Relationship between Density and Strength for High-volume Fly Ash Lightweight Porcelainite Concrete

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Abstract. In concrete construction, there are many advantage in reducing total load on the structure. One of the methods to reduce the load is using lightweight concrete, LWC. The concrete production is not sustainable due to its consuming a lot of Portland cement, which is responsible for the emission of greenhouse gases that cause global warming. One of the effective methods to reduce the impact of negative environmental concrete industry is using by product materials such as fly ash as a partial replacement by weight of cement. In the present study, the ability of producing high-volume fly ash structural lightweight aggregate concrete was verified. This concrete was produced by using Porcelanite aggregate and a large amount of type F fly ash as partial replacement by weight of cement, 50, 60 and 70 %. The studied characteristics are: density, water absorption, compressive and splitting tensile strengths at different ages. Lightweight concretes containing high-volume fly ash, 50 and 60 % by weight of cement, have proven themselves as structural lightweight concrete with compressive strength, \( f_c \), more than 17 MPa at 28 days age. The results in this study showed that increasing fly ash content up to 70 % will decrease the compressive strength but on the other hand it will significantly reduce density and increasing water absorption.

1. Introduction
The best solution for treating the Portland cement impact on environment is using high-volume fly ash light weight concrete where there is a significant reduction in cement content if compare with the conventional mixes. cement is in charge of the main quantity of the energy that consumed in the industry of concert [1] Hence, the replacing high volume of cement (50% or more) with materials by products of industrial such as fly ash or blast furnace slag is going to be highly useful in terms of environment, cost, durability, and low permeability [2]. Jow et al., 2015 [3], reported that the quantity of fly ash wash producing globally in 2008 about 777 million tons, and just 54% has been used.

Wang et al. 2016 [4], stated that the extra huge quantity of fly ash will led to impact of ecological environment, pollution of air, and dust. Arezoumandi et al., 2003; Yao et al., 2015 [5][6], stated that the common ratio of using of fly ash ranged between 15-35% by weight as a fractional cement replacement. Sadati et al., 2016 [7], indicated that the producing normal high-volume fly ash concrete has been deliberate and good established for the latest thirty years. From the other hands the available information related with the properties for high-volume fly ash structural light weight concrete is limited. The common application of using fly ash in light weight concrete was as a partially replacement by weight of cement with moderated ratio [7][8][9]. Additional fly ash was used to make light weight aggregate [10]. The main gold of the present deliberating is to study some physical and properties of mechanical of structural lightweight concrete having fly ash type F with ratio ranged between 50% up to 70% by weight of cement.
2. Experiment work

2.1. Materials

2.1.1 Cement

A cement type 1 produced by Bazain cement factory was used in this work. Chemical analysis results and results of physical tests showed in tables (1 and 2) respectively.

| Chemical configuration | Content % | I.Q.S Limit NO.5\1984 and adaptation No.1and 2 for 2010 |
|------------------------|-----------|-------------------------------------------------------|
| SiO₂                   | 19.98     | ----                                                 |
| CaO                    | 62.47     | ----                                                 |
| MgO                    | 2.26      | ≤5.00                                                |
| Fe₂O₃                  | 3.23      | ----                                                 |
| Al₂O₃                  | 4.98      | ----                                                 |
| SO₃                    | 2.54      | ≤2.8                                                |
| Na₂O                   | 0.3       | ----                                                 |
| K₂O                    | 0.7       | ≤2.80                                               |
| L.O.I                  | 3.02      | ≤ 4.00                                              |
| I.R                    | 1.22      | ≤ 1.5                                               |
| L.S.F.                 | 0.977     | 0.66 - 1.02                                         |

Main Compounds (equations of Bogue)

| Properties            | Result | I.Q.S Limit NO.5\1984 and adaptation No.1and 2 for 2010 |
|-----------------------|--------|---------------------------------------------------------|
| Specific Surface area | 3770   | ≥2300                                                   |
| (Blaine method,cm²/gm)|        |                                                         |
| Soundness             | 0.01   | ≤ 0.8 %                                                |
| (auto clave method)    |        |                                                         |
| Time of setting        |        |                                                         |
| Initial time of setting| 2 : 40 | ≥ 45                                                   |
| Final time of setting  | 4 : 00 | ≤10:00                                                  |
| Compressive Strength   |        |                                                         |
| 3-days N/mm²           | 32     | ≥15                                                    |
| 7-days N/mm²           | 38     | ≥23                                                    |

*The test was done in the N. C. C. L \ Karbala lab.

