Research Article

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Some properties of thermal insulating cement mortar using Ponza aggregate

https://doi.org/10.1515/eng-2022-0478
received March 29, 2023; accepted June 12, 2023

Abstract: Lightweight aggregate (LWA) mortar is made using lightweight or low-density aggregate, which improves properties such as thermal insulation, durability for freezing and thawing, fire and temperature resistance, and sound insulation. This research aims to use lightweight fine aggregate obtained from crushing natural rocks that are locally called "Ponza" to produce LWA mortar with different mix proportions to study the possibility of using it to produce blocks that can be erected on the outer side of the walls of old buildings to provide good thermal insulation. It also presents a study about the internal curing property of the produced cement mortar, which comes from the absorbed water by the used surface-saturated dry Ponza aggregate. The process includes using three mix proportions (1:1, 1:0.7, and 1:0.5) by weight of cement: fine aggregate. The samples were cured by dividing them into five groups, including moist curing for 1, 3, 7, and 28 days and the fifth group was moist cured for 1 day and then covered by a thin layer of flan coat. Dry density, compressive strength, flexural strength, and thermal conductivity for ages (7, 28, and 56 days) have been tested. The findings indicate that it is possible to produce thermal insulating lightweight cement mortar with mixtures of 1:0.7 or 1:0.5 cement to LWA, using Ponza aggregate, since the results showed an acceptable range of compressive and flexural strengths reaching about 14.75 and 2.91 MPa, respectively, a bulk density of less than 1,600 kg/mm^3, and a lower thermal conductivity than many building materials.

Keywords: cement mortar, internal curing, Ponza aggregate

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1 Introduction

In recent years, energy saving through energy-efficient building design has become a significant area of research due to the high energy consumed in building air conditioning. Iraq is known for its high summer temperatures that exceed 50°C, so electricity bills will be increased unless an excellent thermal insulation system is used. Lightweight aggregate (LWA) concrete and masonry units have been shown to provide energy savings because of their unique thermal properties [1]. Thermal conductivity in a material is the transmission of internal energy by particle collisions and electron movement, which depends on the temperature difference between two bodies and the properties of the conductive interface through which heat is meant to transfer [2].

Generally, normal, lightweight concrete (LWC), and cement mortar thermal conductivity ranges between 0.62 and 3.3 W/m K, 0.4 and 1.89 W/m K, and 0.53 and 2.5 W/m K, respectively. This wide range in thermal conductivity is primarily controlled by several variables, including mix proportion, measuring methods, environmental circumstances, composite properties, etc. [3]. Energy conservation is also a crucial issue in sustainability since space air conditioning accounted for about 23 and 26% of total annual electricity consumption in residential and commercial buildings, respectively [4].

Sengul et al. [5] indicated that using perlite LWA in concrete mixes can lower thermal conductivity to about 0.13 W/m K. LWC can be produced by replacing a part or all of the normal aggregates with lightweight materials such as volcanic pumice, expanded clay, slate, shale, scoria, tuff, and perlite. Comparing the different mortars according to their used aggregate type, natural-weight mortars develop higher strength values than lightweight mortars due to the higher strength of the limestone aggregates [6].

Due to its porous structure characteristics, LWA has been used as an internal curing material in concrete. Pre-wetted fine LWA is often used to produce internally cured concrete. The water that absorbs in the LWA is released and is replaced that is consumed by chemical shrinkage

Table 1: Physical properties of cement

Physical properties		Test results	Limits of IQS. No. 5/2019 [13]
Specific surface area (Blaine method)		351 m^2/kg	>230 m^2/kg
Setting time (vacate apparatus) (h: min)	Initial setting	2:55	≥45 min
	Final setting	5:00	≤10 h
Compressive strength (MPa)	At 3 days	20.8 MPa	≥15
	At 7 days	27.4 MPa	≥23
Soundness (autoclave) (%)		0.12	≤0.8

