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A Study on the Effect of Light Expanded Clay Aggregate in Producing Sustainable Lightweight Self-Compacting Concrete

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Abstract:

Light Weight Self Compacting Concrete (LWSCC) combines the benefits of being lightweight and flowable in elements with crowded reinforcing. In this project, Self Compacting Concrete (SCC) is manufactured using LECA (Light Expanded Clay Aggregate) to make the concrete lighter in weight, resulting in Light Weight Self Compacting Concrete (LWSCC). Fine aggregate in Self Compacting Concrete (SCC) is substituted with LECA at 0%, 5%, 10%, and 15% of the volume of fine aggregate. The mix design is created using ENFARC rules and tested for workability requirements. The compressive strength increased with 5% replacement compared to 0% replacement because the spherical shape of LECA aggregates contributed to better self-compaction and hence higher strength. Further replacement resulted in a decrease in strength due to the weaker nature and the inability to obtain water for hydration due to LECA's strong water absorption properties. As a result, replacing fine aggregate in self-compacting concrete with Light Expanded Clay Aggregate (LECA) at a rate of 5% is regarded as optimal.

Keywords: Light Weight Concrete; self compacting concrete; light weight self compacting concrete; LECA, Workability, Clay.

1. Introduction:

Concrete is the most used construction material due to its versatility and structural strength. Conventional concrete has a high density of 2200-2600 kg/m³, increasing the self-weight of structures and requiring larger sections for load-bearing elements and foundations. This leads to increased material consumption and lower cost efficiency. To address this issue, lightweight concrete (LWC) with densities ranging from 300-1850 kg/m³ has been created. Lightweight concrete is often made from porous lightweight particles with a low specific gravity. These aggregates can be natural (pumice, diatomite, scoria, volcanic cinders, sawdust, rice husk, etc.) or man-made (expanded clay, sintered fly ash, bloated shale, foamed slag, vermiculite, perlite, etc.). Artificial aggregates are preferred due to their uniformity and controllability. Light Expanded Clay Aggregate (LECA) is an artificial aggregate made by heating clay at ~1200 °C in a rotating kiln, resulting in bloated, spherical aggregates with low density (250-510 kg/m³ depending on grading [1].

Parallel to this evolution, Self-Compacting Concrete (SCC) has evolved as a concrete technology innovation. SCC is distinguished by its great flowability and ability to travel through congested reinforcement and formwork without causing exterior vibrations. This is accomplished by combining superplasticizers and mineral admixtures (such as silica fume, fly ash, and filler ingredients). Chemical admixtures help to disperse cement particles, improve workability, and reduce water usage, whilst mineral admixtures improve stability and mechanical performance [2].

Recent research have looked into the usage of LECA in SCC. For example, integrating expanded clay into self-compacting lightweight concrete (SCLC) has been shown to lower density while improving thermal insulation and retaining acceptable strength [3]. Another study investigated structural lightweight SCC with LECA as coarse aggregate and hybrid fibers, and found that mechanical strength increased dramatically while being below EFNARC workability constraints [4]. Investigations on reinforced LWSCC beams with LECA replacement (5-25%) revealed lower compressive and flexural strengths at higher replacement levels, although workability criteria were still met [5]. More recently, lightweight SCC including LECA and mineral additions such as lime powder, marble dust, fly ash, and quartz displayed improved fresh and hardened characteristics [6]. Furthermore, durability experiments revealed that steel-fiber reinforced LWSCC with LECA had a higher resistance to internal sulfate attack when fiber reinforcement was applied [7].

Despite these findings, there is little research on the combined use of LECA as a fine aggregate substitute in SCC, which aims to achieve the simultaneous benefits of reduced density and improved workability. As a result, this study seeks to create Lightweight Self-Compacting Concrete (LWSCC) by integrating LECA as a partial replacement of fine aggregate at 0%, 5%, 10%, and 15% by volume, and to assess its fresh and hardened qualities in accordance with EFNARC criteria.

