University of Baghdad
College of Engineering
JOURNAL OF ENGINEERING

Journal of Engineering

journal homepage: www.jcoeng.edu.iq

Volume 32 Number 2 February 2026

Effect of WAPB and LWA Internal Curing on Drying Shrinkage of Concrete

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ABSTRACT

Drying shrinkage can lead to microcracking and reduced durability, especially when external curing is insufficient. Internal curing effectively addresses this issue by supplying additional internal water that sustains hydration when external curing is inadequate, water to the concrete matrix to sustain hydration, and alleviating strains caused by shrinking. This study investigates the influence of internal curing utilizing water-absorbing polymer balls (WAPB), lightweight aggregate (LWA), and their hybrid complex on the drying shrinkage and flexural strength of concrete. Seven concrete admixtures were developed: two references (Rw, Rair), WAPB, 50% LWA, Hybrid (25% LWA + 5% WAPB) following ACI 211.1, and two fully lightweight concretes (LWAw, LWAair) following ACI 211.2. Flexural strength was tested on 100×100×400 mm prisms (9 per mix) at 28, 60, and 90 days according to ASTM C293. Drying shrinkage was monitored on prisms of the same size per ASTM C157 with a 200 mm gauge length. The results showed that the 50% LWA mixture achieved the greatest reduction in drying shrinkage (67.5×10^{-6} at 28 days; 175×10^{-6} at 120 days), decreasing strains by approximately 61% at 28 days and 42% at 120 days compared with the reference mix. The Hybrid mix also demonstrated stable long-term behavior with a 14% increase only between 28 and 120 days. The flexural strength slightly decreased in all internally cured combinations relative to the water-cured reference because of increased porosity; however, it remained within acceptable structural limits.

Keywords: Drying shrinkage, Internal curing, Lightweight aggregate (LWA), Water-absorbing polymer balls (WAPB), Pumice.

1. INTRODUCTION

Curing denotes the measures taken to maintain sufficient moisture and temperature in freshly placed concrete **(ACI 308, 2008).** In hot–dry conditions, sustaining continuous external curing can be difficult; internal curing supplies water from within the matrix to sustain hydration and limit shrinkage-driven capillary stresses, typically by using pre-wetted lightweight aggregates or superabsorbent polymers that store and gradually release water **(Weiss, 2022).**

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Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2026.02.12

Article received: 19/10/2025
Article revised: 01/01/2026
Article accepted: 18/01/2026
Article published: 01/02/2026

Internal curing (IC) agents, such as lightweight aggregates (LWA) and superabsorbent polymers (SAP), improve the performance of concrete due to their porous nature, which allows them to absorb and retain moisture within the concrete matrix. When the internal humidity decreases, the materials liberation stocked moisture into the surrounding cement paste, thus mitigating the negative effects of drying **(De Meyst et al., 2021; Wyrzykowski et al., 2020).** Furthermore, the internal curing method's naivety and ease of integration into conventional concrete mixtures render it an applicable application in the construction industry **(Fawzi and Al-Awadi, 2017).**

Water Absorbent Polymer Balls (WAPB) declare enhanced capability to absorb and release water prior to hydration; no pre-saturation is required. LWA necessitates pre-wetting before enforcement. In the cementitious materials, the increase of demoulding tendency promotes continuous hydration and reduces drying shrinkage by retaining moisture more time to get slow release for stored water. Moreover, SAPs reasonably distribute internal moisture to ensure microstructure soundness and long-term serviceability of concrete **(Mohseni et al., 2024; Xu et al., 2021).**

In addition, drying shrinkage greatly depends on the size of aggregate: as the size of coarse aggregate increases, its restraining effect upon cement paste becomes greater and consequently, drying shrinkage decreases; conversely, it increases with the use offine or light-weight aggregates **(Karim, 2025).** The drying shrinkage is the main reason of the formation of deteriorations in concrete structures. Material contraction is generally restricted by internal or external limits, leading to the development of tensile stresses. It is evident in concrete that it tends to develop cracking when the stress applied exceeds its tensile strength **(Güneyisi et al., 2010).**

