The behavior of Lightweight Aggregate Concrete Made with Different Types of Crushed Bricks

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Abstract. Lightweight concrete can significantly reduce a dead load of structural concrete elements compared to normal weight concrete. The reuse of construction and demolition wastes, especially crushed clay bricks, represents a major contribution to the environment. Due to the nature of clay bricks, it can be considered as source of fine and coarse aggregate to produce lightweight structural concrete. In this study, used three types of crushed clay brick as coarse aggregate for concrete aiming to produce structural lightweight concrete. Density, compressive and flexural strengths were tested. Results show that the 28-day air-dry density, compressive and flexural strengths values of the concrete made with Iso crushed brick were higher than that for concrete made with crushed Iranian and Nahrawan bricks. Results of 28 air-dry density and compressive strength show that the lightweight concretes used were complied with the requirements for lightweight structural concrete.

Keywords: Lightweight concrete, Crushed bricks aggregate, Compressive strength, Flexural strength, Density.

1. Introduction

The use of waste aggregate in concrete is not new, it used widely since World War II in Germany [1]. 400-600 Million cubic meters was used in concrete construction, the use of waste clay bricks is a benefit as it reduces environmental pollution and decreases the cost of concrete since the volume of aggregate in the concrete of about 60-75%. Using waste bricks lead to reduce the density of concrete and also to reduce compressive strength. Hiremath and Sanjay investigation [2], use waste clay brick aggregates as replacement of coarse aggregate with the different ratio from 0 to 100%, compressive strength decreased from about 31 MPa to 11 MPa, but tensile strength increased by 25% replacement with 20% increment in splitting tensile strength. Subramani [3] showed that the using 50% crushed brick as coarse aggregate
replacement increases the value of flexure strength by about 5% compared to reference mix. Waste thermostone also used as coarse and fine aggregate to provide lightweight concrete [4], and lead to reduce compressive strength by 75% by using 100% replacement. Padmini, et al. [5] showed that the density of brick aggregate concrete is 15% lower as compared conventional concrete, and it increases with cement content and reduces with increase in water cement ratio. This investigation aims to study the possibility of produce lightweight concrete using crushed clay bricks as coarse aggregates. In this research, the density, compressive strength and flexural strength are studied. The main variables in this investigation are; types of crushed bricks used (Iranian crushed brick, Nahrawan crushed brick and Iso crushed brick as coarse aggregates), and W/C (0.45 and 0.30)

2. Experimental program

2.1 Materials

2.1.1 Cement

Ordinary Portland cement manufactured by KAR Group was used in all mixes throughout this study. Tables 1 and 2 show the chemical analysis and physical properties of the used cement. The results show that the cement conformed to Iraqi specifications (I.S.O) No. 5/1984.

| Oxides composition          | Content % | I.Q.S.NO.5,1984<sup>50</sup> |
|-----------------------------|-----------|-------------------------------|
| CaO                         | 56        | 0.66-1.02                     |
| SiO<sub>2</sub>              | 19        | < 5%                          |
| AL<sub>2</sub>O<sub>3</sub>   | 3.98      |                               |
| Fe<sub>2</sub>O<sub>3</sub>  | 3.76      |                               |
| Lime saturation Factor(L.S.F) | 0.962   |                               |
| MgO                         | 2.79      | < 2.8%                        |
| C<sub>3</sub>A              | 4.187     |                               |
| SO<sub>3</sub>              | 2.32      | < 4%                          |
| Loss on ignition(L.O.I)     | 3.04      |                               |
| Insoluble Residue           | 1.01      | < 1.5%                        |

*Chemical analysis tests were carried out by the Engineering Consulting Bureau. Laboratories-University of Kufa
Table 2. Physical Properties of Cement*.

| Physical properties                          | Test result | limits of IOS No.5:1984 |
|---------------------------------------------|-------------|-------------------------|
| Fineness: specific surface, Blaine cm²/gm   | 2760        | 2300 (minimum)          |
| Setting time, Vicat’s method:-              |             |                         |
| Initial (hrs: min.)                         | 1:45        | 00:45 (minimum)         |
| Final (hrs: min)                            | 4:10        | 10: 00 (maximum)        |
| Compressive strength of cement mortar using cubes (70.7mm) MPa |             |                         |
| 3 days                                      | 20.3        | 15 (minimum)            |
| 7 days                                      | 28.6        | 23 (minimum)            |

* Physical tests were carried out by the Engineering Consulting Bureau, Laboratories- University of Kufa

2.1.2 water

Ordinary tap water was used for mixing and curing for all concrete mixes of this study.

