Rheological and Engineering Properties of SCLC

A.A. Maghsoudi
Assistant prof., Civil Eng. Dept., Shaheed Bahonar University of Kerman, kerman, Iran..

S. Mohamad pour
M.Sc. Student, Shaheed Bahonar University of Kerman, kerman, Iran.

ABSTRACT: Lightweight concretes have been successfully applied in the building constructions for decades because of their favourable material properties, especially 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 (SCLC) represents an important innovative step in the recent years. This concrete combines the favourable properties of a lightweight concrete with those of a self compacting concrete. Research work is aimed on development of (SCLC) with the use of light aggregates ”Light expand clay aggregate (Leca)”. In this investigation, first by trial and error, different mix design of SCLC were casted and tested to find out the values of slump flow, L-box, V-funnel and 28 day compressive strength. Based on the results obtained, the best so–called standard mix design was selected for further investigation. For two selected mix, engineering properties of SCLC, such as compressive and flexural strength, E-modulus, shrinkage and swelling (expansion) values for three different curing conditions were measured at short and long ages (upto-90 day).The results are shown that use of SCLC can improve the engineering properties as well as the durability of structural concrete made of light weight materials such as Leca.

1 INTRODUCTION

Research work is aimed on development of Self Compacting Light Concrete (SCLC) with the use of light weight aggregates “Leca”. The SCLC is new building material which due to properties, the use of SCLC is very convenient for many cases such as, at rehabilitation of old building constructions, where the use of ordinary SCC would lead to overloading and to necessity of additional strengthening of existing structures. Other very favorable use is for production of precast components with very complicated shapes.

Decisive problems to solve at preparation mix design of this type of concrete are water absorption of Leca aggregates. Furthermore it is evaluation of applicability of conventional mix designing of SCLC. Leca aggregates if well produced are suitable for use in SCLC by reason of spherical shape improving rheological properties of fresh concrete mix. Water absorption of aggregates which has strong influence on rheology, in this research has been compensated by aggregate is ensured by thorough mixing of aggregate in water. Disadvantage of Leca aggregates is its low compressive strength, which resulted in reduced compressive strength of concrete. SCLC combines the already know advantages of lightweight dense concrete and self compacting concrete [Hubertova 2005]. In structural applications, the self weight of the concrete structure is important since it represents a large portion of the total load. Hence by use of the lightweight aggregates it is possible to reduced member size of the structures and foundation force [Caijun & Xiaohong 2005]. Therefore, by reducing the self-weight of the structures, considerable savings could be attained, not only in materials but also in construction costs.

Experimental research is required to understand the mechanical properties of SCC including the light weight aggregate, Leca. The objective of this research study is to i) design and construct so called standard mix design of SCLC and ii) provide information on mechanical properties of SCLC for short and long term ages.

2 MATERIALS USED

To prepare the mix design, Type Ⅱ Portland cement was used and its physical properties and chemical composition are given in Table 1. The aggregate with nominal maximum particle size of 9.5 mm and well graded sand for SCC were employed. The particle size distributions and physical properties of both Leca aggregate and sand were well within ASTM C-33 and ASTM C-127 limits respectively, as shown in Table 2. A poly-carboxylic-ether (PCE) super plasticizer was incorporated in all mixture. It was liquid with a specific gravity of 1.13 and solid content of 40.2%.

Also filler (lime stone powder) with a nominal mean particle size of 0.3 mm was used.

Table 1. Typical analysis of Portland cement and silica fume

Chemical composition %	Cement	Silica fume
CaO	63.04	0.49
SiO_2	21.74	93.86
Al_2O_3	5.00	1.32
Fe_2O_3	4.00	0.87
SO_3	2.30	0.10
Na_2O + 0.658 K_2O	1.00	0.974
Cl	0.035	0.04
MgO	2.00	0.97
C_3S	45.50	-
C_2S	28.00	-
C_3A	6.50	-
C_4AF	12.20	-
Loss on ignition	1.30	-
Insoluble Residue	0.60	-
Free CaO	1.40	-
Na_2O	-	0.31
K_2O	-	1.01
SiC	-	0.53
C	-	0.34
P_2O_3	-	0.16
Fineness (Cm^2 /gr)	2900	200000
Residue on 90 µm sieve %	4.00	-

Table 2. Grading and physical properties of Leca aggregate and sand

Screen size	Sand	Leca
mm	% passing	% passing
9.5	100	100
4.75	97	0
2.36	91	-
1.18	65.8	-
0.60	46.2	-
0.30	21.2	-
0.15	2.5	-
Physical properties		
24-h water absorption, %	2.94	18.02
Moisture content of as-received aggregate, %	0.704	0

3 REOLOGY OF FRESH SCLC

The term self-compacting lightweight concrete 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 SCLC 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.

The interactions of the elastic and viscous properties of a material are, among others, represented in the so-called flow curve (Figure 1). It describes the relation between the applied shear stress (τ) and the resulting shear rate (γ). Whereas Newtonian fluids as water or silicon oil show a purely viscous flowing - the flow curve runs through the origin and its gradient is constant with building material suspensions at first an elastic deformation of the sample can be ascertained. Only when a critical shear stress, the so-called yield stress (τ_0) is exceeded, the deforming behavior is dominated by the viscous properties of the material. This is reflected in a proportionality between the applied shear stress (τ) and the shear rate (γ). Materials which have a yield stress and which show a linear flow curve are called Bingham solids. The tangent gradient of the regression line describes the plastic viscosity (μ) of a mixture. Figure 1 demonstrates as an example the flow curves of a Newtonian fluid, an ideal Bingham solid as well as a real cement paste. Different from the idealization of the Bingham model, at very low shear gradients, real fines pastes show a strong increase of the shear stress with a rising shear gradient. This behavior is especially important for segregation stability of a mixture.