(Arckarapunyathorn et al., 2024) examined how autogenous shrinkage and compressive strength were affected differently by dry and pre-wetted superabsorbent polymer addition techniques. The dry mixing technique demonstrated greater effectiveness, diminishing shrinkage by as much as 27.2% in mortar and 15% in concrete after 42 days. Nonetheless, compressive strength diminished by 20–30%, especially with the pre-wetted technique. **(Akhnoukh, 2018)** examined the use of pre-saturated lightweight aggregate (LWA) for concrete internal curing. LWA effectively reduced early-age shrinkage and improved compressive strength when utilized appropriately. Mixtures with LWA were deemed appropriate for applications such as bridges and highways. Recent studies indicate that pre-wetted lightweight aggregate (LWA) maintains internal relative humidity (RH) and diminishes both drying and autogenous shrinkage, with trade-offs in stiffness due to aggregate porosity, whereas SAP/WAPB provides localized water release that can further stabilize early-age strains **(Bentz and Weiss, 2011; de Sensale, 2014; Weiss, 2022)**. Hybrid approaches combining LWA and SAP have shown amplified reductions in shrinkage up to 88.8% and improved dimensional stability **(Lyu et al., 2024; Mohseni et al., 2024)**. Nevertheless, strength penalties remain mix-dependent and should be contextualized against serviceability benefits **(Hachim et al., 2012).**

The novelty of this study lies in evaluating the combined use of water-absorbing polymer balls (WAPB) and lightweight aggregate (LWA) as dual internal curing agents in normal-strength concrete. Unlike previous studies that focused on each material separately, this research investigates their hybrid effect on long-term drying shrinkage up to 120 days, which has not been sufficiently addressed in the literature.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Cement

The study used OPC (CEM I-42.5 R), complying with **(IQS No.5, 2019)**. The physical and chemical properties of the cement are shown in **Tables 1 and 2.**

Table 1. Physical est of OPC.

Physical properties		Test results	The restrictions of (IQS No.5, 2019)
Setting time	**Initial (mins)**	90	Min. 45 (mins)
	Final (hrs.)	4:42	Max 10 (hrs.)
Compressive strength (MPa)	**2 days**	21.75	Min. 20
	28 days	46.63	Min. 42.5

***Tests were carried out in the Engineering Consulting Office at the University of Baghdad.**

Table 2. Chemical Test of OPC.

Oxide Composition		Content percentage %	The restrictions of (IQS No.5, 2019)
CaO %		60.35	-
SiO_2 %		20.64	-
AI_2O_3 %		5.08	-
Fe_2O_3 %		4.16	-
MgO %		3.86	Max 5
SO_3 %Max	**C3A < 3.5%**	Not applicable	2.5
	C3A > 3.5%	2.67	2.8
LOI %		3.21	Max 4
I R %		0.86	Max 1.5
C3S %		41.07	-
C2S %		28.27	-
C3A %		6.43	-
C4AF %		12.64	-

***Tests were carried out in the Engineering Consulting Office at the University of Baghdad.**

2.1.2 Aggregate

2.1.2.1 Fine Aggregate

Fine aggregate classified as zone II was used in accordance with Iraqi regulation **(IQS No. 45, 1984).** The physical and chemical characteristics in **Tables 3 and 4,** together with the fine aggregate sieve's analytical parameters.

Table 3. Sieve analysis of fine aggregate.

Sieve size (mm)	Passing (%)	Zone II requirements as stated in (IQS No. 45, 1984)
10	100	100
4.75	93	90-100
2.36	75	75-100
1.18	62	55-90
0.6	45	35-59
0.3	22	8-30
0.15	0	0-10

Table 4. Chemical and physical properties of fine aggregate.

