Experimental study on self-compacting concrete with replacement of coarse aggregate by light expanded clay aggregate

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Abstract. The present study deals with fresh and hardened concrete properties of self-compacting concrete while carrying several trial mixes with a variety of water binder ratio and super-plasticizer content and finally achieved a trail mix with satisfying the flow properties as slump flow, V-funnel, and L-box test apparatus values are obtained within the limits of European guidelines. This study was carried out on the properties of Lightweight self-compacting concrete (LWSCC) with a binder content of 517 Kg/m\textsuperscript{3}. In the achieved proportion of the final trail mix, the coarse aggregate will be replaced by Light Expanded Clay Aggregate (LECA) by varying the different percentages of coarse aggregate as 0%, 10%, 20%, 30%, 40%, and 50% by volume replacement. The fresh concrete properties are determined, and the values were found in considerable range as per European guidelines by performing slump flow, V-funnel, and L-Box tests for various proportions (0%, 10%, 20%, 30%, 40%, and 50%) of LECA aggregates by replacing normal coarse aggregates. The hardened concrete properties are determined by performing Compressive strength, split tensile strength, ultrasonic pulse velocity, and rebound hammer tests after curing specimens for 7 days and 28 days. Results indicate that LECA replacement in SCC up to 30% gives fair results in split tensile & compressive strength. NDT results show values are gradually decreasing with an increase in LECA proportion. Beyond 30% of LECA replacement in SCC gives results of split tensile, compressive strength, ultrasonic pulse velocity, and rebound hammer tests which are not inconsiderable range.

Keywords: Compressive strength, light expanded clay aggregate, rebound hammer test, self-compacting concrete, split tensile strength, ultrasonic pulse velocity.

1. Introduction
Currently, SCC can be used as a trending building material. This concrete indicates, no vibration is required to have self compaction. This type of concrete has many advantages a lot over normal concrete. SCC has worked on the nature of concrete and decreases of on-location fixes, quicker development times, lower by and large expenses, and help of the presentation of robotization into concrete development. SCC's properties will contribute to a greater improvement in the nature of a concrete structure and open up new fields for the use of concrete. It may also provide a quick pace of concrete situation, with shorter development times and compacts into each side of a formwork. Hajime Okamura proposed the concept of self-compacting concrete (SCC) in 1986. Professor Ozawa of the University of Tokyo was the first to design this concept in Japan in 1988. Due to its features like high flow properties, SCC is a high-performance concrete that self-cure. [1-2].
Figure 1. The necessity of Self-Compacting Concrete

Nan-Su, et., al. 2001,[3] was presented a mixed design strategy for self-compacting concrete (SCC). First, the amount of aggregate is still in the air, and then the gluing of the sheets compensates for the disadvantages of aggregates to ensure that the resulting concrete has the required fluidity, self-compacting capacity, and other SCC Characteristics. The volume of sand per solution is between 54 and 60%. The results show that the proposed technique can efficiently provide superior SCC. This method is less complicated, easier to perform, and less tedious, requires more modest fixings, and saves material. The Figure 1 illustrates the necessity of SCC.

