STRENGTH AND DEFORMATION OF EXPANSIVE CONCRETE WITH RECYCLED AGGREGATES: A CONCISE REVIEW OF FREE VS RESTRAINED CONDITIONS

Hao Min[1]

[1]аспирантура, Brest State Technical University,

Brest,Belarus,hao20min24@163.com, +375257236527

Abstract: Recycled concrete aggregates (RCA) introduce adhered mortar and higher porosity that typically lower elastic modulus and intensify strain capacity relative to natural-aggregate concrete. This short review collates axial compression evidence for expansive concretes proportioned with RCA and contrasts free versus restrained conditions in terms of compressive strength, peak strain, and initial elastic modulus. To improve cross-study comparability, a normalized stress–strain presentation is recommeded: σ/σpeak versus ε/εpeak, with the initial slope reported as E (window specified). The synthesis shows that free expansion tends to increase εpeak while reducing E, whereas mechanical restraint (e.g., cages or thin sleeves) generally elevates nominal stiffness and σpeak and shifts εpeak downward. The proposed reporting scheme supports clearer test documentation and design-oriented comparison across mixes, restraint types, and curing protocols.

Keywords: recycled aggregate; expansive concrete; restrained expansion; stress–strain curve; elastic modulus

INTRODUCTION

The reuse of construction and demolition waste as recycled concrete aggregates (RCA) has progressed from pilot applications to regular structural practice in many regions. Compared with natural aggregates, RCA carry old adhered mortar and microcracking, which typically weakens the interfacial transition zone (ITZ), reduces elastic modulus, and increases peak compressive strain under uniaxial loading. Stress–strain data from controlled tests consistently indicate a downward shift in stiffness and an upward shift in εpeak as RCA replacement increases, with strength reductions varying by parent-concrete quality and mix design [1].

Expansive systems (e.g., MgO- or CSA-based) are routinely adopted to counteract shrinkage and to redistribute internal stress, but their action is strongly dependent on restraint during and after expansion. Design guides for shrinkage-compensating concretes emphasize that the development of beneficial precompression and crack control requires both adequate expansion potential and an appropriate level of structural or mechanical restraint; mixture proportioning, curing, and detailing are specified to balance these effects [2].

This concise review focuses on the material-level axial response of expansive concretes incorporating RCA. We synthesize representative studies that report full stress–strain curves or sufficient data to extract the initial elastic modulus, peak stress, and corresponding strains under free versus mechanically restrained conditions (e.g., tie cages, thin steel/FRP sleeves, or low-stiffness jackets). Serviceability code checks (deflection/crack limits) are outside the present scope. Our contributions are threefold: (1) a succinct comparison of free versus restrained behavior for strength, εpeak, and initial modulus; (2) a normalized plotting convention, σ/σpeak – ε/εpeak, with a clearly stated modulus window to improve cross-study comparability; and (3) a set of minimal reporting items (specimen size, end friction treatment, loading rate, and curing) to reduce ambiguity in future publications. Together, these elements provide a practical baseline for laboratories and designers to align material tests and interpret restraint effects in expansive RCA systems.

MATERIALS AND METHODS

1.Overview of Recycled Concrete Aggregates

1.1 Composition and provenance

RCA consist of natural aggregate particles partially enveloped by old cement mortar. The quality of the parent concrete (strength class, exposure history) governs the amount and integrity of adhered mortar and the extent of microcracking generated during demolition and crushing. Higher adhered-mortar content generally implies greater porosity and weaker local stiffness around the ITZ, which can alter composite behavior when RCA are introduced at moderate or high replacement levels [3].

1.2 Geometry and physical indices

Key descriptors include grading, shape (e.g., flakiness/elongation), water absorption, bulk and oven-dry densities, and packed density. Relative to natural aggregates, RCA usually exhibit higher water absorption and lower apparent/bulk densities due to the porous adhered mortar. These attributes influence mixture water demand, entrapped air, and the effective paste-to-aggregate volume ratio, with downstream effects on fresh properties and stiffness development. Long-term datasets further show that while supplementary cementitious materials can mitigate permeability and partially recover stiffness, mixes with 100% RCA typically retain lower modulus than controls even after extended curing, underscoring the persistent role of aggregate porosity and ITZ features [4] .

1.3 Basic mechanical indices and implications for E and εpeak

Crushing and Los Angeles abrasion indices tend to be less favorable for RCA than for natural aggregates; in concrete, this translates to a gentler initial slope in the stress–strain response and a shift of ε_peak to larger values as replacement increases, particularly under uniaxial compression. The combined effects of higher porosity, weaker ITZ, and residual microcracks explain the typical pattern observed in expansive RCA concretes: free (unrestrained) specimens show higher strain capacity but lower initial modulus, whereas mechanically restrained configurations leverage confinement to raise nominal stiffness and strength at the expense of peak strain, motivating the free versus restrained comparison developed in the subsequent sections [1,3,4].

