Rational Mix Design of Lightweight Concrete for Optimum Strength

by

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Abstract

In this study, structural lightweight concretes produced by Coarse lightweight Crushed brick and Fine light weight crushed brick (CLWA & FLWA) were investigated. Compressive strength and Density of the concretes were determined in order to make some procedures for mix design of lightweight concrete. In producing the mixtures, superplasticizer (SP) was used in 1% of cement weight to improve the workability. In conclusion, the fresh density of lightweight concrete with fully replacement of sand by FLWA was decreased by about 200 kg/m^3 compared with the mix of fully sand as fine aggregate with no reduction for the compressive strength. It was concluded also that the voids between fine aggregate particles (sand + FLWA) affect on the compressive strength of the mix especially at 28 days. This study suggests inclusion of the voids between fine aggregate particles as a significant factor affects on the compressive strength of lightweight concrete.

1.0 Introduction

Research has been conducted worldwide on a large number of natural or artificial lightweight aggregates. The mix design of lightweight concrete used for structural purposes is more complicated because it depends on the type of lightweight aggregate. The use of a local product depends on its specific properties and the requirements for a particular job. Structural lightweight concrete has its obvious advantages of higher strength/weight ratio, lower co-efficient of thermal expansion and superior heat and sound insulation characteristic due to air voids in the lightweight aggregate. Furthermore, the reduction in dead weight of a construction could result in a decrease in cross-section of structural members and steel reinforcement. (Hossain, 2006)

Structural lightweight concrete has an in-place density (unit weight) on the order (1440 to 1840 kg/m^3) compared to normal weight concrete with a density in the range of 2240 to 2400 kg/m^3. For structural applications the concrete strength should be greater than (17.0 MPa). [ACI 213R, http://www.concrete.org.] The concrete mixture is made with a lightweight course aggregate. In some cases a portion or the entire fine aggregate may be a lightweight product. Lightweight aggregates used in structural lightweight concrete are typically expanded shale, clay or slate materials that have been fired in a rotary kiln to develop a porous structure. Other products such as air-cooled blast furnace slag are also used.

The primary use of structural lightweight concrete is to reduce the dead load of a concrete structure, which then allows the structural designer to reduce the size of columns, footings and other load bearing elements. Structural lightweight concrete mixtures can be designed to achieve similar strengths as normal weight concrete. The same is true for other mechanical and durability performance requirements. Structural lightweight concrete provides a more efficient strength-to-weight ratio in structural elements. (NRMCA, http://www.nrmca.org/aboutconcrete/cips/36p.pdf).

In most cases, the marginally higher cost of the lightweight concrete is offset by size reduction of structural elements, less reinforcing steel and reduced volume of concrete, resulting in lower overall cost. In buildings, structural lightweight concrete provides a higher fire-rated concrete structure. Structural lightweight concrete also benefits from energy conservation considerations as it provides higher R-values* of wall elements for improved insulation properties.

*(http://www.furnacecompare.com/faq/definitions/insulation.html).

The porosity of lightweight aggregate provides a source of water for internal curing of the concrete that provides continued enhancement of concrete strength and durability. This does not preclude the need for external curing. (Neville ,1995).

Structural lightweight concrete has been used for bridge decks, piers and beams, slabs and wall elements in steel and concrete frame buildings, parking structures, tilt-up walls, topping slabs and composite slabs on metal deck. Lightweight concrete can be manufactured with a combination of fine and coarse lightweight aggregate or coarse light- weight aggregate and normal weight fine aggregate. Complete replacement of normal weight fine aggregate with a light-weight aggregate will decrease the concrete density by approximately (160 kg/m^3). Designers recognize that structural lightweight concrete will not typically serve in an oven-dry environment. Therefore, structural design generally relies on an equilibrium density (sometimes referred to as air-dry density); the condition in which some moisture is retained within the lightweight concrete.