As per the guidelines given by European countries for SCC 2005, this article discusses the specification, manufacture, and use of self-consolidating concrete. It is a cutting-edge document intended for designers, manufacturers, and users to improve their knowledge and use of SCC. It also describes the test methods used to support this specification. The attached specifications and test methods are presented in a performative format that reflects current EN concrete standards. J. Alexandre Bogas et., al.[4] The target of this work is to describe oneself compacting cements dependent on lightweight totals (SCLC) accessible in the Iberian Promontory. In U-Box and L-Box self-compaction tests, tolerability is certifiably not a basic element in describing SCLC, gave the total volume isn't excessively high. The stream time with SCLC was roughly 25% higher than with ordinary cements of comparative usefulness. Mehmet Gesog et al., 2013 [5] The paper addresses the goal of portraying new properties of SCC delivered with lightweight, fine and coarse totals (LWFA and LWCA). Lightweight totals were made by chilly granulation of 90 wt% fly debris and 10 wt% Portland concrete in a shifted turning spoon at room temperature. It was seen that expanding the LWA trade proportion brought about a progressive expansion in the crate stature proportion L of SCLC blends. Likewise, the stature proportion of the MC100 came to 1.0, which shows the most elevated liquid conduct. Yong Jic Kim et, al., 2009 [6] This article presents the improvement lightweight SCC. Two kinds of lightweight totals of various densities are utilized. On account of BAP with 100% lightweight coarse total, the compressive strength was 20% lower than that of control concrete with a total thickness of 2.07 g/cm3 and 31% lower with a total thickness of 1.58 g/cm3. Abdurrahman Lotfy et, al.,[7] Whenever made of self-compacting concrete broadly utilized that it is considered more to be "standard cement" as a "unique cement" it will be feasible to have for all time and solid substantial designs that require almost no upkeep. The advancement of SCC was a significant stage toward proficiency on building destinations, levelheaded creation of precast substantial parts, better working conditions and worked on quality and presence of substantial designs. A test concentrate on dependent on response surface innovation was performed to exhibit the impact of key boundaries on the properties of Lightweight Self-Compacting Substantial blends produced using extended mud totals. As far as newness properties, the absolute folio content impacts the functionality and static dependability of the EC-LWSCCs, and the protection from isolation is expanded. Strangely, with HRWRA% solids and w/b the usefulness/passing limit/fill limit is diminished, and the protection obstruction is expanded with the extension of the cover content. Light weight self-compacting substantial consolidates the benefits of SCC and further developed execution in the solidified state.
2. Materials and methodology

2.1 Materials

In this project materials like cement, Fly ash, river sand, Coarse Aggregates (CA), SP and water, and LECA are used in this study. The objective of this study is to evaluate the effect of the LECA on the strength and durability of SCC. The materials used in this study are tested to obtain their properties as per the relevant IS codes.

2.1.1. Cement.

Ordinary Portland Cement - OPC is the most suitable concrete for casting in general. OPC class 53 confirmed with IS: 12269 is used [24]. To avoid exposure to moisture, the cement is maintained in an airtight container and stored in a humidity-controlled environment. Cement physical properties are depicted below [8]. The physical properties are listed in Table 1.

| Physical property          | Obtained value | IS: 12269 Specifications |
|----------------------------|----------------|--------------------------|
| Normal Consistency         | 33 %           | -                        |
| Initial setting time - Vicat (min.) | 105 min | ≥30 min                  |
| Final setting time - Vicat (min.) | 360 min | ≤ 600 min                |
| Specific gravity           | 3.15           | -                        |

Vicat Equipment’s adapting to IS: 5513-1996, [9] balance, whose permissible deviation should be 1000g + 1.0g for a load. Trowels according to IS: 10086-1982 are used to determine the setting time of cement and normal consistency. All the values obtained are within the limits given by IS 12269 [24].

2.1.2 Fly Ash. Fly ash (Class F) is procured from Vijayawada Thermal Power Station, Ibrahimpatnam, Vijayawada. 30 kg packages of light grey fly ash are available. The company’s fly ash complies with all of the IS: 3812-1981 criteria [10] and the constituents are listed in Table 2.

| Constituents | SiO₂ | Al₂O₃ | Carbon | CaO | MgO | SO₃ |
|--------------|------|------|--------|-----|-----|-----|
| Percentages (%) | 30-60% | 15-30% | Up to 30% | 1-7% | Small amounts | Small amounts |

Fly debris is one of the most widely recognized results utilized in development and is like Portland concrete [11]. It is a finely isolated, non-combustible, inorganic buildup that is gathered or hastened by the exhaust gases of modern heaters (Halstead, 1986). Many Class C remains hydrate and solidify in under 45 minutes when presented to water. In concrete, class C fly debris is frequently utilized at measurements of 15-25% by mass of the cementations material, and class C fly debris is utilized at doses of 15-40%. [12] The portion fluctuates relying upon the reactivity of the debris and the ideal consequences for the substantial [13] [14].