2. Mix Design for Expansive Systems and Testing Protocol (text-only)

2.1 Proportioning and expansive systems

Expansive concretes with RCA generally use either MgO-based expansive agents (MEA) or calcium-sulfoaluminate (CSA) components to offset shrinkage while redistributing internal stress. For MEA, the effective dosage depends on reactivity grade (calcination temperature and fineness) and curing; higher early humidity/temperature accelerates periclase hydration and increases early expansion. For CSA systems, ye’elimite content and sulfate balance govern ettringite formation and the timing of expansion. In both cases, the mixture report should state: RCA replacement by mass of coarse aggregate, expansive component dosage by binder mass, water-to-binder ratio, and the curing temperature/humidity window. When curing and restraint are coordinated at design, controlled expansion can mitigate stiffness loss; poorly balanced curing or overdosing can reduce strength and elastic modulus [5].

2.2 Unified metrics and measurement windows

Compressive strength f_c must be tied to specimen geometry (cylinder or cube) and any conversion noted. The initial elastic modulus E is obtained from the early linear/chord portion of the axial stress–strain record; the chosen window should be stated explicitly (e.g., 0–40% of ultimate stress) and derived using the instrumentation and calculation procedures of ASTM C469/C469M, including gage length, sensor type (LVDTs/extensometers), and data acquisition rate. The peak strain ε_{peak} is the axial strain at maximum compressive stress; the crushing strain ε_{cu} should be defined by a reproducible criterion (e.g., residual stress threshold or fixed post-peak offset). Free expansion ε_{free} is measured on prisms or ring-free specimens under minimal restraint, with the measurement start age and environmental history recorded to enable comparison across studies [6].

2.3 Specimens and loading setups

Three canonical cylindrical configurations are recommended for axial compression: (i) free, with no deliberate lateral restraint; (ii) weak restraint, using a thin plastic or FRP sleeve that provides low lateral stiffness and permits hoop-strain pickup on the jacket; and (iii) medium–strong restraint, implemented either by a tie-cage with stated volumetric reinforcement and stirrup spacing or by a thin steel sleeve with thickness and D/t reported. For all configurations, document diameter and height (including H/D), end preparation (ground or capped with low-friction sheets), platen friction mitigation, loading rate (MPa/s or strain-rate), and the placement of axial and, where applicable, hoop strain measurements[5–6].

RESULTS

3. Strength, deformation, stiffness comparison

3.1 Free condition

Under free (unrestrained) curing and testing, expansive RCA mixes typically develop a larger free expansion ε_{free} and show a gentler initial slope in the axial stress–strain record. The peak strain ε_{peak} shifts to higher values relative to non-expansive controls, reflecting microcrack accommodation and a larger inelastic domain; in parallel, the initial elastic modulus E commonly decreases because the adhered mortar and higher porosity in RCA dominate the early chord segment of the curve. This combination produces higher deformability but a lower nominal stiffness in the initial loading range.