2. Materials:

2.1 Cement

This study employed ordinary Portland cement (OPC) in accordance with IS 269:2015 (Reaffirmed 2020), which combines the standards for 33, 43, and 53 grade cements into a single code. The cement utilized is 53-grade quality. The specific gravity is 3.149.

2.2 Mineral Admixture

Class F fly ash was used as a mineral ingredient to improve the workability and durability of self-compacting concrete. Its qualities were assessed in accordance with IS 3812 (Part 1): 2013 [1], which outlines the standards for fly ash as a pozzolanic ingredient in cement, mortar, and concrete. For greater worldwide relevance, the classification also correlates to ASTM C618-19 [2], which specifies the chemical and physical properties of Class F and Class C fly ash. The fly ash utilized in this study (Class F) had a specific gravity of 1.585 and served as a partial replacement for cement.

2.3 Fine aggregate.

Locally procured river sand that met IS 383:2016 - Specification for Coarse and Fine Aggregates for Concrete (Third Revision) was used. The sand is graded Zone III, with a specific gravity of 2.66 and a natural moisture content of 2.4%.

2.4 Coarse aggregate.

Natural crushed coarse aggregate with a maximum size of 12.5 mm was used, which also met IS 383:2016 requirements. It has a specific gravity of 2.73 and water absorption rate of 0.45%.

2.5 Lightweight Aggregate (LECA).

Light Expanded Clay Aggregate (LECA), with particle sizes ranging from 4 to 10 mm, was utilized as a partial volumetric replacement for fine aggregate. The material had a specific gravity of 1.785 and a significant water absorption capacity of 56% (Table 1). The spherical and porous form of LECA particles helps to reduce the overall density of concrete while also enhancing the flowability of the Self-Compacting Concrete (SCC) mixture. However, its high absorption demands pre-wetting to guarantee sufficient water availability for cement hydration (Fig. 1).

Fig.1 - Lightweight Aggregate (LECA)

Table 1 - Physical Properties of Materials

Material	Specific Gravity	Water Absorption
Cement OPC 53 Grade	3.149	
Fly Ash (Class F)	1.585	
River Sand	2.66	2.4% (moisture)
Coarse Aggregate (12.5 mm maximum size)	2.73	0.45%
LECA (4 - 10 mm)	1.785	56%

2.6 Superplasticizer

Superplasticizers, also known as high-range water-reducing admixtures (HRWRAs), are chemical admixtures that are often used in Self-Compacting Concrete (SCC) to create evenly distributed particle suspension and improved workability. In this study, two commercially available superplasticizers were assessed.

The first product tested was TEC MIX 640, which came from Techy Chemy. It is a light brown liquid with a specific gravity of 1.08 that is used as a high-range superplasticizer in concrete applications (Fig. 2). However, TEC MIX 640 performed poorly in terms of reaching the needed SCC flowability.

Enfiiq SuperPlast-400, obtained from ENFIIQ Civil Innovative Systems, was then employed as an alternative. This admixture is a brown liquid with a specific gravity ranging from 1.17-1.19. It acts as a high-range water reducer with a set retarding action, resulting in free-flowing and stable SCC mixes (Fig. 3).

Fig. 2 - TEC MIX 640

Fig. 3 - Enfiiq Super Plast - 400

3. Concrete Mix Proportioning

The Lightweight Self-Compacting Concrete (LWSCC) mix was created in accordance with EFNARC guidelines [2], which state that the air content should be kept at 2%, the volume of coarse aggregates should be between 50-60% to avoid reinforcement blockage, the optimal sand content should be between 40-50% of mortar volume, and the water-to-powder ratio should be between 0.80 and 1.10. Based on these suggestive values, the mix ratio was calculated to be 1:1.61:1.44 (cement: fine aggregate: coarse aggregate), with a water-to-cement ratio of 0.33. Mineral and chemical admixtures were utilized to achieve the required workability and flowability.