2.1.2 Sand

Al-ukhaidur natural normal weight sand was used, chemical and physical properties was described in Tables 3 and 4.
Table 3. Chemical** and Physical* Properties of Sand.

| Property                             | Specification      | Result | Boundary of Specification |
|--------------------------------------|--------------------|--------|--------------------------|
| Bulk Specific Gravity                | ASTM C128 -15     | 2.54   | -                        |
| % of absorption                      | ASTM C128 -15     | 1.42   | -                        |
| Dry loose density (Kg/m³)            | ASTM C 29 - 15    | 1.585  | -                        |
| Sulfate content as (SO₃)             | IQS No. 45/1984 and adaptation | 0.14 | ≤ 0.5 %                  |
| Materials finer than 75µm, %        | No. 2 for 2010    | 2.7    | 5.0 (max.)               |

* The test was done in the N. C. C. L\Karbalalab.
** The test was done in Directory of building research

Table 4. Grading of fine aggregate*

| Sieve opening, mm | % cumulative passing | I. Q. S Limit NO.45/1984 and adaptation No. 2 for 2010 |
|-------------------|----------------------|-------------------------------------------------------|
| 4.75              | 100                  | 89-100                                                |
| 2.36              | 91                   | 60-100                                                |
| 1.18              | 83                   | 30-100                                                |
| 0.600             | 72                   | 15-100                                                |
| 0.300             | 39                   | 5-70                                                  |
| 0.150             | 8                    | 0-15                                                  |

Fineness modulus 2.07

* The test was done in the N. C. C. L\Karbalalab.

2.1.3 Lightweight aggregate
Porcelainite stone which is a Local naturally lightweight aggregate was used as coarse aggregate in this study. The quarry lies in Trefawi zone in Western desert of Iraq. Porcelainite stone was crushed and then sieved by standard sieves to get aggregate with maximum size 19 mm. Table 5, Table 6, and Table 7 were illustrated chemical properties of Porcelanite rocks, grading and physical chemical properties of light weight aggregate. Picture1 shows Porcelanite rocks before and after crushed to desire size.

2.1.4 Fly ash
Fly ash type F was used in this work, Table 8 and Table 9 were presented chemical and physical fly ash properties.

2.1.5 Chemical Admixture (HRWRA)
In this study master GLENIUM51 was used as a high range water reducer admixture. HRWRA has been used in the concrete industry when the high performance and durability are required. HRWRA is ad equated with the condition of ASTM C494 -15. As well as it is well-matched with different kinds of Portland cement. It gives an increase in slump without segregation. It is using by adding the HRWR with the half of mixing water as mention in the guides. Table 10 shows typical specifications of HRWRA

Table 5. Chemical analysis for rocks of Porcelainite

| Chemical Composition | (% of Test Results) * |
|----------------------|------------------------|
| SiO₂                 | 52.36                  |
| CaO                  | 10.19                  |
| MgO                  | 5.77                   |
| Al₂O₃                | 12.34                  |
| Fe₂O₃                | 2.64                   |
| SO₃                  | 0.39                   |
| L.O.I                | 16.30                  |

* The test was achieved by BRD,
Table 6. Grading of Coarse Lightweight Aggregate according to ASTM C330-87*

| Sieve Size, mm | %Passing of ASTM C330-87 | Selected %Passing |
|---------------|--------------------------|-------------------|
| 25            | 100                      | 100               |
| 19            | 90-100                   | 100               |
| 12.5          | -                        | -                 |
| 9.5           | 20-55                    | 50                |
| 4.75          | 0-10                     | 7.5               |
| 2.36          | 0-5                      | 3                 |

* The test was done in the N. C. C. L\ Karbala lab.

