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Mix design and mechanical properties of self compacting light weight concrete

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Abstract

Considering normal concrete (NC) the type of concrete need to be vibrated after placing in the formwork, Lightweight concretes have been successfully applied in the building constructions for decades because of their low specific weight in connection with a high strength, a high capacity of thermal insulation and a high durability. The development leading to a self compacting light weight concrete (SCLWC) represents an important innovative step in the recent years. This concrete combines the favorable properties of a lightweight concrete with those of a self compacting concrete (i.e., the type of concrete need no vibration after placing in the formwork). Research work is aimed on development of (SCLWC) with the use of light weight aggregates " Light expand clay aggregate (Leca)". In this investigation, by trial and error procedure, different mix design of SCLWC were caste and tested to reach a so called standard self compacting concrete in fresh matrix phase such as; values of slump flow, L-box, V-funnel and in hardened phase, the 28 day compressive strength. Based on the results obtained, for two best so-called standard mix design of SCLWC the stress-strain diagrams are drawn and discussed. Also by three different methods, the modulus of elasticity of SCLWC are obtained and discussed here. It was found that a brittle mode of failure is governed in SCLWC.

Keywords: Mix design, Fresh properties Leca, SCLWC.

1. Introduction

Lightweight concrete has been used for a number of applications and is also known for its good performance and durability. In structural applications, the self weight of the concrete structure is important since it represents a large portion of the total load, the reduced self weight of lightweight concrete will reduce gravity load and seismic inertia mass, resulting in reduced member size and foundation force and …

Self compacting concrete (SCC) is a highly flowable, yet stable concrete that can spread readily into place, fill the formwork, and encapsulate the reinforcement, if present, without any mechanical consolidation and without undergoing separation of material constituents. SCC has many advantages over conventional concrete: (1) eliminating the need for vibration; (2) decreasing the construction time and labor cost; (3) reducing the noise pollution; (4) improving the interfacial transitional zone between cement paste and aggregate or reinforcement; (5) decreasing the permeability and improving durability of concrete, and (6) facilitating constructability and ensuring good structural performance [1].

Self-compacting lightweight concrete combines the positive properties of a self-compacting lightweight concrete - self-deairing and a high flowability - with those of a lightweight concrete which features above all a low weight at a high strength. As a pumpable concrete which yields the quality of a fair-faced concrete, it can as well be applied in a precast element plant as also excellently on site [2].

Self compacting concretes, using their own weight for flowing, do not have sufficient internal energy of motion when lightweight aggregate is used, and, compared with the concretes with natural aggregate, they are slightly slower and the worse flow through dense wrap of reinforcement. In spite of this "weight" decisive problems to solve at preparation mix design of this type of concrete are water absorption of Leca aggregates. Furthermore the SCLWC combines the already know advantages of lightweight dense concrete and self compacting concrete [3]. Water absorption of aggregates which has strong influence on rheology, in this research has been compensated by aggregate is ensured by thorough

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mixing of aggregate in water. Never the less the disadvantage of Leca aggregates is its low compressive strength, which resulted in reduced compressive strength of concrete. Leca aggregates if well produced are suitable for use in SCLWC by reason of spherical shape improving rheological properties of fresh concrete mix and it can also effected on the rising of compressive strength of SCLWC.

The basic criteria are required to achieve self compacting light concrete: high deformability, high passing ability or resistance to segregation [3].

The purpose of this study is to develop a design procedure for self compacting lightweight concretes (SCLWCs) using a Leca aggregates and combination of the excess paste theory.

In this investigation, by trial and error procedure, different mix design of SCLWC were caste and tested to reach a so called standard self compacting concrete in fresh matrix phase (i.e., the rheology of fresh SCLWC) such as; values of slump flow diameter, L-box, V-funnel, J-ring, and in hardened phase, the 28 day compressive strength. Based on the results obtained, the two best so-called standard mix designs was selected and the stress-strain diagrams and modulus of elasticity of SCLWC which are important factors while designing reinforced SCLWC are obtained and discussed here.