3.1. Workability Tests

The quantity of concrete ingredients were proportioned according to the initial mix design. Cement, fly ash, sand, and coarse aggregate were completely mixed in a dry environment, either manually or by machine. Before adding the chemical admixture (superplasticizer) to the concrete, it was premixed with water to achieve a consistent consistency. The admixture solution was then added to the dry mixture and thoroughly mixed to establish uniformity. Class F fly ash was used as a mineral additive, replacing 10%

of the cement by weight, according to IS 3812 (Part 1): 2013 [7], which is worldwide comparable to ASTM C618-19 [8]. A high-range water-reducing superplasticizer known as Tec Mix 640 (Techy Chemy Pvt. Ltd., India) was added to cement at 3% by weight to improve dispersion and self-compactibility.

3.1.1. Slump Flow Test:

To assess the fresh properties of Lightweight Self-Compacting Concrete (LWSCC), a series of workability tests were carried out in accordance with EFNARC guidelines [2]. The tests included the slump flow test, which measured concrete's horizontal flow and resistance to segregation [2-4], the J-ring test, which assessed passing ability through simulated reinforcement [2,4,5], the V-funnel test, which assessed viscosity and resistance to segregation [2,3,6], the L-box test, which assessed flow and passing ability through confined spaces [2,4], and the U-box test, which assessed filling ability and resistance to segregation.

The slump flow test is the most common and practical way to evaluate self-compacting concrete, particularly under site conditions. It monitors the horizontal flow of concrete in the absence of obstructions and determines both filling capacity and segregation resistance. A greater spread diameter results in increased flowability, allowing concrete to fill formwork with its own weight. The EFNARC recommends a minimum slump flow of 650 mm for SCC [2]. When segregation occurs, mortar and paste travel toward the perimeter, indicating weak stability, whereas coarse particles remain concentrated in the flow's center (Fig. 4)..

Fig. 4 - Progress of slump flow test

3.1.2. J - Ring Test:

The J-Ring test (Fig. 5) assesses SCC's passing capacity in the presence of crowded reinforcement. The equipment is made up of a steel ring with vertical reinforcing bars measuring 10 mm in diameter and 100 mm long. To mimic reinforcement congestion at the site, the bars are often set at clear spacings of three times the maximum aggregate size. During testing, the difference in concrete height inside and outside the ring is measured, with an acceptable range of 0-10 mm based on EFNARC recommendations [2]. This test provides a good indication of SCC's capacity to pass through reinforcement without segregation or blockage. Recent research has also demonstrated its significance in forecasting the combined impacts of flowability and passing ability in self-compacting concrete [3, 4, 5].

Figure 5: Progress of the J-Ring test.

3.1.3. V-Funnel Test.

The V-funnel test (Fig. 6) is used to assess the filling capacity (flowability) of self-compacting concrete. In this approach, newly mixed concrete is allowed to flow down a narrow V-shaped funnel, and the time required for complete discharge is measured. According to EFNARC recommendations [2], the flow time should be between 8 and 12 seconds for optimal filling ability. The V-funnel at T_5minutes test evaluates SCC's segregation resistance with an acceptable flow duration of 8-15 seconds. Lower flow times often imply more flowability, however extremely high numbers may suggest poor workability or a possibility of blockage. Recent studies have confirmed that the V-funnel test is a good measure of viscosity and stability in SCC mixtures [3, 4, 6].

Figure 6: Progress of V Funnel Test.

3.1.4. L-Box Test.

The L-box test (Fig. 7) assesses both the flow properties of self-compacting concrete (SCC) and its susceptibility to blocking when passing through reinforcement. The apparatus consists of a vertical segment connected to a horizontal channel, separated by steel bars that simulate congested reinforcement. After lifting the gate, fresh concrete flows from the vertical leg to the horizontal part. The blocking ratio, which compares the concrete height at the far end (H_2) to the near end (H_1), is used to assess passing ability. For a perfect free-flowing concrete, the ratio (H_2/H_1) approaches unity, suggesting minimal blockage. According to EFNARC [17], appropriate blocking ratio values typically fall between 0.8 and 1.0. Previous research confirms that the L-box test is a useful and dependable method for determining SCC flow under constrained conditions [2-4].

Fig. 7: Progress of L-box test.