2.1.3 High Range Water Reducing Admixture (HRWRA)

A high performance concrete superplasticizer based on modified polycarboxylic ether, which is known commercially (SP 90), was used throughout this investigation as a (HRWRA). It is the third generation of superplasticizers and it complies with ASTM C 494-2003 Type F.

2.1.4 Fine aggregate

Normal weight natural sand, brought from Al-Najaf quarry was used as fine aggregate in this work. The grading is given in Table 3. The physical and chemical tests on sand used throughout this work are shown in Table 4. Results indicated that the fine aggregate grading and sulfate content are within the requirements of the Iraqi specification No.45/1984.

Table 3. Grading of the used sand and the requirements of I.O.S 45/1984.

| Sieve size | % Passing | % Passing limits of I.O.S 45/1984 (Zone 2) |
|------------|-----------|------------------------------------------|
| 10 mm      | 100       | 100                                      |
| 4.75 mm    | 100       | 90-100                                   |
| 2.36 mm    | 97        | 75-100                                   |
| 1.18 mm    | 80        | 55-90                                    |
| 600 µm     | 53        | 35-59                                    |
| 300 µm     | 12        | 8-30                                     |
| 150 µm     | 6         | 0-10                                     |
Table 4. Chemical and physical properties of the used sand.

| Property                                          | Specification       | Result | Limit of I.O.S No. 45/1984 |
|---------------------------------------------------|---------------------|--------|-----------------------------|
| Bulk Specific gravity                             | ASTM C128-2003      | 2.53   |                             |
| Absorption, %                                     | ASTM C128-2003      | 1.9    |                             |
| Dry loose unit weight, kg/m³                       | ASTM C29-2003       | 1580   |                             |
| Sulfate content (as SO₃), %                       | I.O.S No.45-84      | 0.08   | 0.5 (Max.)                  |
| Materials finer than 0.075 mm sieve, %            | I.O.S No.45-84      | 1.1    | 5.0 (Max.)                  |

2.1.5 Coarse aggregate

Three types of crushed bricks with maximum size (19 mm) were used in this study as shown in Figure 1. Table 5 shows the compressive strength of bricks and the density and absorption of crushed bricks. Table 6 shows the grading of crushed brick aggregate.

Table 5. Properties of three types of crushed bricks used as coarse aggregate.

| Brick type    | Density, kg/m³ | Absorption % | Compressive strength of brick (MPa) |
|---------------|----------------|--------------|------------------------------------|
| Iranian Bricks| 816            | 32.30        | 10.10                              |
| Nahrawan Brick| 835            | 23.14        | 17.08                              |
| Iso-Bricks    | 889            | 15.87        | 30.21                              |

Figure 1. Crushed bricks (a) Iranian brick (b) Nahrawan brick (c) Iso brick
Table 6. Selected grading of coarse lightweight aggregate.

| Sieve size (mm) | Selected % passing | % Retained | % Passing ASTM C330 |
|-----------------|--------------------|------------|---------------------|
| 19              | 100                | 0          | 90-100              |
| 12.5            |                    |            |                     |
| 9.5             | 50                 | 50         | 10-50               |
| 4.75            | 10                 | 40         | 0.15                |
| 2.36            | 0                  | 10         | -                   |

2.2 Mix concrete design

Six different LWAC (Lightweight Aggregate Concrete) mixes (identified as MIR, MNH, MIS, MIR-H, MNH-H, and MIS-H), were used in this study. [MIR-mix made with Iranian crushed bricks, MNH-mix made with Nahrawan crushed bricks, MIS-mix made with Iso crushed bricks] and the other three mixes containing High Range Water Reducing Admixtures. The six concrete mixes differed by water/cement ratio and the type of crushed brick used. These mixes were designed in accordance with ACI committee 211-2[6] to produce a structural LWAC. The details of the mixes used throughout this investigation are given in Table 7.

