Moisture-driven shrinkage and long-term creep in recycled aggregate concrete: crack-control implications for community water infrastructure

Naveena M.P, Arjun P , Dharmesh N, Beerendra Kumar

Abstract: *Decentralized water and sanitation facilities rely on durable concrete for support slabs, chambers and retaining elements, yet moisture-driven dimensional change can introduce cracking that compromises serviceability. An existing M30 recycled aggregate concrete programme was re-examined to interpret the effects of recycled coarse aggregate (RCA) on 180-day drying shrinkage, sustained-load creep and water-demand accounting. Replacement levels were 0%, 25%, 50% and 100%, with natural and recycled coarse aggregates reported to absorb 1.1% and 5.2% water in 24 hours, respectively. At 180 days, creep increased from 850 microstrain in the control to 980, 1120 and 1320 microstrain, while drying shrinkage rose from 480 to 560, 690 and 840 microstrain. These correspond to maximum increases of 55.3% and 75.0%, respectively. Twenty-eight-day compressive strength decreased from 38.8 to 30.4 MPa. Listed batch-water quantities increased from 186.0 to 232.2 L/m³ at full RCA replacement, but the source's simultaneous claim of saturated surface-dry aggregate conditioning creates uncertainty about effective mixing-water demand. Increased shrinkage is pertinent to restraint-induced crack risk, although crack widths, permeability and leakage were not measured. The paper proposes a conservative material-screening framework that separates low-risk ancillary components from liquid-retaining construction and specifies the measurements needed for water infrastructure qualification. Existing machine-learning and empirical creep-model claims are reported as preliminary because the full modelling dataset is unavailable and one stated empirical equation does not reproduce its tabulated end-point.*

Keywords: *Rural Water Distribution, Gravity-Fed Systems, Pump-Driven*

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Drying Shrinkage; Recycled Aggregates; Water Infrastructure; Moisture Transport; Sustained-Load Creep; Crack Control

Introduction

Concrete in water and sanitation infrastructure is valued not only for compressive resistance but also for its ability to maintain serviceability under moisture changes, temperature variation and long-term loading. Slabs, valve chambers, support structures, collection tanks and treatment basins may experience alternating wet and dry periods, while stored-water pressures and restrained shrinkage can turn small cracks into pathways for unwanted leakage or ingress. For these applications, long-term dimensional stability is a relevant component of environmental-engineering design, distinct from the strength of the concrete in a short-duration compression test.

Recycled aggregate concrete (RAC) can reduce dependence on quarried mineral aggregates and divert clean demolition rubble into new infrastructure [1, 2]. However, recycled coarse aggregate (RCA) contains adhered mortar, which is less dense and generally more absorptive than intact natural stone [1, 3]. Recent work combining experiments and machine learning has examined recycled-aggregate concrete across different strength regimes [4], but strength is only one dimension of its long-term behaviour. The added mortar phase can affect both the exchange of water with the surrounding air and the transfer of stress through the composite. Shrinkage responds to drying and internal capillary processes; creep is time-dependent strain under sustained loading after correcting for shrinkage and initial elastic deformation [5–7]. At the structural scale, these time-dependent strains accumulate as axial shortening of vertical members, an effect that has been examined together with flexural rigidity through nonlinear finite-element analysis of RC buildings [8].

The difficulty for water-service practice is that higher moisture sensitivity may influence crack initiation, yet shrinkage alone cannot predict crack width. Restrained deformation depends on reinforcement, member geometry, restraint, curing, elastic modulus, relaxation and environmental gradients. Liquid-retaining concrete also requires explicit pressure and leakage checks; IS 3370 (Part 2):2021 [9] and ACI 350-20 [10] provide relevant design frameworks for such structures. Accordingly, increased shrinkage should be treated as an informative warning, not a measured leakage rate.

The present reanalysis has a focused question: how do 0–100% RCA substitutions alter aggregate absorption, the reported batch-water ledger, 180-day creep, drying shrinkage and strength, and what do the resulting trade-offs imply for preliminary material selection in community-scale water facilities? The laboratory observations are used as measured material indicators; recommendations for water-system applications are explicitly conditional because neither field performance nor liquid-tightness was part of the original tests.

