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Short-Term Shrinkage and Creep of Perlite Concrete Reinforced with Hybrid Fibers

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ABSTRACT

Shrinkage and Creep, especially in light-weight concrete, are recognized as complicated phenomena that significantly impact the serviceability of concrete. This may be attributed to the significant influence of the surface layer's behavior at the interfacial transition zone (ITZ) between the aggregate and the surrounding cement paste on shrinkage and creep phenomena. In this article, the short-term creep and shrinkage of structural lightweight aggregate (LWA) concrete up to 90 days were studied. The concrete was made with a combined coarse and fine perlite aggregate, and the water cement ratio (W/C) was 0.4. Two types of fibers were used: polypropylene and recycled copper wire. Additionally, metakaolin was used as a pozzolanic material. Results indicated that the creep and shrinkage of reinforced concrete is lower than that of lightweight concrete without fiber. The total shrinkage of the MF mix was (1098.5×10^{-6}), comparable to (1229×10^{-6}) of the reference mix (RM) after three months. However, the total creep was (1991×10^{-6}) of the fiber mix (FM) equivalent to (2596×10^{-6}) of the RM after three months. The elevated creep and shrinkage values of the lightweight concrete (LWC) mixtures resulted from the increased porosity of the (LWA) used and the release of moisture retained inside the particles owing to their prewetting during the mixing process.

Keywords: Perlite, Shrinkage, Creep, Hybrid fibers, Cooper fiber, Polypropylene fiber.

1. INTRODUCTION

The concrete is made up of either a mixture of lightweight aggregate (LWA) and normal-density aggregate or is fully composed of lightweight aggregate. As a structural lightweight aggregate concrete, it has a density of (1120-1920kg/m^3) at equilibrium, and it has a min. compressive strength of (17MPa) after 28 days **(ACI 213R, 2014)**. Structural lightweight concrete offers enhanced thermal and acoustic insulation capabilities, as well as an elevated strength/weight ratio, attributable to the air voids included in the LWA. Moreover, reducing the total weight of a structure may lead to a reduction in the dimensions of structural components and the total amount of required steel reinforcement. **(Hossain, 2006)**.

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Perlite is a volcanic glass composed primarily of silica that can significantly increase in volume when heated. The volume expands by a factor of 4 to 20 from the initial volume when subjected to temperatures exceeding 870 °C **(Chandra and Berntsson, 2002)**. Expanded Perlite Aggregate (EPA) improves the acoustic, thermal, and freeze-thaw resistance of concrete while reducing its density. Perlite, an amorphous substance with a water content of two to five per cent, is a manifestation of rhyolitic and andesitic magma. It transforms into a thin, cellular substance when heated to 900–1000°C. It has been suggested that this material be used in structural components for dynamically loaded portions because, when suitably reinforced with fibers, the reduction in concrete weight might lessen damage during earthquakes. **(Kramar and Bindiganavile, 2011)**. The use of waste materials in concrete production, with the inclusion of alternative constituents and the reduction of OPC manufacture, is critically significant because of a number of sustainability and environmental considerations. OPC is the essential element used in the traditional concrete manufacturing process. Nonetheless, the OPC sector has raised environmental concerns due to its substantial CO_2 emissions. A more sustainable material, using metakaolin as a pozzolanic agent, may act as a replacement for OPC, thereby reducing CO_2 emissions into the environment **(Qasim and Fawzi, 2024).**

(Fawzi et al., 2013) investigated the influence of Metakaolin on the characteristics of Porcelanite lightweight aggregate concrete. Various proportions of MK, between 5% and 20%, were used as a replacement for cement in the concrete formulations. The findings indicate that all lightweight concrete formulations using metakaolin (MK) exhibited superior mechanical capabilities relative to the reference mix devoid of MK. The findings suggest that a replacement level of 15% metakaolin (MK) was found to be optimal. Furthermore, it has a high modulus of elasticity along with superior tensile and flexural characteristics. Creep and shrinkage are two physical characteristics of concrete. The assessment of stresses in frame structures resulting from creep and shrinkage is a multifaceted issue. Despite extensive research on these effects, the phenomena of creep and shrinkage remain intriguing subjects of study and are not yet entirely understood. Shrinkage and creep of concrete are mostly affected by mixed proportions, curing methods, and the applied stress-strength ratio **(Neville, 1995)**. Numerous factors influence concrete shrinkage, including aggregate grade, microstructure, water content, curing conditions, and environmental conditions such as temperature and relative humidity **(Wang et al., 2023; Karim, 2025).** Creep is influenced by several aspects, including the kind of material, the quantities of the mixture, and the ambient circumstances. The magnitude of the load imposed, and the duration of its application are the two key concerns **(Hong et al., 2023)**. Creep and drying shrinkage are interconnected processes influenced by several variables. The factors involve the aggregate type and quantity, the cement type, the aggregate grading, the content of water in the mixture, the aggregate moisture content during mixing, the entrained air amount, the age at which loading commences, the applied stress, the method of the curing, the specimen size, the relative-humidity of the ambient air, and the duration of loading sustained **(ACI 213R, 2014; Al-Mulla et al., 2024b; 2024a)**.

