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**STUDY ON THE COMPRESSIVE MECHANICAL PROPERTIES
OF RECYCLED AGGREGATE EXPANSIVE CONCRETE****MIN HAO, Doctor of Technical Sciences, Professor V. TUR
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Recycled aggregate concrete (RAC) is a promising low-carbon alternative to conventional concrete, yet its higher porosity and weaker interfacial transition zones (ITZs) often lead to reduced stiffness and increased deformation, which may amplify shrinkage-related serviceability risks. This study investigates the 28-day uniaxial compressive response of RAC incorporating a magnesium-oxide expansive agent (MEA) using a full factorial matrix. Twelve mixtures were prepared at a fixed water-to-binder ratio of 0.40 by crossing recycled coarse aggregate (RCA) replacement levels (0%, 30%, and 50%) with MEA dosages (0%, 6%, 8%, and 10% by binder mass). Cube specimens (100 mm) were tested under displacement control, and peak stress, peak strain, and static elastic modulus were obtained from the recorded load–deformation data; the modulus was evaluated by linear regression on the ascending branch within 0.2–0.5 of the peak stress. At 0% MEA, increasing RCA replacement decreased peak stress from 38.0 MPa to 33.4 MPa and reduced modulus from 32.0 GPa to 26.4 GPa, while peak strain increased from 1.75×10^{-3} to 2.30×10^{-3} . Across all RCA levels, MEA exhibited a non-monotonic effect: a modest improvement at 6% was followed by strength and stiffness reductions and higher peak strain at 8–10%, indicating a limited beneficial dosage window. The coupled trends suggest that deformation-related performance of MgO expansive RAC should be assessed using measured pairs of stiffness and strain capacity rather than peak stress alone. Given $n = 1$ per mixture at 28 days, the findings are interpreted as trend-based observations and motivate further replicated testing and microstructural verification.

Keywords: recycled aggregate concrete, MgO expansive agent, compressive strength, elastic modulus, peak strain.

Introduction. Driven by resource constraints and carbon reduction, recycled aggregate concrete (RAC) is widely regarded as a key pathway to the sustainability of cementitious materials; however, residual old mortar and a porous microstructure weaken the interfacial transition zone (ITZ), lower the elastic modulus, and increase sensitivity to shrinkage cracking, which continues to limit structural applications [1]. To improve volumetric stability and service reliability, the concept of expansive concrete has been adopted to use expansion to counteract shrinkage; among these systems, magnesium-oxide (MgO) expansive agents have seen systematic engineering application because their delayed expansion can be tailored, with long-standing practice and standards particularly in mass concrete and concrete-face rockfill dams in China [1].

From a materials mechanism perspective, the action of an MgO expansive agent centers on the hydration and crystal growth from MgO to Mg(OH)₂ (brucite), which occurs mainly in confined pores along pore walls and produces controllable delayed expansion; unlike CaO or calcium sulfoaluminate systems that rely on early ettringite formation, the rate and magnitude of expansion with a magnesium-oxide expansive agent are highly sensitive to particle reactivity, calcination conditions, curing temperature, and restraint [2]. Experimental studies and reviews further show that reactivity and dosage jointly define an effective window for compensating shrinkage and suppressing cracking; highly reactive MgO can compensate drying and autogenous shrinkage at early ages, whereas excessive dosage or a mismatch in reactivity may introduce diffuse microcracking and impair mechanical performance and durability [3].

Compared with normal concrete, the mechanical limitations of RAC are more closely tied to ITZ quality and the pore-size distribution; recent work has quantified the dominant roles of ITZ and pore structure in controlling compressive strength and stiffness and has indicated room for improvement through interfacial densification and internal curing [4]. Against this background, introducing an MgO expansive agent into RAC to balance volumetric stability with mechanical performance has become a recent focus, but much of the existing work targets shrinkage and cracking control in high-performance or specialized systems; under coupled conditions of RCA replacement and magnesium-oxide expansive-agent dosage, a systematic understanding of uniaxial compressive behavior, including the stress-strain response, elastic modulus, and peak strain, remains limited [5]. New reports also suggest that the optimum MgO dosage in recycled systems may shift with RCA content and curing regime, yet the quantitative laws and mechanisms that govern compressive constitutive behavior and stiffness deterioration or recovery still require clarification through a full-factorial test matrix [6].

Accordingly, this study examines recycled-aggregate concrete with an MgO expansive agent. A two-factor full matrix crossing RCA replacement levels of 0%, 30%, and 50% with magnesium-oxide expansive-agent dosages of 0%, 6%, 8%, and 10% was established at a fixed water-to-binder ratio; standard cube specimens were prepared, and compressive strength, stress-strain curves, elastic modulus, and peak strain were obtained. The aim is to elucidate the competing effects of RCA-induced weakening and densification or microcracking induced by the magnesium-oxide expansive agent under restraint, to identify an effective dosage window for MgO in recycled systems, and to provide practical recommendations that reconcile volumetric stability with compressive performance.

