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Lightweight concrete in hot coastal areas

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Abstract

An experimental study was carried out to examine different mixtures made with selected lightweight aggregates for the purpose of producing lightweight concrete. A relatively suitable product is sought in order to provide good quality building materials that can satisfy the conditions of hot coastal environments. Three ways of producing lightweight concrete were used, i.e., lightweight crushed bricks, lightweight expanded clay aggregate (LECA), and no-fines concrete. Physical and mechanical properties of the mixtures were examined to ascertain the suitability and applicability of the three concretes. The results of this pilot study suggest that there are possibilities of producing structural lightweight concrete using crushed bricks with the condition of further refinements in the mixture design.

Keywords: Lightweight concrete; Durability; Environment; Mix design; Properties; Crushed bricks

1. Introduction

Lightweight concrete (LWC) is an ideal material of construction in the hot coastal environment that prevails in the Arabian Gulf because of its thermal insulation characteristics [1]. Unfortunately, in the Gulf, there is a scarcity of both naturally occurring materials like clays and shales, and suitable industrial byproducts like fly ash and granulated blast furnace slag which are normally used in the manufacture of lightweight aggregate (LWA) [2]. Severe weather conditions associated with the coastal desert; abundance of chloride and sulphates in the environment, in ground, and water; and the limited supply of good quality aggregates all pose yet additional challenges to the durability of concrete and concrete structures [3–8]. There are of course worldwide environmental, economic and technical impetuses to encourage the structural use of LWC [9,10]. Low density products reduce the self-weight, foundation size and construction costs. Accordingly, a pilot research project was undertaken at Kuwait University to investigate the possibilities of producing LWC using lightweight crushed bricks (LWCB) which are available as a waste product. In order to broaden the scope of this investigation, two additional methods of producing LWCs were adopted to compare their characteristics with that of LWCB concrete. This paper contains the results of the preliminary investigation.

2. Experimental program

The objective was to produce LWCs of different strength and unit weight using LWCB, lightweight expanded clay aggregate (LECA), and normal weight gravel without the use of natural fine aggregate (no-fines concrete). Crushed lightweight bricks have been used as a coarse aggregate and are available in large quantities as a waste product in construction sites. Accordingly, lightweight bricks were brought in as a waste product and crushed in a mechanical crusher to different sizes. The physical properties of the aggregates are shown in Table 1 and the grading analysis in Table 2. LECA was imported and its characteristics are also presented in Table 1 as well as those of the gravel. The sieve analysis of LECA is included in Table 2. The coarse aggregate was used in a saturated surface dry condition (SSD) and the mixing water was computed as if aggregates were non-absorbent. Trial mixes were made to check the consistency of the concrete mixes. The consistency of the trial mixes was kept nearly uniform at a slump of 80–100 mm.

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Table 1
Physical properties of the coarse aggregate

Property	Crushed lightweight bricks	LECA	Gravel
Apparent specific gravity (gm/cm^3)	0.703	0.725	2.59
Absorption percentage (%)	47	28	1.02

Table 2
Sieve analysis of aggregates and combined aggregate used

Sieve size	% Passing by weight				
	Fine aggregate	LECA	Crushed lightweight bricks	LECA with 28.6% fine aggregate	Bricks with 28.6% fine aggregate
37.5 mm	–	100	94	100	96
20 mm	–	95	68	97	77
10 mm	100	60	38	72	56
5 mm	92	0	6	19	31
2.36 mm	66	0	0.4	11	19
1.18 mm	39	0	0	6	11
600 μm	22	0	0	4	7
300 μm	13	0	0	0	4
150 μm	0	0	0	0	0

2.1. Crushed lightweight bricks concrete

The method adopted for design was the absolute volume method. The quantities required for approximately 1 m^3 of finished concrete for different mixes are given in Table 3.

Lightweight aggregates were soaked in water for 24 h and then spread on cotton bags for 30 min to obtain SSD conditions. Mixing of materials was done in a mechanical mixer (half of the LWA, sand, cement and then the remaining LWA) for about half a minute. The water was then added and mixing continued till a uniform concrete was obtained, usually after 2 min. Fresh concrete was tested for slump and compacting factor.