Properties	Tests result	Restrictions outlined in (IQS No. 45,1984)
Fineness modulus	2.8	-
SO_3 %	0.22	≤ 0.5(%)
Absorption %	0.72	-
Specific gravity	2.6	-
Bulk density (kg/m^3)	1580	-

***Tests were carried out in the Engineering Consulting Office at the University of Baghdad.**

2.1.2.2 Coarse Aggregate

Crushed coarse aggregate with a maximum size of 12.5 mm was used in this study. The characteristics and classification of this aggregate are presented in **Tables 5 and 6**, in accordance with **(IQS No. 45, 1984)** Iraqi Specification.

Table 5. Sieve analysis of coarse aggregate.

Sieve size (mm)	Passing (%)	Passing % (5-14) - according to (IQS No. 45, 1984)
20	100	100
12.5	100	90-100
9.5	80	50-85
4.75	8	0-10
2.36	0	-----

Table 6. Chemical and physical properties of coarse aggregate.

Properties	Tests result	Limitations according to (IQS No. 45, 1984)
Specific gravity	2.65	-
Bulk density (kg/m^3)	1620	-
Absorption %	0.78	-
SO_3 %	0.08	≤ 0.1 (%)

***Tests were carried out in the Engineering Consulting Office at the University of Baghdad**

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2.1.3 Light-weight Aggregate

Pumice lightweight aggregate (pre-soaked) with a maximum size of 12.5 was used. The characteristics and grading of this aggregate are shown in **Tables 7 and 8**, which conform to the limitations specified by **(ASTM C330/C330M-17, 2017**).

Table 7. Sieve analysis of lightweight aggregate.

Sieve size (mm)	Passing (%)	Restrictions as per the (ASTM C330/C330M-17, 2017) Passing % (12.5-4.75) mm
19	100	100
12.5	100	90-100
9.5	75	40-80
4.75	7	0-20
2.36	0	0-10

Table 8. Chemical and physical properties of lightweight aggregate.

Properties	Tests result	Restrictions as per the (ASTM C330/C330M-17, 2017)
Specific gravity	0.76	-
Dry Loose Bulk Density	680	880
Absorption %	30	-
SO_3 %	0.08	-

***Tests were carried out in the Engineering Consulting Office at the University of Baghdad.**

The gradation curves of the coarse aggregate and pumice lightweight aggregate are presented in **Fig. 1.**

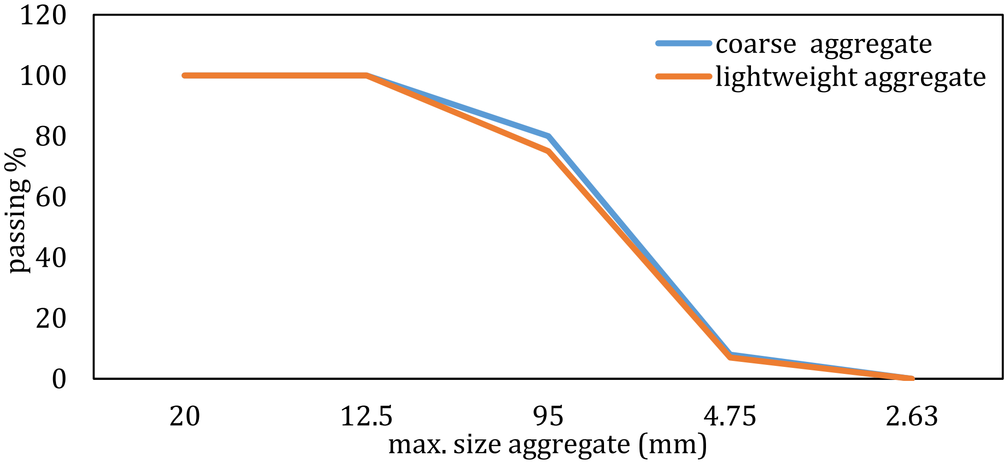

Figure 1. Sieve analysis of coarse aggregate and pumice lightweight aggregate used in this study.