Table 2: Chemical properties of cement

Constituent	Content (%)	Limits of IQS. No. 5/2019 [13]
CaO	61.53	—
Al_2O_3	4.86	—
SiO_2	20.91	—
Fe_2O_3	2.75	—
MgO	2.37	≤6%
SO_3	2.18	≤2.3%
Loss on ignition	1.23	≤3%
Insoluble material	0.42	≤0.75%
Lime saturation factor	0.87	—
C_3S	47.61	—
C_2S	24.8	—
C_3A	4.27	—
C_4AF	9.04	—

during the hydration reaction or water evaporation. The results indicated that water desorption of LWA significantly affected concrete's internal curing effect, mechanical strength, and pore structure evolution [7–9]. LWA has a connected and fine pore structure, which could absorb about 30.6% water by mass and quickly attain saturation. More than 95% of the water absorbed was released at 97% relative humidity, compared to the high-strength mortars with the same mixing water content [10,11].

Degirmenci and Yilmaz [12] found that it is possible to develop the strength of mortar exceeding 12 MPa. They had a dry density of 1,140–1,146 kg/m^3 using 100% pumice as sand, satisfying the criteria for lightweight mortar, and it can be used for cast-in-place walls for both load-bearing and non-load-bearing purposes.

This research aims to use lightweight fine aggregate, known as "Ponza," after crushing their rocks to produce LWA mortar with different mix proportions to study the possibility of producing an outer shield layer for buildings that work as a thermally insulating layer, and also, study the internal curing property of the produced cement mortar.

2 Experimental investigation

2.1 Materials

2.1.1 Cement

The cement type used in this study is ordinary Portland cement (type I) [13]; the physical and chemical properties of the cement are given in Tables 1 and 2.

2.1.2 Fine aggregate

Lightweight Ponza stones were crushed and sieved to a maximum of 2.36 mm for acceptable aggregate use. Then, they were wetted to reach surface saturated dry condition before being used in all cement mortar mixtures. Figure 1

(a) (b)

Figure 1: Lightweight Ponza aggregate: (a) before crushing and (b) after crushing.

Table 3: Sieve analysis of Ponza aggregate

Sieve size (mm)	Passing by weight (%)	Limits according to ASTM C332-17 [14]
4.75	—	—
2.36	100	100
1.18	89.42	85–100
0.6	47.34	35–85
0.3	13.6	2–40
0.15	1.83	0–10

Table 4: Properties of the lightweight Ponza aggregate

Properties	Specification	Test results	Limits of specification
Specific gravity	ASTM C127-15	1.27	—
Absorption (%)	ASTM C127-15	41.7	—
Dry loose unit weight (kg/m^3)	ASTM C29/ C29M-17	471	—
Sulfate content (as SO_3) (%)	IQS, No. 45/1984	0.083	≤0.1%

shows the Ponza aggregate before and after crushing to the required size as recommended in ASTM C332-17 [14].

Tables 3 and 4 indicate sieve analysis and properties of the used fine aggregate.

Table 5: 28-day dry density of cement mortar with different curing methods

Mix proportion	Curing type	Dry density (kg/m^3)
1:1	A	1,116
	B	1,136
	C	1,156
	D	1,220
	E	1,248
1:0.7	A	1,216
	B	1,276
	C	1,280
	D	1,300
	E	1,369
1:0.5	A	1,396
	B	1,352
	C	1,456
	D	1,452
	E	1,574

2.2 Mixture proportions

Three types of mixtures were cast, as shown in table, including 1:1, 1:0.7, and 1:0.5 by weight of cement: fine aggregate. The used w/c ratios for the mixes were 0.7, 0.55, and 0.45, respectively, to attain a flow of 110 ± 5% according to ASTM C1437-15 [15].