2.2. Cast and curing of specimens

The following specimens were cast for each type of concrete:

150 mm cubes for compressive strength [6]
150×300 mm^2 cylinders for compressive strength [6]
$100\times100\times700$ mm^3 beams for flexural strength [3]
150×300 mm^2 cylinders for indirect tensile strength [6]
150×300 mm^2 cylinders for bond strength [3]
150×300 mm^2 cylinders for modulus of elasticity [3]
$75\times75\times300$ mm^3 prisms for drying shrinkage [3]
$200\times200\times120$ mm^3 slabs for water permeability [3]

Immediately after mixing, concrete was placed in molds and consolidated on a vibrating table and stored in the

Table 3
Quantities required for 1.0 m^3 of LECA, crushed bricks and no-fines concretes

Mix designation	LECA (kg)	Bricks (kg)	Gravel (kg)	Sand (kg)	Mixing water (liter)	Cement (kg)
L1	310	–	–	500	120	250
L2	300	–	–	500	140	300
L3	290	–	–	500	160	350
C1	–	320	–	160	120	250
C2	–	300	–	140	140	300
C3	–	280	–	120	160	350
N1	–	–	1550	–	120	250
N2	–	–	1500	–	140	300
N3	–	–	1450	–	160	350

concrete laboratory. Twenty four hours after casting, the specimens were demolded and placed in a control room maintained at 50 + 3%. Relative Humidity (RH) and 23 ± 2°C, till the day of test. The compressive and splitting tensile strengths of the concrete were determined both at 7 and 28 days, whereas all other tests were performed at 28 days. The results presented in this paper are the average of three tests.

3. Results and discussion

3.1. Properties of fresh concrete

There was no difficulty in controlling the consistency of the various concretes because the coarse aggregates were used in SSD condition and the additional water for the mix was calculated to control the slump. For various mixes the slump varied between 80–100 mm, and the compacting factor values ranged between 0.86 and 0.94. The concrete used in these tests generally showed very good workability and compatibility.

3.2. Properties of hardened concrete

The test results of the three different types of concrete are included in Tables 4–6.

3.2.1. Density

The density of LECA concrete varied from 1470 to 1520 kg/m^3; that of crushed lightweight bricks concrete from 1560 to 1670 kg/m^3 and of the no-fines concrete between 1830 and 1900 kg/m^3. According to the density values, only the latter can be classified as structural lightweight concrete [11].

3.2.2. Water permeability

Permeability of concrete to water was carried out according to DIN 1048 [12]. This test was performed on plate shape specimens of 200 × 120 mm^2. The test takes four days for completion. First a pressure of 1 bar was applied for 24 h, then pressure of 3 and 7 bar, each for 24 h. Immediately after the test, the plate was split in the middle and the water penetration depth and its distribution were measured. Generally the water permeability

Table 4
Properties of hardened LECA concrete

Mix designation		L1	L2	L3
Cement content (kg/m^3)		250	300	350
Cube compressive strength (MPa) – days	7	14.5	16.0	21.0
	28	15.5	19.5	29.0
Cylinder compressive strength (MPa) – days	7	11.0	13.0	18.0
	28	13.0	15.0	22.0
Indirect tensile strength (MPa) – days	7	1.6	1.8	2.3
	28	1.8	2.2	3.3
Flexural strength (MPa) – days	28	3.6	4.5	6.1
Bond strength (MPa) – days	28	2.4	3.1	4.1
Modulus of elasticity (GPa) – days	28	10.0	11.0	13.0
Shrinkage (μs) – days	28	93	146	193
Dry unit weight (kg/m^3) – days	28	1470	1490	1520

Table 5
Properties of hardened crushed lightweight bricks concrete

Mix designation		C1	C2	C3
Cement content (kg/m^3)		250	300	350
Cube compressive strength (MPa) – days	7	10.5	12.0	15.0
	28	13.0	14.5	21.0
Cylinder compressive strength (MPa) – days	7	8.0	9.8	11.5
	28	10.5	12.0	15.0
Indirect tensile strength (MPa) – days	7	1.2	1.5	1.9
	28	1.5	1.7	2.2
Flexural strength (MPa) – days	28	2.9	3.2	3.8
Bond strength (MPa) – days	28	2.0	2.6	2.9
Modulus of elasticity (GPa) – days	28	8.5	9.2	10
Shrinkage (μs) – days	28	113	169	212
Dry unit weight (kg/m^3) – days	28	1560	1600	1670

Table 6
Properties of hardened no-fines concrete

Mix designation		N1	N2	N3
Cement content (kg/m^3)		250	300	350
Cube compressive strength (MPa) – days	7	7.0	8.0	8.0
	28	8.0	8.5	9.5
Cylinder compressive strength (MPa) – days	7	5.5	6.2	7.1
	28	6.0	7.0	8.0
Indirect tensile strength (MPa) – days	7	1.0	1.1	1.3
	28	1.1	1.3	1.6
Flexural strength (MPa) – days	28	2.1	2.9	3.4
Bond strength (MPa) – days	28	1.8	2.4	3.1
Modulus of elasticity (GPa) – days	28	6.5	7.3	8.9
Shrinkage (μs) – days	28	71	84	98
Dry unit weight (kg/m^3) – days	28	1830	1870	1900

was considerably high for the three investigated lightweight concretes at the age of 28 days. The water penetrated all specimens to the full depth, i.e., 120 mm. One reason for this high value of water penetration was the lack of curing; none of these concretes were properly cured, neither in a humidity/temperature control room nor in water.