2.1.4 Water

Tapped water is employed in this study. Additionally, each item is consistent with **(IQS No. 1703, 2018).**

2.1.5 Superplasticizer

The superplasticizer employed was ViscoCrete-180 GS. The manufacturer recommended a dosage of plasticizing concrete at 0.5 - 1% by weight of binder, equating to 500 - 1000 grammes for every 100 kilogrammes of cement. ViscoCrete®-180 GS conforms with Type G of **(ASTM C-494, 2019),** rendering this admixture appropriate. The manufacturer identifies the primary attributes of this superplasticizer in **Table 9.**

Table 9. Properties of the superplasticizer.

Properties	description
Color	Light brownish liquid
PH- value	4-6
Specific gravity	1.070 +-(0.005) g/cm^3
Chloride content	Nill

***According to the manufacturer**

2.1.6 Water Absorption Polymer Balls (WAPB)

WAPB are cross-linked polyacrylate-based superabsorbent polymer spheres capable of absorbing several hundred grams of water per gram of dry polymer. Their internal network structure allows gradual water release as the relative humidity inside the cement matrix decreases. Typical physical properties include particle size in the range 1–3 mm, bulk density between 500–700 kg/m^3, and equilibrium water uptake between 50–300 g/g depending on the ionic composition of the surrounding pore solution. These properties are consistent with previously reported behavior of SAP-based internal curing agents used in concrete **(Snoeck et al., 2015; Lee et al., 2019; Zhou et al., 2024),** as depicted in **Fig. 2**. This investigation utilized a concrete mix of 10% polymer spheres by weight of cement as a standard proportion **(Ahmed, 2017; Ahmed and Ameer, 2017).**

Figure 2. Water absorption polymer balls in concrete

2.2 Mix Design

The concrete mixtures were designed according to (**ACI 211.1, 2009),** for a desired compressive strength of 35 MPa, a target slump of 75-100 mm was used for both conventional concrete and structural lightweight concrete according to **(ACI 211.2, 1998).** The mix proportions are shown in **Table 10.**

Table 10. Details about the mix design

Mix symbol	Cem. (kg/m^3)	F.A (kg/m^3)	Coarse agg. (kg/m^3)	Pumice (kg/m^3)	Water (kg/m^3)	SP (% by cement weight)	Water absorption polymer balls % (WAPB)
Rw	460	730	875	-	173	0.6	-
Rair	460	730	875	-	173	0.6	-
WAPB	460	730	875	-	173	0.6	10
50% LWA	460	730	437.5	180	173	0.6	-
Hybrid	460	730	656.3	90.15	173	0.6	5
LWAw	452	705	-	476	152	0.6	-
LWAair	452	705	-	476	152	0.6	-

The mix designations are as follows: Rw (reference, water cured), Rair (reference, air cured), WAPB (10% of cement, air cured), 50% LWA (50% pumice replacement, air cured), Hybrid

(25% pumice + 5% WAPB, air cured), LWAw (lightweight agg. mixture, water cured), LWAair (lightweight agg. mixture, air cured). The inclusion of WAPB does not complicate the mix-design procedure, as the polymer balls are added as a fixed percentage of cement weight (10%). No adjustments to water-cement ratio or aggregate proportions were required, and the mixture remained consistent with standard **(ACI 211.1, 2009)** design procedures
The selected mixtures were designed to evaluate the individual and combined effects of lightweight aggregate (LWA) and water-absorbing polymer balls (WAPB) on internal curing efficiency. The 50% LWA mixture represents a commonly used replacement level in literature, while the Hybrid mixture (25% LWA + 5% WAPB) was included to investigate potential synergistic effects. Rw and Rair were used as water-cured and air-cured references, respectively, to provide baseline shrinkage behavior. LWAaw and LWAair were added to differentiate the influence of moisture conditioning on LWA performance.