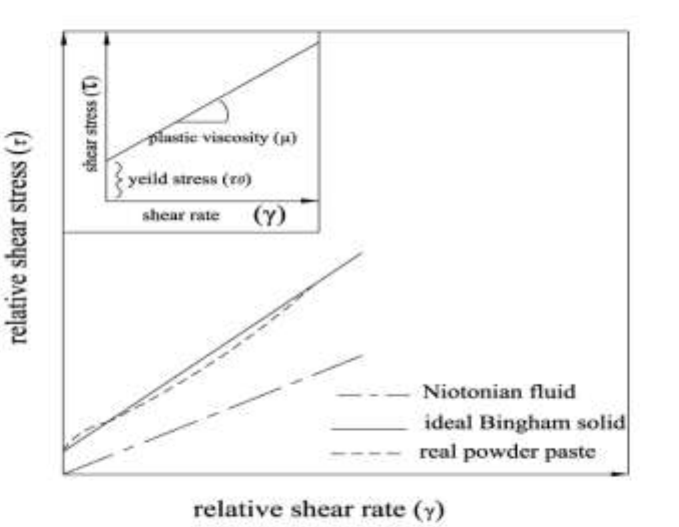

Figure 1. Flow curve [Muller & Haist 2004]

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. Furthermore, 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 [Muller & Haist 2004]. A part of this investigation, was the study of properties of fresh concrete for SCLC (see item 5).

4 SCC MIXTURE PROPORTIONS

At present three different concepts for the production of SCC are distinguished. In contrast to normal concrete (NC) for the production of SCC the powder content is increased (Powder Type), a viscosity agent (Viscosity Agent Type) or both possibilities are combined (Combination Type) [Dehn 2000].

Whereas, here Powder Type was chosen to produce SCLC too. In this investigation, first by trial and error procedure, different mix design were caste and tested to find out the fresh concrete properties of SCLC such as value of the slump flow, J-ring, V-funnel, L-box and hardened concrete properties of SCLC such as the average value of tree cube specimens at 28 day compressive strength (the full report of trial tests are given in [Mohamad pour 2006]. Based on these results, the following two mixes called as SL1, SL2, (see Table 3) was selected for further investigation of properties of fresh and short and long term age of hardened SCLC. In this Table, S and L are defined as self compacting concrete and light weight aggregate, Leca, respectively and 1 and 2 are defined as mix number 1 and 2 respectively.

The concrete mixtures had water-cementitious material ratios (w/cm) of 0.38 and 0.35. The 10% silica fumes by mass of cementitious materials as cement replacement was used. The volume content of the coarse aggregates (Leca) and powder materials (cement, silica fume and lime stone powder) for mixes SL1 and SL2 was kept constant at 175 and 550 (kg/m^3) respectively. Leca, sand, lime stone powder, cement, and silica fume were mixed first for 1 min, then PCE that was mixed in water was added last for 1 to 2 min. Then all the materials were mixed for 2 to 4 min.

Table 3. Mix proportions of SCLC for 1 m^3

Mix No.	SL1	SL2
w/cm	0.38	0.35
Water kg/m^3	256.40	240.33
Cement kg/m^3	360	450
Silica fume kg/m^3	40	50
Lime stone powder kg/m^3	150	50
PCE L/m^3	4.950	4.675
Leca kg/m^3	175	175
Sand kg/m^3	1133.80	1153.40

5 PROPERTIES OF FRESH SCLC

There is as yet no universally accepted standard for characterizing of SCLC. 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 [Poppe 2001]. Hence, almost same procedure was employed to produce SCLC too. Immediately after the mixing, the value of slump flow, J-ring, L-box and V-funnel test were determine by the following methods.

5.1 *Slump flow test*

The slump flow test was used to evaluate the free deformability and flowability of SCLC in the absence of obstruction. A standard slump flow cone 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 [Sakata et al. 1996].

A slump value ranging from 500 to 700 mm for a concrete to be self compacted in normal SCC [Nagataki & Fujiwara 1995]. 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. The slump flow test for SCLC is shown in Figure 2.

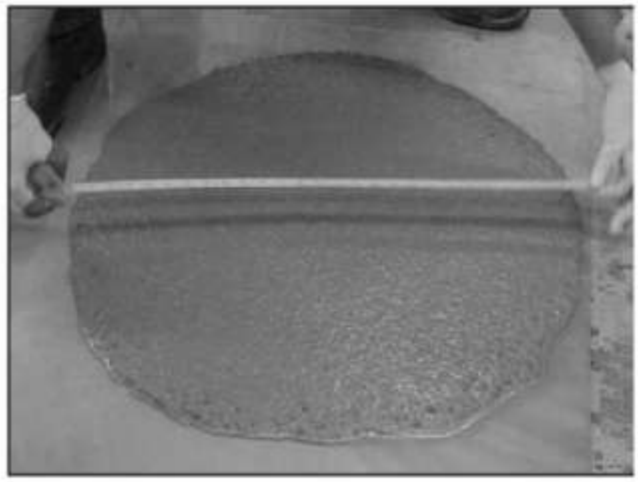

Figure 2. Slump flow test of SCLC

5.2 *J-ring test*

The J-ring test is used to determine the passing ability of the SCLC (Fig. 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 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.

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 [EFNARC 2002].