Materials and methods

2.1 Aggregates and mixing programme

Four M30 mixtures were described in the source: NAC (no RCA), RAC-25, RAC-50 and RAC-100. OPC 43-grade cement had a reported specific gravity of 3.08. The fine aggregate was Zone II natural river sand with fineness modulus 2.72, specific gravity 2.61 and absorption 1.1%. Natural coarse aggregate was crushed granite, nominal maximum size 20 mm, with specific gravity 2.76 and 24-hour absorption 1.1%. Crushed and washed demolition-derived RCA had specific gravity 2.54 and absorption 5.2%. The difference of 4.1 percentage points in aggregate absorption underpins the source's water correction formula.

The source reports 413 kg/m³ cement, 655 kg/m³ sand and 1128 kg/m³ total coarse aggregate, with RCA substituting natural coarse aggregate on an equal-mass basis. Nominal water-to-cement ratio was reported as 0.45. The source tabulates added-water adjustments proportional to RCA content, yet also says RCA was soaked and brought to saturated surface-dry condition; this affects interpretation. Total listed water divided by listed cement mass varies across the mixes, so a constant *effective* ratio should not be assumed without the original moisture ledger.

Figure 1. Table 1. Aggregate substitution and source-reported batch-water quantities (fine aggregate 655 kg/m³; cement 413 kg/m³ for all mixes).

Mix	RCA (%)	Natural CA (kg/m³)	RCA (kg/m³)	Listed water (L/m³)	Rise vs NAC
NAC	0	1128	0	186.0	+0.0%
RAC-25	25	846	282	197.6	+6.2%
RAC-50	50	564	564	209.2	+12.5%

Mix	RCA (%)	Natural CA (kg/m³)	RCA (kg/m³)	Listed water (L/m³)	Rise vs NAC
RAC-100	100	0	1128	232.2	+24.8%

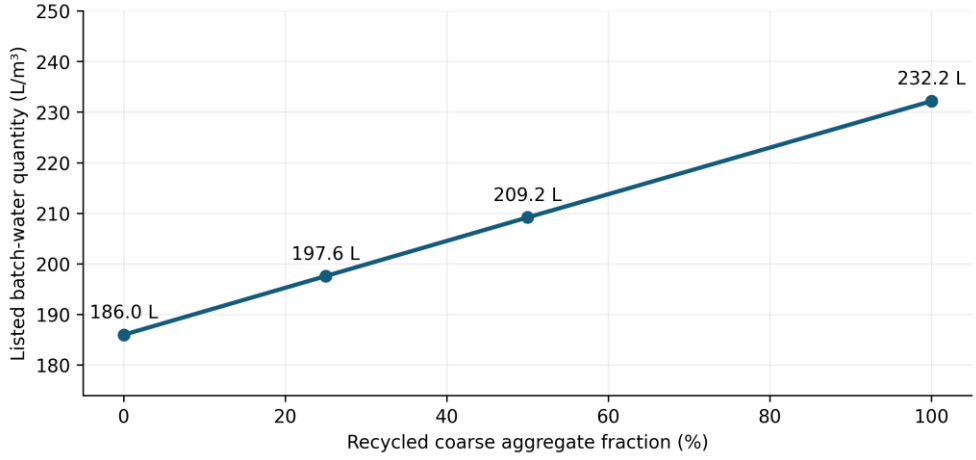


Figure 1. Listed batch water increases with RCA replacement; the actual absorbed versus free-water fractions require laboratory confirmation.

2.2 Test programme and environmental conditions

The source states that 150 mm cubes were water-cured and tested in compression at 3, 7, 14 and 28 days. For creep, three 150 × 300 mm cylinders per mix were subjected to sustained compression at 40% of each mix's 28-day compressive strength using spring-loaded rigs. Readings were reported at 1, 3, 7, 14, 28, 56, 90, 120, 150 and 180 days. Companion unloaded cylinders were maintained at 23 ± 2°C and 65 ± 5% relative humidity; creep strain was calculated by subtracting initial elastic strain and the companion shrinkage response from the total measured strain.

Unloaded companion cylinders were reportedly monitored for drying shrinkage during 180 days after 28-day water curing. The resulting time series in the source tables are retained without numerical alteration. Cylindrical specimens and the stated drying procedure may not be identical to the standard prism-based shrinkage method; the original laboratory protocol, gauge placement, length reference and exact standard must be verified by the authors. Temperature, humidity and sustained stress influence reported deformation, so the observed values should not be transferred directly to an alternative climate or loading programme.

2.3 Reanalysis strategy and limits

This paper compares reported mean measurements by RCA level and time, recomputes percentages directly from the source tables, and relates the trends to moisture-sensitive serviceability. It does not reconstruct missing raw data, manufacture statistical replicates or claim that water leakage, permeability, field climate, crack width or carbon emissions were experimentally assessed. The source reports three specimens per mix for the principal tests, but underlying specimen-level values and independently reproduced uncertainties are not available here.