1. Materials and Methods

1.1 Materials

Ordinary Portland cement (P.O 42.5) conforming to GB 175 was used to ensure stable strength grade and consistent chemical composition across batches¹. Recycled coarse aggregate (RCA) was obtained from crushed demolition concrete. The source concrete was jaw-crushed, water-washed for 2 h to remove loose adhered mortar, oven-dried to constant mass, and then characterized for apparent density, water absorption, and flakiness index in accordance with GB/T 25177². Source of recycled coarse aggregate – Provided by Beijing Jingyulu Construction Engineering Co., Ltd., Natural coarse aggregate was continuously graded crushed stone (5–20 mm), and the fine aggregate was medium sand with a fineness modulus of 2.6 and silt content $\leq 2\%$. A polycarboxylate high-range water-reducing admixture was added at 1.0% of the binder mass to achieve comparable workability following JGJ/T 55³. The expansive component was a magnesium-oxide-based expansive agent (MEA) in powder form; the MgO content, fineness (or D50), and reactivity grade were provided by the manufacturer. MEA dosages were set to 0%, 6%, 8%, and 10% of the binder mass.

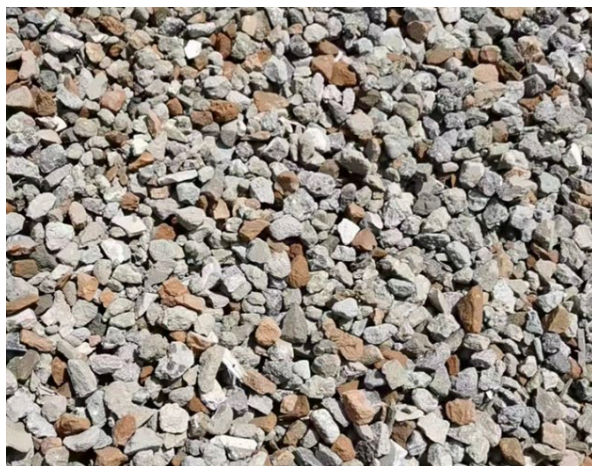


Figure 1. – Source of Recycled Coarse Aggregate

1.2 Mix design and experimental matrix

The water-to-binder ratio (w/b) was fixed at 0.40. A full two-factor matrix was adopted by crossing RCA replacement levels (0%, 30%, and 50%) with MEA dosages (0%, 6%, 8%, and 10%), yielding 12 mixtures denoted as R0–M0 to R50–M10 (Table 1). Mix proportions were designed in accordance with JGJ/T 55 to maintain comparable fresh consistency among mixtures⁴. The target testing ages (28 days) and the corresponding procedures were selected according to GB/T 50081⁵. The MEA dosage window (0–10% by binder mass) was selected to cover the commonly reported effective range for shrinkage compensation/volume stability while avoiding potential performance deterioration at excessive dosages, based on previous studies and reviews of MgO expansive systems [7–9].

Table 1. – Factorial mix matrix for recycled-aggregate MgO expansive concrete

Mix ID	RCA replacement (%)	MEA (MgO) dosage (% of binder)	w/b
R0-M0	0	0	0.40
R0-M6	0	6	0.40
R0-M8	0	8	0.40
R0-M10	0	10	0.40
R30-M0	30	0	0.40
R30-M6	30	6	0.40
R30-M8	30	8	0.40
R30-M10	30	10	0.40
R50-M0	50	0	0.40
R50-M6	50	6	0.40
R50-M8	50	8	0.40
R50-M10	50	10	0.40

Notes. RCA replacement \times MEA dosage; w/b = 0.40; mix IDs R0–M0 to R50–M10.

¹ State Administration for Market Regulation, National Standardization Administration GB 175-2023 General Portland Cement. – 2023. URL: https://www.chinesestandard.net/PDF.aspx/GB175-2023?English_GB%20175-2023.

² General Administration of Quality Supervision, Inspection and Quarantine, China National Standardization Administration GB/T 25177-2010 Recycled Coarse Aggregates for Concrete. – 2010. URL: <https://www.chinesestandard.net/PDF/English.aspx/GBT25177-2010>.

³ The Ministry of Housing and Urban Rural Development of the People's Republic of China JGJ 55-2011 Code for Design of Ordinary Concrete Mix Proportion. – 2011. URL: <https://www.doc88.com/p-7059188863793.html>.

⁴ See footnote 3.

⁵ The Ministry of Housing and Urban Rural Development of the People's Republic of China GB/T 50081-2019 Standard for Test Methods of Physical and Mechanical Properties of Concrete. – 2019. URL: <https://ebook.chinabuilding.com.cn/zbooklib/bookpdf/probation?SiteID=1&bookID=114599>.