Figure 3. J-ring test of SCLC

5.3 *V-funnel flow time test*

The V-funnel test consists of V- shaped container as shown in Figure 4. The deformability through restricted area can be evaluated using V-funnel test [Ozawa et al. 1994]. In this test, the funnel shown in Figure 4, was filled completely with SCLC and the bottom outlet was opened, allowing the concrete to flow out. The time of flow from the opening of outlet to the seizure of flow was recorded. Acceptable value for SCC range between 4 to 10 s [Chai 1998].

Figure 4. V-funnel test of SCLC

5.4 *L-box test*

The test assesses the effect of reinforcement on free flow of concrete constrained by formwork. The L-box test for SCLC shown in Figure 5. With the L-box apparatus, it is possible to measure different properties such as flowbility, blocking and segregation of the concrete [Sonebi & Bartos 1999]. 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 200 mm and 40 mm from the sliding door. In addition to the basic result, times T_{20} and T_{40} (in seconds), which it takes for the concrete to reach the marks, are sometimes measured [Bartos 2005]. 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 [Nehdi & Ladanchuk 2003]. This limit, however, has been proposed to be within 0.8 and 1.0 by EFNARC guidelines [EFNARC 2002].

Many versions of L-box equipment have been used. The version selected for this study has inside dimensions of; column: 200mm × 100mm, 600mm tall; trough: 200mm × 150mm, 700mm long and uses at set of three vertical reinforcing bars. For this study, a gap of 55 mm between the 12 mm diameter bars was selected where the top aggregate size was 20 mm. This test requires 12.7 liters of concrete. Blocking caused both by oversize coarse aggregate or its excessive content can be detected, as well as blocking generated by moderate severe segregation. The mix can be regarded as possessing a segregation resistance, if the particles of coarse aggregate are seen to be distributed on the concrete surface all the way to the end of the horizontal part. Blocking usually manifests itself as coarse aggregates wedged between the reinforcement bars [Bartos 2005].

The results of properties of fresh self compacting light concrete used in this investigation are well between the mentioned values and presented in Table 4.

Figure 5. L-box test of SCLC

Table 4. Results of properties of fresh SCLC

Mix No.	Slump flow diameter cm	J-ring cm	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

6 EXPEIMENTAL TESTS AND RESULTS OF HARDENED SCLC

6.1 *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° C for 48 h. They were than demolded and cured in three different storage conditions. For the first 7 days, all specimens are cured in water which is saturated with lime. Then some specimens are cured in air, (D) condition, with a surrounding temperature of 20° C ±3 and relative humidity of 30 ± 5 %, some sample even after 7 days are also kept at same condition up to 28 days age and then (after 28 days age) they are cured in air, (W) condition and the remaining after 7 days are cured in 5% sulphate sodium solution, (S) condition. The specimens (10 ×10 × 10) cm density of light weight concrete after they were demolded was 1800-1900 kg/m^3. Which is about 600 kg/m^3 less than the normal SCC (it is noted that, different attempts was made to produce the SCLC with a density lower than 1900 kg/m^3, but their 28 day compressive strength were low. Also, 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).

6.2 *Compressive strength tests and results*

For two cases of studied at three storage condition, the total number of 48 concrete cube specimens of (10×10×10)cm were casted and tested at 3, 7, 28 and 90 days age. The results for average value of three specimens at each storage condition, and each age are shown in Figures 6 to 8. Meanwhile, the slope of the lines (m), which are presenting the growing up rate of compressive strength between ages are founded and given in Table 5. As indicated in figures approximately the amount of compressive strength at 28 and 90 days for specimens SL1 and SL2 in (W) is more than (D) and (S) storage conditions. Also, the compressive strength for SL1 and SL2 samples is approximately similar for both (D) and (S) storage conditions.

