reproduced from the source laboratory description; original instrument outputs and individual batch sheets were not supplied for independent inspection.

Marble dust originated from stone cutting, and recycled glass powder was produced by crushing and ball milling post-consumer clear glass. Both were described as

approximately 70 µm nominal size. The original chemical descriptions indicate predominantly carbonate-bearing marble powder and silica-rich soda–lime glass. As particle-size distributions, reactive silica tests, scanning electron microscopy and leachate chemistry were not provided, mineral filler and pozzolanic mechanisms are treated as plausible interpretations rather than verified findings.

Figure 1. Table 1. Selected reported constituent properties (transcribed from the original manuscript).

Constituent	Specific gravity	24-h water absorption	Role in mixture
OPC 53-grade	3.04	Not reported	Primary binder
Natural fine aggregate	2.60	0.6%	Sand skeleton
Natural coarse aggregate	2.78	0.8%	Conventional coarse fraction
Recycled coarse aggregate	2.42	5.4%	Demolition-derived coarse fraction
Marble dust	2.68	Not reported	Fine mineral replacement
Glass dust	2.51	Not reported	Fine mineral replacement

2.2 Mix design, water accounting and specimens

The source study assigned four mixture identifiers, M1–M4. Across the sequence, RCA replaced 0%, 20%, 40% and 60% of the coarse aggregate, while the combined MD–GD content replaced 0%, 10%, 15% and 20% of cement. Each non-zero replacement contained equal masses of MD and GD. Cement, fine aggregate and coarse aggregate were proportioned with reference to IS 10262:2019 [12] for a nominal M30 concrete. The experiment does not include an equal-RCA control without the powders, an equal-powder control without RCA, or a factorial design; therefore, separate effects of RCA, MD and GD cannot be inferred.

Figure 2. Table 2. Source mix quantities and directly calculated change in listed batch water. Masses are the source paper's stated quantities; changes are arithmetic, not measured water footprints.

Mix	RCA (%)	Cement (kg/m³)	MD+GD (kg/m³)	Listed water (L/m³)	Increase vs M1
M1	0	410.75	0.00	197.6	+0.0%

Mix	RCA (%)	Cement (kg/m³)	MD+GD (kg/m³)	Listed water (L/m³)	Increase vs M1
M2	20	369.68	41.08	207.2	+4.9%
M3	40	349.14	61.62	216.8	+9.7%
M4	60	328.60	82.16	226.4	+14.6%

The source formula for the nominal additional water allowance was $\Delta W = \alpha \times W_CA \times (WA_RCA - WA_NCA)/100$, where α is the RCA fraction, $W_CA = 1129$ kg/m³ and aggregate absorption values are 5.4% and 0.8%. This gives increasing listed water quantities of 197.6–226.4 L/m³. Crucially, the same source states that recycled particles were placed in SSD condition before mixing. Whether the additional quantities were supplied as free mixing water, prewetting water or bookkeeping corrections is not resolved in the available text. Hence it is inappropriate to treat the nominal water-to-binder ratio of 0.48 as verified and constant without original batch records and moisture corrections.

The source states that 150 mm cubes, 150 × 300 mm cylinders and 100 × 100 × 500 mm prisms were cast and water-cured at 27 ± 2°C. Compressive strengths were reported at 3, 7, 14 and 28 days, and splitting and flexural tests at 7 and 28 days. For absorption, the source describes drying specimens at 105°C to constant mass, immersing for 24 hours, surface-drying, and calculating $WA = 100 \times (M_s - M_d)/M_d$. The originally cited IS 2386 Part III principally addresses aggregates; the applicability of this method and any pass/fail threshold to the hardened concrete specimens must be checked against a suitably specified concrete test method.

2.3 Scope of reanalysis

The present work is an analytical reframing of the reported four-mix data rather than a new experimental campaign. Simple percentages and material-mass differences have been recomputed from the published summary tables. No additional specimens, pore-size measurements, field applications or simulated water-quality readings have been introduced. The comparison is descriptive because specimen-level variation, a full independent water balance and controls separating mixture variables are unavailable.