3.1.5. U-Box Test

The U-box test (Fig. 8) is used to assess the filling and passing properties of self-compacting concrete (SCC) under simulated congested situations. The equipment consists of two compartments separated by a sliding gate and vertical reinforcing bar. After lifting the gate, fresh concrete is poured into one compartment and allowed to flow into the other. The difference in concrete height between filled and empty compartments (h_2 - h_1) is measured, and lower values indicate better passage ability. EFNARC [1] recommends (h_2 - h_1) values ranging from 0 to 30 mm for optimal flow and minimal segregation.

EFNARC [17] also sets broad acceptance requirements for SCC workability testing (Table 1), such as slump flow, T50 time, V-funnel, L-box, U-box, J-ring, and segregation resistance. These characteristics ensure that SCC meets all three structural performance requirements: filling ability, passage ability, and segregation resistance. In the current study, the findings of the workability tests did not meet all of the EFNARC acceptability limitations, forcing additional changes to the concrete mix fraction.

Figure 8: Progress of the U-box test.

Table 1. Acceptance Criteria for self - compacting concrete according to EFNARC (2002)

Sl. No.	Property	Test Methods	Unit	Minimum	Maximum
1	Filling Ability	Slump Flow	mm	650	800
		T50 cm Slump	sec	2	5
		V - Funnel	sec	6	12
2	Passing Ability	L - Box	h2/h1	0.8	1.0
		U - Box	(h2-h1) mm	0	30
		J - Ring	mm	0	10
3	Segregation Resistance	V Funnel at T5minutes	sec	6	15

The workability test results failed to meet the EFNARC [17] acceptance standards. As a result, the mix proportions were adjusted to attain the necessary performance.

3.2. Adjusting the Mix

When the first mix did not meet the workability standards, the proportions were modified based on EFNARC [6] guidelines. The adjustments included changing the type and dosage of superplasticizer, adding mineral admixtures, and altering the water content to improve the water-powder ratio. After multiple experiments, the optimal mix that met the approval criteria was established with a ratio of

1:1.61:1.44 and a water-cement ratio of 0.47. A superplasticizer (Enfiiq Super Plast 400) was added at 6% by weight of cement, and 20% of the cement was replaced with fly ash.

4. Preparation and Testing of Specimens

4.1. Preparation of Specimens

The goal of this study was to combine the benefits of Light Weight Concrete (LWC) with Self-Compacting Concrete (SCC) to create Light Weight Self-Compacting Concrete (LWSCC). For this aim, fine aggregate in SCC was partially substituted with Light Expanded Clay Aggregate (LECA) at 0%, 5%, 10%, and 15% by volume, yielding four distinct combinations. The needed quantities of materials were batched and mixed, and the mixes' fresh qualities were assessed using slump flow, J-ring, V-funnel, L-box, and U-box tests. Following the workability tests, the concrete was scooped into moulds, ensuring that no external vibration occurred. The surfaces were smoothed, and following final setting, the specimens were demoulded and water-cured.

4.2. Testing Specimens

Compressive strength is widely regarded as the most important of the different concrete strength metrics. Cube specimens were compressive strength evaluated using a compression testing machine in accordance with IS 516:1964 [7] (Fig. 9). The specimens were positioned centrally in the machine and loaded at a consistent rate of 140 kg/cm²/min until failure occurred. The compressive strength was calculated by dividing the greatest load at failure by the cross-sectional area of the sample.

LWSCC 0 (560 kN)

LWSCC 5 (640 kN)

Fig. 9: Compression strength test after 7 days (LWSCC 0 and LWSCC 5).

5. Results and Discussion.

5.1. Properties of Fresh Concrete.

Table 2 shows the fresh properties of self-compacting concrete (SCC) with partial replacement of fine aggregate by Light Expanded Clay Aggregate (LECA).

Table 2: Properties of Fresh Self-Compacting Concrete.