Table 7. Details of the mixes used throughout this study.

| Type of mix | Cement Kg/m³ | Fine agg. Kg | Crushed brick as Coarse Agg. Kg | Type of crushed brick | w/c | HRWRA% by wt. of cement | Slump mm |
|-------------|---------------|--------------|---------------------------------|-----------------------|-----|------------------------|----------|
| MIR         | 350           | 960          | 480                             | Iranian               | 0.45| -                      | 100      |
| MNH         | 350           | 960          | 480                             | Nahrawan              | 0.45| -                      | 105      |
| MIS         | 350           | 960          | 480                             | Iso                   | 0.45| -                      | 110      |
| MIR-H       | 350           | 960          | 480                             | Iranian               | 0.30| 2.00                   | 110      |
| MNH-H       | 350           | 960          | 480                             | Nahrawan              | 0.30| 2.00                   | 105      |
| MIS-H       | 350           | 960          | 480                             | Iso                   | 0.30| 2.00                   | 110      |

2.3 Preparation and Curing of Test Specimens

All concrete specimens were cast in steel moulds in layers. Each layer was compacted by a steel rod. The specimens were kept in their molds at room temperature with a plastic sheet cover to minimize water losses for 24 hours. After that they were demolded and immersed in water tank up to the age of 28 days at laboratory temperature of about (23±2 °C).

2.4 Tests

2.4.1 28-Day Air Dry Density

The test was performed in accordance with ASTM C567 (2003) [7] using 150×300 mm cylindrical specimens. After demolding the specimens were left for 6 days in air-tight polyethylene sheets. After that, they were removed and immersed in water for one day. The next day, saturated surface dry and
suspended- immersed weight were taken. The specimens were left in the laboratory for 21 days, then the dried specimens were weighed and the 28-day air-dry density was calculated

**2.4.2 Compressive strength test**

The compressive strength test was determined according to B.S. 1881 Part 116 [8]. This test was conducted on 150 mm cubes using an electrical testing machine with a capacity of 2000 kN at a loading rate of 15 MPa per minute.

**2.4.3 The flexural strength**

The flexural strength test (two point load) was determined according to B.S. 1881 Part 118 [9]. This test was conducted on 100x100x400 mm prisms using an electrical testing machine with a capacity of 2000 kN.

### 3- Results and discussion

#### 3.1 28 air-dry density

The 28 day air dry density of all types of LWAC mixtures are presented in Figure 2. Results show that the 28 day air dry density of lightweight concretes produced from different types of crushed bricks aggregate ranged between (1935-1990) kg/m³. However, all LWAC mixes conform to the requirements of structural LWAC, according to RILEM (1975) [10] classification, which limits the maximum density to 2000 kg/m³. As expected, the 28-day air-dry unit weight values increase with the decrease of w/c ratio. The values of air-dry unit weight ranged between (1988-1990) kg/m³. This is attributed to the low water content and consequently, low air voids.

#### 3.2 Compressive strength

The results of the compressive strength for each mix tested at 28 days are shown in Figure 3. It is clear from these results that the compressive strength value of the concrete made with Iso crushed brick was higher than that for concrete with crushed Iranian and Nahrawan bricks by about 42.5% and 18.6% respectively. This may be because of the high porosity and low strength of Iranian and Nahrawan bricks comparing to Iso, which affects negatively on the strength.