2.1.3 Light Expandable Clay Aggregates (LECA).

LECA knows the material used in concrete technology, as shown in figure 2 and test details are listed in Table 3. LECA is specialized clay that has been pelletized and burnt at a high temperature in a rotating kiln. The organic chemicals in the clay burn during firing, causing the granules to expand and produce honeycombs when the outside surface of each granule melts and sinters. The ceramic pellets that arise are light, porous, and have a high tensile strength. LECA is a natural product that is free of dangerous chemicals. It has a neutral pH, is
resistant to frost and chemical agents, does not disintegrate in water, is not biodegradable, is not flammable, and provides good sound and thermal insulation.

Figure 2. The Appearance of Light Expandable Clay Aggregates

This material is incredibly versatile and is used in an ever-increasing number of applications.

Table 3. Table for pycnometer experiment values for determining Specific Gravity of LECA (Light Expanded Clay Aggregate)

| TRAILS | $W_1$ (g) | $W_2$ (g) | $W_3$ (g) | $W_4$ (g) | Specific gravity |
|--------|-----------|-----------|-----------|-----------|-----------------|
| 1      | 651       | 745       | 1446      | 1490      | 0.681           |
| 2      | 651       | 749       | 1430      | 1490      | 0.6202          |

2.1.4 Fine Aggregate.

The stream sand (locally accessible) is utilized for the current review. The sand is tried for the different properties and the particular gravity of sand is viewed as 2.64 Fine total going through 4.75mm IS strainer and held on 75 microns IS sifter is utilized [15]. Later strainer examination, the fineness modulus of fine total is 2.75.

2.1.5 Coarse Aggregate.

The total which is held over IS Strainer 4.75 mm is named as coarse total [16]. The fineness modulus of coarse total is 7.17.

Impact Test: The test comprises of totals estimated 10.0 mm-12.5 mm. Totals might be dried by warming at 100-110° C for 4 hours and cooled [17]. The test subtleties are represented in Table 4. Hence, the effect esteem is 50.1%.

Table 4. Observation of Impact Test.

| Observations                                      | Sample 1 | Sample 2 |
|--------------------------------------------------|----------|----------|
| Total weight of the dry sample ($W_1$ gms)       | 79       | 76       |
| Weight of portion passing 2.36 mm sieve ($W_2$ gms) | 40.29    | 37.24    |
| Aggregate Impact Value (%) = $W_2$ / $W_1$ X 100 | 51       | 49.2     |

Crushing Test.

The total pulverizing esteem test on coarse totals gives a general appraisal of a total’s protection from pounding when a compressive burden is progressively applied as displayed in Figure 3.
HI-BOND super-plasticizer (Figure 5) was used in this concrete and the working mechanisms of super plasticizers are presented in Figure 4 [18].

2.2 Mixing of Concrete.

Concrete today is almost mixed by machine and only in exceptional cases can concrete be mixed by hand as per standards [19]. It should be noted that compared to mechanical concrete, it is necessary to mix more concrete by hand to obtain concrete of the same strength. The Figure 6 depicts the mixing of SCC.