Test Methods	LWSCC 0	LWSCC 5	LWSCC 10	LWSCC 15
Slump Flow	621	645	682	697
T50cm Slump	3.3	3.2	3	2.8
V - Funnel	9	8.3	7.5	6
L - Box	0.84	0.86	0.91	0.94
U - Box	27	24	22	19
J - Ring	5	4.3	3.2	2.7
V - Funnel at T5 minutes	13.2	12	10.4	8.8

The results of the fresh property tests show that the filling ability, passing ability, and segregation resistance of all LWSCC mixtures meet EFNARC standards [6]. Furthermore, the workability of the concrete improved as the LECA level increased. This improvement can be due to LECA particles' spherical form, which decreases the possibility of blocking and enhances flowability [8], as well as their smooth surface texture, which reduces internal friction and hence promotes higher flow [9]. Similar findings regarding the influence of aggregate morphology on the fresh qualities of SCC have been reported in previous research [10], confirming that the addition of LECA improves the fresh performance of self-compacting concrete.

5.2. compressive strength

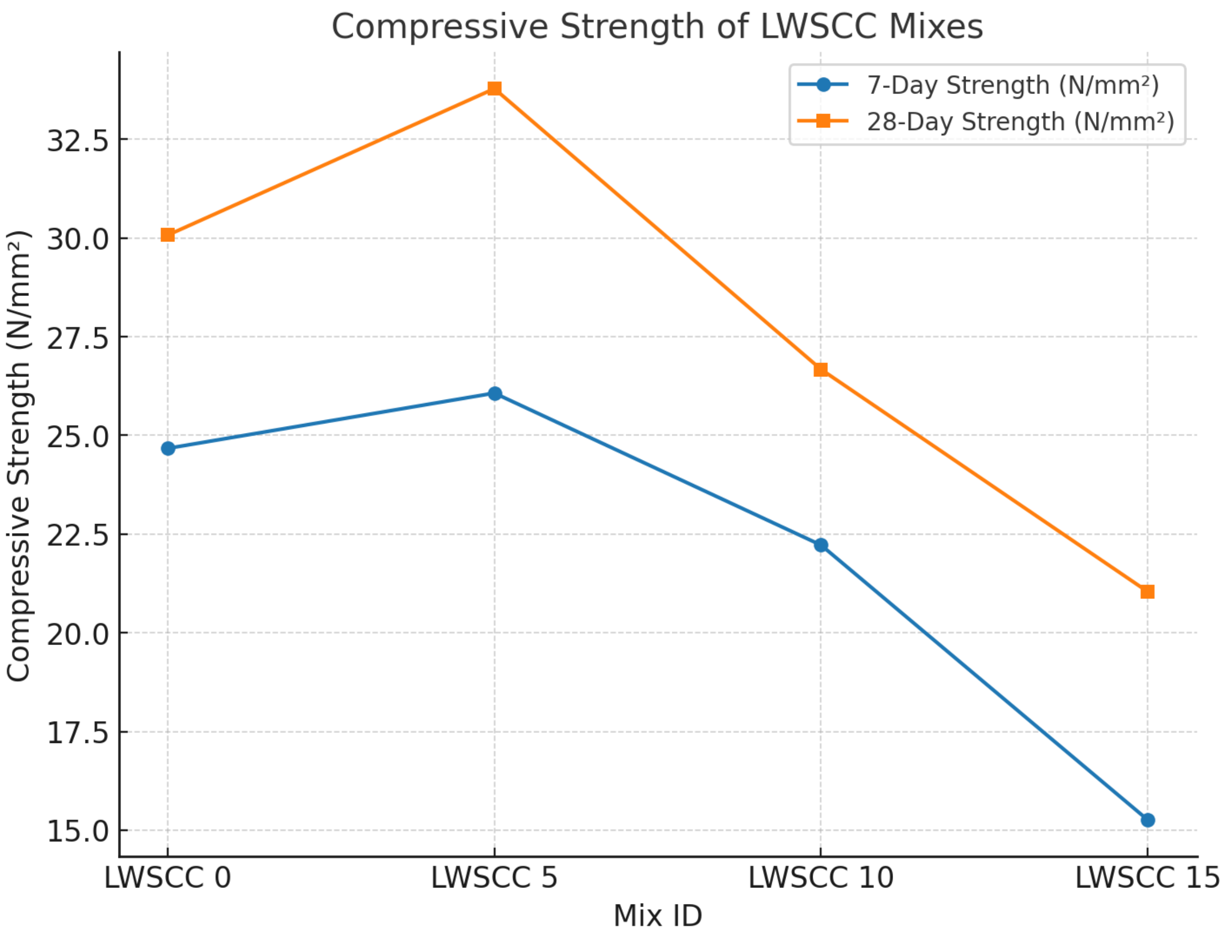
Table 3 shows the compressive strength values at 7 and 28 days for cube specimens with varied degrees of fine aggregate replacement by LECA.