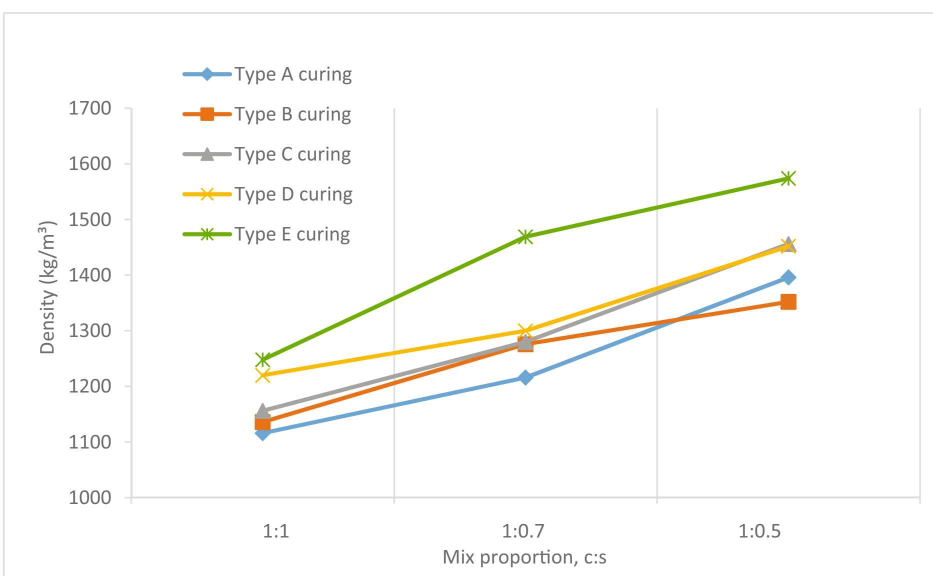

Figure 2: Effect of mix proportion on bulk density of cement mortar with different curing types.

Figure 3: Compressive strength test.

Table 6: Compressive strength of cement mortar with different curing methods

Mix proportion cement: Ponza sand	Curing method	Compressive strength (MPa) at age (days)			% Avg. from the value of mix E
		7	28	56	
1:1	A	5.1	6.2	6.65	71
	B	5.3	7.6	7.9	82
	C	5.5	7.6	8.05	83
	D	6.5	8.05	9.45	92
	E		9.05	10.05	—
1:0.7	A	7.65	10.8	11.6	75
	B	8.9	11.85	12.1	83
	C	10.3	12.05	12.4	88
	D	10.9	12.75	14.1	94
	E		14.05	14.75	—
1:0.5	A	9.1	12.6	13.3	74
	B	10.2	14.0	15.2	83
	C	12.3	13.55	14.5	79
	D	12.8	15.06	16.8	93
	E		16.6	17.9	—

2.3 Mixing, casting, and curing procedures

Cement mortar samples have been mixed according to ASTM C305-14 [16], then cast and compacted into prisms and cubes. After 24 h of mixing, the samples were demolded and divided into five curing groups, as shown below:

Type A: 1-day water curing, then left in the lab environment till testing age.

Type B: 1 day of water curing, followed by flan coat coating, were left in the lab environment until testing age.

Type C: 3-day water curing, then left in the lab environment till testing age.

Type D: 7-day water curing, then left in the lab environment till testing age.

Type E: 28-day water curing, then left in the lab environment till testing age.

3 Testing results and discussion

3.1 Dry density

The dry density of cement mortar was measured using 50 mm cubes, according to BS EN 1015-10 [17]. As expected, the results showed that the density decreased with increasing the amount of Ponza aggregate in the mix due to its low specific gravity. In contrast, the mixture with a mixing ratio 1:1 showed the weakest results. In comparison between the curing methods, it is noted that the longer the water curing period, the greater the density of the specimens; this is often due to the filling of voids with hydration products with the continuation of treatment. Table 5 presents the outcomes of the dry density test at 28 days of age. The results showed that all samples of the produced cement mortar were lightweight by comparing them with the bulk density results of many previous studies [18–20], where different types of LWAs were used in cement mortar. As shown in Figure 2, all samples (with varying proportions of mix) have higher density when using type B curing than those using type A curing, although they have the same period of water curing of 1 day. Also, the density of samples with mix 1:0.7 and type B curing reached 99.7% of those with type C curing, which were water cured for 3 days. This is because samples with type B curing have the advantage of preventing the evaporation of