Equilibrium density is a standardized value intended to represent the approximate density of the in-place concrete when it is in service. Project specifications should indicate the required equilibrium density of the lightweight concrete. Equilibrium density is defined in ASTM C 567, and can be calculated from the concrete mixture proportions. Field acceptance is based on measured density of fresh concrete in accordance with ASTM C 138. Equilibrium density will be approximately (50 to130 kg/m^3) less than the fresh density and a correlation should be agreed upon prior to delivery of concrete. The tolerance for acceptance on fresh density is typically (±50 kg/m^3) from the target value. (Holom 2000 ,Holom & Valsangkar 2001, Sturm et. al. 2000).

This study is aimed to conduct the factors affected on the structural lightweight mix design by using coarse lightweight aggregate crushed brick and incorporate different percentages of fine lightweight aggregate crushed brick and study the conductivity of these mix proportions from the most important properties of lightweight structural concrete which is the density and compressive strength.

2. Material and mix proportions

2.1. Materials

The cement used in mortar mixtures was ordinary portland cement a product of (Tasek Corporation Berhad). The chemical composition of ordinary portland is given in Table 1. The superplasticizer, Conplast SP1000 supplied by Fosroc Sdn. Bhd. was used at 1 % to give the properties of desirable workability for all mixes. The fine aggregate used is natural sand, whose fineness modulus is 2.86 and the maximum size is less than 5 mm (shown in Fig.1) and the fine lightweight crushed brick aggregate (FLWA) whose grading is shown in Fig.2 .The coarse lightweight aggregate used is also from crushed brick with a maximum aggregate size of 20 mm, and Fig.3 illustrates the grading curve of the material. Table 2 gives the physical properties of Sand, FLWA & CLWA.

Table 1 Chemical composition of ordinary portland cement and silica fume

Constituent	Ordinary Portland Cement, % by weight
Lime (CaO)	64.64
Silica (SiO2)	21.28
Alumina(Al2O3)	5.60
Iron Oxide(Fe2O3)	3.36
Magnesia(MgO)	2.06
Sulphur Trioxode (SO3)	2.14
N2O	0.05
Loss of Ignition	0.64
Lime saturation factor	0.92
C3S	52.82
C2S	21.45
C3A	9.16
C4AF	10.2

Table 2 Physical properties of fine and coarse lightweight aggregate

Physical properties	Sand	Fine lightweight aggregate	Coarse lightweight aggregate
Specific gravity	2.6	1.85	2.05
Absorption	1.0 %	18.2 %	15.4%

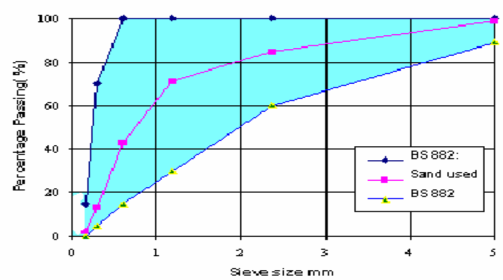

Fig. 1 Grading curve of Sand.

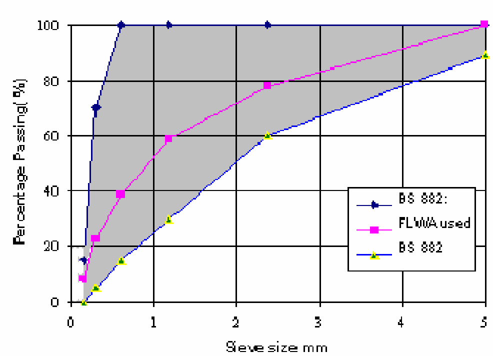

Fig. 2 Grading curve of Fine lightweight aggregate(FLWA)