2. Rheology of fresh SCLWC

The term SCLWC describes a highly flowable lightweight concrete which de-airs without the supply of compacting energy and which simultaneously features a high resistance to sedimentation and to the segregation regarding the buoyancy of the lightweight aggregate, respectively. To ensure these properties, the classic methods of concrete technology only partly achieve their aim. It is however possible to ensure the desired flowability of the concrete by adding super plasticizers or by increasing the paste content, but this entails also a growing tendency of the concretes to segregate. The key to a successful development and manufacturing of SCLWC lies above all in a careful regulation of the rheological properties of the mortar matrix and the powder paste matrix of the concrete.

The rheological behavior of fresh building material suspensions, as there is fines paste or mortar, is a result of the interaction between the properties of an elastic solid and a viscous fluid. The elastic and viscous properties can be separately recorded by means of rheological measuring methods.

A further special feature of the building material suspensions is that their rheological properties distinctly depend on the shear history and the age. This means that their rheological properties change in the course of time as well as in consequence of the flowing process. Especially the ability of the building material suspensions to rebuilt a stabilizing structure during the state of rest which follows an intensive shearing, has a positive influence on the processing abilities as well as on the stability and on the homogeneity of the respectively prepared concrete mixtures during and after the casting. Decisive for all mentioned rheological properties is, among others, the water content of the mixture.

The results of the rheological investigations of fines pastes and mortars with lightweight fine sand and lightweight sand show that the yield stress as well as the plastic viscosity of the examined suspensions decrease considerably when the water contents rises. Further more, both characteristics are influenced by the material composition of the mixtures and by the properties of the single solid raw materials (particle size distribution, shape of the particles, etc.). In order to ensure a high flowing ability as well as a good de-airing of the concrete, a low yield stress and viscosity are necessary. At the same time, both characteristics have to be chosen high enough to prevent the lightweight aggregate from buoying upwards or blocking, respectively. These requirements, contradictory in principle, have to be finely adjusted within the framework of an optimizing process [2]. A part of this investigation, was the study of properties of fresh concrete for SCLWC (see item 4).

3. Materials used and procedure

The sieve analyses of the coarse aggregates (Leca) and fine aggregates (sand) are given in Table 1. The size of Leca aggregates were between 4.75 to 9.5mm. The water absorption of the Leca aggregate was 18.02%, and the fineness modulus of the sand was 2.76, specific gravity was 2.62, and absorption value was 2.94. Type II Portland cement was used in all mixes with a specific gravity of 3.15. The 10% silica fume (micro silica) by mass of cementitious materials as cement replacement was used. A poly-carboxylic-ether (PCE) super plasticizer was incorporated in all mixture, the PCE used was in the liquid form with a specific gravity of 1.13 and solid content of 40.2%. To enhance the stability of SCLWC also filler (lime stone powder) with the nominal particle size of 0.15 and 0.3mm was used. Leca, sand, lime stone powder, cement, and silica fume were mixed first for 1 min, and then PCE that was mixed in water was added (due to high value of water observation of Leca, several attempts were made to find out the way of adding PCE and water content of the mixture, and finally it was found that the PCE mixed in total water is a good solution when one is used Leca aggregate in the SCC). Then all the materials were mixed for 2 to 4 minutes.

Several design procedure based on scientific theories or

Table 1. Grading and physical properties of Leca aggregate and sand

Screen size	Sand	Leca
mm	%passing	%passing
9.5 (3/8")	100	100
4.75 (#4)	97	0.0
2.36 (#8)	91	-
1.18 (#16)	65.8	-
0.60 (#30)	46.2	-
0.30 (#50)	21.2	-
0.15 (#100)	2.5	-
PHYSICAL PROPERTIES		
24-h water absorption (%)	2.94	18.02
Moisture content of as-received aggregate (%)	0.704	0.0

empirical experience have been proposed for normal SCC [4]. In general, these procedures fall into the following three categories: (1) combination of super-plasticizer and high content of mineral powders, (2) combination of super-plasticizer and viscosity-modifying admixture with or without defoaming agent, and (3) a combination of super-plasticizer, mineral powder and viscosity-modifying admixture [1]. Here, to achieve the SCLWC mix design, among the three mentioned basic criteria suggested to produced normal SCC, a combination of super-plasticizer and high content of mineral powders type was chosen and it was found that it is working well for a light weight concrete to be self consolidating. Figure 1 is shown the mixing procedure.