Results

3.1 Water uptake across the mixed replacement series

The primary result for a water-focused interpretation is that the reported 24-hour absorption rose continuously from 2.10% in M1 to 4.35%, 4.65% and 5.10% in M2–M4 (Table 3). The M4 value is 3.00 percentage points greater than M1, or 142.9% higher relative to the control. The large first step between M1 and M2 and smaller subsequent steps are descriptive features of these four combined formulations, not evidence of a unique transport mechanism. They may reflect competing contributions from recycled aggregate pores, binder dilution and powder-related filling; the experiment cannot quantify the individual shares.

In particular, a material may develop higher compressive strength yet retain more accessible pores capable of storing water. Absorption also depends on drying treatment, test duration, exposed area and specimen conditioning. A larger 24-hour uptake does not by itself quantify steady-state leakage under hydrostatic pressure, but it does identify a reason for caution when water contact or repeated wetting is central to performance. The original manuscript's statement that all mixtures meet a universal 5.5% IS 2386 concrete-absorption limit is not retained because that acceptance rule has not been established for the tested concrete.

Figure 3. Table 3. Reported hardened-concrete results used to assess the strength–water-uptake trade-off.

Mix	RCA (%)	MD+GD (%)	28-d strength (MPa)	28-d flexure (MPa)	24-h absorption (%)
M1	0	0	28.43	4.15	2.10
M2	20	10	30.10	4.55	4.35
M3	40	15	32.85	5.30	4.65
M4	60	20	35.40	6.25	5.10

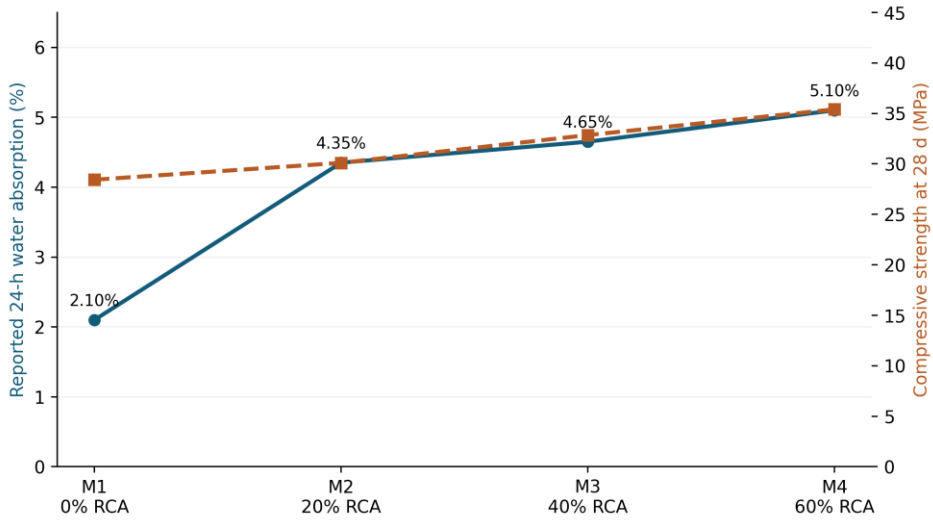


Figure 1. Water absorption and 28-day compressive strength of the four combined RCA–MD–GD formulations (source data; dual axes have different units).

3.2 Mechanical capacity as a parallel performance criterion

At 28 days, compressive strength rose from 28.43 MPa in M1 to 30.10, 32.85 and 35.40 MPa in M2–M4. The maximum measured value is 24.5% above the control. Reported 28-day splitting tensile strengths were 3.05, 3.32, 3.95 and 4.75 MPa; flexural strengths were 4.15, 4.55, 5.30 and 6.25 MPa. These increases imply that high absorption is not necessarily accompanied by lower strength in this particular combined formulation series. They do not prove improved resistance to cracking under restrained drying or improved liquid tightness.