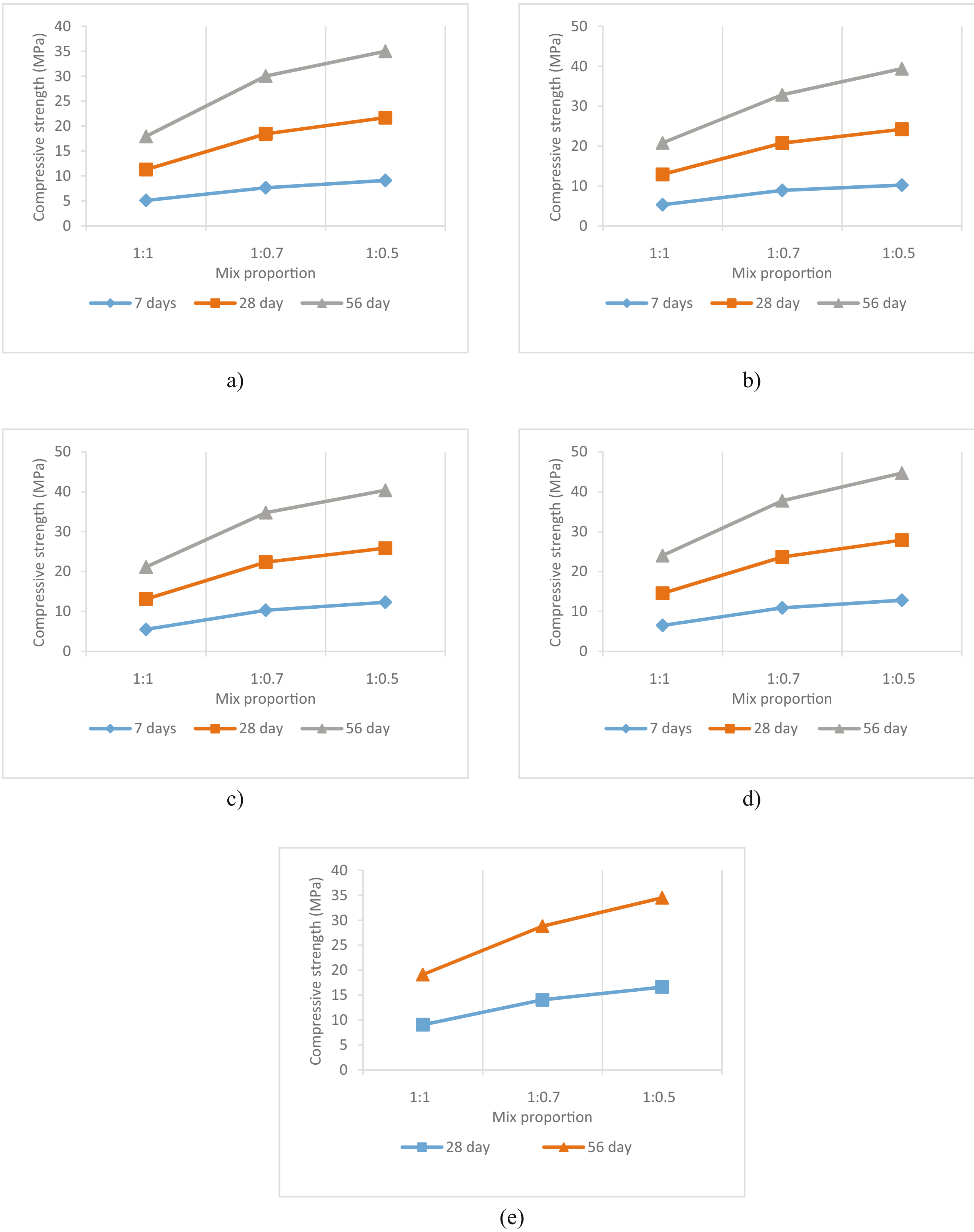

Figure 4: Effect of mix proportion on compressive strength of cement mortar with different curing types: (a) type A curing, (b) type B curing, (c) type C curing, (d) type D curing, and (e) type E curing.