Design of trail mixes and acceptance criteria for workability and results of trail mixes are shown in table 5 and table 6 respectively.
Table 5. Table for Trail mixes

| Trails | Cement (Kg/m³) | Fly ash (Kg/m³) | Coarse aggregate (Kg/m³) | Fine aggregate (Kg/m³) | Water content (Kg/m³) | Super-plasticizer (Kg/m³) |
|--------|---------------|----------------|--------------------------|------------------------|----------------------|--------------------------|
| Trail1 | 425           | 92.35          | 667.5                    | 988.07                 | 187.0                | 4.65                     |
| Trail2 | 425           | 92.35          | 667.5                    | 988.07                 | 212.91               | 4.288                    |
| Trail3 | 450           | 74.95          | 667.5                    | 988                    | 237.0                | 5.344                    |
| Trail4 | 425           | 92.35          | 667.5                    | 988.07                 | 212.61               | 5.1                      |

Table 6. Table for Acceptance criteria for workability and results of trail mixes

| No of trails | Slump diameter (mm) | Slump time in (sec) | V-funnel (sec) | L-Box H/H₁ |
|--------------|----------------------|---------------------|----------------|------------|
| limits       | 650-800              | 2-5                 | 6-12           | 0.8-1      |
| Trail-1      | Not in limit         | Not in limit        | Not in limit   | Not in limit |
| Trail-2      | Not in limit         | Not in limit        | Not in limit   | Not in limit |
| Trail-3      | 650 mm               | 4.2 sec             | Not in limit   | Not in limit |
| Trail-4      | 570 mm               | 6 sec               | 5.6 sec        | 0.22       |

2.3 Compression Test

The compressive strength is quite possibly the main characteristic utilized in the plan rules for substantial designs and numerous other mechanical qualities and actual properties of SCC are additionally communicated as an element of this boundary [20]. The figure 7 and figure 8 portrays the testing course of action of substantial examples.

![Figure 7. Compressive Test](image1.png)

![Figure 8. Failure of the cube in compression.](image2.png)

2.4 Rebound Hammer Test

The rebound R values of the Sample Cubes were measured using the concrete hammer. Der Widerstand in Kompression was then determined with the pressure testing machine. Einschränkungen: the hammer offers to know about the uniformity of concrete [21]. The figure 9 depicts the testing arrangement of Rebound hammer.
2.5 Ultrasonic Pulse Velocity Test

The speed of ultrasonic heartbeats traveling through a strong material relies upon the thickness and the flexible properties of that material. The nature of materials is now and then identified with their versatile firmness, so the estimation of the UPV in such materials can frequently be utilized to demonstrate quality just as to decide their properties. It is moderately simple to lead an UPV test (Figure 10) [22].

![Figure 10. Ultrasonic pulses velocity test set up.](image)

The concrete specimen's surface is wiped with a carborundum stone to achieve a homogeneous surface devoid of dust and other foreign materials. Then, on opposing sides of the specimen, transducers are put since this is the most sensitive way because the receiving transducer receives the most energy from the transmitted pulse. The vibration beat is changed over into an electrical sign by a second electroacoustic transducer which is kept in touch with the other surface of the substantial component in the wake of having voyaged a known way length (L) in the substantial example, and the travel time (T) of the beat is estimated by an electronic planning circuit. Utilizing the connection, the UPV (V) is determined.

Pulse velocity $V = \frac{\text{Path length (L)}}{\text{Travel time (T)}}$ (3.5)

The nature of SCC as far as consistency, the presence or nonattendance of interior blemishes, breaks and isolation, and different variables demonstrative of the degree of workmanship utilized would thus be able to be surveyed utilizing the rules gave in Table 3.10 by Leslie et al (1949), which have been created for portraying the nature of cement in structures as far as ultrasonic heartbeat speed.
2.6 Split Tensile Strength

In this test, a substantial chamber of size 150 mm widths and 300 mm length is put with its pivot flat between the plates of the testing machine [23]. The Figure 11 and 12 delineates the disappointment of LECA for half and 10%.

![Figure 11. Split tensile failure for LECA 50%](image1.png)

![Figure 12. Split tensile failure for LECA 10%](image2.png)

3. Results and Discussion:

After achieving a mix proportion, the mixes are designated as LECA 0%, LECA 10%, LECA 20%, LECA 30%, LECA 40%, and LECA 50% indicates the replacing of coarse aggregate as LECA aggregates. We have cast 36 cubes and 24 cylinders with varying proportions of 0%, 10%, 20%, 30%, 40%, 50% LECA aggregates with partial replacement of coarse aggregate. The results of slump flow values are presented in table 7.