Results

3.1 Mechanical performance at 28 days

The source gives 28-day compressive strengths of 38.8, 36.5, 34.2 and 30.4 MPa for NAC, RAC-25, RAC-50 and RAC-100, respectively. The fall at full replacement is 21.6%. The fact that the mixes were labelled M30 does not itself establish code conformity across applications; an appropriate acceptance check must use the governing sampling and characteristic-strength procedure. More importantly, satisfactory short-term strength cannot establish a serviceability margin against crack formation caused by restraint and drying.

3.2 Creep strain under sustained compression

The reported creep strain at 180 days rose monotonically from 850 microstrain in NAC to 980 in RAC-25, 1120 in RAC-50 and 1320 in RAC-100. Relative to the natural-aggregate reference, the increases are 15.3%, 31.8% and 55.3%. The source also lists corresponding creep coefficients of 2.14, 2.47, 2.83 and 3.32. The progressive increase is consistent with added old-mortar volume and increased compliance of the recycled composite, although no separate measurement of the adhered-mortar fraction or full pore network was supplied.

Figure 2. Table 2. Original reported creep-strain time series in microstrain, under sustained compression; values reproduced without adjustment.

Mix	7 d	14 d	28 d	56 d	90 d	120 d	150 d	180 d
NAC	180	340	520	670	760	810	835	850
RAC-25	210	390	600	770	880	935	960	980
RAC-50	240	450	680	880	1010	1075	1100	1120

Mix	7 d	14 d	28 d	56 d	90 d	120 d	150 d	180 d
RAC-100	290	540	830	1070	1220	1290	1310	1320

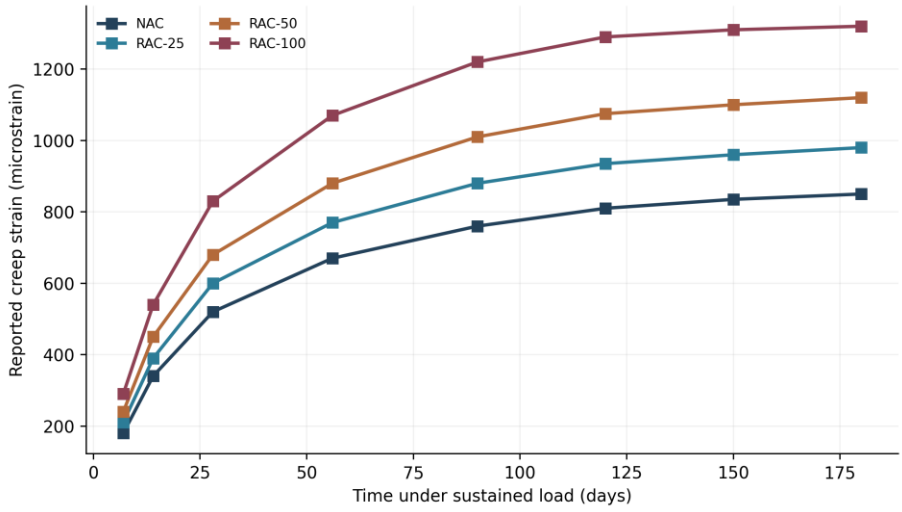


Figure 3. Reported 180-day time-dependent creep development by RCA replacement level.

Most of the recorded deformation occurs during the early part of the 180-day observation window, followed by a slowing rate of accumulation. This temporal shape is compatible with common creep evolution, but the source does not provide continuous moisture measurements or internal relative-humidity profiles. It would be speculative to attribute a particular fraction of creep to moisture redistribution, pore structure or microcracking. Longer monitoring and direct strain-gauge validation would be needed before using these curves to determine an ultimate creep coefficient for design.

3.3 Drying shrinkage and moisture-sensitive stability

Drying shrinkage rose from 480 microstrain in NAC at 180 days to 560, 690 and 840 microstrain in RAC-25, RAC-50 and RAC-100. The increments relative to the control are 16.7%, 43.8% and 75.0%. In each replacement case, the relative shrinkage increase was larger than the relative creep increase. This pattern highlights the particular importance of moisture-linked dimensional stability when selecting mixtures with higher amounts of adhered mortar. It should not, however, be converted into a predicted crack width without restraint and member-level testing.