After 12 weeks, light-weight concrete (LWC) made with volcanic pumice aggregate had a drying shrinkage 22% greater than conventional concrete, while light-weight concrete made with volcanic scoria had a drying shrinkage 27% greater than conventional concrete. Their drying shrinkage values are larger, but they are all still within the range allowed by ASTM C330. **(Anwar Hossain, 2004; Hossain, 2004)**.

(Lo et al., 2008) Examined the short-term creep and shrinkage of (LWC) for 100 days, with designated strengths of (25 and 35MPa). The results indicated that both creep and shrinkage increased in lower-strength LWC. The total shrinkage of the G-35mix was ($320×10^{-6}$), while the G-25mix exhibited a shrinkage of ($415×10^{-6}$) after three months. Although the overall creep remains constant at ($590×10^{-6}$), the basic creep (MPa) of the G-35mix is 16.4% lower than that of the G-25mix after 3 months.
This study aims to reduce cement consumption and use waste materials to make concrete with other ingredients to achieve sustainability and develop SLWAC with good mechanical, low shrinkage, and creep qualities, utilizing EPA and other sustainable resources.

2. METHODS AND MATERIALS

2.1 Materials

2.1.1 Cement (C)

Throughout the experiment, OPC type CEM I-42.5R was utilised. **Tables 1 and 2** present the Chemical and Physical parameters of this cement, respectively. The results conform to **(IQS No.5, 2019).**

Table 1. Cement Composition

Oxide	Weight (%)	I.Q.S Limits
(CaO)	63.21	-
(Fe_2O_3)	3.92	-
(Al_2O_3)	5.31	-
(SiO_2)	19.95	-
(I.R)	0.58	Max(1.5)
(MgO)	2.75	Max(5)
(L.O.I)	2.44	Max(4)
(SO_3)	2.38	$SO_3 \leq 2.8$ if $C_3A > 3.5$ $SO_3 \leq 2.5$ if $C_3A \leq 3.5$

Table 2. Cement's Physical Properties.

Properties	Results	I.Q.S. NO.5 Limits
Soundness-(Autoclave)(%)	0.18	≤0.80
Setting-Time (Vicat's)		
Initial(min)	134min	≥ 45min
Final(hr.)	6.5hr.	≤ 10hr.
-(Blaine)(m^2/ kg)	397	≥280
Compressive Strength (MPa)		
At 2-Days	27	≥20
At 28-day	47	≥42.5

2.1.2 Water (W)

The water utilized in this study is sourced from the drinking water supply of Baghdad city and is used for mixing and also for curing purposes, and it conforms to **(IQS 1703, 2018).**

2.1.3 Expanded Perlite Aggregate (EPA)

This study utilised EPA from the chain as a composite of coarse and fine aggregates, which complied with **(ASTM C330, 2017)** standards, the EPA density was (193 kg/m^3) and absorption of (16.4%) **(ASTM C128, 2015).** Chemical characteristics are presented in **Tables 3 and 4**, showing the gradation of perlite used.

Table 3. EPA's Chemical Composition.

Oxide	**(CaO)**	**(Fe_2O_3)**	**(Al_2O_3)**	**(SiO_2)**	**(I.R)**	**(MgO)**	**(SO_3)**	**(L.O.I)**
Weight (%)	0.25	0.56	7.6	69.8	---	0.04	0.02	5.8

Table 4. EPA Gradation.