Table 7. Illustrates Physical and Chemical Test Results for L.W.A*

| Property                        | Test According to | Result  |
|---------------------------------|-------------------|---------|
| Specific of Gravity             | ASTM C127-15      | 1.65    |
| % of absorption                 | ASTM C127-15      | 29.5    |
| Dry-loose density, Kg/m³        | ASTM C29-15       | 625     |
| Dry-rodmed density, Kg/m³       | ASTM C29-15       | 734     |
| Aggregate crushing value (ACV), % | Bs812:part110:1990 | 16      |
| Sulfate content as (SO₃)%**     | Bs3797:part2:1981 | 0.39**  |

* The test was done in the Karbala lab.
* *The test was achieved by BRD,
*** the max is 1%

A: Porcelainite rocks
B: Porcelainite aggregated after sieved on stander sieves

Picture 1. Porcelainite rocks before and after broken for desiring sizes

Table 8. Chemical Analysis of fly ash*

| Oxide Composition | Oxide Content % |
|-------------------|-----------------|
| SiO₂              | 61.4            |
| CaO               | 2.24            |
| MgO               | 2.2             |
| SO₃               | 0.3             |
| Al₂O₃             | 25.78           |
| Fe₂O₃             | 4.65            |
| L.O.I             | 3.29            |

* Tests were carried out in building research directory
Table 9. Physical Requirement of fly ash* **

| Physical Properties                                      | results |
|----------------------------------------------------------|---------|
| Fineness : Surface area,(Blaine method, cm²/gm)          | 3800    |
| Activity index of pozzolanic with cement type1 % from control mix in 7 days | 87      |
| 28 days                                                  | 93.5    |
| % Retain on sieve 45µ                                    | 23.78   |
| Specific gravity                                         | 2.59    |

**Tests were carried out in the N. C. C. L\ Karbala lab.

Table 10. Typical specifications of master GLENIUM51*

| property          | Result                                      |
|-------------------|---------------------------------------------|
| shape             | Liquid Sticky                               |
| Colorant          | Bright Brown                                |
| Relative unit weight | 1.1 at 20 cente grate degree                |
| Thickness         | 128+/−30cps @ 20°C                          |
| pH                | 6.6                                          |
| Amount            | (0.5-1.6)litter for 100kg of cement         |
| Transport         | Not classified as dangerous                 |

* These Properties are supplied by the manufacturer

2.2. Mix proportion

The mix proportions of light weight concrete were selected from previous study to gain a compressive strength more than 28 mpa at 28 days [11], and then replacement cement by 50% of fly ash, 60% of fly ash, and 70% of fly ash to get FA50, FA60, and FA70 respectively. Table 11 shows proportion of mixes. Picture 2 shows slump test

Table 11. proportion of mixes

| Type of mix                      | FA50  | FA60  | FA70  |
|----------------------------------|-------|-------|-------|
| Water cement ratio               | 0.255 | 0.245 | 0.27  |
| C+FA:sand: agg                   |       | 654:475:475 |
| HRWRA L/100kg cement             |       | 1.48  |       |
| Slump (mm)                       | 120   | 120   | 120   |
2.3. Samples preparation and test method
The ingredient of mixture was mixed together in a mechanical mixer has 20 litter capacity. natural sand and Porcelanite aggregate were mixing together in the mixer for 2 minutes, then the mixture of cementitious materials (FA+C) was added and mixing continuous for 2 minutes, then adding half of mixing water while the mixing continued, the other half of water mixing with admixture was mixed and poured in mixer, mixing was continued for 2 minutes. Cubes (100×100×100) mm were casting for compressive strength test, and water absorption test, while a cylinder (100×200) mm were casting for dry density and splitting tensile test. the strength tests were carried out in building research directory by using 2000kN compression machine. After casting of concrete samples, the samples were compacted and then de molded after 24 hours after casting. The specimen curried with water saturated with lime until the age of test. The samples were testing at 7, 28, and 56 days. The results of compressive which is reported in this work represent average of three tests, while the other result is average of two test. Picture 3 illustrated strength tests
3. Results and discussion