Figure 4. Table 3. Original reported drying-shrinkage time series in microstrain; storage condition described as 23 ± 2°C and 65 ± 5% RH.

Mix	7 d	14 d	28 d	56 d	90 d	120 d	150 d	180 d
NAC	95	180	290	380	435	460	472	480
RAC-25	112	215	335	440	510	535	550	560
RAC-50	138	260	415	545	635	665	680	690
RAC-100	168	320	510	665	780	815	832	840

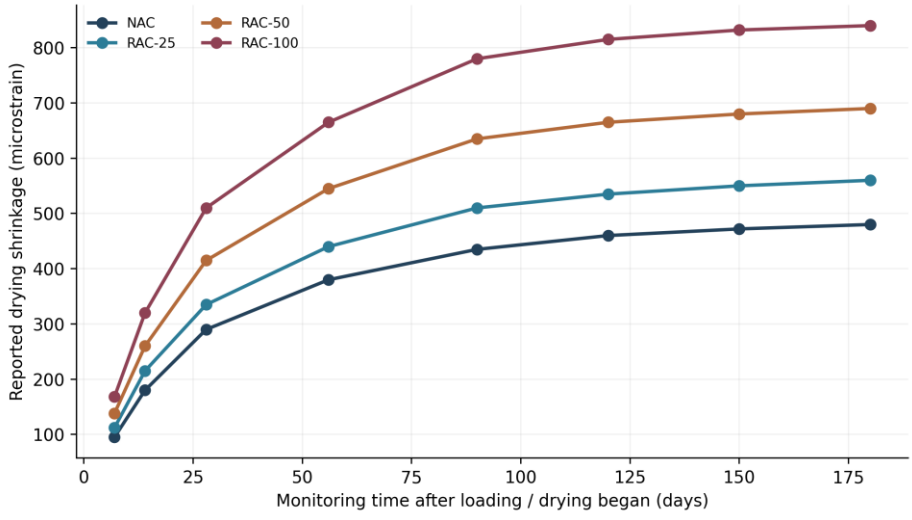


Figure 3. Reported drying-shrinkage evolution with RCA level over 180 days.

At 28 days of monitoring, the shrinkage values were 290, 335, 415 and 510 microstrain, representing 60.4%, 59.8%, 60.1% and 60.7% of their respective 180-day end points. Thus approximately three-fifths of the final recorded shrinkage had accumulated by the first 28 days under the reported exposure. This result motivates explicit early-age curing and restraint-control planning, especially for thin sections. Internal-curing approaches, such as polyethylene-glycol-based self-curing concrete [11], are one possible means of addressing this early-age window, although their effect on RCA shrinkage was not tested in the source programme. The precise distribution of cracking risk requires a separate test on restrained specimens.

3.4 Cross-property summary and resource trade-off

Figure 5. Table 4. Parallel mechanical and time-dependent properties from the original programme.

Mix	RCA (%)	28-d strength (MPa)	180-d creep (με)	180-d shrinkage (με)	Creep coefficient
NAC	0	38.8	850	480	2.14
RAC-25	25	36.5	980	560	2.47
RAC-50	50	34.2	1120	690	2.83
RAC-100	100	30.4	1320	840	3.32

RAC-25 incurs a relatively small absolute reduction in compressive strength in the source, while both 180-day creep and shrinkage rise by about one-sixth. RAC-50 produces a larger shrinkage penalty, and full replacement produces the highest deformation in both modes. There is no single universal optimum without assigning a service environment, structural role and acceptable cracking criterion. Furthermore, the listed batch-water increase reaches 46.2 L/m³ at 100% RCA, or 24.8% above NAC; this should be viewed as a water-accounting issue requiring validation, not as a measured saving or depletion of a local water resource.

Implications for water supply, sanitation and environmental works

4.1 Moisture deformation as an early material-screening criterion

For non-liquid-retaining components such as support pads, access surfaces and external foundations around pumps or decentralized treatment plants, designers may consider recycled aggregate when appropriate strengths and durability are demonstrated. The 180-day creep and shrinkage curves provide a basis for identifying mixtures that warrant additional serviceability checks. For components whose function depends on resistance to leakage, however, the reported material strains are insufficient on their own. Joint detailing, membrane systems, structural restraint and crack-control reinforcement often govern performance more directly than mean free shrinkage.