Size of Sieve(mm)	**Cumulative Passing-Wt.**	**Limits of ASTM C330)(0-9.5) mm**
12.5	100	100
9.5	100	90-100
4.75	89	65-90
2.36	43.6	35-65
0.3	11.6	10-25
0.15	5.8	5-15
0.075	0	0-10

2.1.4 Metakaolin (MK)

The metakaolin used in this investigation came from western Iraq after kaolinitic clay was calcined for two hours at temperatures as high as 700°C. This study utilized it to substitute 15% of the cement weight. **Table 5** shows the chemical analysis to comply with **(ASTM C618, 2019)**.

Table 5. The (MK) chemical constitution.

Oxides	**Test results**	**Limitation of (ASTM C618, 2019)**
(SiO_2)	54.3	(SiO_2)+(Al_2O_3)+(Fe_2O_3) =98.57 Min. (70 %)
(AL_2O_3)	43.9	
(Fe_2O_3)	0.37	
(MgO)	0.16	------
(SO_3)	1.35	Max.(4 %)
(CaO)	0.191	------
L.O.I	5	Max. (10 %)

2.1.5 Recycle Copper Wire Fibers (CF)

Copper wire fibers are a sustainable material obtained from various electrical devices. CF sourced from the coils of non-functional water pumps was utilized in this study. The fiber used had a dia. of 0.25mm and a length of 10mm, and a density of 8960kg/m^3.

2.1.6 Polypropylene Fibers (PP)

This study utilized polypropylene fiber specifically engineered for incorporation into concrete. Commercial Product Name Reinforced Polypropylene (PP) Micro Fiber or Monofilament Polypropylene Fiber. Country of Origin: China. **Table 6** details the specifications and characteristics of the fiber used in the experimental study provided by the supplier.

Table 6. Characteristics of PP by Manufacturer.

Properties	Details
Fiber-Length	12mm
Diameter	0.016mm
Tensile-Strength	400MPa
Density	900Kg/m^3

2.1.7 Admixture-Super-Plasticizer (SP)

A superplasticizer known as BETONAC®350 was used in the deployment. According to the manufacturer, it is by the **(ASTM C494, 2017)** Type G standard, and it has a density of 1.06 ±0.02 g/mL.

2.2 Mix Proportion

The created and mixed using **(ACI211.2, 1998; ACI213, 2014)**. The cement-to-perlite ratio for all mixes has been set at 1:2 by volume, with a water-cement ratio (W/C) of 0.4, and a cement content of 350kg/m^3. A dosage of 1000ml of superplasticizer per 100kg of cement was utilized to ensure a uniform W/Cm. Metakaolin was incorporated as a replacement for 15% of the cement's weight, while the fiber content was set at 1% of the concrete's volume**(ASTM C1116, 2009)**. **Table 7** presents the SLWAC Mixture.

Table 7. Concrete Mix Design.

Mix	C (kg/m^3)	W/C	Mix proportion (cement: perlite) volumetric	MK (Kg/m^3)	CF (Vf%)	PP (Vf%)	SP ml/100 kg cement
MR	262.5	0.4	1:2	52.5	---	---	1000
MF	262.5	0.4	1:2	52.5	0.5	0.5	1000

2.3 Test Method

2.3.1 Density Test

The test cylinders for the oven-dry density were constructed with a diameter of 150mm and a height of 300mm, and were utilized in accordance with **(ASTM C567, 2014).** The calculation of the density is performed using the equation presented in Eq. (1) below.

$$Om = \frac{(D \times 997)}{(F - G)} \quad (1)$$

where:
Om: the density(kg/m^3).
G: suspended-immersed cylinder's apparent mass (Kg).
D: cylinder mass(kg).
F: mass of the cylinder in SSD (kg).

2.3.2 Compressive Strength Test

The compressive strength was measured using **(ASTM C39, 2021)** on a cylinder with dimensions of 150×300 mm. At 7,28, and 90 days post-casting, the specimens were tested.

Until they broke, the concrete samples were put through their paces. The specimen's compressive strength is calculated using Eq. (2) as follows:

$$fc = \frac{P}{Ac} \tag{2}$$

where:
f_c: Compressive-Strength (MPa).
A_c: Area(mm^2).
P: Load(N).