3.1. density

Oven dry density, and demolded density at different age are illustrated in Table [12]. Result demonstrated that density of all mixes with in the limit of density of structural light weight concrete [12]. Also, the result exhibited that the density of FA60 was lower than FA50, while FA70 was lower than FA50 and FA60 by 5.2% and 4.8% respectively at 28 days. This reduction is attributed to lowering density of fly ash compared with cement density.

| Mix type | Density kg/m³ | De-molded | Oven dry at |
|----------|---------------|-----------|-------------|
|          |               | 7 days    | 28 days     | 56 days     |
| FA50     | 1935          | 1784      | 1816        | 1838        |
| FA60     | 1934          | 1.766     | 1.807       | 1826        |
| FA70     | 1866          | 1671      | 1720        | 1730        |

3.2. Compressive strength

The compressive strength of FA50, FA60, and FA70 at different age are illustrated in table 13. Result showed that there is a clear reduction with increasing content of fly ash. This behavior may be attributed to adversely effect of increasing fly ash ration on quickness of process of hydration. Also, the results showed that a clear developing in compressive with increasing age as a result of progressing of pozzolinc reaction.
Table 13. Compressive strength of mixes at different age

| Mix type | Compressive strength N/mm² at |
|----------|-------------------------------|
|          | 7 days | 28 days | 56 days |
| FA50     | 21     | 22      | 28      |
| FA60     | 16.77  | 21.5    | 27      |
| FA70     | 11     | 13      | 17      |

3.3. Splitting strength
The result of splitting strength test of all types of mixes are shown in table 14. Result showed a slightly different in splitting strength between FA%50 and FA60. The result also showed that the splitting strength of FA70 is lower than FA50 and FA60, this behavior attributed to highly water cementitious ratio of FA70 which led to increasing porosity of interfacial transition zone, and tensile strength highly depended on quality and properties of interfacial transition zone compared with compressive strength [13].

Table 14. Splitting strength of mixes at different age

| Mix type | Splitting strength N/mm² at |
|----------|----------------------------|
|          | 7 days | 28 days | 56 days |
| FA50     | 1.42   | 1.92    | 2.30    |
| FA60     | 1.37   | 1.91    | 2.25    |
| FA70     | 0.89   | 0.98    | 1.22    |

3.4. Absorption of water
The absorption can be considered one of the ways for estimation the durability of concrete. Neville,2008 [14] reported that the absorption of water is not a clear indicator to express of concrete quality, when absorption of concrete lies under 10% by mass, concrete can be classified as a good concrete [14]. Table (14) illustrated the result of absorption test for all mixes with different age. The results showed the absorption of all mixes near 10% or lower except FA70, and also from the results it is clear that percent age of absorption increases with increasing fly ash ratio and decreasing with increasing of age, this decreasing may be attributed to improve the quality of adjacent paste of cement around the particle of Porcelanite aggregate.

Table (15) Percentage absorption of all mixes for different age

| Type of mix | % absorption at |
|-------------|-----------------|
|             | 7 (days) | 28 (days) | 56 (days) |
| FA50        | 8.6      | 7.13      | 4.5      |
| FA60        | 9.1      | 7.37      | 5.2      |
| FA70        | 13.3     | 11.5      | 10.1     |

4. Conclusion
Depended on the result of this study, the next conclusion could be drawn:
1- A structural lightweight concrete could be produced with high-volume fly ash, up to 60%. This concrete could be considered as environmentally friendly type for its low cement content.
2- The density of high volume fly ash reducing with highly fly ash ratio due to lowing specific gravity of fly ash compared with cement.
3- The compressive strength of FA50 and FA60 at 28 days is adequate to the requirement of structural lightweight concrete.
4- Result of water absorption at 28 day showed that FA50 and FA60 could be categorized a good light weight concrete rather than FA70.
5- Result showed splitting strength at 28day, it is suitable to suggest that the approval age for Porcelanite high volume fly ash concrete be replacement to a higher age instead of 28days or the concrete strengthen by using fiber reinforcement.

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