Strength and durability performance of Light Weight Self-Compacting Concrete (LWSCC) with Light Expanded Clay Aggregate (LECA)

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Abstract: Lightweight concrete (LWC) have been successfully implemented in the construction of structures for decades mainly due to its favourable material properties, especially their low specific weight in connection with a high capacity of thermal insulation, strength and durability. Development of Light Weight Self-Compacting Concrete (LWSCC) is an innovative step in the recent years in the construction sectors. LWSCC provides the combined favourable benefits of LWC with those of a Self-Compacting Concrete (SCC). Research work is aimed on development of (LWSCC) with the use of light aggregates namely “Light expand clay aggregate (LECA)”. In this present investigation, five different mixes of (LWSCC) were casted and tested to find the workability and to calculate the mechanical properties at the age of 28 days. Water penetration test was conducted to examine the durability of LWSCC. Based on the results obtained, the best mix design was identified and selected for further investigation.

Keywords: Lightweight concrete (LWC), Self-Compacting Concrete (SCC), Light expand clay aggregate (LECA), Light Weight Self-Compacting Concrete (LWSCC).

1. INTRODUCTION

The concept of SCC was proposed in 1986 by Professor Hajime Okamura, but it was first developed in 1988 in Japan by Professor Ozawa (1989) at the University of Tokyo. Self-Compacting Concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under self-weight filling formwork and achieving full compaction even in the areas of congested steel reinforcement. In the hardened state, SCC has strength and durability that are comparable to that of conventional concrete. Worldwide, the use of SCC has gained wide acceptance in the precast industry as well as in-situ constructions on account of reduction in the time of construction, reduction in the noise of construction by eliminating vibration, possibility of usage of complex formworks and members with highly congested reinforcement etc. leading to achievement of a better final product in terms of finish and durability. SCC consists of the same ingredients as the conventionally vibrated concrete viz., cement, aggregates and water along with chemical and mineral admixtures in varied proportions.

Light Expanded Clay Aggregate (LECA) is made from a special grade of clay suitable for expansion. The ground clay mixed with additive to bloat and passed through a rotary or vertical shaft kiln fired by a mixture of pulverized coal and oil at temperature of about 1200°C. Finally, the material produced consists of hard rounded particles with a smooth dense surface texture and honeycomb interior.
cellular structure so formed is kept hold on cooling and the product is used as light-weight aggregate. This is called as Light Expanded Clay Aggregate (LECA).

2. LITERATURE REVIEW

Jiajun et al. [2006] attempted to study the effect of pre-wetted light-weight expanded clay aggregate on the internal relative humidity and autogenous shrinkage of concrete. It is stated that the amount of water introduced by pre-wetted light-weight aggregate into the concrete controls the Internal Relative Humidity (IRH). The process of the reduction of IRH can be delayed by importing an appropriate amount of water from aggregate. Obviously, the autogenous shrinkage of concrete can be reduced.

Lo et al. [2008] studied the effect of LECA aggregate on water absorption at interfacial zone of lightweight concrete. The findings revealed that the pore area available at the Interfacial Transition Zone (ITZ) was higher than the pore area in hardened cement paste. The aggregate with higher water absorption produced more pore area percentage at the ITZ of concrete. The pore area percentage in the concrete varied from 14.4% to 21.7% depending on water absorption of aggregates (8.9 to 11%).

Maghsoudi et al. [2011] showed that SCC with LECA aggregate requires more internal energy of motion than the concrete consisting of natural aggregate. However, the spherical shape of LECA improves the rheological characteristics of fresh concrete. SCC with LECA can produce light weight concrete of density less than 1900 kg/m³ with sufficient compressive strength.

Famili et al. [2012] made SCC mixtures containing micronized quartz powder, silica fume, Portland cement and with or without 25% pre-saturated LECA aggregate. The results reveal that internal curing with Saturated Surface Dry (SSD) lightweight aggregate was very effective in reducing early age autogenous shrinkage. The compressive strength of concrete with saturated LECA aggregates is same as that of concrete with conventional curing.