2.3.3 Length Change Test (Drying Shrinkage)

A drying shrinkage test was performed on samples with dimensions of 400 mm x 100 mm x 100 mm following a 28-day water curing period, according to the American standard **(ASTM C 341.2013; ASTM C157, 2017; ASTM C490, 2021)**. Two stainless steel demec points were secured to two adjacent sides of the sample, with a spacing of 200mm, utilizing epoxy as the adhesive. The length differences of the samples were quantified using an extensometer. A dial gauge featuring a reading accuracy of 0.001mm is employed in this test, as illustrated in **Fig. 1(a). Fig. 1(b**) presents the specimen and the testing procedure. The length change is calculated by using Eq. (3), the following formula:

$$L = \frac{Lx - Li}{G} \tag{3}$$

Where :
L: Change in length at(x)age(mm).
Lx: Comparator measurement at(x)age minus reference bar comparator measurement at age (x)(mm).
Li: Comparator reading subtracted from the bar reading at same time(mm).
G: Gauge length(mm).

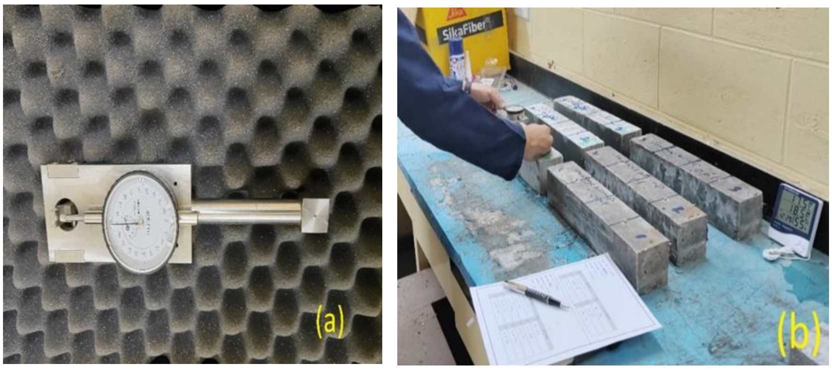

Figure 1. (a)Dial Gauge used, (b)Test of Specimen.

2.3.4 Creep Test

A creep test was conducted on two mixtures. A concrete cylinder with dimensions of 150 mm in diameter and 300 mm in height was prepared by **(ASTM C192, 2019)**. Before loading, the specimens were demolded and kept in a tap water tank for 28 days. A 100mm extensometer with a demic point was used to measure strain. A length compression meter, often referred to as an extensometer or extensometer, was used to measure the specimen's length difference. Following **(ASTM C490, 2021)**, as illustrated in **Fig. 2(a)**. All creep test specimens were subjected to surface flattening post-curing. The compressive strength of the specimens was calculated immediately before loading. Creep test specimens were loaded utilizing creep test rigs, also referred to as loading frames **(ASTM C512, 2015)**. The load rate at this loading point constituted 40% of the total compressive strength illustrated in **Fig.2(b).**

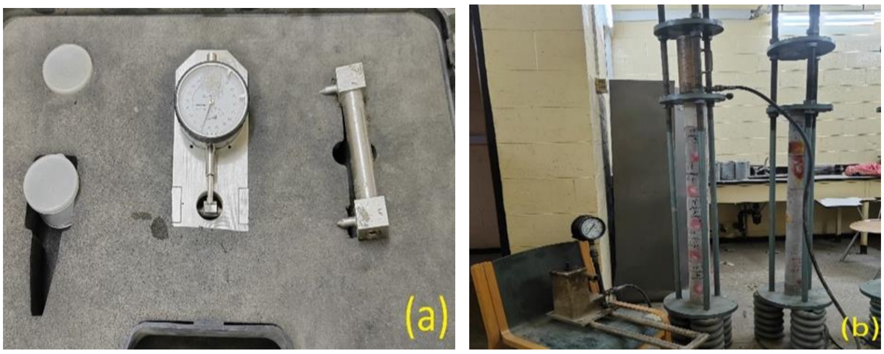

Figure 2. (a)extensometer, (b)Test of Specimen.

3. RESULTS AND DISCUSSION

3.1 Oven Dry

The SLWAC density, evaluated by **(ASTM C567, 2014)**. The results may be seen in **Fig. 3** and **Table 8**. The low density of perlite is the major advantage of utilizing it **(Mladenovič et al., 2004)**. A concrete structure's structural parts experience less strain when its total weight is reduced. As a result, the loads placed on the foundation of the building are decreased. As a result, improving the structural characteristics of the components is made easier by lowering the structure's total weight. The decreased weights provide a more cost-effective total expense for the building. Concrete with a lower density puts fewer stress points on the formwork, which lowers formwork costs **(Libre et al., 2011; Sengul et al., 2011)**.