2.3 Experimental Methods

The two tests were conducted: flexural strength and drying shrinkage. These tests were used to evaluate the mechanical and deformation characteristics of the internally cured concrete mixtures. The flexural strength test was performed on prism specimens with dimensions of 100 × 100 × 400 mm in accordance with (**ASTM C293, 2016) ,** as illustrated in **Fig. 3.** Three specimens were tested for each mixture at the ages of 28, 60, and 90 days, and the average value was recorded as the representative flexural strength. The center-point loading method was used, and the modulus of rupture (R) was determined using the formula:

$$R = \left(\frac{3\mathrm{PL}}{2\mathrm{bd}^2}\right) \tag{1}$$

where R is the modulus of rupture (MPa), P is the maximum applied load (N), L is the span length (267 mm), and b and d are the average width and depth of the specimen (100 mm each). The drying shrinkage test was conducted using prisms of the same size (100 × 100 × 400 mm) according to **(ASTM C192/C192M, 2019; ASTM C157/C157M, 2014).** Two stainless steel demec points were fixed on opposite faces, spaced 200 mm apart, as shown in **Fig. 4.** The length change was measured using an extensometer **Fig. 5**, satisfying the requirements of **(ASTM C490/C490M, 2014).**

Figure 3. Flexural strength test.

Figure 4. Demec points in the specimen.

Figure 5. Drying Shrinkage Test by using an Extensometer

3. TEST RESULTS AND DISCUSSION

3.1 Test of Flexural Strength

The flexural strength results showed an overall reduction in all internally cured mixes compared to the water-cured reference. Rw exhibited the highest strength (6.11 MPa), whereas LWAair showed the lowest strength (3.10 MPa), corresponding to a 49.26% reduction. The 50% LWA showed a slight reduction in flexural strength due to its lower density and higher porosity **(Abbas and Abbas, 2022).** Mixtures including WAPB and Hybrid (25% LWA + 5% WAPB) showed moderate reductions in flexural strength, ranging from 14.79% to 17.06% at 28 days. Although internal curing substantially alleviated shrinkage, it resulted in a slight decrease in flexural strength, primarily due to increased porosity. WAPB demonstrated the least strength loss among all internally cured mixtures, while the Hybrid and 50% LWA mixes exhibited comparable reductions. The strength values remained within acceptable limits for structural applications, particularly in light of the advantages obtained in shrinkage control, despite this reduction. These observations are in line with findings reported by **(Hachim et al., 2012; Zheng et al., 2021)**

While internal curing induced moderate reductions in flexural strength (14–17% for WAPB/Hybrid at 28 days), controlling drying shrinkage and the associated microcracking offers measurable durability and serviceability gains; thus, the trade-off is acceptable for normal-strength structural applications. The flexural strength test results at 28, 60, and 90 days are displayed in **Table 11** and **Fig. 6.**

Table 11. Results of flexural strength test.

Mix Symbol	Flexural strength (MPa)		
	28 days	60 days	90 days
Rw	6.11	7.91	8.43
Rair	5.91	7.81	7.96
WAPB	5.21	5.75	6.24
50% LWA	5.16	5.67	5.98
Hybrid	5.07	5.46	5.72
LWAw	3.70	3.90	4.61
LWAair	3.10	3.65	4.13