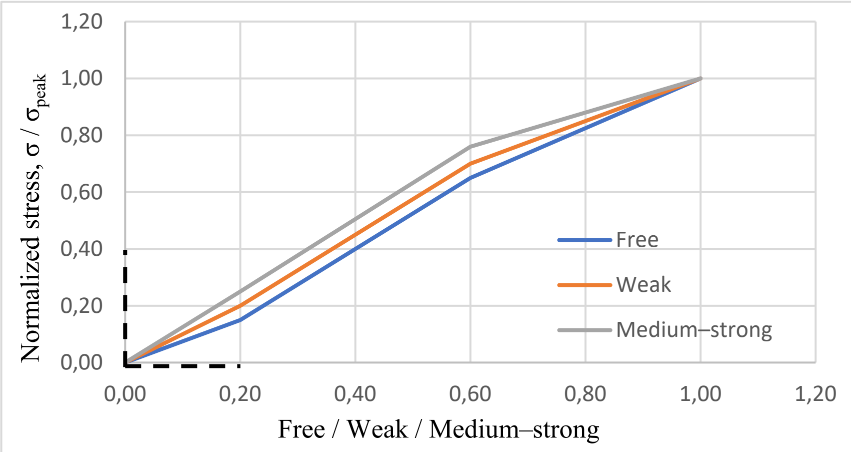
3.2 Restrained condition

When mechanical restraint is introduced, by a thin plastic/FRP sleeve (weak restraint) or by a tie cage/thin steel sleeve (medium–strong restraint), the lateral dilation is limited and part of the expansive tendency is converted into compressive stress. As restraint increases, the nominal modulus E and the peak stress σ_{peak} tend to increase, while ε_{peak} shifts downward relative to the free case. Failure patterns evolve from crack-dominated responses toward crushing with confinement interaction as the restraint stiffens. The same trend underlies standard restrained-expansion practice for shrinkage-compensating concretes, where higher restraint systematically suppresses free expansion and modifies subsequent mechanical response [7]. For interpreting the confined curves and presenting comparable data across setups, it is useful to adopt the established confined-concrete curve organization that emphasizes normalized stress, normalized strain, and the identification of the initial modulus segment [8].

3.3 Unified presentation

To make cross-study overlays unambiguous, plot normalized stress–strain with ordinate σ/σ_{peak} and abscissa $\varepsilon/\varepsilon_{peak}$. Mark the initial modulus window explicitly (e.g., 0–40% of ultimate stress), and report specimen geometry, loading rate, end treatment/friction mitigation, and curing history alongside each curve. In the same figure, overlay three representative curves, free, weak restraint, and medium–strong restraint, so that the increase in initial slope and σ_{peak}, and the downward shift of ε_{peak} with restraint, are visible at a glance [7,8].

Figure 1. Normalized axial stress–strain for expansive RCA under free, weak restraint, and medium–strong restraint. The E evaluation window (0–40% of σu) is



indicated.

Data note: Schematic normalized overlays (σ/σpeak vs. ε/εpeak); E taken in the 0–40% σu window per ASTM C469/C469M; trends with restraint reflect the literature [6–8].

CONCLUSION

This concise review clarifies the axial response of expansive recycled-aggregate concrete under free and mechanically restrained conditions. In the free case, mixes develop larger ε_{free}, a gentler initial slope, and an upward shift of ε_{peak}; the initial elastic modulus E commonly decreases, yielding greater deformability at lower nominal stiffness. Introducing restraint, ranging from thin plastic/FRP sleeves (weak) to tie cages or thin steel sleeves (medium–strong), suppresses lateral dilation, raises E and σ_{peak}, and shifts ε_{peak} downward; failure evolves from crack-dominated patterns toward crushing with confinement interaction. A normalized presentation $\sigma/\sigma_{peak} - \varepsilon/\varepsilon_{peak}$ with an explicit E evaluation window (0–40% of σ_u) provides like-for-like overlays and reduces ambiguity across studies. For reproducibility, reports should state specimen geometry ($D \times H$, H/D), end preparation and friction mitigation, loading or strain rate, instrumentation and gage length, and curing history; where restraint is applied, disclose jacket thickness or volumetric reinforcement and include hoop-strain measurements. Together, these conventions offer a practical baseline for laboratories and design-oriented studies of expansive RCA under controlled free and restrained conditions.

REFERENCES

[1] Xiao J., Li J., Zhang C. Mechanical properties of recycled aggregate concrete under uniaxial loading // Cement and Concrete Research. 2005. Vol. 35, no. 6. P. 1187–1194. DOI: 10.1016/j.cemconres.2004.09.020.

[2] ACI PRC-223-21. Shrinkage-Compensating Concrete—Guide. Farmington Hills: American Concrete Institute, 2021.

[3] Silva R. V., De Brito J., Dhir R. K. Establishing a relationship between modulus of elasticity and compressive strength of recycled aggregate concrete // Journal of Cleaner Production. 2016. Vol. 112. P. 2171–2186.

[4] Kou S. C., Poon C. S. Long-term mechanical and durability properties of recycled aggregate concrete prepared with the incorporation of fly ash // Cement and Concrete Composites. 2013. Vol. 37. P. 12–19. DOI: 10.1016/j.cemconcomp.2012.12.011.

[5] Zhang J. Recent advance of MgO expansive agent in cement and concrete // Journal of Building Engineering. 2022. Vol. 45. Art. 103633.

[6] ASTM C469/C469M-22. Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression. West Conshohocken, PA: ASTM International, 2022.

[7] ASTM C878/C878M-20. Standard Test Method for Restrained Expansion of Shrinkage-Compensating Concrete. West Conshohocken, PA: ASTM International, 2020.

[8] Mander J. B., Priestley M. J. N., Park R. Theoretical stress–strain model for confined concrete // Journal of Structural Engineering. 1988. Vol. 114, no. 8. P. 1804–1826. DOI: 10.1061/(ASCE)0733-9445(1988)114:8(1804).