Hubertova and Hela [2013] carried out studies on the durability of self-compacting concrete with LECA in chemically aggressive liquid and gaseous environments. The results indicate that SCC made with LECA produced high compressive strength and more resistant to aggressive environment.

Su et al. [2001] developed a simple mix design method for self-compacting concrete. It is obvious that the amount of binders, fine aggregate, coarse aggregate, mix water and superplasticizer govern the mix design of SCC. It is suggested to consider less than 0.30 water/binder ratios, 52–58% volume ratio of aggregate, the coarse aggregate content equivalent to about 50% of the dry packed unit weight and water 160–185 kg/m³ for making SCC. Also, the packing factor of aggregate is suggested to be in the range of 1.12 to 1.16. The volume of sand to mortar can be taken in the range of 54–60%. As a whole it is clear that, large amount of powder materials and less coarse aggregates are required to promote the self-compatibility.

Sonebi and Bartos [2002] attempted to assess various methods used for measuring filling ability and plastic settlement of SCC. It was found that the experimental error in plastic settlement is very small whereas, it is higher in filling ability. Further, it is clear that the nature of sand influences significantly slump flow and flow time. The higher slump flow and flow time enhances the segregation of ingredients.

Khatib [2008] studied the effect of fly ash as a partial replacement of cement on the performance of SCC. The partial replacement of cement by fly ash has significantly increased workability of concrete and thereby, eliminated the necessity of superplasticizer to obtain a same workability as that of conventional concrete. The strength and shrinkage of SCC with high volume of fly ash is same as that of conventional concrete. Also, SCC shows less permeability and water absorption due to the
refinement of pore structure.

Nanthagopalan and Santhanam [2008] presented a new and systematic approach based on the concept of particle packing and rheology for optimizing mineral and chemical admixtures to be used in SCC. Accordingly, the powder combinations (cement and fly ash) and superplasticizer dosage are optimized. The optimum ratio of cement to fly ash is 60:40. Also, the volume fraction of the system occupied by solids achieved by using only water was 0.617 and by using superplasticizer with water was 0.627.

Bhattacharya et al. [2008] examined the effects of aggregate size and distribution, mineral admixture and filler on properties of fresh and hardened SCC. It is found that equal distribution of aggregate having 25 mm and 9.5 mm size favoured to gain higher slump flow. Low water-powder ratio and increased paste volume are the major factors influencing the property of SCC than water-cementitious ratio. Also, the characteristics of SCC are prominently influenced by admixture types, dosage and filler.

3. MATERIALS AND METHODS

3.1 Cement
Ordinary Portland Cement (OPC) 53 Grade conforming to IS: 12269-1987 was used in the present work. The physical and chemical characteristics of cement were measured using the procedure prescribed by IS: 4031-1988 and IS: 12269-1987. The physical characteristics are furnished in Table 1.

| Physical Properties of Cement | Test Results |
|------------------------------|--------------|
| N.C I.S.T F.S.T              | 31.5 220 280 |
| 1 Day N/mm²                  | 16.8 30.9 40.8 |
| 3 Day N/mm²                  | 30.9 40.8 53.8 |
| 7 Day N/mm²                  | 40.8 53.8 7% |
| 28 Day N/mm²                 | 53.8 7%     |
| 45 mic                       | 2%          |
| 90 mic                       | 7%          |

3.2 Fine Aggregate
Locally available M-sand with fraction passing through 4.75 mm sieve and retained on 150µm sieve was used as fine aggregate and tested as per IS: 2386-1963. The fineness modulus of sand and specific gravity is found to be 2.74 and 2.70 respectively. The physical properties of M Sand are presented in Table 2. M Sand conforms to grading zone II of IS: 383-1970.

| Physical Properties of Fine Aggregate | Test Results |
|--------------------------------------|--------------|
| Physical Properties                  |              |
| Specific Gravity                     | 2.70         |
| Bulk Density(Loose)                  | 1616Kg/m³    |
| Bulk Density(Compacted)              | 1650Kg/m³    |
| Fineness Modulus                     | 2.74         |
| Water Absorption                     | 2.84         |