Figure 5: Flexural strength test.

Table 7: Effect of curing method on flexural strength of cement mortar

Mix proportion	Type of curing method	Flexural strength (MPa) at age (days)			% Avg. from the value of mix E
		7	28	56	
1:1	A	1.12	1.20	1.41	79
	B	1.26	1.31	1.50	86
	C	1.24	1.23	1.48	84
	D	1.38	1.53	1.62	91
	E		1.70	1.85	—
1:0.7	A	1.47	1.89	2.31	76
	B	1.65	2.12	2.35	83
	C	1.51	2.14	2.30	80
	D	2.00	2.45	2.81	97
	E		2.52	2.91	—
1:0.5	A	2.20	2.71	2.90	81
	B	2.28	2.88	3.00	85
	C	2.35	2.80	2.98	85
	D	2.62	3.17	3.30	93
	E		3.41	3.55	—

water and introducing the internal curing property by using the water in the pores of lightweight Ponza sand.

3.2 Compressive strength

The compressive strength test was carried out using 50 mm cubes, according to ASTM C109/C109M-20 [21], using a digital compressive machine from the ELE International Company (Figure 3). Table 6 lists the effect of the curing method on the compressive strength of lightweight cement mortar. The results showed that all samples' 28-day compressive strengths, with different mixes and curing methods, are within ASTM C270-19a standards [22], which set the minimum average compressive strength of cement mortar at 5.2 MPa when used for non-load-bearing masonry. The findings also indicate that compressive strength decreases as the Ponza aggregate ratio increases that mix 1:1. It is logical because of the high void percentage in the Ponza aggregate. It is also demonstrated that the compressive strength increases with age, even with 1-day water curing, due to the internal curing property that results from the water's high absorption of Ponza aggregate and the release of the amount of water required to complete the hydration process. Figure 4 depicts that mix B shows higher compressive strength than mix A, similar to samples cured with type C. This is because the samples are covered with flan coats, which prevent water evaporation. So, mixed with type B curing, it can produce precast units with 1-day water curing. The results, presented in Table 6, also indicate that samples cured for 7 days (mix D) gain about 90% of compressive strength than those continuously cured for 28 days, which reduces the curing time before marketing the precast units made from this lightweight mortar.

3.3 Flexural strength

The flexural strength was evaluated using the third-point loading test method using prisms with 40 × 40 × 160 mm^3 (Figure 5) following the ASTM C348-21 specification [23], and the averages of three samples were listed for each testing age. Similar to the compressive strength, the flexural strength