Based on the 30 trial and error mixes results on fresh and hardened compressive concrete phase, the following two mixes called as SL1, SL2, (see Table 2) was recognized as the two best so-called standard mix designs as SCLWC, and their stress-strain diagrams and modulus of elasticity which are important factors while designing reinforced SCLWC are obtained and discussed here. The volume content of the coarse aggregates (Leca) and powder materials (cement, silica fume and limestone powder) for both mixes was kept constant at 175 and 550 (kg/m^3) respectively. In Table 2, S and L are defined self compacting concrete and lightweight aggregate (Leca) respectively and the numeral 1 and 2 are defined as mix number 1 and 2 respectively.

Fig. 1. Mixing of SCLWC

Table 2. Mix proportions of SCLWC for 1 m^3

Mix No.	SL1	SL2
W/Cm	0.38	0.35
Water kg/m3	256.40	240.33
Cement kg/m3	360	450
Silica fume kg/m3	40	50
Limestone powder kg/m3	150	50
PCE L/m3	4.950	4.675
Leca kg/m3	175	175
Sand kg/m3	1133.80	1153.40

The main requirement of fresh SCC is a high rate of workability caused by high flow and mobility with sufficient cohesion and resistance to segregation during transportation and placement. The significant requirement is also resistance to blocking during concrete work of densely reinforced components and prolonged time of workability. Concrete design to fulfill such requirement can completely fill the forms and moulds of complex, densely reinforced component by its own weight and, at the same time, 'compact it self' uniformly within as much as 90 minute after mixing. It is also important for mixing water not to separate from concrete and, thus not bleed on the surface. The benefit of this technology is certainly also the fact that the SCC technologies considerably utilize waste materials, e.g. fly ashes, blast furnace slags or stone dusts. Workability of fresh SCC generally depends on viscosity of cementing compound, quantity and type of used super plasticizers, total specific surface area of concrete and additives, quantity of filler fine portion <(0.25mm) with the given water-cement ratio, cementing compound volume and quantity and quality of used aggregate. When designing SCC, increased content of cement and fine portions is considered and super plasticizers of new generation are used [3].

There is as yet no universally accepted standard for characterizing of SCLWC. Nevertheless, a few testing methods seem to reappear several times in literature and tend to become internationally recognized as suitable methods to characterize the self normal compacting concrete [5]. Hence, as mentioned earlier, almost same procedure was employed to produce SCLWC too with the following tests in the fresh phase.

4. Properties and discusions of fresh SCLWC

Immediately after the mixing, the value of slump flow, J-ring, L-box and V-funnel test were determine by the following methods.

Slump flow test

The slump flow test was used to evaluate the free deformability and flowability of SCLWC in the absence of obstruction. A standard slump flow cone (height 300mm, base and top diameter 200 and 100mm respectively), was used for the test and the concrete was poured in the cone without compaction and leveled. Slump flow value represented the mean of two perpendicular diameters of concrete after lifting the cone [6].

A slump value ranging from 500 to 700 mm for a concrete to be self compacted in normal SCC [7]. By this test in addition to assessing the deformability of the concrete, it is possible to observed segregation of aggregates near the edges of the spread out concrete visually. What is particularly noted is the occurrence of any 'rim' of fine mortar or just paste/laitance as 'segregation' border [8].The slum flow test for SCLWC is shown in Figure 2.

J-ring test

The J-ring test is used to determine the passing ability of the SCLWC (Figure 3). The equipment consists of a rectangular section (30mm×25mm) open steel ring, drilled vertically with holes to accept threaded sections of reinforcement bar. These

Fig. 2. Slump flow test of SCLWC

Fig. 4. V-funnel test of SCLWC

sections of bar can be of different diameter spaced at different intervals; in accordance with normal reinforcement considerations, 3 (the maximum aggregate size) might be appropriate. The diameter of the ring of vertical bars is 300 mm, and the height 100 mm.