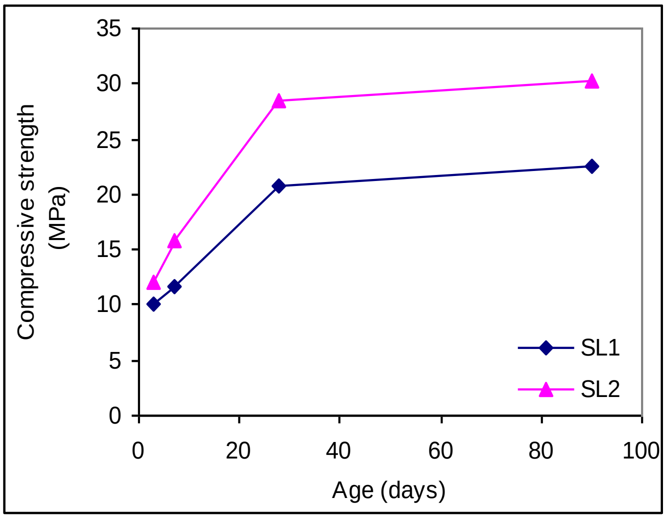

Figure 6. Compressive strength of SL1, SL2 in (W) condition

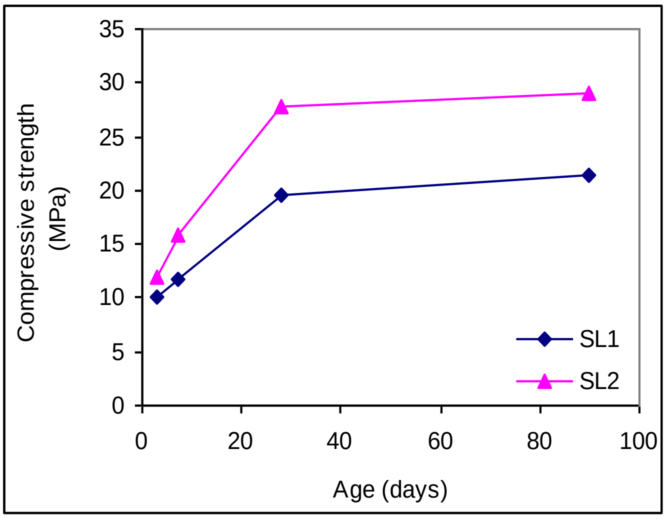

Figure 7. Compressive strength of SL1 and SL2 in (D) condition

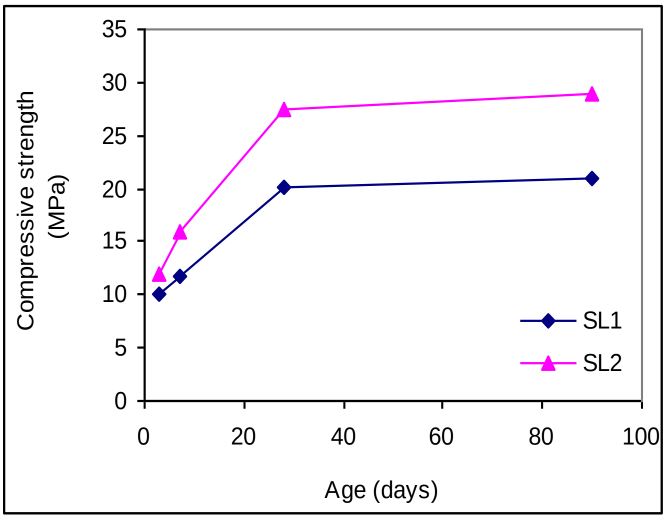

Figure 8. Compressive strength of SL1, SL2 in (S) condition

Table 5. Growing up rate of compressive strength

Mix No.		SL1	SL2
m_{3-7}	W,D,S	0.400	0.975
m_{7-28}	W	0.433	0.600
	D	0.376	0.562
	S	0.404	0.552
m_{28-90}	W	0.029	0.027
	D	0.030	0.029
	S	0.009	0.038

6.3 *Stress-Strain curve of SCLC*

To observe the stress-strain behavior of SCLC specimens, for some cub samples, the electrical strain gages were fixed and during the test (Fig. 9), 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 10, 11.

The obtained ultimate strain and slope of the curves at $f_{cu}/3$ (i.e., E_c) are 0.00241, 0.00222 (which is less than the minimum value suggested in building codes for traditional concrete, i.e., ε_{cu}=0.003) and 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 (see Table 9). The SL1 and SL2 were in 90 days age and (D) storage conditions.

Figure 9. Uniaxial compressive test

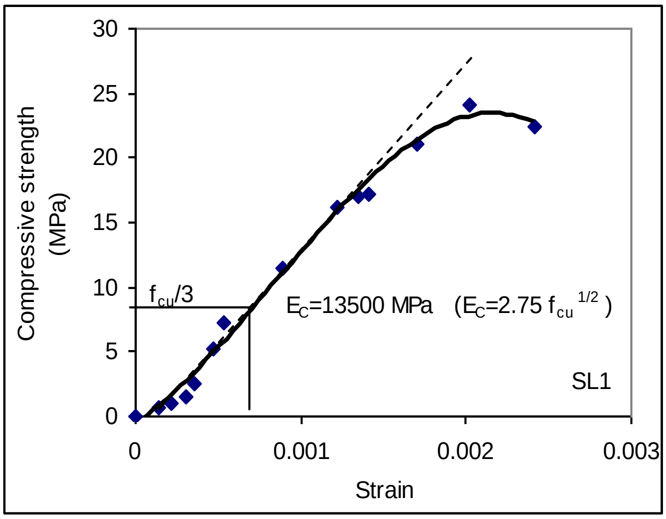

Figure 10. Stress-strain curve for SL1

Note: Where E_c is in GPa and f_{cu} is in MPa

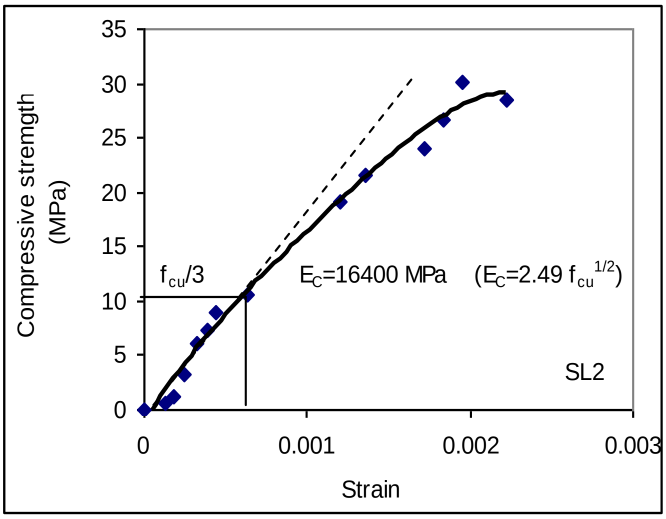

Figure 11. Stress-strain curve for SL2

Note: Where E_c is in GPa and f_{cu} is in MPa

6.4 Flexural specimens tests and results

For two cases of studied at two (W) and (D) storage conditions the total number of 16 prism specimens of (10 ×10 × 45 cm) were casted and tested at 28 and 90 days age and the average values of the test results are shown in Figures 12 to 15.

For two mixes, By comparison of the strength results, it can be concluded that for both conditions, a better behavior for (W) storage condition at 28 and 90 days are obtained. The flexural strength of SL2 specimen is higher than SL1 which indicates that similar to normal concrete, by increasing the compressive strength, the flexural strength of SCLC will be increased.