3.3 Coarse Aggregate
Locally available crushed aggregate of maximum size 12.5 mm conforming to well graded aggregate as per IS: 383-1970 was chosen for the present investigation. Coarse aggregate was tested using the procedure prescribed by IS: 2386-1963 and the results are furnished in Table 3.
Table 3: Physical Properties of Coarse Aggregate

| Physical Properties          | Test Results |
|-----------------------------|--------------|
| Specific Gravity            | 2.76         |
| Bulk Density (Loose)        | 1520 Kg/m³   |
| Bulk Density (Compacted)    | 1560 Kg/m³   |
| Water Absorption            | 0.4          |
| Aggregate Impact Value      | 14.44%       |
| Aggregate Crushing Value    | 12.22%       |

3.4 Water
Potable tap water available in the local as conforming to the requirements prescribed by IS: 456-2000 was used in this investigation.

3.5 Superplasticizer
Superplasticizer is a chemical compound used to enhance the workability without adding more water. Auramix 300 superplasticizer, namely a product of Fosroc Company having a specific gravity of 1.10 was utilized in this work. It complies with IS: 9103-1999 as a high range water reducing admixture. The risk of bleeding and segregation can be minimized with the addition of Auramix 300.

3.6 Light Expanded Clay Aggregate (LECA)
LECA was purchased from GBC; India, Ahmadabad, Gujarat. The base material is plastic clay which is pre treated and then heated and expanded in a rotary kiln. Finally, the product is burned at about 900°C to 1250°C to form the finished LECA product. It comprises of small, light weight, bloated particles of burnt clay (Figure 1). The thousands of small, air filled cavities provide thermal insulation properties to LECA. The physical properties of LECA were studied using the procedure prescribed by ASTM: C330-2000 and IS: 2386-1963 and furnished in Table 4.

Table 4: Physical Properties of LECA Clay

| Physical Properties          | Test Results |
|-----------------------------|--------------|
| Specific Gravity            | 1.42         |
| Bulk Density (Loose)        | 400 Kg/m³    |
| Size of Aggregate           | 10-12.5mm    |
| Fineness Modulus            | 2.74         |
| Water Absorption            | 40%          |
4. MIX PROPORTIONING OF LWSCC

The mix composition shall satisfy all performance criteria for the concrete in both the fresh and hardened states. In the present work, EFNARC guidelines were followed for design of LWSCC mixes. The optimum water-powder ratio used in the mix is 0.865. Also, 0.7% of super plasticizer by weight of powder material was used in LWSCC to impart required workability. The Coarse aggregate was replaced in the mixes in the range of 0% to 20% with 5% interval on volume basis. The Coarse aggregate was replaced in the mix by LECA to the maximum extent of 20% by volume with 5% increment. The ingredient such as prewetted LWAs, Msand, cement and coarse aggregate were mixed thoroughly in dry condition. Then the polycarboxylate ether-based superplasticizer mixed in water was added to the mix and later thoroughly mixed to cast specimens. Twenty-four hours after casting, the specimens were demoulded and covered with plastic sheets to minimize moisture loss.

The mix without LECA is taken as control mix (CM). One mix was cured with water (CM). The mixes coded with letter “L” and designates mixes with LECA respectively. The numeral in the mix code (subscript) designates the percentage of replacement of natural Coarse aggregate by volume with LECA. The final mix proportion is shown in Table 5.