Table 8. Density Test Result.

Mix	Density (kg/m³)
MR	1631.8
MF	1696.7

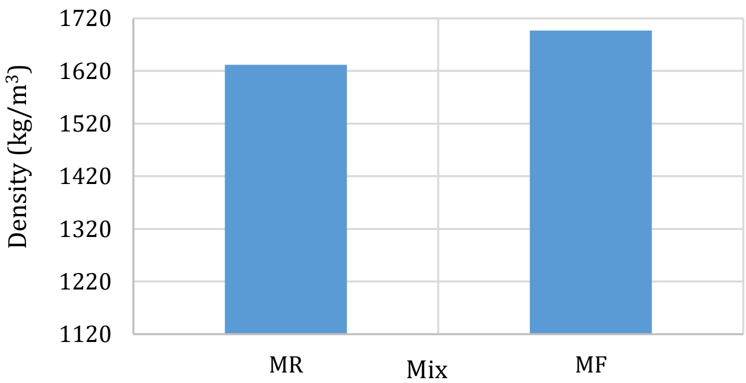

Figure 3. Relationship Between Mixes and Density

3.2 Compressive-Strength Result

The compressive strength of hardened concrete is an important property that is strongly correlated with other physical properties. **Table 9** and **Fig. 4** show the results of compressive strength tests performed on cylinders of various concrete mixes after 7, 28, and 90 days. MF mix had increases of 16.78%, 13.98%, and 14.22% during 7,28, and 90 days, respectively, surpassing MR. This conclusion aligns with the findings of **(Sofi and Naidu Gopu, 2019; Suhirkam et al., 2020; Gopu and Sofi, 2021)**.

Table 9. Result of Compressive Strength.

Mix	Compressive strength		
	7 days	28 days	90 days
MR	14.66	20.96	23.84
MF	17.12	23.89	27.23

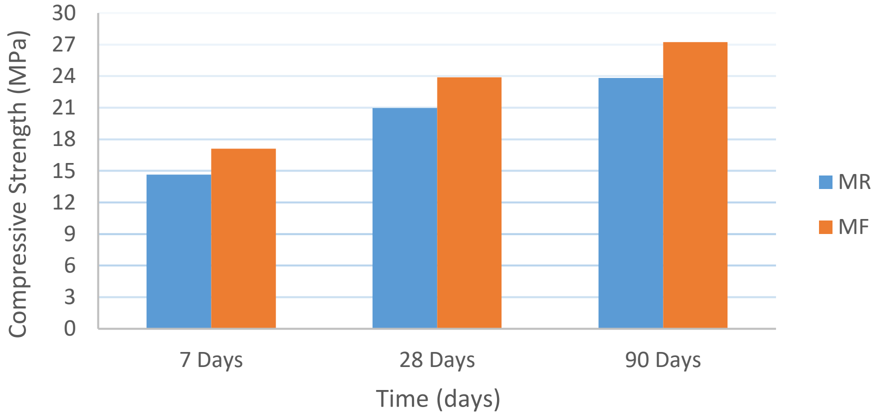

Figure 4. Results of Compressive Strength Results

3.3 Drying Shrinkage

Table 10 and **Fig. 5** present the results of the drying shrinkage tests conducted at intervals of 1, 2, 3, 4, 5, 6, 7, 14, 28, 32, 39, 45, 60, 75, and 90 days. The findings show a slight difference between the combination with and without fiber. The integration of fibers minimizes concrete shrinkage by joining these fibers with the products of cement hydration, resulting in a better microstructure and less cracking, thereby minimizing shrinkage **(Madhavi et al., 2015).** The total shrinkage after three months was between (0.000465-0.001229) for the MR mix and (0.000406-0.0010985) for the MF mix, which conforms with **(Lo et al., 2008).** The increased shrinkage value results from the moisture loss retained inside the aggregate owing to the prewetting of LWA during concrete mixing.**(Lo et al., 2008; Lukin, Popov and Lisyatnikov, 2020)**

Table 10. Drying-Shrinkage test results.