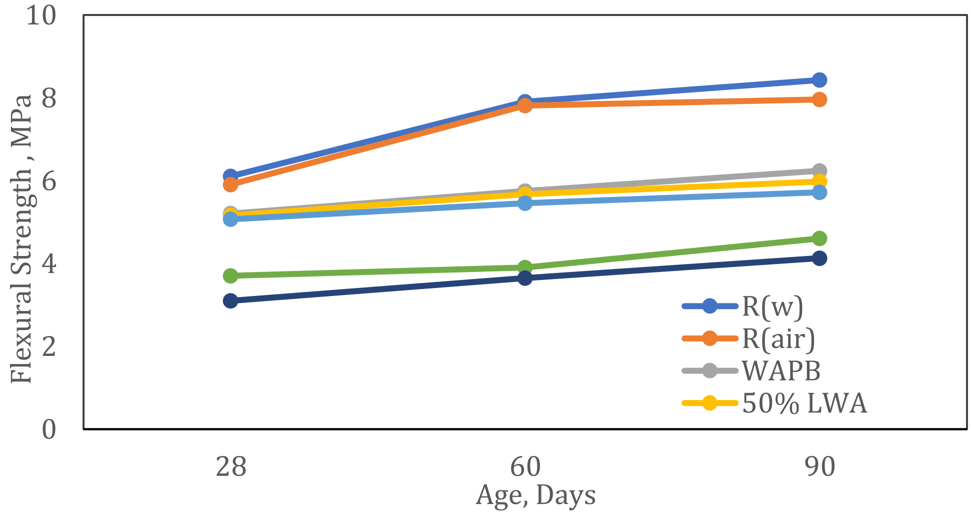

Figure 6. Correlation between flexural strength and compositions at different ages

3.2 Drying Shrinkage Test

At 28 days (**Fig. 7**), the 50% LWA mix recorded the lowest drying shrinkage (67.5 $\times 10^{-6}$), exhibiting the efficacy of pre-wetted lightweight aggregates in supplying internal curing water during initial hydration. The shrinkage sequence was followed in order: 50% LWA < Rw < LWAw < WAPB < Hybrid < LWAair < Rair. Reduced shrinkage in LWA mixes results from gradual moisture release that maintains internal humidity **(Bentz and Weiss, 2011).** Air-cured mixes (Rair, LWAair) demonstrated the greatest shrinkage as a result of rapid surface drying. Polymer-containing mixes (WAPB, Hybrid) showed intermediate values, as the water stored in WAPB is gradually released over time, making a more substantial contribution to shrinkage mitigation at later ages **(Zhou et al., 2024).**

At 120 days (shown in **Fig. 8**), 50% LWA consistently exhibited the lowest absolute shrinkage (175 $\times 10^{-6}$), followed by Rw ≈ Hybrid < WAPB < LWAw < Rair < LWAair. The synergistic efficiency of LWA and WAPB in maintaining long-term internal moisture levels was confirmed by the Hybrid combination, which exhibited the minimal time-dependent increase (approximately 14%) **(Liu et al., 2017).** The Rw mixture exhibited adequate performance, with a moderate increase that was the gradual drying that occurred after external curing, rather than a decrease in mechanical restraint. Fully lightweight concretes (LWAw, LWAair) exhibited larger increments as a result of their gradual reduction of moisture and low stiffness **(Cusson and Hoogeveen, 2008).**

At 28 days, the 50%LWA mix achieved the maximum drying shrinkage reduction by about 61%, compared to the reference mix 'R w '. 35% improvement was still observed in later ages at 120 days **(Fig. 8)** as evidence that pre-socked lightweight aggregates were able to continuously play their role and act as internal curing agents. The other combinations were unpronounced or negative, and it was confirmed that the 50% LWA mix had the highest water retention capacity **(Milla, 2021).**

Hybrid had the most stable long-term performance, and the 50% LWA presented the least total shrinkage at all ages. This is consistent with that found in other studies proposing a synergy in the internai-curing effect of combining WAPB and LWAs. This is due to reductions in drying shrinkage and improvement in dimensional stability **(de Sensale et al., 2014; Mohseni et al., 2024).**