Table 5. Mix proportion for SCSCC with LECA aggregate

| MIX ID | CM | L5 | L10 | L15 | L20 |
|--------|----|----|----|----|----|
| W/C    | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| CEMENT | 500 | 500 | 500 | 500 | 500 |
| FA     | 767 | 767 | 767 | 767 | 767 |
| CA-10  | 721 | 685 | 648 | 611 | 574 |
| CA-20  | 309 | 309 | 309 | 309 | 309 |
| LECA   | 0   | 9  | 18.5 | 27  | 37  |
| WATER  | 175 | 175 | 175 | 175 | 175 |
| SP     | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 |

5. FRESH PROPERTIES OF LWSCC

The workability SCSCC can be characterized by the following properties.

i) Filling ability
ii) Passing ability
iii) Segregation resistance

A concrete mix can only be classified as SCC if the requirements for all the three aforementioned characteristics are fulfilled. General test methods are available to evaluate the characteristics of SCC. These methods have not been standardized by national and international organizations. The details of more common tests used for evaluating the compacting characteristics of fresh SCC are given below.

5.1 Slump Flow and T50 cm Slump Test

The slump flow test examines the horizontal unrestricted flow of SCSCC without any obstacles. Base plate of about 1000 mm x 1000 mm and slump cone having 200 mm internal diameter at base and 100 mm at top were used to perform the test (Figure 2). The slump cone was placed at the centre of the table that has a circle of 500 mm diameter, drawn concentrically. Concrete was poured without any compaction. The poured concrete was screeded and leveled from the top of the cone to ensure the required amount of concrete is within the cone. Then, the cone was lifted in an upward direction and the time of the concrete to reach 500 mm diameter mark (T50 cm time) was recorded. The slump flow was recorded as the average of two measurements. Typically, slump flow values ranging from 650 to 800 mm and T50 time ranging from 2 to 5 seconds are acceptable for filling ability.
5.2 V- Funnel Test
The test was developed in Japan and it is used to determine the filling ability of the concrete with a maximum aggregate size of 20 mm. The equipment consists of a V-shaped tunnel as shown in Figure 3.

After filling the V-funnel with concrete, the trap door was opened within 10 sec to allow the concrete to flow out under gravity. The stop watch was started when the trap door was opened and the time was recorded for the discharge to complete. This is taken when light is seen from above through the funnel. V-funnel apparatus is shown in Figure 3. The whole test was performed within 5 minutes. The mix has to show 6 to 12 sec to conform the filling ability of SCSCC.

5.3 J - Ring Test
The J Ring test principle has been developed at the University of Paisley. The test is used to determine the passing ability of the concrete. The apparatus consists of a rectangular section of 30 mm x 25 mm, open steel ring, bored vertically with holes to allow threaded sections of reinforcement bar as shown in Figure 4. These bars consist of various diameters and spaced at different spacing according to typical reinforcement. Usually it is 3 times the maximum size of aggregate.
To perform the test, the base plate was moistened and it was placed on level stable ground. The J-ring was kept centrally on the base plate and the slump-cone positioned centrally inside it and held down firmly. The cone was filled with fresh concrete. The concrete was leveled at the top of the cone using trowel without any compaction. The surplus concrete around the base of the cone was removed. The cone was raised vertically and allowed the concrete in two perpendicular directions. The average of the two measured diameters was calculated. The difference in height between the concrete at just inner side and outer side of the bars was measured as shown in Figure 4.

5.4 L-Box Test

This test set up was designed by Peterson for underwater concrete. L-Box test measures passing ability properties of SCC. The test appraises the flow of the concrete and also typically gives the degree to which it is subjected to interruption by reinforcement.

The L box apparatus consists of vertical and horizontal rectangular section which is separated by a sliding gate. At the junction of vertical and horizontal rectangular sections, three 12 mm vertical bars with a clear spacing 35 mm are fixed as shown in Figure 5. The concrete was filled in the vertical section, and then the gate was raised to allow the concrete to flow into the horizontal section. Once, the concrete was ceased to flow, the height of the concrete at the vertical end (H1) and the horizontal end (H2) was measured. The blocking ratio is the ratio of concrete height (H2/H1) in the horizontal portion to that in the vertical portion of the box is measured. EFNARC has specified that the blocking ratio is in the range of 0.8 to 1 to confirm the passing ability requirements. The results after evaluating the compacting characteristics were listed in table 6.