1.3 Specimen preparation and curing

All mixtures were produced using a pan mixer. Coarse and fine aggregates were first dry blended with cement and MEA to achieve a uniform distribution of powders and aggregates. Gauging water pre-mixed with the polycarboxylate superplasticizer was then added, and the mixtures were remixed until a homogeneous consistency was obtained. Fresh concrete was cast into $100 \times 100 \times 100$ mm steel molds and compacted using table vibration to minimize entrapped air. The specimen was demolded after the initial setting was completed. And cured in a standard curing room at 20 ± 2 °C and relative humidity $\geq 95\%$ until testing at target ages of, 28 days, in accordance with GB/T 50081⁶. For each mixture and age, $n = 1$ specimen was tested; therefore, all reported values correspond to single measurements, and the experimental scatter was not quantified in this study.

1.4 Compression testing and instrumentation

Uniaxial compression tests were conducted on a servo-hydraulic compression testing frame under displacement control at $0.5 \text{ mm} \cdot \text{min}^{-1}$. The loading platens were lapped, and a small seating preload was applied before formal loading. Load and axial deformation were continuously recorded. Axial deformation was measured using two opposed LVDTs mounted at mid-height of the specimen. The axial strain was obtained from the average LVDT extension divided by the gauge length L_0 , where $L_0 \geq 50$ mm, consistent with GB/T 50081⁷. Engineering stress–strain curves were constructed for each specimen.



Figure 2. – Example of Servo Hydraulic Compression Testing Machine

1.5 Data reduction and definitions of reported variables

To ensure traceability of the reported response variables, peak stress, peak strain, and static elastic modulus were calculated from the recorded load–deformation data using the following definitions.

(1) Engineering compressive stress and peak stress.

Engineering compressive stress was calculated as

$$\sigma = A \div P, \quad (1)$$

where P is the instantaneous load (N) and A is the loaded area (mm^2). For 100 mm cube specimens, $A \approx 100 \times 100 = 10,000 \text{ mm}^2$ (or calculated using the measured face dimensions). The peak stress (reported as Peak Stress, MPa) was defined as

$$\sigma_{\max} = \max(\sigma). \quad (2)$$

Note that $1 \text{ MPa} = 1 \text{ N/mm}^2$.

(2) Axial strain and peak strain.

Axial strain was calculated as

$$\varepsilon = \frac{\Delta L_{\text{avg}}}{L_0}, \quad (3)$$

where ΔL_{avg} is the mean deformation from two opposed LVDTs and L_0 is the gauge length. Peak strain ε_{\max} was defined as the axial strain corresponding to σ_{\max} . For reporting convenience, peak strain was presented as $\varepsilon_{\max} \times 10^3$ ($\times 10^{-3}$).

⁶ See footnote 5.

⁷ See footnote 5.

(3) Static elastic modulus.

The static elastic modulus E was evaluated on the ascending branch of the engineering stress–strain curve. For each specimen, the peak stress σ_{\max} was first determined, and all data points $(\varepsilon_i, \sigma_i)$ satisfying

$$0.2\sigma_{\max} \leq \sigma_i \leq 0.5\sigma_{\max} \quad (4)$$

were selected. The modulus E was then obtained as the slope of the least-squares linear regression of σ against ε within this interval:

$$\sigma = a + E\varepsilon, \quad (5)$$

where a is the regression intercept and E is the regression slope. When σ is in MPa and ε is dimensionless, E is obtained in MPa and was converted to GPa by dividing by 1000. This “windowed” evaluation provides a reproducible static modulus and aligns with the customary working-stress concept used in ASTM C469/C469M, while differing from its standard two-point chord definition and specimen geometry⁸.

2. Results

2.1 Compressive strength (peak stress at 28 d)

The 28-day compressive response is reported in terms of peak stress (σ_{\max}), defined as the maximum engineering stress obtained from the recorded load divided by the loaded area (Section 2.5).

Table 2. – Peak stress (σ_{\max}) of recycled-aggregate concrete with MgO expansive agent at 28 days

RCA replacement (%)	MEA dosage (% of binder)	Peak stress, σ_{\max} (MPa)
0	0	38.0
0	6	39.2
0	8	36.5
0	10	34.1
30	0	36.1
30	6	37.2
30	8	34.7
30	10	32.5
50	0	33.4
50	6	34.4
50	8	32.1
50	10	30.1