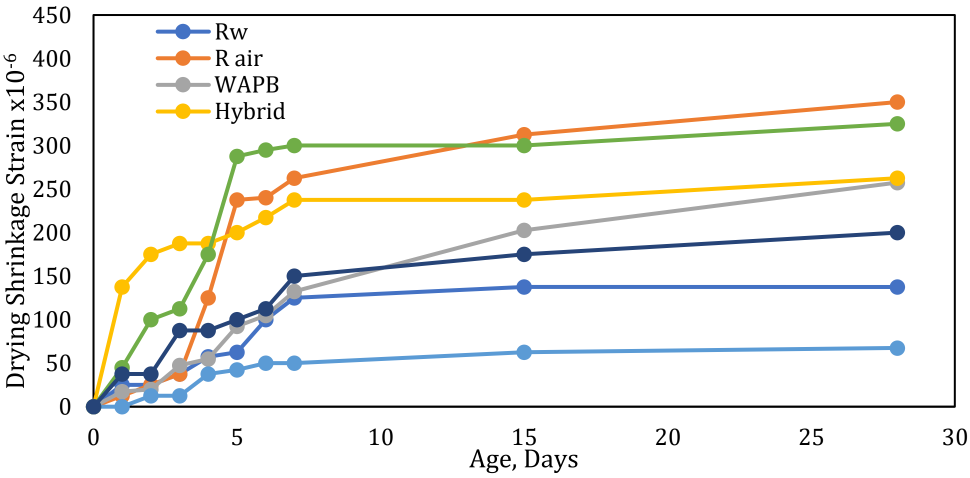

Figure 7. Development of drying shrinkage strain in various concrete mixtures over a period of 28 days

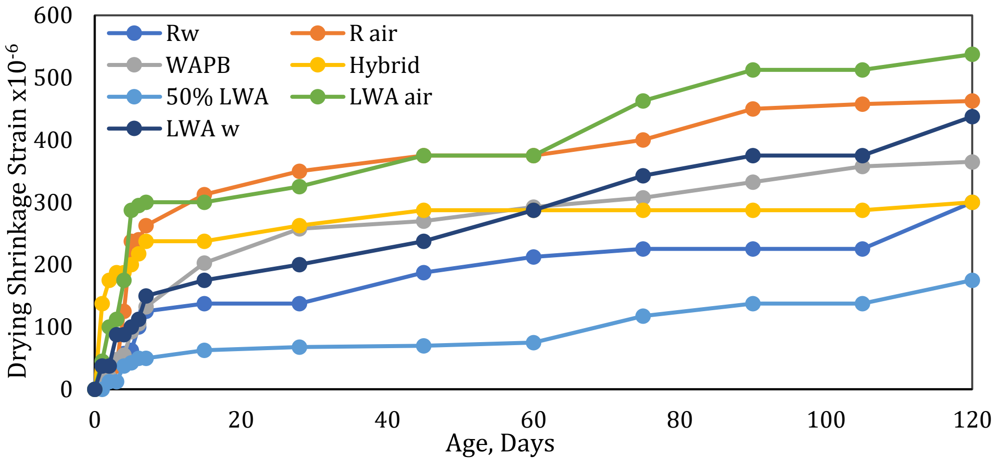

Figure 8. Development of drying shrinkage strain in various concrete mixtures over a period of 120 days.

4. CONCLUSIONS

This study evaluated internal curing using pre-wetted lightweight aggregate (LWA) and water-absorbing polymer balls (WAPB) and its influence on the drying shrinkage of normal-strength concrete under different curing conditions. The following conclusions are drawn:

1. Compared with the reference mix (Rw), internal curing reduced drying shrinkage. The 50% LWA mix showed the lowest shrinkage, 67.5×10^{-6} (28 days) and 175×10^{-6} (120 days), corresponding to about 51% and 42% reduction, respectively.
2. The Hybrid mix (25% LWA + 5% WAPB) provided the most stable long-term behavior, showing only an 14% increase from 28 to 120 days, indicating improved internal moisture retention over time.
3. At 28 days, the water-cured reference (Rw) achieved the highest flexural strength (6.11 MPa). Internal curing caused moderate reductions (WAPB: 5.21 MPa; 50% LWA: 5.16 MPa; Hybrid: 5.07 MPa), while LWAair recorded the lowest value (3.10 MPa).
4. Overall, pre-wetted 50% LWA is recommended when maximum shrinkage reduction is required, whereas the Hybrid system is preferred when minimizing time-dependent shrinkage growth is the priority.