![Figure 5. Measurement of L – box](image)

Table 6: Fresh Properties of LWSCC

| MIX ID | CM | L5 | L10 | L15 | L20 |
|--------|----|----|-----|-----|-----|
| SLUMP FLOW (mm) | 700 | 680 | 705 | 710 | 720 |
| T50 SLUMP (SEC) | 3.1 | 3.3 | 3.0 | 2.9 | 2.7 |
| V-FUNNEL (SEC) | 8 | 10 | 9 | 8 | 8 |
| J RING (mm) | 650 | 630 | 640 | 660 | 670 |
| L BOX | 0.81 | 0.85 | 0.88 | 0.92 | 0.95 |
| U BOX | 29 | 30 | 27 | 31 | 35 |
| SIEVE SEGREGATION | 12.51 | 11.56 | 8.75 | 7.50 | 4.25 |
6. MECHANICAL PROPERTIES OF LWSCC

The mechanical properties of SCSCC with LECA such as compressive strength, split tensile strength, flexural strength, modulus of elasticity and bond stress were evaluated in the present work.

6.1 Compressive Strength Test

The compressive strength of concrete was determined using 150 mm x 150 mm x 150 mm concrete cubes as per IS: 516-1959. The cube specimens were tested in dry condition, after wiping the surface moisture with clothes. For each mix, three identical specimens were tested at the age of 7 days, 28 days. A total of 45 cube specimens were cast for the test. The test was conducted in 3000 kN compression testing machine (Figure 6). The load was applied at the rate of 140 kg/cm²/min until the failure of the specimen as per IS: 516-1959. The maximum load applied over the specimen to cause failure was recorded.

![Figure 6. Compressive Strength Testing](image_url)

The compressive strength of test results of SCC with LECA is furnished in Table 7. It is evident from Figure 6 that the compressive strength of the LECA incorporated SCC concrete up to 7 days is significantly less than the control concrete (CM). Thereafter, a remarkable gain in compressive strength is noticed in SCC mixes (L10, L15) making it on par with CM mix at the age of 28 days and surpassed at later ages. Further, it is evident that 15% of LECA is the optimum percentage to replace natural Coarse aggregate to impart maximum compressive strength to SCC. Beyond 15% of LECA content, the compressive strength reduced slightly and it is less than CM mix. It is perhaps due to either weaker nature or very pronounced water absorption characteristics of the LECA aggregate (Kockal and Ozturan 2011).

The SCC with 15% of LECA has exhibited 5.73% higher compressive strength than the control concrete (CM) at age of 28 days respectively. It is due to the presence of required moisture content available in the pre saturated LECA aggregate for hydration process. The LECA aggregate allows moisture content to move from inside to outside to ensure complete hydration process in concrete. The pre-wetted lightweight aggregate is used in the concrete promote self curing and to ensure the compressive strength of concrete (Dayalan and Buellah 2014, Golias et al. 2013). The results obtained are in agreement with the results reported by Maghsoudi et al. (2011) and Mousa et al. (2015).

| Mix Id | Compressive Strength (MPa) | 7 days | 28 days |
|--------|----------------------------|--------|--------|
| CM     | 27.64                      | 42.59  |
| L5     | 25.12                      | 42.68  |
| L10    | 26.22                      | 43.98  |
| L15    | 28.15                      | 45.03  |
| L20    | 25.36                      | 43.39  |
6.2 Split Tensile Strength Test
This is an indirect test to estimate the tensile strength of concrete. Splitting tensile strength tests were carried out at the age of 7 days, 28 days on the concrete cylinder specimens of size 150 mm diameter and 300 mm height using 3000 kN compression testing machine (Figure 7) as per IS: 5816-1970. For each mix, three identical specimens were tested at the age of 7 days, 28 days. A total of 45 cylindrical specimens were cast for the test. The load was applied gradually till the specimen fails and the readings were recorded.