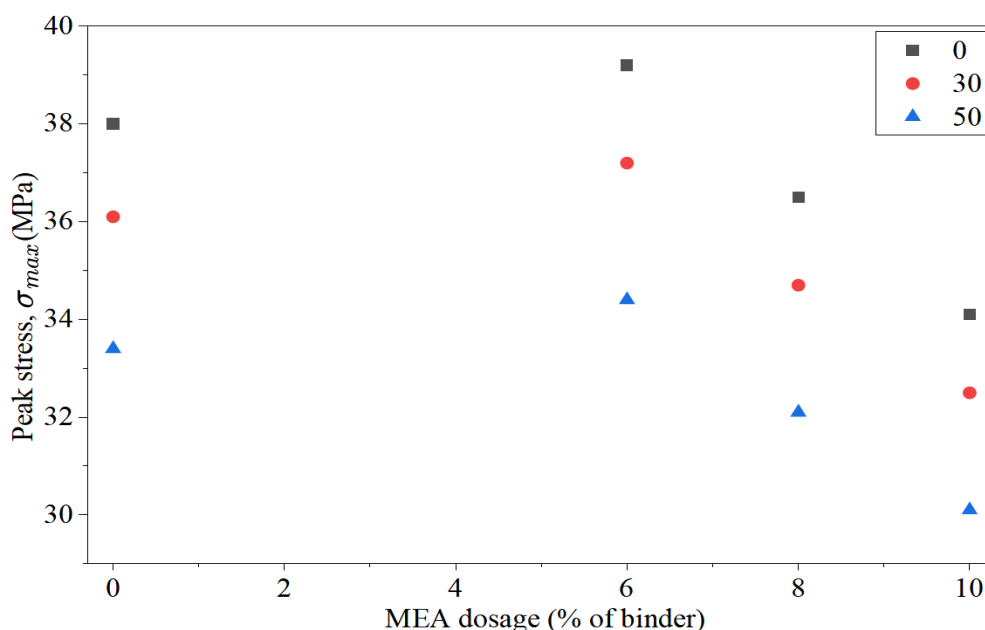


Figure 3. – Peak stress (σ_{\max}) of recycled-aggregate concrete with MgO expansive agent at 28 days

⁸ ASTM International. ASTM C469/C469M-22: Standard Test Method for Static Modulus of Elasticity and Poisson’s Ratio of Concrete in Compression. – 2022. URL: https://store.astm.org/c0469_c0469m-22.html.

The results are summarized in Table 2 and illustrated in Figure 3. At a fixed water–binder ratio, σ_{\max} is primarily governed by the RCA replacement level: with 0% MEA, σ_{\max} declines from 38.0 MPa at 0% RCA to 36.1 MPa at 30% RCA and 33.4 MPa at 50% RCA (Table 2; Figure 3), which is consistent with widely reported behavior of recycled-aggregate concrete. At any RCA level, MEA shows a non-monotonic dosage effect: σ_{\max} exhibits a slight increase at 6% MEA and then decreases at 8% and 10% MEA. For example, at 0% RCA the values are 38.0, 39.2, 36.5, and 34.1 MPa at 0%, 6%, 8%, and 10% MEA, respectively; corresponding trends are observed at 30% and 50% RCA (Table 2; Figure 3).

At 0% MEA, σ_{\max} decreases with increasing RCA replacement, from 38.0 MPa at 0% RCA to 36.1 MPa at 30% RCA and 33.4 MPa at 50% RCA (Table 2; Figure 3). This monotonic reduction agrees with widely reported behavior of recycled-aggregate concrete, where adhered old mortar and a generally weaker interfacial transition zone tend to reduce compressive performance as RCA content increases [10].

For a given RCA level, MEA shows a non-monotonic dosage effect. A 6% MEA dosage is associated with a modest increase in σ_{\max} relative to 0% MEA, whereas 8% and 10% MEA lead to lower σ_{\max} in all RCA series. Specifically, at 0% RCA, σ_{\max} equals 38.0, 39.2, 36.5, and 34.1 MPa at 0%, 6%, 8%, and 10% MEA, respectively; at 30% RCA the corresponding values are 36.1, 37.2, 34.7, and 32.5 MPa; and at 50% RCA they are 33.4, 34.4, 32.1, and 30.1 MPa. Such an “optimum-at-moderate-dosage” response is consistent with the general understanding that MgO-based expansive systems can be beneficial within an appropriate dosage/reactivity window, while excessive expansion may introduce internal damage and reduce peak stress; however, the mechanistic interpretation should be regarded as qualitative in the absence of replicate specimens [1; 7; 8].

2.2 Elastic modulus (28 d)

The static elastic modulus E was evaluated from the ascending branch of the engineering stress–strain curve by ordinary least-squares regression within 0.2–0.5 σ_{\max} , as defined in Section 2.5. Because $n = 1$ for each mixture at 28 d, the values in Table 3 and Figure 4 represent single measurements and are interpreted primarily through consistent trends across the factorial matrix.

As shown in Table 3 and Figure 4, the elastic modulus decreases with increasing RCA replacement. At 0% MEA, E declines from 32.0 GPa (0% RCA) to 28.8 GPa (30% RCA) and 26.4 GPa (50% RCA), which is consistent with the generally reduced stiffness reported for recycled-aggregate concrete due to the higher proportion of adhered old mortar and the altered interfacial transition zones [10].