Drying-Shrinkage strain×10^{-6}		
Temperature 21°C, Humidity 35%		
Age (Days)	**MR**	**MF**
1	0	0
2	465	406
3	487.5	414.5
4	495	422
5	755	548
6	777.5	572.5
7	1005	921
14	1000	964
28	1080	983.5
32	1147.5	1003
39	1108	998.5
45	1190	1084
60	1218	1061
75	1201	1054
90	1229	1098.5

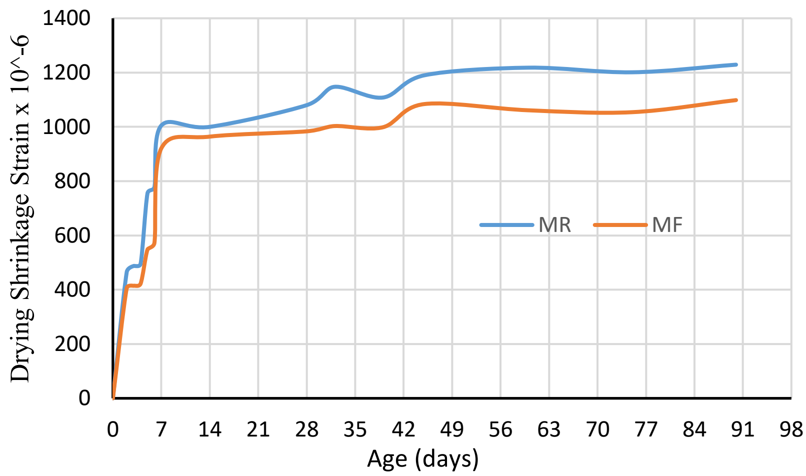

Figure 5. Relationship Between Age of Curing and Shrinkage Test.

3.4 Creep

The test results are shown in **Table 11** and **Fig. 6.** Creep is the time-dependent rise in strain when exposed to a steady load. The test focuses on the drying creep caused by the drying process. Creep and shrinking are closely connected. Creep strain is measured in micro-strain(strain×10^{-6}) **(Neville and Brooks, 2010)**. Creep may be linked to the movement of water inside hardened concrete and the loss of adsorbed water under prolonged pressure. The porous characteristics of lightweight aggregate (LWA) often enable the influence of moisture migration on creep in lightweight concrete (LWC) to be more pronounced than in NWC. Consequently, when a hydrated cement pastes of lightweight concrete (LWC) experiences prolonged stress, the calcium silicate hydrate (C–S–H) loses significant amounts of physically adsorbed water, resulting in creep strain; the dia. of the gel hole progressively decreases, and creep intensifies. Creep strain of the cement paste component of concrete composite diminishes with the conclusion of the cement hydration process **(Lo et al., 2008)** The results indicated a minor difference in creep between the mixes, attributed to the addition of fiber in the MF mix compared to the MR mix. The total creep observed after three months ranged from 0.00079 to 0.002596 for the MR mix and from 0.000527 to 0.001991 for the MF mix, following **(Lo et al., 2008)**

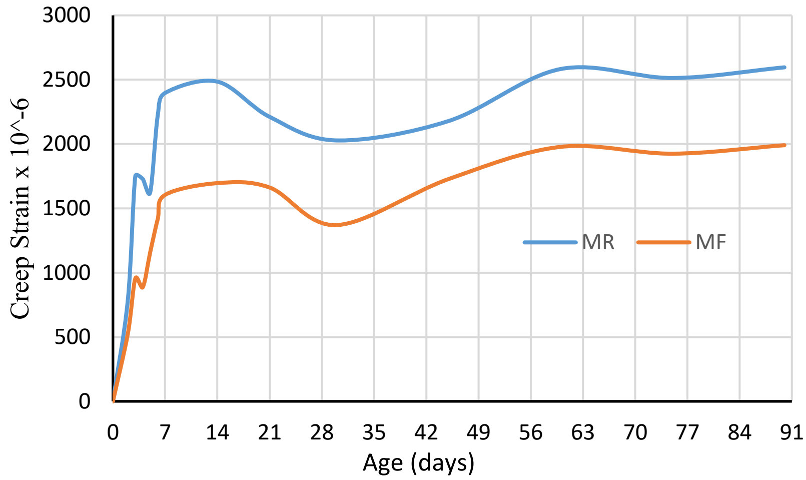

Figure 6. Relationship Between Age of Curing and Creep Test.