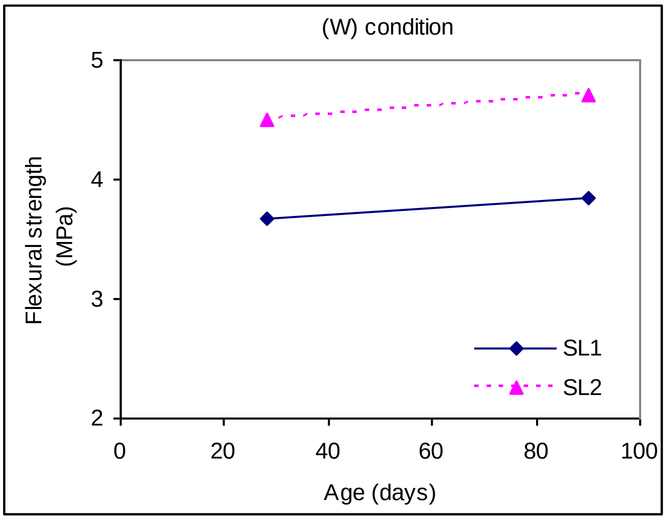

Figure 12. Flexural strength of SL1 and SL2 in (W) condition

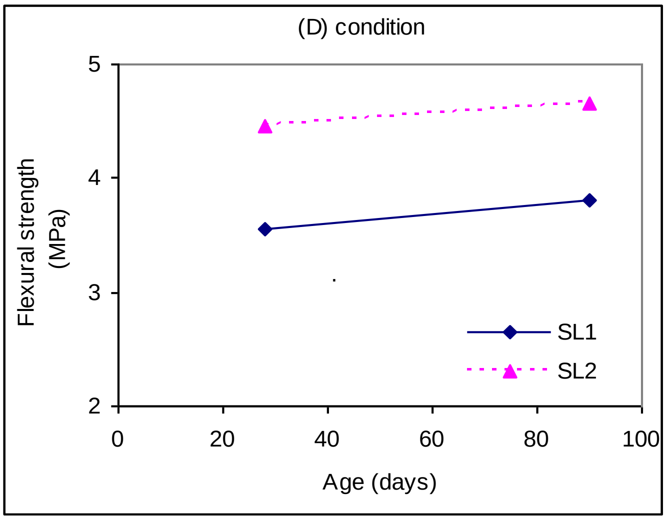

Figure 13. Flexural strength of SL1 and SL2 in (D) condition

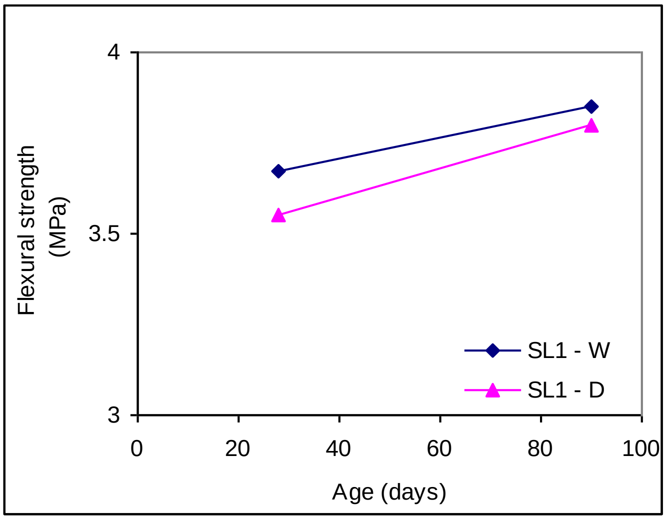

Figure 14. Flexural strength of SL1 in (W) and (D) conditions

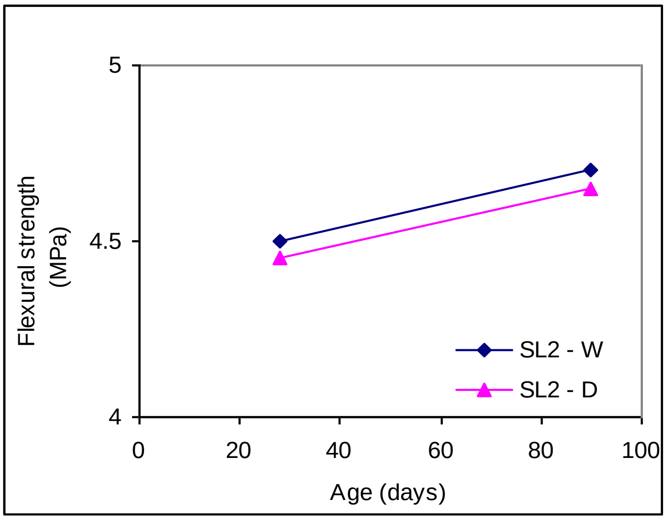

Figure 15. Flexural strength of SL2 in (W) and (D) conditions

6.5 *Modulus of elasticity tests and results*

This type of tests were carried with a Universal Testing Machine which was able to draw the load deflection curves and the full report of the author's proposed method of finding the modulus of elasticity appeared in [Mohamad pour 2006]. However, here only the results are shown in Table 6 and Figures 16 to 17. Also the growing up rate of modulus of elasticity is shown in Table 7. As shown in figures, for all storage conditions at different ages, the modulus of elasticity of SL2 specimens is higher than SL1. Also modulus of elasticity SL1 and SL2 at (W) storage condition is more than those for (D) condition at 90 days age.