Repeated wetting and drying in drainage and sanitation facilities might alter deformation relative to the constant 65% RH laboratory condition; the study does not establish the magnitude or direction of that change. For buried or continuously submerged members, lower external drying may reduce the relevance of the measured shrinkage exposure, while chemical attack, groundwater contamination

and reinforcement corrosion introduce other concerns. Application should therefore be conditional on the real exposure regime rather than an assumed direct relationship between 180-day laboratory shrinkage and in-service leakage.

4.2 Material circularity and construction water

The largest material-circularity benefit demonstrated directly by this dataset is substitution of virgin coarse aggregate, up to the listed 1128 kg/m³ at full replacement. Because cement mass remains at 413 kg/m³ in all mixes, a large cement-related carbon reduction cannot be asserted from the mix table alone. Any life-cycle estimate must consider acquisition and transport of demolition debris, crushing, grading, washing, added water and the anticipated structural service life. If an RCA mixture needs more water, pumping or treatment during production, those burdens should be represented in both water-footprint and life-cycle analyses.

For small community infrastructure, reliable supply of batching water and the possibility of water recycling may affect the feasibility of local recycling schemes. Future work could quantify water withdrawn for washing, the fraction recycled, final wash-water quality, water used for curing and the effective absorbed water in RCA. The current dataset contains none of those field values. Accordingly, an environmental-engineering conclusion should be limited to resource substitution potential and the need for a measured water balance.

4.3 Priorities for water-retaining applications

A valid water-retaining concrete qualification campaign should include restrained ring or slab shrinkage tests, crack width under representative restraint, flexural behavior of reinforced panels, water penetration under hydraulic pressure, permeability or sorptivity evaluated alongside mechanical properties [12], and direct leakage testing of representative joints. Where some cracking cannot be avoided, autonomous crack-healing strategies such as microbially induced calcite precipitation [13] may merit evaluation as a secondary leakage-mitigation measure. Appropriate exposure-based chemical and reinforcement durability testing should be added for wastewater or chlorinated-water service. These are proposed future tests, not activities already completed in the source programme. Design checks should follow the applicable version of IS 3370 [9] and other relevant standards before implementation.

Predictive modelling and verification limitations

The source manuscript reports a multi-output ANN with an 8–12–8–3 architecture trained on a stated 160-record compilation, with test R^2 values of 0.981 for strength, 0.977 for creep and 0.975 for shrinkage. It also describes comparisons with Random Forest, XGBoost and support vector regression, together with SHAP feature attribution. Because the specimen-level database, mapping to original literature and model code are not provided, these performance values cannot be independently reproduced in this rewrite. A future model used for water-service decisions should have grouped validation by source study, uncertainty intervals and transport/crack-related output measurements.

A specific inconsistency must be corrected before submitting the empirical-model component. The source proposes a creep coefficient $\varphi = 2.14 \times [1 + 0.00124 \times \alpha\text{^}1.07]$, where α is stated as RCA percentage. At $\alpha = 100$ the expression gives approximately 2.51, whereas the source reports 3.32 for RAC-100. This is a material discrepancy, not a rounding difference. The fitted relation is therefore not presented as validated or recommended for codal adoption; it needs recalculation with the correct variable definition, source data and model coefficients, followed by benchmarking against established prediction frameworks such as ACI 209R-92 [14]. Other limitations concern the short four-level experimental design, the potential role of aggregate batch variability, the laboratory's fixed temperature and humidity, lack of raw specimen observations, and the absence of actual leakage or permeation testing. These constraints mean the results demonstrate deformation sensitivity to RCA content within one materials programme; they do not justify general limits for all water-storage concrete or changes to national design standards.

Conclusions

• Relative to the natural aggregate control, complete RCA substitution increased the reported 180-day creep strain by 55.3% and drying shrinkage by 75.0%, whereas compressive strength declined by about 21.7%.
• The 25% and 50% RCA mixtures represent progressively larger trade-offs between virgin-aggregate substitution and moisture-sensitive deformation; the appropriate choice depends on the intended exposure and serviceability criteria.
• Under the reported drying exposure, approximately 60% of the 180-day shrinkage developed during the first 28 days of monitoring, reinforcing the importance of early restraint and curing assessments.

• The tabulated water additions increased by as much as 46.2 L/m³, but actual construction-water consumption and effective water-to-cement ratios cannot be established until the SSD/prewetting accounting is reconciled.
• Neither the deformation curves nor the reported machine-learning scores constitute proof of liquid tightness. Water infrastructure adoption requires direct penetration, leakage, reinforced-cracking and durability testing.
• The originally proposed creep coefficient equation is numerically inconsistent with the tabulated full-RCA coefficient and must be corrected and independently validated before design use.

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