For a given RCA level, MEA exhibits a limited “moderate-dosage” window. At 0% RCA, E increases slightly from 32.0 GPa (0% MEA) to 32.5 GPa at 6% MEA, and then decreases to 30.4 GPa (8% MEA) and 28.8 GPa (10% MEA). Similar behavior is observed at 30% RCA, where E reaches 29.3 GPa at 6% MEA before decreasing to 27.4 GPa and 25.9 GPa at 8% and 10% MEA, respectively. At 50% RCA, E is unchanged between 0% and 6% MEA (26.4 GPa), but decreases at higher dosages (25.1 GPa at 8% and 23.8 GPa at 10%). These results are consistent with the general understanding that MgO-based expansive systems can be beneficial within an appropriate dosage/reactivity range, whereas excessive expansion may introduce internal damage that preferentially reduces stiffness [1; 8].

Notably, the modulus reduction at higher MEA dosages is coherent with the concurrent increase in peak strain discussed in the next section, indicating a transition toward a more deformable response near peak when MEA is excessive (see Table 3 and Figure 4).

Table 3. – Elastic modulus (E) of recycled-aggregate concrete with MgO expansive agent at 28 days

RCA replacement (%)	MEA dosage (% of binder)	Elastic modulus, E (GPa)
0	0	32.0
0	6	32.5
0	8	30.4
0	10	28.8
30	0	28.8
30	6	29.3
30	8	27.4
30	10	25.9
50	0	26.4
50	6	26.4
50	8	25.1
50	10	23.8

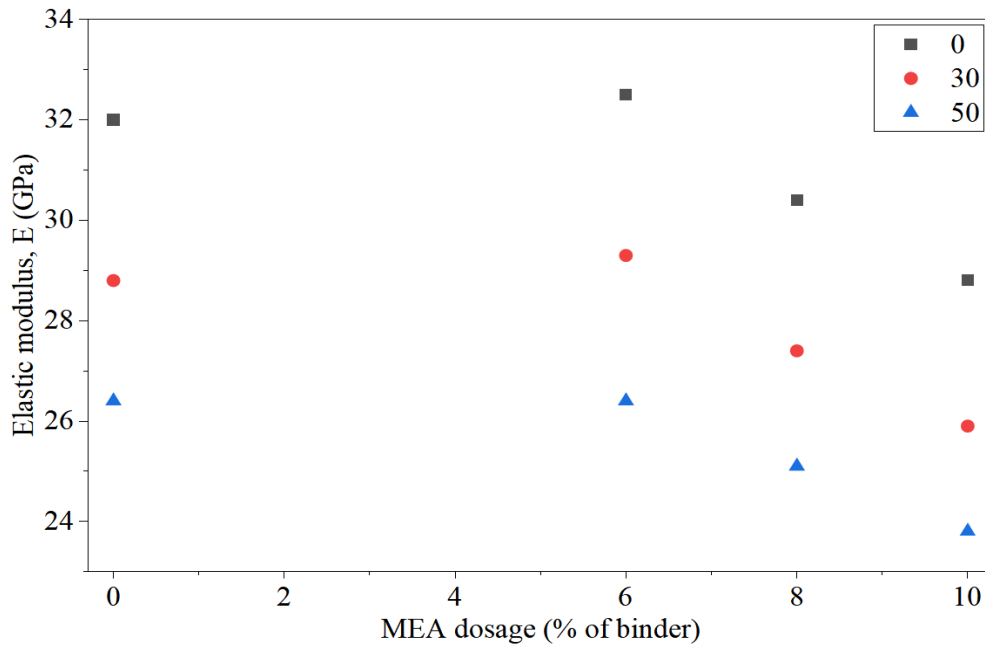


Figure 4. – Elastic modulus (E) of recycled-aggregate concrete with MgO expansive agent at 28 days

2.3 Peak strain (28 d)

Peak strain ϵ_{\max} is defined as the axial strain corresponding to the peak stress σ_{\max} on the engineering stress–strain curve. For reporting convenience, ϵ_{\max} is presented in $\times 10^{-3}$. Because $n = 1$ for each mixture at 28 d, the values reported in Table 4 and Figure 5 represent single measurements and are interpreted through consistent trends across the matrix.

As shown in Table 4 and Figure 4, peak strain increases with RCA replacement. At 0% MEA, ϵ_{\max} increases from 1.75×10^{-3} (0% RCA) to 2.05×10^{-3} (30% RCA) and 2.30×10^{-3} (50% RCA). This trend is compatible with published observations that recycled-aggregate concrete often exhibits greater deformability under compression due to higher heterogeneity and the presence of adhered mortar and multiple ITZs, which can promote earlier nonlinear deformation [11].