Table 6. Modulus of elasticity in (W) and (D) conditions

Mix No.	Modulus of elasticity MPa			
	28 days		90 days	
	W	D	W	D
SL1	14150	13650	14700	14200
SL2	15900	15250	16100	15650

Table 7. Growing up rate of modulus of elasticity in (W) and (D) conditions

Mix No.	$m_{28\text{-}90}$	
	W	D
SL1	8.7	8.7
SL2	3.2	6.4

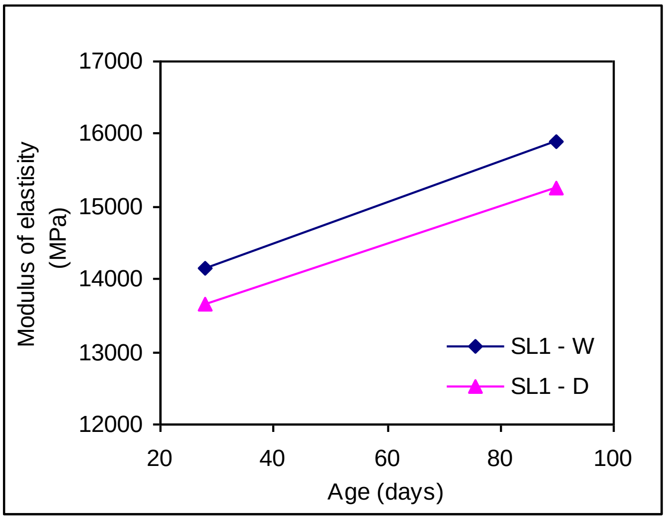

Figure 16. Modulus of elasticity of SL1 in (W) and (D) conditions

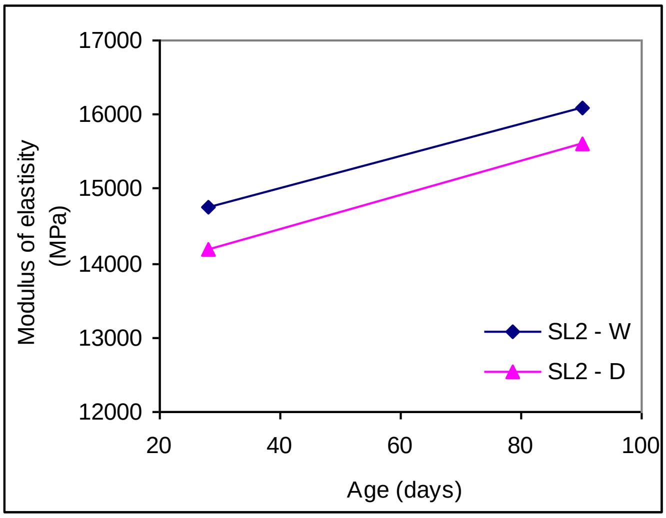

Figure 17. Modulus of elasticity of SL2 in (W) and (D) conditions

6.6 *Shrinkage tests and results*

When exposed to dry environment after an initial moist curing, the shrinkage of concrete my be divided into two components: drying shrinkage and autogeneous shrinkage.

According to ACI 116R, the drying shrinkage is defined as "shrinkage resulting from loss of moisture," whereas the autogenous shrinkage is defined as "change in volume produced by the continued hydration of cement, exclusive of the effects of applied load and change in either thermal condition or moisture content. The autogenous shrinkage is a consequence of the withdrawal of water from the capillary pores by the hydration of cement a process known as self desiccation.

Typical values of autogenous shrinkage of ordinary concrete are approximately 40 $\times 10^{-6}$ at the age of 1 month and 100 $\times 10^{-6}$ after 5 years, which are relatively low compared with those of drying shrinkage. Because of this, autogenous shrinkage has been ignored for practical purpose for ordinary concrete. For concrete with a low w/c, however, particularly when it contains silica fume, autogenous shrinkage may be important. Because of this, the shrinkage of concrete exposed to a dry environment is a combination of the drying shrinkage and autogeneous shrinkage.

According to ACI material journal [Zang et al. 2005], the incorporation of 5% silica fume reduced the shrinkage of concrete significantly. Because the pozzolanic reaction of silica fume refines the pore structure and densifies the cement paste, the loss of water from the cement paste and that absorbed inside the light weight aggregate would probably reduced. This water absorbed inside the aggregate provided a means for continued cement hydration and pozzolanic reaction, thus further densifying the cement paste. This might have contributed to the lower shrinkage of the lightweight concrete with silica fume.

It is well known that, in normal concrete (NC), different factors are effecting drying shrinkage such as relative humidity, type of aggregate used, w/c, modulus of elasticity of aggregate used, the amount of aggregate, ... However, experimental research is required while considering SCLC.

For each mix of Table 3, 4 prism specimens and the total number of 8 prism specimens of (10 × 10 × 45 cm) were casted and at the age of one day, the Demec points were fixed on two opposite surface of the specimen and then they are kept either at (D) or (W) storage condition. At different age the amount of shrinkage were measured by the mechanical strain gauge (with the gauge length of 10 cm) and the results of average of two opposite surface reading of three specimens were plotted on Figures 18 to 21. As expected the amount of shrinkage for the samples kept at (D) condition is more than the value for (W) condition. It is because; the curing time for (W) condition was 3 weeks more than (D) condition. The amount of shrinkage for the (SL1) samples which contains w/cm=0.38, is more than the (SL2) samples having w/cm=0.35. The results are indicating that, similar to normal concrete, the amount of shrinkage has an direct relationship with the w/cm for SCLC too. Growing up rate of shrinkage at early ages is more than the last age in SL1 and SL2 at both storage conditions.