NOMENCLATURE

Symbol	Description	Symbol	Description
b, d	width and depth of the specimen (100 mm each)	P	maximum applied load (N)
L	span length (267 mm)	R	modulus of rupture (MPa)
LWA	Lightweight Aggregate	Rair	Air-cured reference concrete
LWAair	Air-cured lightweight concrete	Rw	Water-cured reference concrete
LWAw	Water-cured lightweight concrete	WAPB	Water Absorbing Polymer Balls

Acknowledgements

This work was supported by the Civil Engineering Department, College of Engineering, University of Baghdad.

Credit Authorship Contribution Statement

Saba Alshammari: Conceptualization, Methodology, Experimental investigation, Data curation, Analysis, Writing – original draft.
Ikram AL-Mulla: Supervision, Methodology review, Validation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial or personal interests that could have appeared to influence the work reported in this paper.

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تأثير المعالجة الداخلية باستخدام كرات البوليمر الماصة للماء والركام الخفيف على الانكماش الجاف للخرسانة

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الخلاصة

يُعدّ الانكماش الناتج عن الجفاف أحد الأسباب الرئيسة لتكوّن الشقوق الدقيقة في الخرسانة وتدهور متانتها، ولاسيما في الحالات التي تفشل فيها طرق المعالجة التقليدية. تؤدي المعالجة الداخلية دورًا فعّالًا في معالجة هذه المشكلة من خلال تزويد الخرسانة بكميات مناسبة من الماء داخل المصفوفة الخرسانية للحفاظ على استمرار الإماهة والتقليل من الإجهادات الناتجة عن الانكماش. تتناول هذه الدراسة تأثير المعالجة الداخلية باستخدام كرات البوليمر الماصة للماء (WAPB) والركام الخفيف (LWA) ومزيجهما الهجين على الانكماش الناتج عن الجفاف ومقاومة الانحناء في الخرسانة. تم تحضير سبع خلطات خرسانية، شملت خلطتين مرجعيتين (Rair ،Rw)، وخلطة تحتوي على كرات البوليمر الماصة للماء (WAPB) ، وأخرى باستبدال 50% من الركام الطبيعي بركام خفيف، وخلطة هجينة (25% WAPB 5% + LWA)، بالإضافة إلى خلطتين خفيفتين بالكامل (LWAw، LWAair). أظهرت النتائج أن المعالجة الداخلية قلّلت بشكل ملحوظ من مقدار الانكماش الناتج عن الجفاف مقارنة بالعينة المرجعية المعالجة بالهواء. سجّلت خلطة الركام الخفيف بنسبة 50% أقل قيمة للانكماش عند عمري 28 و120 يومًا (67.5×10^{-6} و 175×10^{-6} على التوالي)، في حين أظهرت الخلطة الهجينة أقل زيادة طويلة الأمد (حوالي 14%). أما مقاومة الانحناء فقد انخفضت نسبيًا في جميع الخلطات التي خضعت للمعالجة الداخلية مقارنة بالخلطة المرجعية المعالجة بالماء، ويُعزى ذلك إلى زيادة المسامية، إلا أنها بقيت ضمن الحدود الإنشائية المقبولة. إن الجمع بين الركام الخفيف وكرات البوليمر الماصة للماء أدى إلى تقليل كبير في الانكماش مع فقدان بسيط في المقاومة، مما يؤكد كفاءة تقنية المعالجة الداخلية في تحسين أداء الخرسانة التقليدية.

الكلمات المفتاحية: الانكماش الجاف ، المعالجة الداخلية، الركام الخفيف (LWA)، كرات البوليمر الماصة للماء (WAPB)، الخفاف