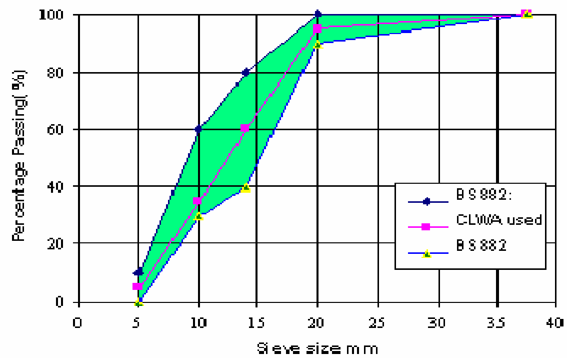

Fig. 3 Grading curve of Coarse lightweight aggregate(CLWA)

2.2 Mix proportions

Approximate concrete composition is given in Table 3. The mixture is designed according to the absolute volume method given by ACI .At the beginning of the mixture design, as the maximum aggregate size is 20 mm, it is convenient to make the first trial mix using equal volumes of fine and coarse aggregate [Neville, 1995] .Concrete Cement content (360 kg/m^3) and water–cement ratio (0.45) were chosen for the Mix (S1)(normal sand & Coarse light weight aggregate).A partial replacement to a full replacement of sand by weight with fine light weight crushed aggregate were achieved at mixes (S2-S6); then the weight and the volume of the ingredients for each mix were determined depend by assuming that 3% air is trapped in fresh concrete. All mixes were designed depend on a slump of (50 - 60 mm).

Table 3 Light weight Concrete Mixes

Index	Cement Kg./m^3	Water Kg./m^3	Sp %	W+ SP /C	Sand Kg./m^3	FLWA Kg./m^3	CLWA Kg./m^3	Volume of Sand %	Volume of FLWA %	Volume of CLWA %
S1	360	160	1	0.45	900	-----	700	35.0	----	35.0
S2	335	150	1	0.45	420	420	655	16.1	22.6	32.7
S3	325	145	1	0.45	245	570	635	9.4	30.8	31.7
S4	330	150	1	0.45	330	495	645	12.7	26.8	32.2
S5	340	155	1	0.45	510	340	665	19.6	18.4	33.2
S6	310	140	1	0.45	-----	775	605	----	42.0	30.3
S7	345	155	1	0.45	605	260	675	23.3	14.1	33.8

2.3 Test methods

Three cube samples 100 mm on each side were used for each mix to test of density and compressive strength after water curing condition until the age of test. The test of fresh density were achieved directly after casting in cubes according to ASTM C567. The cube specimens were left in the molds for 24 h at room temperature of 20 °C. After demolding, the specimens were kept in water curing till the age of test. The test of saturated surface dry of specimens at the age of test was adopted and implemented as BS 1881: Part 114.The test of compressive strength was achieved directly after the density test according to BS: Part 116 for each test age.

3.0 Results and Discussion

3.*1. Fresh Density*

Table 4 show the results of the fresh y and hardened density for all mixes, and from the results, it's clear that the fully replacement of sand by the FLWA reduce the fresh density of 200 kg/m^3 (comparison mix S1 with mix S6) and this may happened because of the specific gravity of FLWA less than the specific gravity of sand and in general the inclusion of FLWA in the mixes reduces the fresh density.

3.2. Compressive strength and saturated surface dry density

From the Table 4, it can be concluded that the amount of cement and the volume of CLWA affect on the compressive strength of 7 days, Fig .4 illustrate the relation between the volume of CLWA and the compressive strength at 7 days. From this curve, it's clear that there is an optimum percentage of the volume of CLWA to give the higher compressive strength and this maybe due to the best grading of fine and coarse aggregate in the mix which leads to minimize the voids among aggregate particles and improve the compressive strength and density.