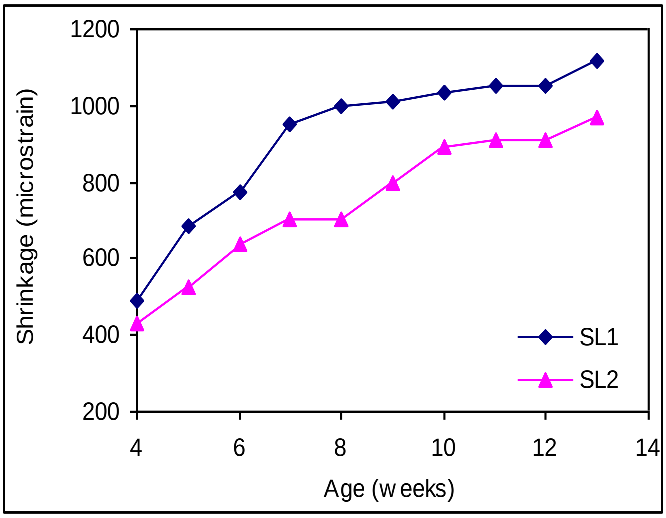

Figure 18. Shrinkage of SL1 and SL2 in (W) condition

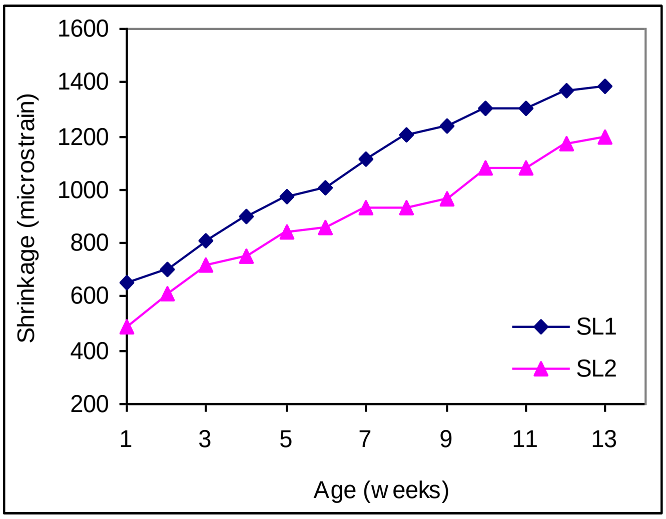

Figure 19. Shrinkage of SL1 and SL2 in (D) condition

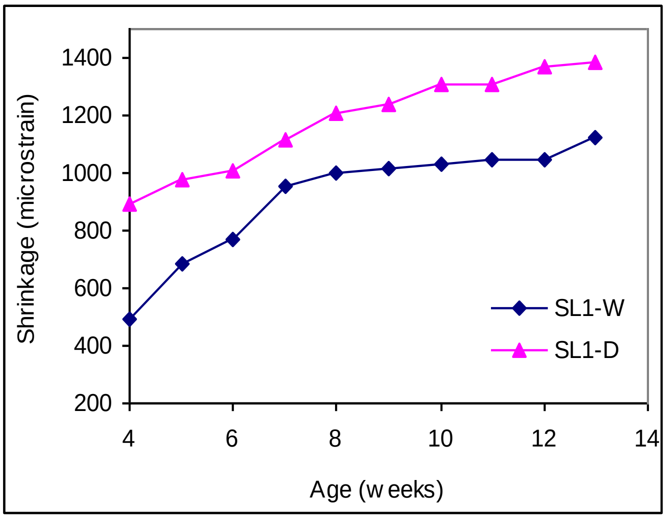

Figure 20. Shrinkage of SL1 in (W) and (D) conditions

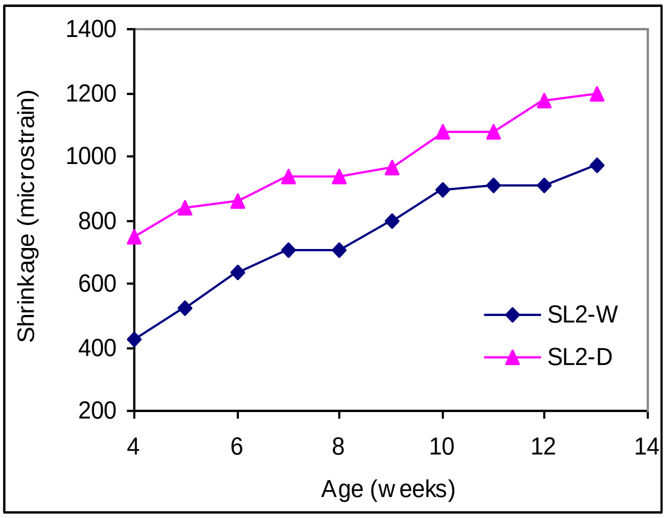

Figure 21. Shrinkage of SL2 in (W) and (D) conditions

6.7 *Swelling and results*

The specimens (10 × 10 × 45) were casted and at the age of one day, the Demec points were fixed as with shrinkage specimens and then they were kept in water which is saturated with lime. The amounts of swelling at different ages were measured by mechanical strain gauge and the results are shown in Figure 22. The results are indicating that, amount of swelling for SL1 is more than SL2 specimens. It seems that similar to shrinkage, the swelling value for SCLC will be increased as the ratio of w/cm is increased and decrease as compressive strength is decreased.