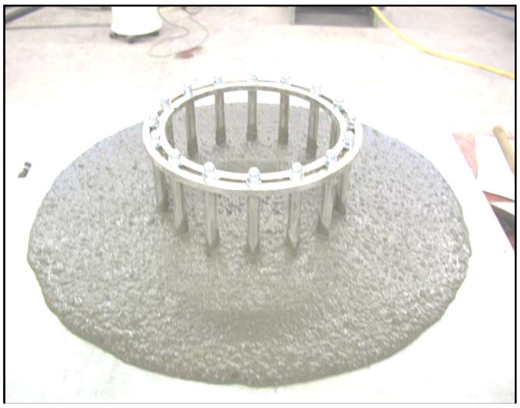

Fig. 3. J-ring test of SCLWC

After the test, the difference in height between the concrete inside and that just outside the J-ring is measured. This is an indication of passing ability, or the degree to which the passage of concrete through the bars is restricted [9].

V-funnel flow time test

The V-funnel test is used to determine the deformability through restricted area [4]. The version selected for evaluation in this study had a rectangular crossing tapering to a bottom opening of 65mm×75mm.The funnel was fitted with a trap door. The test result is given as a flow time, FT (seconds). The V-funnel selected can deal with mixes containing aggregate of size not exceeding 25mm. A sample of fresh concrete of between 12 to 15 litters in volume is required [8]. Acceptable value range for FT is between 4 and 10s [10]. The test was carried out for SCLWC as shown in Figure 4.

L-box test

The test assesses the effect of reinforcement on free flow of concrete constrained by formwork. The L-box test for SCLWC is shown in Figure 5. By this test it is possible to measure different properties such as flowbility, blocking and segregation of the concrete [11, 12]. Concrete is allowed to flow from the vertical column section into the horizontal trough. The basic test result is the 'blocking ratio' h_2/h_1. It is the ratio between the height of the concrete surface in the vertical column part of the apparatus (h_1) and the height of the concrete surface in the through at its far end (h_2), after the passage through vertical reinforcing bars. There are two additional marks on the horizontal trough at 200mm and 400mm from the sliding door. In addition to the basic result, times T_{20} and T_{40} (in seconds), are sometimes measured [8]. The ratio between these two heights (h_2/h_1), which is usually 0.7-0.9, was used to evaluate the ability of the SCC mixture to flow around obstruction [13,14]. This limit, however, has been proposed to be within 0.8 and 1.0 by EFNARC guidelines [9]. For this study, a gap of 55mm between the 12mm diameter bars was selected where the top aggregate size was 9.5mm.

Fig. 5. L-box test of SCLWC

The results of properties of fresh self compacting light concrete used in this investigation are well between the mentioned values and presented in Table 3.

Table 3. Results of properties of fresh SCLWC

Mix No.	Slump flow diameter (cm)	J-ring	V-funnel (s)	L-box (h_2/h_1)
SL1	72	1.2	5.0	0.85
SL2	67	1.5	5.5	0.83

5. Experimental tests and discusions of hardened SCLWC

Casting and curing of test specimens

After casting, the molded specimens were covered with two layer of plastic and left on the casting room at 20 ºC for 48 h. They were than demolded and cured in water which is saturated with lime with a surrounding temperature of 20º C ±3 and relative humidity of 30 ± 5 % for 28 days age. The specimens (10×10×10cm) density of light weight concrete after they were demolded was 1800-1900 kg/m³. Which are about 600 kg/m³ less than the normal SCC. It is noted that, i) different attempts was made to produce the SCLWC with a density lower than 1800 kg/m³, but their 28 day compressive strength were lower than 20MPa, and therefore such strength can not be considered as structural concrete in reinforced concrete structures, ii) for the same mix but only receiving Leca at different time (date) from the supplier, it was found that the compressive strength was varied considerably, it seems such a founding is due to not well product of Leca in the factory which need to be reconsidered by the manufacturer.

Compressive strength tests and results

For two cases of studied, the total number of 12 concrete cube specimens of (10×10×10cm) was caste and tested at 3, 7, 28 and 90 days age. The results for average value of three specimens, and each age are shown in Figure 6. Meanwhile, the slop of the lines (m), which are presenting the growing up rate of compressive strength between ages are founded and given in Table 4.