Table11. Creep Test Results.

Creep strain, ×10^{-6}		
temperature 21 °C, humidity 35%		
Age (Days)	**MR**	**MF**
1	0	0
2	790	527
3	1750	955
4	1728	887
5	1625	1160
6	2220	1415
7	2397	1605
14	2485	1696
21	2211	1662
30	2028	1370
45	2179	1728
60	2583	1978
75	2513	1925
90	2596	1991

4. CONCLUSIONS

- It is possible to produce SLWAC concrete with perlite aggregate.
- The density is limited by the SLWAC (1120–1920 kg/m3). The use of recycled copper wire and polypropylene fibers as hybrid fibers may enhance the density of the MF mix by 3.98% compared to MR.

- The compressive strength of concrete including fibers at a volume of 1% exceeds that of the control mixture (MR). The compressive strength remains within the range of SLWAC, min.17-28 MPa, as per ASTM C330.
- The Shrinkage and Creep of reinforced LWAC specimens were less than that obtained for the lightweight concrete without fibers.
- The Shrinkage and Creep of both concrete mixes exhibit similar patterns, increasing rapidly during the first month and then continuing to rise steadily up to 90days.
- The shrinkage and creep of lightweight concrete (LWC) are associated with the density of the lightweight-aggregate (LWA) employed. Lower-strength light-weight concrete demonstrates increased shrinkage and creep values.

NOMENCLATURE

Symbol	Description	Symbol	Description
LWAC	Light-weight-Aggregate-Concrete	SLWAC	Structural Lightweight Aggregate Concrete
MK	Meta-kaolin	SP	Super-plasticizer
LWC	Light-weight-Concrete	PP	Polypropylene-fibers
EPA	Expanded-Perlite-Aggregate	CF	Copper-Fibers
C	Cement	W	Water
NWC	Normal weight concrete	HP	Hybrid Fibers

Credit Authorship Contribution Statement

Ahmed Jasim: Review, editing and original draft writing, Nada Mahdi: Methodology, validation, editing, and supervision

Declaration of Competing Interest

The authors declare that they have no known conflicting financial interests or personal ties that might have influenced the work presented in this study.

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الانكماش والزحف قصير المدى لخرسانة البيرلايت المسلحة بالألياف الهجينة

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الخلاصة

الانكماش والزحف، وخاصة في الخرسانة خفيفة الوزن، ظاهرتان معقدتان تؤثران بشكل كبير على قابلية الخرسانة للخدمة. ويمكن أن يعزى ذلك إلى التأثير الكبير لسلوك الطبقة السطحية في منطقة الانتقال بين الركام وعجينة الأسمنت المحيط بظاهرتي الزحف والانكماش. في هذه المقالة، تمت دراسة الزحف والانكماش قصير المدى حتى 90 يومًا للخرسانة الإنشائية خفيفة الوزن. حيث تم تصنيع الخرسانة باستخدام مزيج ركام بيرلايت ناعم وخشن، وكانت نسبة الماء إلى الأسمنت هي 0.4. وتم استخدام نوعين من الألياف: البولي بروبلين والأسلاك النحاسية المعاد تدويرها. بالإضافة إلى ذلك، تم استخدام الميتاكاولين كمادة بوزولانية. أشارت النتائج إلى أن الزحف والانكماش في الخرسانة المسلحة خفيفة الوزن أقل من الخرسانة خفيفة الوزن بدون ألياف. كان الانكماش الكلي للخلطةMF هو 10^{-6} × 1098.5 ، بينما كان 1229 × 10−6 لخلطة MR بعد ثلاثة أشهر. على الرغم من أن الزحف الكلي بلغ 10^{-6}×1991 للخلطة MF، وهو ما يُقارن بـ 10^{-6}×2596 للخلطة MR بعد 3 أشهر. نتجت قيم الانكماش والزحف المرتفعة لخلطات الخرسانة خفيفة الوزن عن زيادة مسامية الركام خفيف الوزن المستخدم، وإطلاق الماء المحتجزة داخل الفراغات في الركام نتيجةً لتبليلها المُسبق أثناء عملية الخلط.

الكلمات المفتاحية: بيرلايت، انكماش، زحف، الالياف الهجينة، الياف البولي بروبلين، الياف النحاس.