Table 3: Results of Compressive Strength Test.

S. No.	Mix ID	7-Day Strength (N/mm²)	28-Day Strength (N/mm²)
1	LWSCC 0	24.67	30.07
2	LWSCC 5	26.07	33.78

3	LWSCC 10	22.22	26.67
4	LWSCC 15	15.26	21.04

Figure 10 shows the compressive strength of LWSCC mixtures at 7 and 28 days.



The results show that the compressive strength of the control mix (LWSCC 0) was 24.667 N/mm² at 7 days and 30.074 N/mm² at 28 days. LWSCC 5 showed an increase in strength to 26.074 N/mm² and 33.778 N/mm² after 7 and 28 days. This enhancement is due to the spherical form of LECA particles, which facilitates greater compaction and contributes to increased strength [8,9].

However, beyond 5% replacement, compressive strength decreased. LWSCC 10 strength decreased to 22.222 N/mm² and 26.667 N/mm² after 7 and 28 days, respectively. The reduction is attributed to the lightweight and intrinsically weaker nature of LECA aggregates when utilized in higher quantities [10]. At 15% replacement (LWSCC 15), compressive strength decreased dramatically to 15.259 N/mm² and 21.037 N/mm² after 7 and 28 days, respectively. This drop can be due to both LECA's low strength and high water absorption capacity, which presumably limited the availability of free water for complete cement hydration [11].

6. Conclusions.

This experimental investigation shows that replacing fine aggregate with Light Expanded Clay Aggregate (LECA) up to 5% by volume in self-compacting concrete (LWSCC) achieves the greatest combination of fresh and hardened qualities.

6.1. Fresh Properties

All LWSCC mixes met the EFNARC's filling, passing, and segregation resistance standards [2].
The spherical shape and smooth surface texture of LECA aggregates greatly improved workability and flowability [1,3].

6.2. Compressive Strength Performance

At 5% LECA replacement, compressive strength increased compared to conventional SCC due to better self-compaction aided by LECA's morphology [1,4]. Higher replacement levels resulted in a decrease in strength. Ningampalli et al. [5] showed similar patterns, with compressive strength decreasing from 44.56 MPa in control mixtures to 32.73 MPa with 25% LECA replacement. Correia et al. [3] demonstrate that, whereas expanded clay improves workability, mechanical strength diminishes as LECA content increases due to its reduced density.

6.3. Conclusions and Recommendations

The filling ability, passage ability, and segregation resistance of all LWSCC mixtures meet the EFNARC requirements [2]. The spherical shape of LECA, as well as its smooth surface texture, increased the workability and flowability of the fresh concrete mix [1, 3].

The compressive strength of the SCC with fine aggregate replaced by LECA by 5% of the volume of fine aggregate was higher than that of conventional SCC, as the spherical shape of LECA aggregates contributed to better self-compaction and hence greater strength [1,4,5]. Compressive strength decreased when fine aggregate was replaced with LECA [3, 5].

As a result, 5% is deemed the optimal fine aggregate replacement level by LECA in self-compacting concrete, which is consistent with findings from recent studies [3, 5].

Based on the current findings and comparisons with other studies, LECA has selected 5% as the optimal fine aggregate replacement for retaining LWSCC performance while preserving compressive strength [3, 5].

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