The M30 designation is a nominal mix-design target. Its control mean of 28.43 MPa is below 30 MPa in the summary table, so blanket statements that every mixture meets M30 requirements are unwarranted without the appropriate characteristic-strength assessment and relevant acceptance sampling. The replacement sequence also changes both the supplementary fine powders and the recycled coarse fraction together. Mechanistic statements about the glass causing the strength gain remain hypotheses until an independent mixture design and hydration characterization isolate the contribution.

3.3 Material substitution and water demand

The reported cement content falls from 410.75 to 328.60 kg/m³ between M1 and M4, a nominal reduction of 82.15 kg/m³ or 20%. M4 also incorporates approximately

677 kg/m³ of recycled coarse aggregate according to the original table. These are direct material-substitution measures, not carbon savings. Emission benefits would require verified binder production data, glass milling energy, marble processing, recycled-aggregate washing, haulage distances and functional equivalence over the infrastructure service life.

The listed mixing-water quantity increases by 9.6, 19.2 and 28.8 L/m³ for M2, M3 and M4 relative to M1. The M4 rise is 14.6%. Such an increase is relevant wherever construction water supply is constrained, but water actually consumed cannot be read from these quantities alone: prewetting water, returns from washing, curing-water reuse and actual effective mixing water are not reported. Equally, drinking-water substitution or reclaimed wastewater utilization is not part of this experiment.

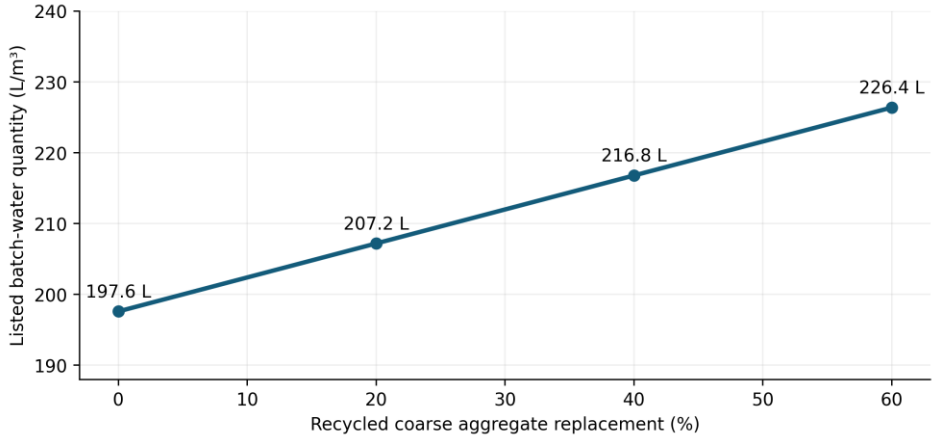


Figure 2. Listed batch-water quantities plotted against RCA replacement. These values do not constitute a life-cycle water footprint.

Interpretation for water and environmental engineering

4.1 Appropriate distinction between ancillary and liquid-retaining applications

The most defensible practice implication concerns screening of low- or moderate-consequence components around small water systems: paving around pumping stations, equipment foundations outside the wetted zone, inspection-area slabs and other non-retaining civil works. For these uses, designers can weigh reduced virgin-mineral demand against the observed increased absorption, strength performance, drainage, exposure class and maintenance needs. Multi-objective formulations that couple mechanical strength with permeability [13], and subjective–objective

weighting schemes for sustainable material selection [14], offer structured ways to make this trade-off explicit rather than ranking mixtures by strength alone. The data cannot establish readiness for potable-water tanks, wastewater basins, open channels, submerged conduits or linings that must resist persistent hydraulic gradients.

Watertight concrete is a system-level outcome rather than a cube-strength outcome. Crack width, joints, reinforcement, curing and construction quality can govern leakage even when the uncracked paste is relatively dense. IS 3370 (Part 2):2021 [10] and ACI 350-20 [11] are relevant frameworks for checking liquid-retaining environmental concrete structures. Their existence should not be interpreted as a certification that the mixtures reported here comply with their requirements.