Within each RCA level, MEA dosage produces a distinct response: ϵ_{\max} is unchanged or slightly lower at 6% MEA (e.g., 1.70×10^{-3} at 0% RCA; 2.00×10^{-3} at 30% RCA; 2.25×10^{-3} at 50% RCA), but increases at 8% and 10% MEA. For example, at 50% RCA, ϵ_{\max} rises from 2.25×10^{-3} (6% MEA) to 2.50×10^{-3} (8% MEA) and 2.70×10^{-3} (10% MEA). The simultaneous increase in peak strain and the reduction in modulus at higher MEA dosages indicates a shift toward a more deformable response near peak when MEA is excessive. A plausible explanation is that over-expansion under restraint may introduce distributed micro-defects that reduce stiffness and allow larger inelastic deformation before peak stress, although this mechanistic interpretation should be regarded as qualitative given the single-specimen nature of the dataset [7; 8].

From a practical perspective, these results highlight that serviceability-related parameters (stiffness and strain capacity) may not be inferred from peak stress alone for MgO expansive recycled-aggregate concrete; therefore, it is advisable to consider measured pairs of E and ϵ_{\max} when comparing mixtures and assessing deformation-related performance (Table 3 and Table 4; Figure 3 and Figure 5).

Table 4. – Peak strain (ϵ_{\max}) of recycled-aggregate concrete with MgO expansive agent at 28 days

RCA replacement (%)	MEA dosage (% of binder)	Peak strain, ϵ_{\max} ($\times 10^{-3}$)
0	0	1.75
0	6	1.70
0	8	1.85
0	10	2.00
30	0	2.05
30	6	2.00
30	8	2.20
30	10	2.40
50	0	2.30
50	6	2.25
50	8	2.50
50	10	2.70

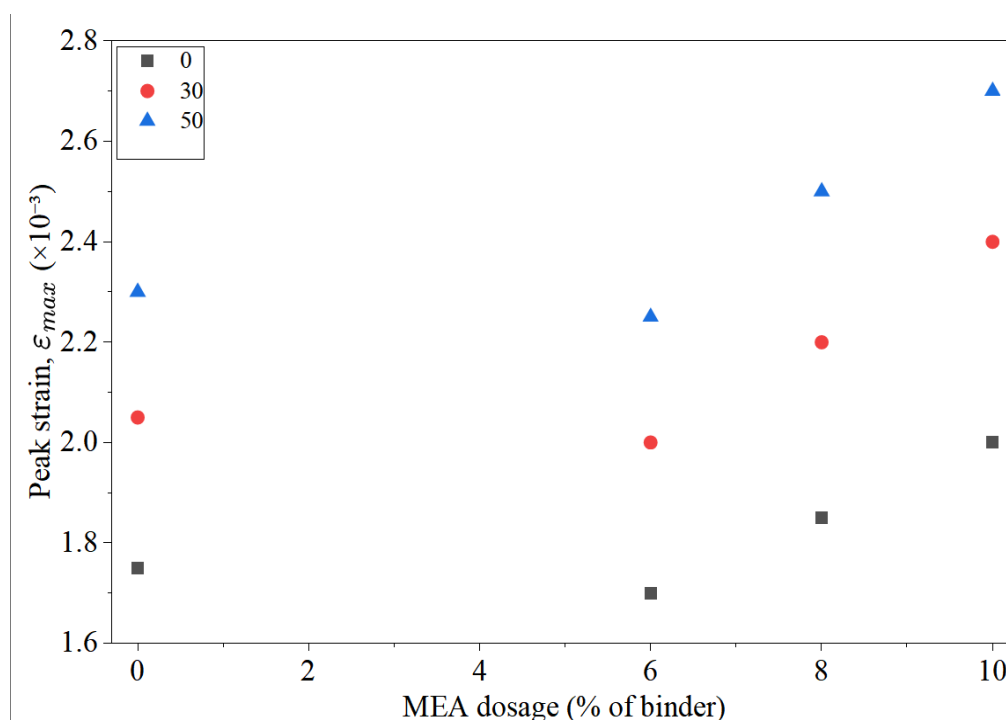


Figure 5. – Peak strain (ϵ_{max}) of recycled-aggregate concrete with MgO expansive agent at 28 days

Discussion. At a constant $w/b = 0.40$, the coupled trends of peak stress, elastic modulus, and peak strain indicate that the dominant mechanical penalty originates from RCA replacement, while MEA mainly modulates the response within a limited dosage window. As RCA increases, the reduction in peak stress and stiffness is consistent with the generally higher porosity and heterogeneity introduced by adhered old mortar and the presence of multiple interfacial transition zones in recycled aggregate systems [12]. In parallel, the larger peak strain observed at higher RCA levels agrees with published uniaxial compression observations that RAC tends to exhibit reduced modulus and increased deformation capacity at comparable strength, reflecting earlier nonlinear deformation development under compression [13].