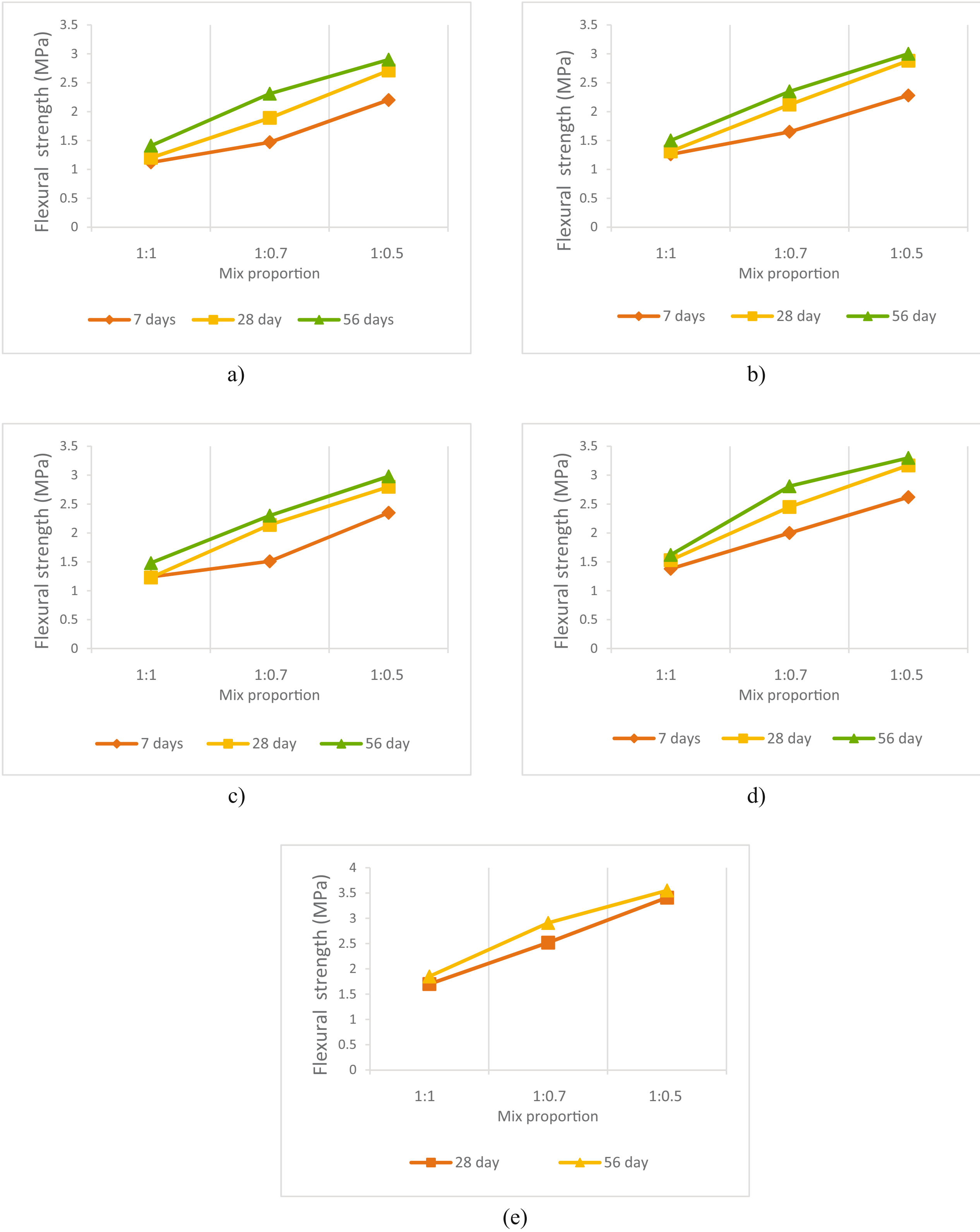

Figure 6: Effect of mix proportion on flexural strength of cement mortar with different curing types: (a) type A curing, (b) type B curing, (c) type C curing, (d) type D curing, and (e) type E curing.

Figure 7: Thermal conductivity measuring apparatus.

Table 8: Thermal conductivity of lightweight cement mortar

Mix proportion cement: fine aggregate	Thermal conductivity coefficient (W/m K)
1:1	0.3145
1:0.7	0.3667
1:0.5	0.4622

results of samples decreased by increasing the amount of Ponza aggregate; they both seem to be controlled by density. Samples with 1:0.7 and 1:0.5 mix proportions have higher flexural strengths by about 48.23 and 86.47%, respectively, than samples with 1:1 mix proportion when continuous water curing is used and tested at 28 days of age. Table 7 and Figure 6 indicate that the effects of internal curing on the flexural strength of samples with different mix proportions follow the

Table 9: Thermal conductivity of some building materials [24]

Material	Thermal conductivity coefficient (W/m K)
Blockwork (light)	0.38
Blockwork (medium)	0.51
Brick (exposed)	0.84
Brick (protected)	0.62
Concrete (cellular 1,200 kg/m^3)	0.4
Cement mortar	0.80
Plaster (gypsum)	0.46
Stone (limestone)	1.30
Stone (sandstone)	1.50

same trend as those affected by their compressive strength. The results showed that samples cured for 7 days (mix D) gain