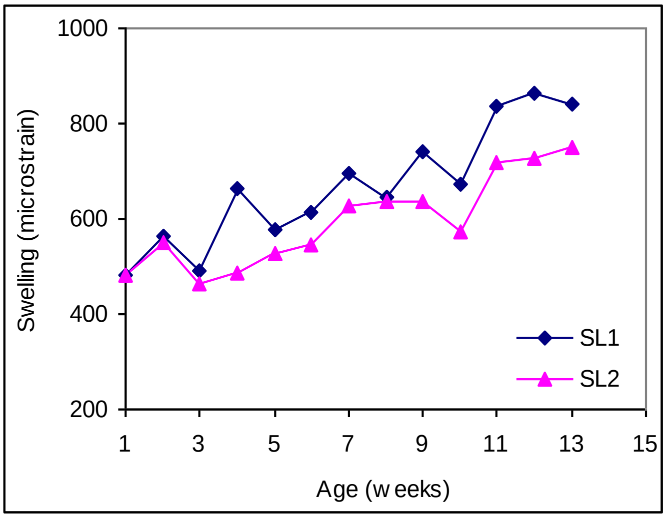

Figure 22. Swelling of SL1 and SL2 samples

7 CONCLUSIONS

Based on experimental research on SCLC, the following conclusions are obtained:

1. It was possible to produce an internationally suitable self compacting light concrete (SCLC) mixes in Iran.
2. Different storage condition will affect the compressive strength of (SCLC) and the highest strength of specimens for long time ages is reached under the (W) storage condition.
3. By use of well grained aggregates, Leca and 400 and 500 kg/m^3 of cement containment, it was possible to produce a self compacting light concrete mix with compressive strength of 20.8 and 28.5 MPa at 28 days respectively. This strength is allowed in structural reinforced concrete codes.
4. The increase in flexural strength of (SCLC) specimens is depending upon their 28 days compressive strength value.
5. For longer initial time of storage, the amount of shrinkage for samples kept at (W) condition is lower than (D) condition.
6. By increasing amount of compressive strength, the swelling value will be decreased.
7. The growing up rate of the shrinkage results are much regular than the swelling results. However, for better judgment it is suggested that for different type of filler the long time tests to be carried out.

REFERENCES

Bartos, peter J.M. 2005. Testing–SCC: Towards new European standards for fresh SCC. *Fist international symposium on design, performance* *and use of self consolidating concrete. SCC 2005 – China, 26 – 28 May 2005, Changsha, Hunan, China.*

Caijun Shi and Xiaohong Yang. 2005. Design and Application of Self Consolidating Lightweight Concretes. *Fist international symposium on design, performance and use of self consolidating concrete. SCC 2005 – China, 26 – 28 May 2005, Changsha, Hunan, China.*

Chai, H. 1998. Design and testing of self compacting concrete. *PhD thesis, University of London, 1998.*

Dehn, F. 2000. Betontechnologische Voraussetzungen Zur Herstellung Von Sebstverdichtendem Beton.10. Lepzinger Massivbauseminar.

EFNARC, *Specification and Guidelines for Self Compacting Concrete*. http://www.efnarc.org, Feb. 2002, 32 pp.

Hubertova, M. Self Compacting Light Concrete with Liapor Aggregates. *Proc. of intern. conf., Univ. of Dundee, Scotland, UK. 7th July, 2005.*

Mohamad pour, S. 2006. Mix design, construction and Eng. properties of self compacting light concrete. *MSc. Dissertation, Civil Eng. Dept. of Shaheed Bahonar University of Kerman, Kerman, Iran (to be published).*

Muller, H.S. & Haist, M. 2004. Erste Allgemeine Bauaufsichtliche Zulassung Selbstverdichtendder Leichtbeton. *(First General Technical Approval Self Compacting Lightweight Concrete). Bundesverband Leichtzuschlang Industrie e.V. Gerhard Koch Straße 2. 73760 Ostfildem (Scharnhauser Park).*

Nagataki, S. & Fujiwara, H. 1995. Self Compacting Property of Highly Flowable Concrete. *ACI, SP-154, June 1995, pp. 301-314.*

Nehdi, M. and Ladanchuk, J.D. 2004. Fiber synergy in fiber- reinforced self consolidating concrete. *ACI Material Journal, V.101, No.6, November-December 2004, pp. 508-517.*

Ozava, K., Sakata, N. and Okamura, H. 1994. *Evaluation of Self Compatibility of Fresh Concrete Using Funnel Test. Proc. JSCE 90(23), pp. 59-75.*

Poppe, A.M. & De Schutter, G. 2001. Influence of the nature and the grading curve of the powder on the rheology of self compacting concrete. *Proceeding of the fifth CANMET/ACI international conference recent advantages in concrete technology, Singapore, July-August 2001, pp. 399-414.*

Sonebi, M. & Bartos, P.M.J. 1999. Hardened SCC and its Bond with Reinforcement. *Proceeding of RILEM International Symposium on Self Compacting Concrete*. Edited by SKarendahl, A. and Petersson, O. Stockholm, 13-15 September 1999, pp. 275-290.

Sakata, N., Maruyama, K. and Minami, M. in: Bartos, P.J.M., Marrs, D.L. and Cleland, D.J. (Eds.) 1996. Basic properties and effects welan gum on self consolidating concrete. *Production methods and workability of concrete, E & FN spon, London, uk, 1996, pp. 237-252. ISBN 0419220704.*

Zhang Ming-Hong, Li Lian, & Paramasivam, P. 2005. Shrinkage of high-strength lightweight aggregate concrete exposed to dry environment. *ACI Material Journal. V. 102, No. 2, March-April 2005, pp. 86-92.*