3.2.3. Drying shrinkage

The drying shrinkage strain of LECA concrete, as shown in Fig. 1, ranged from 93 to 193 μs, while the drying shrinkage of crushed lightweight brick concrete and no-fines concrete varied from 113 to 212 μs and 71–98 μs, respectively.

It can also be noticed that generally, drying shrinkage is higher for the same type of aggregate for the mixtures containing a higher amount of cement factor.

Considering the effect of aggregate type on drying shrinkage, crushed lightweight bricks had the highest values, whereas no-fines concrete displayed the lowest results for all cement contents. This finding is attributed to the porosity and absorption capacity of different aggregates, the higher the porosity, the higher the drying shrinkage. Crushed lightweight bricks, LECA and no-fines had absorption percentages of 47%, 28% and 1%, respectively, which resulted in a higher demand for mixing water and an increased water-to-cement ratio, both contributing to higher drying shrinkage strains.

3.2.4. Effect of aggregate type on cube compressive strength

The influence of aggregate type on cube compressive strength is shown in Fig. 2. Generally it was found that the compressive strength varied within the range of 8–29 MPa. For the similar cement content, the LECA concrete produced the highest compressive strength.

3.2.5. Effect of cement content on cube compressive strength

The effect of cement content on cube compressive strength can also be seen in Fig. 2. As anticipated, increasing of cement content resulted in an increase in concrete strength. However, the rate of increase was less pronounced for 250–300 kg/m^3 than that obtained for 300–350 kg/m^3.

3.2.6. Effect of specimen shape on compressive strength

It is well known that for the purposes of the quality control, both cubes and cylinders are employed. Conversion factor between the two strengths as yielded from

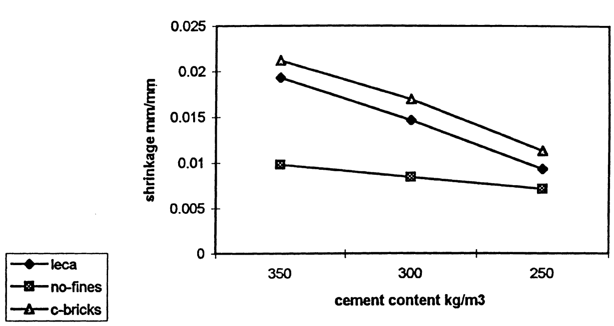

Fig. 1. Relationship between 28 days shrinkage and cement content of the three types of lightweight concretes tested.

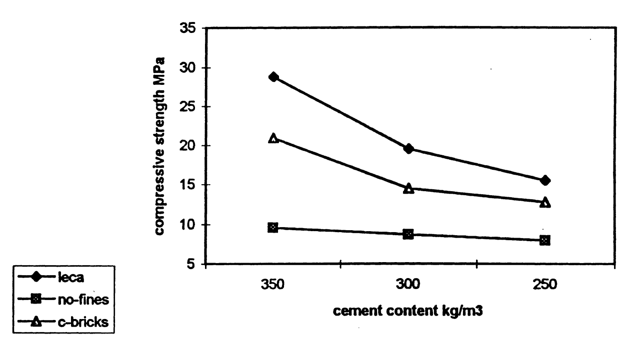

Fig. 2. Relationship between cement content and 28 days compressive strength for the lightweight concretes tested.

different specimens is of practical importance. The correlation between the cube strength and cylinder strength at the ages of 7 and 28 days is given in Table 7 and Fig. 3, respectively. A general relation for lightweight concretes for the aggregates used in this work is given below:

cubes = 1.28 (cylinder) – 0.22.

The overall average value of the ratio of the cylinder to cube strength, at the age of 28 days for all the LWCs tested was 0.78, which is also similar to the individual averages of the three concretes. The value quoted more often for this ratio is 0.85 even though a great variation in this value is reported in the literature [13].

3.2.7. *Splitting, flexural and bond strengths*

The splitting strength varied between 1.1 and 3.3 MPa, the flexural strength between 2.1 and 6.1, and the bond strength between 1.8–4.1 MPa as can be seen in Tables 4–6. Further, for the same cement content, the LECA concrete has yielded the highest value of these reported strengths.