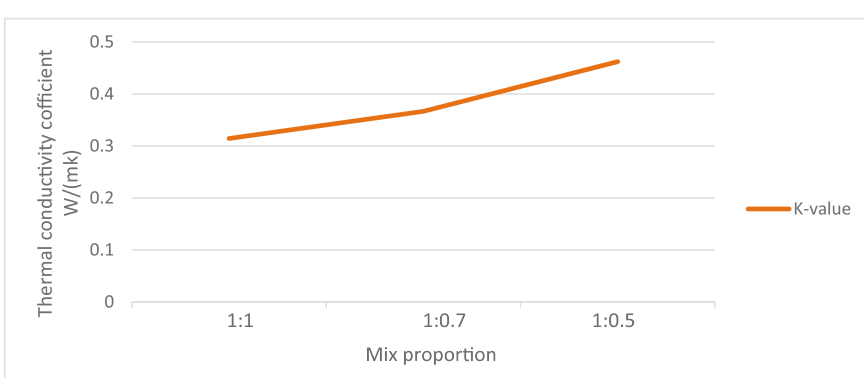

Figure 8: Thermal conductivity of cement mortar with different mix proportions.

about 91% of the flexural strength than those continuously cured for 28 days, which reduces the curing time before marketing the precast units made from this lightweight mortar.

3.4 Thermal conductivity

The thermal conductivity coefficient for the 100 mm cubes of lightweight cement mortar was conducted on 10 mm cubes according to ASTM C1113/C1113M-09 [25], using the apparatus shown in Figure 7. Table 8 and Figure 8 indicate the thermal conductivity of lightweight cement mortar mixtures cured by type E method. Results indicate that Ponza aggregate has a pronounced effect on reducing the thermal conductivity as mixtures 1:0.7 and 1:1 have lower thermal conductivity than 1:0.5 by about 20.66 and 31.95%, respectively, as well as lower thermal conductivity than many building materials which are indicated in Table 9. Therefore it is possible to use this material as an outer shield for building walls as the thermal insulating layer when recommended [26,27].

4 Conclusions

Based on the outcomes of this investigation, the following conclusions can be summarized:

1. It is possible to produce thermal insulating lightweight cement mortar using Ponza aggregate with mixtures 1:0.7 or 1:0.5 cement: LWA. So, for economical purposes, choosing a mixture of 1:0.7 to produce thermal insulating units to be erected as outer shields for building walls can be recommended.
2. Ponza fine aggregate can be used as an internal curing agent after moisturizing it to reach a surface-saturated dry condition in the production of cement mortar since the obtained results indicate that samples with moist curing for only 7 days (mix D) gain about 90% of compressive and flexural strength compared to those continuously cured for 28 days.
3. Covering lightweight cement mortar with a layer of flan coat was beneficial in preventing water evaporation and thus enhancing the effect of Ponza aggregate as internal curing agent.
4. Low thermal conductivity results were obtained for mixtures of 1:1 and 1:0.7 cement: lightweight fine aggregate, reaching about 0.3667 and 0.3145 W/m K, respectively.
5. The 28-day dry density of the produced cement mortar ranged between 1,116 and 1,574 kg/m^3 depending on the mix proportion and method of curing.
6. The 28 days age compressive strength of samples with different mix proportions and curing methods ranged between 6.2 and 16.6 MPa and flexural strength between 1.2 and 3.41 MPa.
7. It is recommended to produce building units from these mortar mixes in different sizes and study their properties compared to lightweight building units available locally and globally, whose properties were mentioned when comparing the values obtained in the research.

Funding information: The authors state no funding involved.

Conflict of interest: The authors state no conflict of interest.

Data availability statement: Most datasets generated and analyzed in this study are in this submitted manuscript. The other datasets are available on reasonable request from the corresponding author with the attached information.

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