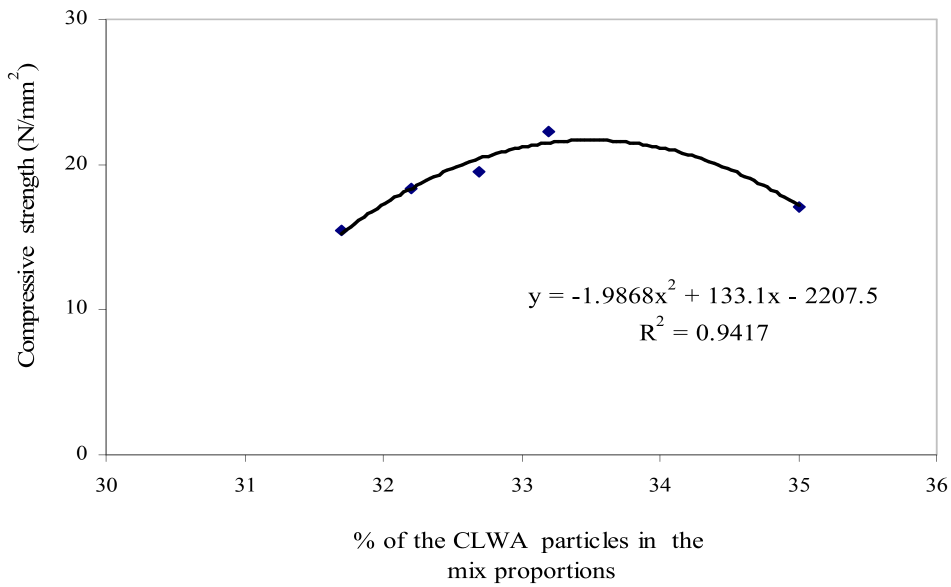

Fig. 4 Relation between of volume percentages of CLWA and the compressive strength at 7 days.

The results of compressive strength at 28 days as shown in Table 4, leads to another conclusion that, the voids between fine aggregate particles in the mix determine the compressive strength of the mix, in another word, the mix with minimum voids gives the higher compressive strength (Fig

.5).Therefore, mix (S5), gives the higher compressive strength as the voids between fine aggregate particles were the least.

The conductivity of hardened density can not be attributed to relation with one factor because of different aggregate proportions with different specific gravities as its' shown in Table 4. Generally, Fig.6, gives a satisfied relation between the volume of CLWA with density where with an increase in the volume of coarse lightweight aggregate, the increase in density can be obtained.

Table 4 Lightweight concrete mixes: (Depending on volumetric proportions)

Index	**Voids between Fine aggregate particles* %**	**Volume of Mortar %**	**Volume of CLWA %**	**Volume of paste %**	**Fresh Density Kg./m^3**	**Density Kg./m^3 7days**	**Compressive Strength (MPa) 7days**	**Density Kg./m^3 28days**	**Compressive Strength (MPa) 28days**
S1	37.3 (13.11%)	62.0	35.0	27.4	2080	2070	17.1	2100	21.5
S2	34.0 (13.5%)	64.3	32.7	25.6	1970	2040	19.5	2040	21.1
S3	31.6 (12.7%)	65.2	31.7	25.0	1865	2000	15.4	2020	27.4
S4	32.1 (12.72%)	65.0	32.2	25.5	1890	2010	18.3	2000	24.5
S5	32.2 (12.2%)	64.1	33.2	26.1	2000	2045	22.3	2065	30.4
S6	31.8 (13.4%)	66.0	30.3	24.0	1880	1915	15.4	1940	21.8
S7	34.9 (13.1%)	63.9	33.8	26.5	1920	1935	14.8	1965	21.0

* Between the brackets means the percentage of voids between aggregate particles in the mix.