3.2.8. *Modulus of elasticity*

Fig. 4 shows the modulus of elasticity as correlated with cement content. The modulus of elasticity varied between 6.5 and 13 GPa (see Tables 4–6). For the same cement content, the LECA concrete had the highest modulus of elasticity. The ranges of the moduli of the LECA, crushed bricks and no-fine concretes are: 10–13, 8.5–10 and 6.5–8.9 GPa, respectively. Fig. 5 shows the correlation between the modulus of elasticity and the compressive strength, it can be observed that for the range of strengths and the types of aggregates investigated, the modulus increased as the compressive strength increased (see Table 8).

Table 7
Relationship between cube and cylinder strength for each concrete type

Type	Equations
LECA concrete	Cubes = 1.31 (cylinder) – 0.99
Crushed lightweight bricks concrete	Cubes = 1.57 (cylinder) – 3.11
No-fines concrete	Cubes = 0.85 (cylinder) + 2.64

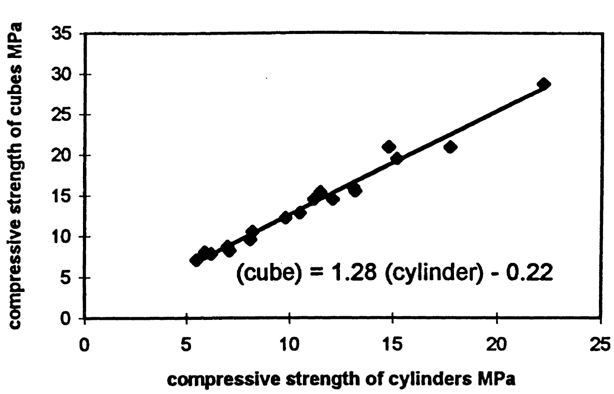

Fig. 3. Variation of cube compressive strength with cylinder strength for the lightweight concretes tested.

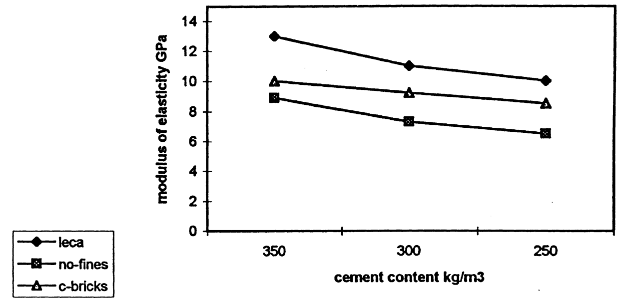

Fig. 4. Relationship between 28 days modulus of elasticity and cement content of the lightweight concretes tested.

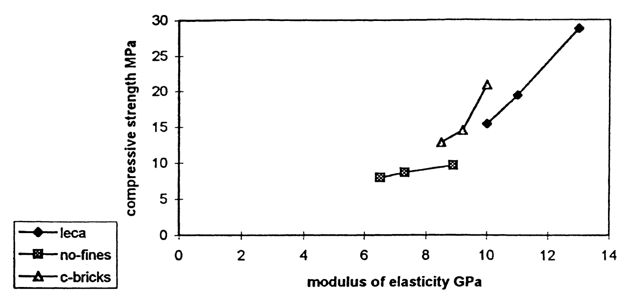

Fig. 5. Relationship between 28 days modulus of elasticity and compressive strength of the lightweight concretes tested.

4. Concluding remarks

Three types of LWCs manufactured and characterized in this investigation gave a huge range in their physical and mechanical properties (see Table 8). The results suggest that such concretes have the potential to be used in construction, according to their properties, as insulation material, block work or structural members to reduce dead loads, improve energy efficiency and enhance the environment.

Due to the high porosity of the lightweight concretesinvestigated for comparatively lower cement content, the water penetrability and hence its vulnerability to damaging species is higher. In addition, the strength and rigidity of the lightweight concretes are also low. Nonetheless, with proper mix design, using both mineral and chemical admixtures including superplasticisers, the strength and durability of the concrete using crushed bricks can be enhanced considerably.

Table 8
The main properties of hardened concrete

Property	LECA concrete	Crushed lightweight bricks concrete	No-fines concrete
Density (kg/m^3)	1470–1520	1560–1670	1830–1900
Shrinkage (μs)	93–193	113–212	71–98
Compressive strength (MPa)	15.5–29.0	13–21.0	8–9.5
Indirect tensile strength (MPa)	1.8–3.3	1.5–2.2	1.1–1.6
Flexural strength (MPa)	3.6–6.1	2.9–3.8	2.1–3.4
Bond strength (MPa)	2.4–4.1	2–2.9	1.8–3.1
Modulus of elasticity (GPa)	10–13	8.5–10	6.5–8.9

Costs versus performance, energy conservation and environmental impacts are important areas to consider in the feasibility or the value analysis to study different aspects affecting the best choice to be implemented in the construction industry. Structural elements and prototype testing are being undertaken to investigate the durability and serviceability of some of the optimized lightweight concretes.

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