![Table 7. Table for slump flow values.](image3.png)

Theoretical density is illustrated in Table 8. Since the theoretical density from the laboratory does not contain air, compare this laboratory weight with the fresh weight, which contains air. The air in the fresh weight sample makes it lighter than the theoretical one.

Theoretical Density = actual density (fresh unit weight) / theoretical x 100 = calculated air content.

![Table 8. Table for densities of concrete for various proportions.](image4.png)
Table 9. Rebound hammer and ultrasonic pulse velocity test results

| % Of LECA | Weight of cube(kg) | Average RBH NO | UPV Wave time(µs) | Velocity(m/s) |
|-----------|--------------------|----------------|-------------------|--------------|
| LECA 0    | 8.25               | 33.5           | 32.25             | 4651         |
| LECA 10   | 7.8                | 33.25          | 33.125            | 4530         |
| LECA 20   | 7.55               | 32.875         | 33.3              | 4454         |
| LECA 30   | 7.3                | 32.5           | 33.475            | 4378         |
| LECA 40   | 6.9                | 32             | 34.4875           | 4301         |
| LECA 50   | 6.5                | 31.5           | 35.5              | 4224         |

Up to an age of 28 days, the cured concrete has been tested physically and mechanically. The rebound hammer and ultrasonic pulse velocity test results are shown in table 9. The compressive and split tensile strength tests reveal that the six mixes result in concretes are presented in the table 10.

Table 10. Compressive and split tensile strength values

| % Replacement of LECA | Compressive Strength (N/mm²) | Split tensile strength (N/mm²) |
|-----------------------|------------------------------|-------------------------------|
|                       | 7 days                       | 28 days                       | 7 days    | 28 days   |
| LECA 0                | 30.35                        | 40.9                          | 2.205     | 3.105     |
| LECA 10               | 29.26                        | 37.99                         | 1.995     | 2.32      |
| LECA 20               | 28.37                        | 36.94                         | 1.86      | 2.154     |
| LECA 30               | 27.48                        | 35.89                         | 1.725     | 1.9885    |
| LECA 40               | 26.27                        | 32.1                          | 1.457     | 1.761     |
| LECA 50               | 25.06                        | 28.5                          | 1.19      | 1.535     |

Figure 13. Compressive strength test of LECA with various replacements in %.
The filling ability, passing ability and blocking ratio of all lightweight self-compacting mixes are within the limits of European guidelines for self-compacting concrete. Compression and Split tensile strength values are decreasing gradually as shown in figure 13 and figure 14 individually. To compensate split tensile strength fibers are to be used in further investigation. Rebound hammer values are decreasing in appreciable manner and also in considerable range with increase in LECA proportions. Due to increase in LECA proportion, densities of concrete are decreasing gradually. The maximum of 13.2% occurs at 50% LECA replacement.

4. Conclusions

1. The workability of lightweight self-compacting concrete is found to be increased by the increase in % replacement of coarse aggregate with LECA.
2. It was found that the compressive strength test results for (0%, 10%, 20%, 30% LECA replacement) gradually decrease, but subsequently, the strength drops sharply (40%, 50% LECA replacement).
3. The slump flow time increases up to 30% of LECA replacement, after which the slump flow time is reduced due to an increase in LECA proportions.
4. As per ultrasonic pulse velocity test results, LECA proportions of 0%, 10% 20% fall under excellent quality, and LECA proportions of 30%, 40%, 50% fall under good quality concrete, due to an increase in LECA proportion, densities of concrete are decreasing gradually. The maximum of 13.2% occurs at 50% LECA replacement.
5. The replacement of coarse aggregates with LECA up to a ratio of 30% results in lightweight self-compacting concrete with better performance, with lower weight and low density.

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