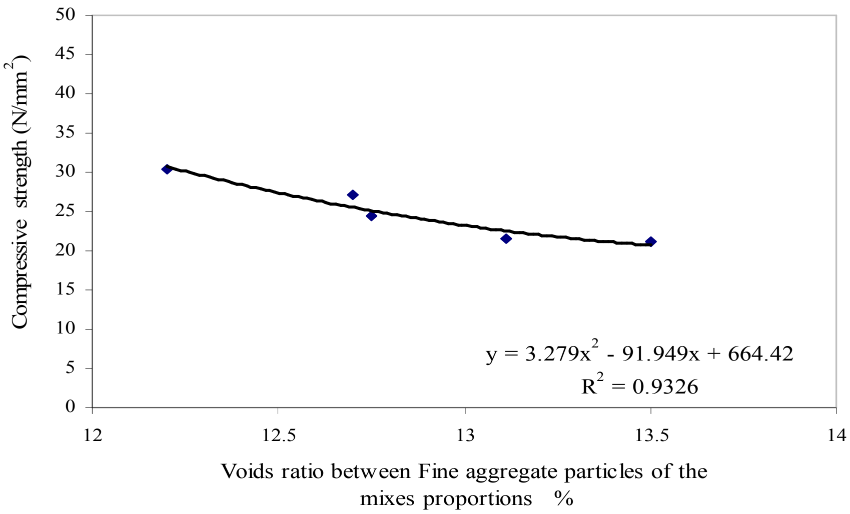

Fig. 5 Relation between the voids ratio between fine aggregate particles (FLWA) of the mix proportions and the compressive strength of mixes at 28 days.

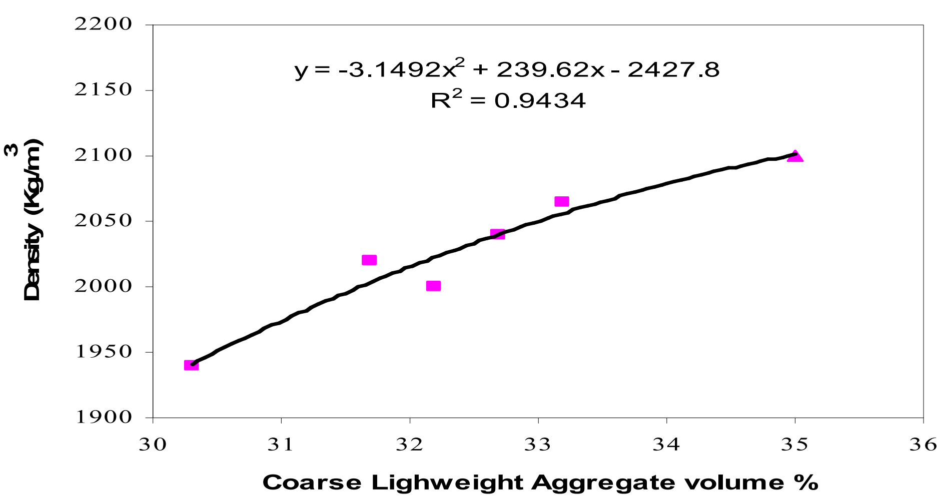

Fig. 6 Relation between the volume ratio of Coarse lightweight aggregate particles (CLWA)of the mix proportions and the density of mixes at 28 days.

4. Conclusions

This study was conducted to assess the factors affect on the properties of lightweight concrete in mix design when CLWA & FLWA (from crushed brick) is used. The following conclusion can be drawn from the present study:

1. The replacement of sand by FLWA for the production of structural lightweight concrete lessen the density of lightweight concrete without reduction of compressive strength, and this consider as a significant economical factor in the production of this type of concrete.

2. Among the factors affect on the density of Lightweight concrete mixes, the volume of CLWA was found to be the most important factor where the lessening of density can be obtained by reducing the volume of CLWA in the mix.

3. The incorporation of FLWA with sand improves the compressive strength because of the lessening of voids between fine aggregate particles which leads to increase the compressive strength of the lightweight concrete mixes.

4. The test of unit weight and specific gravity for the mix proportions of sand and FLWA should have done before doing the trial mixes, where the best mix proportion can be got by the least voids between particles.

5. The volume percent for the CLWA and cement content are also important factors that determine the ultimate compressive strength of lightweight concrete mixes.

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