![Figure 7. Split Tensile Strength Testing](image)

The split tensile strength of SCC with LECA was measured at the age of 7,28 days and the test results are furnished in Table 8.

| Mix Id | Split Tensile Strength (MPa) |
|--------|-----------------------------|
|        | 7 days | 28 days |
| CM     | 2.96   | 3.92   |
| L5     | 1.85   | 3.37   |
| L10    | 1.82   | 3.65   |
| L15    | 1.91   | 4.32   |
| L20    | 1.92   | 3.34   |

Similar to compressive strength, the tensile strength of SCC with LECA is relatively less than CM at early ages (7 days). However, a remarkable gain in tensile strength is noticed in SCSCC with LECA at the age of 28 days. Further, it is observed that L15 mix has shown maximum tensile strength among all SCC mixes. This mix has yielded 8.54%, more split tensile strength than CM at the age of 28 days. These results are in conformity with the observation reported by Gifta et al. (2013). The pre-wetted LECA incorporated in concrete provided required water content for internal curing to ensure complete hydration and thereby to increase tensile strength (Mousa et al. 2015).

6.3. Modulus of Rupture Test
Flexural test was carried out at the age of 7 days, 28 days, on the 100 mm x 100 mm x 500 mm prism specimen using 100 kN capacity Flexural Testing Machine (FTM). Two point loading method was adopted to determine the modulus of rupture as per IS: 516-1959. For each mix, three identical specimens were tested at the age of 7 days, 28 days. A total of 30 prism specimens were cast for the test. The typical test set up is shown in Figure 8.
Figure 8. Modulus of Rupture Test

The modulus of rupture test results of SCC with LECA is furnished in Table 9. The SCSCC with 15% LECA has gained a higher modulus of rupture than control concrete as well as other SCC mixes with LECA. The F15 mix attained 18.70%, more strength than CM at 7, 28, days respectively.

Table 9: Modulus of Rupture of SCC with LECA

| Mix Id | Modulus of Rupture (MPa) | 7 days | 28 days |
|--------|--------------------------|--------|--------|
| CM     | 5.65                     | 6.63   |
| L5     | 5.55                     | 6.02   |
| L10    | 5.67                     | 6.65   |
| L15    | 5.83                     | 7.91   |
| L20    | 5.30                     | 7.33   |

7. DURABILITY PROPERTIES OF LWSCC

Durability is the ability of concrete to resist weathering action, chemical attack and abrasion by retaining its preferred engineering properties. No standardized method exists for measuring the durability of concrete in general. However, the following tests were carried out for assessing the durability properties of LWSCC in the present work.

7.1 Water Permeability Test

Figure 9. Water Permeability Test

The specimen is cured for 28 days and then water pressure is applied on the middle roughened portion so that water can penetrate inside the concrete. The water pressure is maintained as 3 bars for next 72 hours are shown in (Figure 9). After this, the specimen are split to know the penetration of water. The specimen are split in compression machine by applying concentrated load at two diagonally opposite points slightly away from central axis. The average of three maximum values of penetration is calculated. The depth of penetration of water should not be more than 25mm otherwise the specimen are considered to be failed in permeability test.
The durability properties of SCC Water permeability test were determined for the select SCC mixes (CM, L15). The Water Penetration depth of Concrete was found 8mm in Control mix and 6mm in L15 Mix.

8. CONCLUSION

The following conclusions are drawn based on the experimental test results:

- The workability properties of SCC mixes are in conformity with the requirements prescribed by EFNARC. However, SCC with more than 15% of LECA affects adversely passing ability due to reduction in the weight of concrete.
- The 15% of LECA is the optimum percentage to replace natural coarse aggregate to impart maximum compressive strength to SCSCC.
- Also, all SCSCC mixes (L15) exhibited relatively higher compressive strength than the control mix. The L15 SCC mixes yielded 5.73% more compressive strength respectively than control at the age of 28 days. Further, all SCC mixes have demonstrated relatively more split tensile strength, modulus of rupture behaviour than control mix. It is due to incorporation of pre-wetted lightweight aggregates as self-curing agents to ensure complete hydration of cement to improve the quality of concrete in terms of porosity and permeability and thereby strength. In general, all SCSCC mixes have demonstrated better durability than control mix.

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