Test results also showed that using an HRWRA increases the compressive strength with the decrease in w/c ratio. This can be first attributed to the better dispersion of the cement particles throughout the concrete mix, and second to the lower initial volume of voids that are needed to be filled by the products of hydration due to the reduction in the volume of mixing water. The compressive strength were 17.70, 22.36 and 25.49 MPa for concrete mixes made with Iranian, Nahrawan and Iso crushed bricks respectively. These results show that the lightweight concretes used were complied with the requirements of ACI Committee 213R for structural lightweight concrete [11].

#### 3.3 Flexural strength

The results of flexure strength tests are shown in Figure 4. The test results showed that the flexure strength values were 2.29, 3.63 and 3.98 MPa for concrete mixes with Iranian, Nahrawan and Iso crushed brick respectively. It is clear that mix with Iranian crushed brick give smaller values than Nahrawan and Iso crushed Bricks due to its low weight and high water absorption.
Results also indicate that the incorporation of HRWRA in LWAC leads to higher flexural strength compared to their corresponding reference concrete. This behavior is mainly attributed to the significant reduction in the capillary porosity of the cement matrix as well as to the good dispersion of the cement grains throughout the mix. The flexural strength values were 3.89, 4.08 and 4.44 MPa for mixes with Iranian, Nahrawan and Iso crushed brick respectively.

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{figure2.png}
\caption{Air dry density of concrete with different crushed bricks.}
\end{figure}
Figure 3. Compressive strength of concrete with different crushed bricks.

Figure 4. Flexural strength of concrete with different crushed bricks.
4. Conclusions

1. The 28-day air-dry density of lightweight concretes produced from different types of crushed bricks aggregate ranged between (1935-1990) kg/m³.

2. The compressive strength value of the concrete made with Iso crushed brick was higher than that for concrete with crushed Iranian and Nahrawan bricks by about 42.5% and 18.6% respectively. Test results also showed that using an HRWRA increases the compressive strength values.

3. The flexure strength of the lightweight concrete cast using Iso crushed brick is higher than lightweight concretes cast using Iranian and Nahrawan crushed brick, as aggregates by about 42% and 9%, respectively. Results also indicate that the incorporation of HRWRA in LWAC leads to higher flexural strength compared to their corresponding reference concrete.

4. The results of 28 air-dry density and compressive strength show that the lightweight concretes used were complied with the requirements for lightweight structural concrete.

References

[1] Otoko G 2004 Used of crushed clay bricks as aggregate in concrete , International journal of engineering and technology research, vol 2 NO.4, ISSN 2327 – 0349 pp. 1-9.

[2] Hiremath M and Sanjay S 2017 Replacement of coarse aggregate by demolished Brick waste in concrete. International Journal of science technology and engineering, vol 4 issue 2 pp. 31-36.

[3] Subramani, T. 2015 Experimental investigation of using concrete waste and brick waste as coarse aggregate. Intern jour of application & innovation in engineering & management vol 4 issue 5 pp. 294 – 303.

[4] Borhan T 2015 Effect of using recycled lightweight aggregate on the properties of concrete. Journal of Babylon University, engineering sciences vol 23 No.2 pp 1-12.

[5] Padmini AK, Ramamurthy K and Mathews MS 2001 Behavior of concrete with low-strength bricks as lightweight coarse aggregate. Magazine of Concrete Research vol.53 No.6 pp. 367-375.

[6] ACI Committee 211.2 2003 Standard Practice for Selecting Proportion for Structural Lightweight Concrete ACI Manual of Concrete Practice, Part 1 pp.1-16.

[7] ASTM C567 2003 Standard Test Methods for Determination Density of Structural Lightweight Concrete Annual Book of ASTM Standard, Vol. 04-02 pp302-304.

[8] BS 1881 Part 116 1983 Method for Determination of Compressive Strength of Concrete Cubes British Standard Institute 1983 pp. 1-3

[9] BS 1881 Part 118: 1983 Method for Determination of flexural Strength of Concrete British Standard Institute, pp 1-6

[10] RILEM 1975 Terminology and Definitions of Lightweight Concrete. Recommendation LCI. 1st edition.

[11] ACI 213 R 2003 Guide for Structural Lightweight-Aggregate Concrete' ACI Manual of Concrete Practice "2003

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