Stress-Strain curve of SCLWC

To observe the compressive stress-strain behavior of SCLWC specimens, for some cub samples, the electrical strain gages were fixed and during the test the data from the load cell and electrical strain gage were recorded by the data logger for any load increment and the typical stress-strain diagrams for SL1 and SL2 samples are plotted and shown in Figures 7, 8. Where E_c is in GPa and f_{cu} is in MPa.

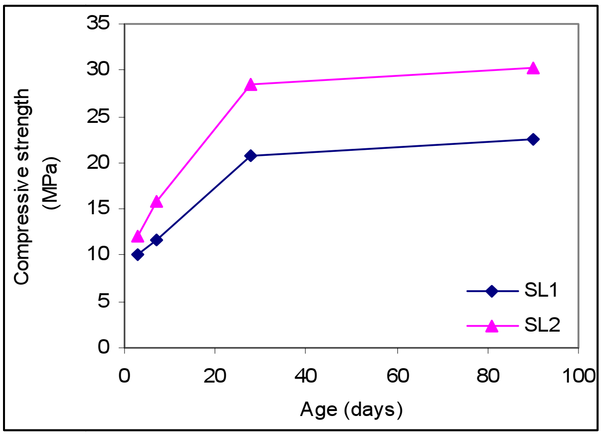

Fig. 6. Compressive strength of SL1, SL2

Table 4. Growing up rate of compressive strength

Mix No.	SL1	SL2
m_{3-7}	0.400	0.975
m_{7-28}	0.433	0.600
m_{28-90}	0.029	0.027

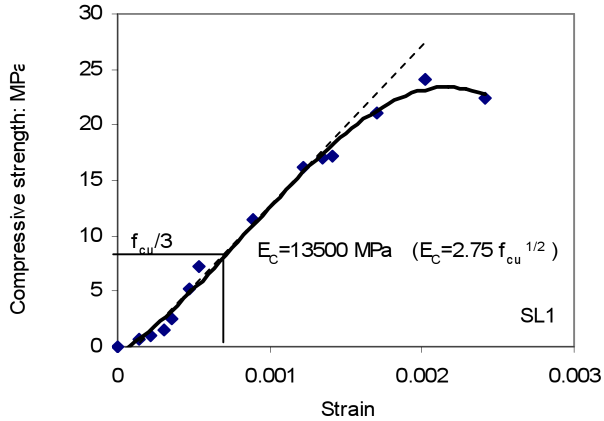

Fig. 7. Stress-strain curve for SL1 specimen

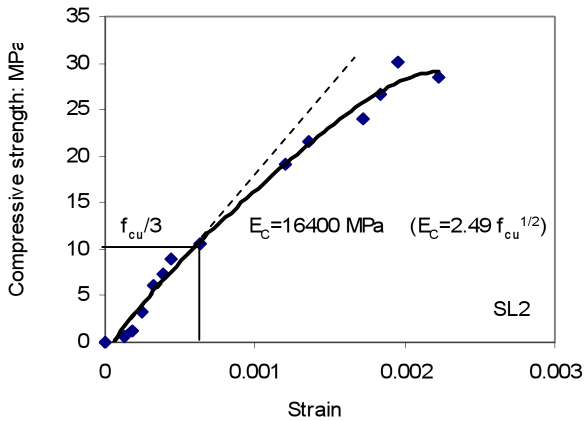

Fig. 8. Stress-strain curve for SL2 specimen

The obtained values of maximum strain for SL1 and SL2 specimens are 0.0024 and 0.00222 respectively (which is less than the value suggested in building codes for traditional normal weight concrete, i.e., ε_{cu}=0.003). The slope of the curves at $f_{cu}/3$ are also presented in the Figures 8, 9, and therefore calculated modulus of elasticity, E_c are 13500, 16400 MPa for SL1 and SL2 respectively. The amount of E_c obtained by this method is closed to those obtained by the Universal Testing Machine test reported in section D bellow.

Modulus of elasticity and results by bending tests

For each mix, four prism specimens and the total number of 8 prism specimens of (10×10×45cm) were caste and tested at 28 and 90 days age under four point bending test in a Universal Testing Machine [15-16].

This type of tests was carried with a Universal Testing Machine which was able to draw the load deflection curves. However, here only the results are shown in Figure 9. As shown in Figure, at different ages, the modulus of elasticity of SL2 specimen is higher than SL1.