Within each RCA level, MEA shows an evident “moderate-benefit / excessive-penalty” pattern: a small recovery in peak stress (and in some cases modulus) at 6% MEA is followed by reductions at 8–10% MEA. This behavior is compatible with the concept that MgO hydration products (brucite) can provide restrained expansion and local pore refinement when dosage and reactivity are appropriate, but may generate distributed micro-defects or expansion-induced microcracking when expansion becomes excessive, thereby reducing stiffness and strength while permitting larger peak strain [14]. The mechanistic plausibility is supported by microstructural and pore-scale discussions that link brucite growth pressure and confinement effects to expansion behavior and strength sensitivity [7]. Recent studies on MgO expansion agents further emphasize that the stable performance of MEA is strongly dosage- and activity-dependent, and that excessive contents can deteriorate volume stability and microstructure, which aligns qualitatively with the stiffness loss and strain increase at higher MEA dosages in the present matrix [15].

From a design and interpretation standpoint, the joint reading of $(\sigma_{max}, E, \epsilon_{max})$ suggests that peak stress alone is insufficient to represent deformation-related performance for MgO expansive RAC, particularly when MEA exceeds the moderate range and stiffness becomes more sensitive than strength. Because each 28 d result corresponds to $n = 1$, the discussion should be framed as a trend-based interpretation across a consistent factorial matrix rather than a statistically validated conclusion; accordingly, the present results are best positioned as an initial mechanical mapping that motivates future replication (≥ 3 specimens per mix-age) and complementary evidence (e.g., MIP/SEM or restrained expansion/shrinkage measurements) to confirm whether the inferred micro-defect/ITZ mechanisms are indeed governing the stiffness–strain shifts.

Conclusion. At 28 days and $w/b = 0.40$, RCA replacement set the baseline mechanical level. Without MEA, peak stress decreased from 38.0 MPa (0% RCA) to 36.1 MPa (30% RCA) and 33.4 MPa (50% RCA), while the elastic modulus dropped from 32.0 GPa to 28.8 GPa and 26.4 GPa; peak strain increased from 1.75×10^{-3} to 2.05×10^{-3} and 2.30×10^{-3} . These coupled changes indicate a progressively more compliant and deformable compressive response as RCA content increased.

MEA showed a limited beneficial dosage range. A 6% dosage produced a small strength recovery across all RCA levels, whereas 8–10% generally reduced strength and stiffness and increased peak strain. This combination points to a trade-off: higher MEA dosages may increase deformation capacity near peak but at the expense of stiffness and, in several mixes, peak stress.

For interpretation and mixture selection, peak stress alone does not capture the deformation-related response of MgO expansive RAC. Reporting and comparing mixtures using the paired indicators (E , ε_{\max}) together with σ_{\max} is more informative, especially when MEA exceeds the moderate range. Because $n = 1$ for each mix at 28 days, the findings should be treated as trend-based observations that require replicated testing to quantify variability.