4.2 Environmental risks requiring examination

The use of recycled waste can shift impacts rather than remove them. Demolition material should be screened for contaminants and variable source quality. Recycled glass may contain alkalis, making alkali–silica reaction evaluation relevant; any proposed direct contact with potable water would also require independent migration and leaching tests against applicable drinking-water material requirements. Neither safe contact with drinking water nor chemical resistance to wastewater has been examined in the source study. The 24-hour water-absorption measurements cannot substitute for such assessments.

Where recycled aggregate is washed, environmental performance also depends on sourcing and treatment of wash water and management of fines. Crushing and milling require energy. A future cradle-to-gate inventory should tabulate water withdrawals, non-potable reuse, wastewater from processing, energy inputs and the transport of each waste-derived component. This is particularly important when considering communities with seasonal water scarcity or decentralized supply arrangements.

4.3 Measurements needed for water-service qualification

A direct extension should examine sorptivity, water penetration under pressure, accessible porosity, bulk electrical resistivity, chloride ingress where relevant, wetting–drying cycles, restrained-shrinkage cracking, and leakage in representative reinforced wall or slab panels. To distinguish waste-powder effects from the RCA effect, a factorial matrix should include fixed RCA percentages with multiple MD–GD dosages and matched effective water-to-binder ratios. Replicate data, confidence

intervals and the exact absorption test standard should be provided. For contact with treated or potable water, leachate and microbiological compatibility evaluations would be separately necessary.

Data-driven modelling: limited supporting evidence

The source manuscript also reports a seven-input, five-output artificial neural network with a 7–14–10–14–5 topology, trained using a stated 180-observation compilation from the experiment and external publications. Its reported held-out R^2 values include approximately 0.984 for compressive strength and 0.980 for flexural strength. This information has been retained as a contextual modelling claim rather than independently verified evidence. The external row-level observations, harmonisation rules, specimen grouping and code are not supplied. Consequently the model cannot legitimately be used here to predict hydraulic permeability, leaching, leakage or safe service life, none of which was a training output. Machine-learning prediction has also been applied to recycled-aggregate concrete [5] and to low-carbon concrete containing agro-residue pozzolans [7]; in each case, transferability depends on transparent data provenance and validation grouped by data source.

Model interpretation through SHAP in the source is similarly restricted to predictive association. RCA level and MD–GD dosages change together across the local experimental matrix, so importance rankings cannot be read as causal estimates of how one component independently changes water absorption. A model developed specifically for water infrastructure would require verified transport and cracking targets, source-based train/test separation and calibration on field-exposure conditions.

Limitations and reproducibility

Four combined mix formulations provide useful screening observations but not a full response surface. The original source lacks an equal-RCA reference with no mineral-powder substitution, direct permeability or sorptivity testing, water-contact chemistry and field monitoring. It also reports SSD conditioning while adding aggregate-absorption water allowances, so the actual water ledger and effective water-to-binder ratios must be resolved from laboratory notebooks. Without raw replicate masses and failure loads, this rewrite cannot independently validate

reported precision or calculate standard errors. None of these limitations can be overcome by changing the study title or by post hoc numerical estimation.

Conclusions

• In the tested combined replacement series, reported 24-hour absorption increased from 2.10% to 5.10% as RCA increased from 0% to 60% alongside 0–20% combined marble–glass cement substitution; increased strength did not imply decreased water uptake.
• Reported 28-day compressive strength rose from 28.43 to 35.40 MPa, while M4 had the greatest measured absorption. Hence mixture selection for moisture-exposed applications requires a multi-criterion rather than strength-only assessment.
• The tabulated cement reduction of 82.15 kg/m³ and recycled mineral inputs represent demonstrable material substitution, but the net carbon footprint and process-water footprint remain unknown.
• The listed batch-water quantity increased from 197.6 to 226.4 L/m³; SSD conditioning and water adjustments require reconciliation before claiming a constant effective water-to-binder ratio or a measured water-consumption benefit.
• These observations may inform preliminary material screening for ancillary construction around decentralized water facilities. They do not qualify the concrete for potable-water contact, wastewater containment or liquid-retaining structural service without further testing.

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