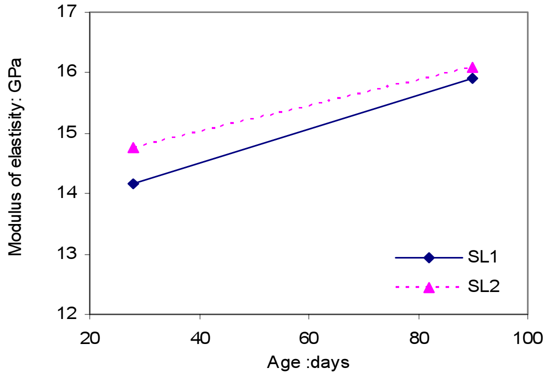

Fig. 9. Modulus of elasticity of SL1 and SL2 specimens

For two mixes of this study, the bending test results of Ec as well as the compressive test results at two ages are shown in Table 5. (Where CS-28, CS-90 and E-28, E-90 are compressive strength and modulus of elasticity at 28 and 90 day respectively).

Table 5. compressive and modulus of elasticity results

Mix No.	SL1	SL2
CS-28	20.8	28.5
E-28	14.15	15.90
CS-90	22.6	30.2
E-90	14.70	16.10

As can be seen the difference between the E_c values for different mixes of two ages are close each others. The reason for this can be due to low w/cm ratios, the first initial 28 day water curing condition, and lightweight aggregate used in concrete. The failure to gain strength in consequence of inadequate curing, i.e. through loss of water by evaporation, is more pronounced in thinner elements and in richer mixes, but less so for lightweight aggregate in traditional normal concrete [17].

The Eq. (1) and Eq. (2) is suggested by British standard [18] and Eurocode 2 [19] respectively, for normal concrete:

$$E_c = 1.7\,\rho^2 f_{cu} \times 10^{-6} \qquad (1)$$

Where E_c is static modulus in GPa,   is density in kg/m³ and f_{cu} is compressive strength in MPa.

$$E_{cm} = 9.5(f_{ck}+8)^{1/3} \qquad (2)$$

Where E_{cm} is secant modulus of elasticity in kN/mm² and f_{ck} is characteristic cube compressive strength of the concrete in N/mm².

Based on equation (1) and (2), the calculated values of modulus of elasticity of SCLWC are found and shown in Table 6.

The comparison of results for E_c obtained by three different mentioned methods are closed each others however; using Equation (2) recommended by European standard causes the highest values.

Table 6. Calculated values of Ec based on Eq. (1) and Eq. (2)

Mix No.	ρ kg/m³	CS-28 MPa	E-28 GPa	E-28 GPa
SL1	1890	20.8	16.53	28.79
SL2	1870	28.5	17.96	31.13

6. Conclusions

The following important results can be summarized by the investigation carried out on the SCLWC tests:

1. By use of Leca as lightweight aggregate and 400 and 500 kg/m³ of cement containment, it was possible to produce a self compacting light concrete (with a specific weight less than 1900 kg/m³) mix with compressive strength of 20.8 and 28.5 MPa at 28 days respectively. Such concrete strengths are recognized as structural concretes in structural reinforced concrete codes. Never the less the disadvantage of Leca aggregates is its low compressive strength, which resulted in reduced compressive strength of concrete. Leca aggregates if well produced are suitable for use in SCLWC by reason of spherical shape improving rheological properties of fresh concrete mix and it can also effected on the rising of compressive strength of SCLWC by use of lower amount of cement.
2. Similar to traditional concrete, the rate of compressive strength between ages in SCLWC will be increased.
3. The obtained values of maximum strain for SL1 and SL2 specimens are 0.0024 and 0.00222 respectively (which is less than the value suggested in building codes for traditional normal weight concrete, i.e., $\varepsilon_{cu}=0.003$). This factor is important while designing such concrete in seismic zones for ductility considerations. In other words by using SCLWC, the failure of structures are more brittle.
4. The comparison of results for modulus of elasticity obtained by three different mentioned methods are closed each others however; using Equation recommended by European standard causes the highest values of modulus of elasticity.

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