REFERENCES

1. Mo L., Deng M., Tang M., Al-Tabbaa A. MgO expansive cement and concrete in China: Past, present and future // *Cement and Concrete Research*. – 2014. – Vol. 57. – P. 1–12. DOI: 10.1016/j.cemconres.2013.12.007.
2. Cao F., Miao M., Yan P. Hydration characteristics and expansive mechanism of MgO expansive agents // *Construction and Building Materials*. – 2018. – Vol. 183. – P. 234–242. DOI: 10.1016/j.conbuildmat.2018.06.164.
3. Influence of reactivity and dosage of MgO expansive agent on shrinkage and crack resistance of face slab concrete / L. Wang, G. Li, X. Li et al. // *Cement and Concrete Composites*. – 2022. – Vol. 126. DOI: 10.1016/j.cemconcomp.2021.104333.
4. Influence of interfacial transition zones (ITZs) and pore structure on the compressive strength of recycled aggregate concrete / C. Lu, Q. Yu, J. Wei et al. // *Construction and Building Materials*. – 2024. – Vol. 456. DOI: 10.1016/j.conbuildmat.2024.139299.
5. Mechanical performance and autogenous and drying shrinkage of MgO-based recycled aggregate high-performance concrete / V. Revilla-Cuesta, L. Evangelista, J. de Brito et al. // *Construction and Building Materials*. – 2022. – Vol. 314(3). DOI: 10.1016/j.conbuildmat.2021.125726.
6. Cao H., Wu B. Strength development of MgO recycled aggregate concrete with recycled sand from WRSR and compressive behavior of recycled lump-aggregate concrete // *Journal of Building Engineering*. – 2024. – № 95(03). DOI: 10.1016/j.jobeb.2024.110336.
7. Zhang J. Recent advance of MgO expansive agent in cement and concrete // *Journal of Building Engineering*. – 2022. – Vol. 45. DOI: 10.1016/j.jobeb.2021.103633.
8. Gu L., Qin X., Feng J. Experimental studies on the volume stability of MgO expansion agent in concrete // *Journal of Building Engineering*. – 2023. – Vol. 79. DOI: 10.1016/j.jobeb.2023.107866.
9. Mitigating shrinkage in ultra-high-performance concrete using MgO expansion agents with different activity levels / Z. Zhang, S. Li, P. Chen et al. // *Frontiers in Materials*. – 2022. – Vol. 9. DOI: 10.3389/fmats.2022.1033467.
10. Silva R.V., de Brito J., Dhir R.K. The influence of the use of recycled aggregates on the compressive strength of concrete: A review // *European Journal of Environmental and Civil Engineering*. – 2015. – Vol. 19(7). – P. 825–849. DOI: 10.1080/19648189.2014.974831.
11. Xiao J., Zhang K., Akbarnezhad A. Variability of stress-strain relationship for recycled aggregate concrete under uniaxial compression loading // *Journal of Cleaner Production*. – 2018. – Vol. 181. – P. 753–771. DOI: 10.1016/j.jclepro.2018.01.247.
12. Le H.-B., Bui Q.-B. Recycled aggregate concretes—a state-of-the-art from the microstructure to the structural performance // *Construction and Building Materials*. – 2020. – Vol. 257. DOI: 10.1016/j.conbuildmat.2020.119522.
13. Interfacial transition zones in recycled aggregate concrete with different mixing approaches / W. Li, J. Xiao, Z. Sun et al. // *Construction and Building Materials*. – 2012. – Vol. 35. – P. 1045–1055. DOI: 10.1016/j.conbuildmat.2012.06.022.
14. Uniaxial compressive stress–strain relation of recycled coarse aggregate concrete with different carbonation depths / K. Tu, J. Wu, Y. Wang et al. // *Materials*. – 2022. – Vol. 15(15). DOI: 10.3390/ma15155429.
15. Use of MgO expansion agent to compensate concrete shrinkage in jointed reinforced concrete pavement under high-altitude environmental conditions / K. Huang, X. Shi, D. Zollinger et al. // *Construction and Building Materials*. – 2019. – Vol. 202. – P. 528–536. DOI: 10.1016/j.conbuildmat.2019.01.041.

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ВЛИЯНИЕ МАГНЕЗИАЛЬНОЙ РАСШИРЯЮЩЕЙ ДОБАВКИ НА РАБОТУ ПРИ СЖАТИИ И ДЕФОРМАЦИОННЫЕ СВОЙСТВА БЕТОНА НА ВТОРИЧНЫХ ЗАПОЛНИТЕЛЯХ

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Переработанный агрегатный бетон (РАС) является перспективной альтернативой обычному бетону с низким содержанием углерода, однако его более высокая пористость и более слабые интерфейсные переходные зоны (ITZ) часто приводят к снижению жесткости и увеличению деформации, что может усилить риски обслуживания, связанные с сужением. В этом исследовании изучается 28-дневная одноосная реакция на сжатие РАК, включающая в себя экспансионный агент оксида магния (МЭА) с использованием полной факториальной матрицы. Двенадцать смесей были приготовлены при фиксированном соотношении воды к связывающему веществу в размере 0,40 путем пересечения уровней замены переработанного грубого агрегата (РКА) (0%, 30% и 50%) с дозами МЭА (0%, 6%, 8% и 10% по массе связывающего вещества). Кубические образцы (100 мм) были испытаны под контролем смещения, а пиковое напряжение, пиковая деформация и статический модуль эластичности были получены из зарегистрированных данных нагрузки-деформации; модуль был оценен линейной регрессией на

восходящей ветви в пределах 0,2–0,5 пикового напряжения. При 0% МЭА увеличение замены РСА уменьшило пиковое напряжение с 38,0 МПа до 33,4 МПа и уменьшило модуль с 32,0 GPa до 26,4 GPa, в то время как пиковое напряжение увеличилось с $1,75 \times 10^{-3}$ до $2,30 \times 10^{-3}$. На всех уровнях РКА МЭА демонстрировал немонотонный эффект: за скромным улучшением на 6% последовало снижение прочности и жесткости и более высокое пиковое напряжение на 8–10%, что указывает на ограниченное полезное окно дозировки. Совместные тенденции предполагают, что характеристики, связанные с деформацией MgO экспансивного РАС, следует оценивать с использованием измеренных пар жесткости и нагрузочной способности, а не только пикового напряжения. Учитывая, что $n = 1$ на смесь в течение 28 дней, результаты интерпретируются как наблюдения, основанные на тенденциях, и мотивируют дальнейшее повторное тестирование и микроструктурную проверку.

Ключевые слова: переработанный агрегатный бетон, MgO экспансивный агент, прочность к сжатию, модуль эластичности, пиковое напряжение.