REVISTAMATÉRIA V.30
ISSN 1517-7076 articles e20240813, 2025

Evaluation of self compacting concrete performance incorporated with presoaked lightweight aggregates

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ABSTRACT

The study aims the performance of presoaked light expanded clay aggregate (LECA) and fly ash aggregate (FAA) as partial replacement of river sand in self compacting concrete (SCC). On a volume basis, presoaked LECA and FAA partially replace river sand. LECA and FAA are presoaked for 24 hours before casting of SCC. The water retained in the lightweight aggregates (LWAs) pores acts as an internal curing reservoir. SCC workability characteristics, including as flowability, filling and passing capabilities, resistance to segregation, and concrete bleeding, were evaluated using slump cones, U-boxes, L-boxes, V-Funnels, and J-ring tests. Addition of LECA and FAA reduces the water for curing and also attain good workability and strength of SCC. The durability characteristics such as sulphate attack, acid attack are conducted in various durations like 7, 28, 56, 90, 180 days. Further, bond strength and accelerated corrosion tests also conducted. From all the mechanical and durability tests on SCC with LECA and FAA by 15% replacement for fine aggregate shows more beneficial effect in strength, microstructural and durability properties than those demonstrated by control mix concrete.

Keywords: Self compacting concrete; Lightweight aggregates; Fly ash aggregates; Light expanded clay aggregate; Internal curing.

1. INTRODUCTION

Self Compacting Concrete is a fluidity concrete that can be placed and compacted itself. It can fill formwork fully and achieve full compaction by flowing under its own weight, even when there is congested reinforcement present. The density and homogeneity of the hardened concrete are comparable to those of regular vibrated concrete, and it also has the same durability. The settlement of aggregates is connected to the viscosity of fresh concrete, according to the Self Compacting Concrete (SCC) principle [1]. This concrete have more powder contents like binding material, minerals & chemical admixture, lower water cement ratio and lower content with lower size coarse aggregate. SCC mix proportion detailed procedure given in European Federation Dedicated to Specialist Construction Chemicals and Concrete Systems (EFNARC) proposals. SCC has grown as a result of construction sites' noise, vibration, and lack of skilled personnel. Global concern has been raised over concrete's lack of durability, which is mostly caused by skilled workers' inadequate compaction [2]. The demand and price of river sand are also rising day by day; this crisis will be solved by replacing of river sand by artificial fine aggregate [3, 4]. Increasing the volume of different fly ash substitutions enhances the potential durability of SCC [5]. Inclusion of fly ash, slag, and micro-silica in SCC, enhances the flow properties, strength properties and durability charateristics such as water absorption, permeability, rapid chloride penetration of the SCC properties [6]. High strength SCC having fineness of the sands and supplementary cementitious materials majorly influences the strength and durability. Higher yield stress of concrete which contributes the high quantity of fine sand. The processed sand mixes is found improved flow characteristics in contrast with the mixes having washed natural fine sand, unwashed crushed sand, washed plaster sand [7]. Concrete's compressive strength was higher than that of the control mix at all ages when 10% fine aggregate was substituted for granite powder [8]. Vibrated concrete and SCC shows the same strength and acid attack shows the lower weight loss [9]. Pozzolanic materials and their filler efficiency in concrete have positive impacts, especially on capillary strength, chloride permeability, freeze-thaw attack and elevated temperatures (up to 800°C) [10].

Corresponding Author: Gopi Rajamanickam Received on 20/11/2024 Accepted on 04/01/2025

DOI: https://doi.org/10.1590/1517-7076-RMAT-2024-0813

Curing is the process of keeping concrete from losing moisture as the cement hydrates. To achieve desirable strength and durability characteristics, curing is essential [11]. For proper hydration of cement curing is essential. Since curing has a major influence on how well hardened concrete performs, the importance of properly curing concrete cannot be overstated. Curing techniques and duration is the main contribution to curing efficiency [12]. Different methods used in concrete curing, majorly two categories. First one is water adding method and second is water retaining method. The internal curing method is a water retaining or preservation technique. The internal curing concrete provides massive saving of water particularly for developed countries [13]. A common ingredient used to supply water to the concrete mix and ensure internal curing is lightweight aggregate. Internal curing is based on three elements. The amount of water accessible for internal curing is the first consideration. The amount of water that the saturated light-weight aggregate can produce for internal curing is the second factor. The distribution of the saturated light weight aggregate within the mixture, which allows it to supply water wherever it is needed, is the third factor [14]. The concept of internal curing shown in Figure 1.

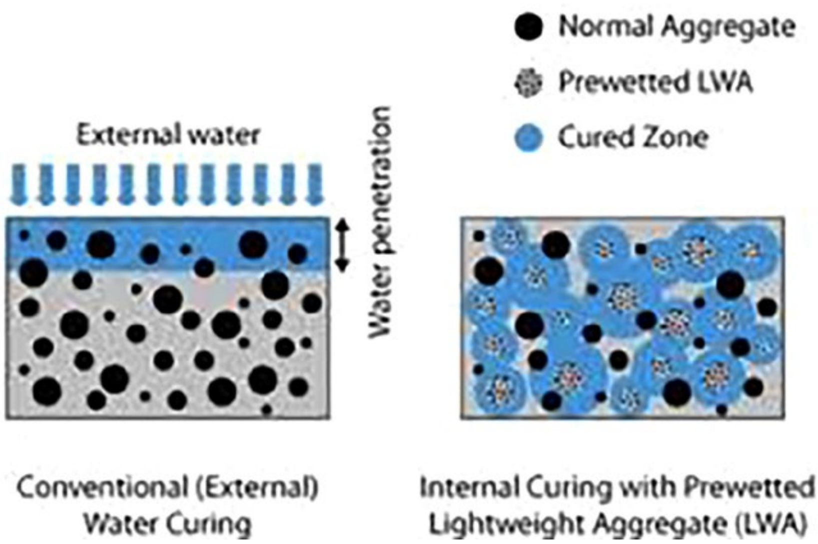

Figure 1: Concept of internal curing.

In case of effective water curing process, the relative humidity is maintained more than 80% to continue the hydration of cement to ensure the development of necessary calcium silicate hydrate (C-S-H). C-S-H gel influences the foremost strength providing reaction product of cement hydration. Also, it reduces porosity and thus transforms into dense microstructure in concrete. Inadequate C-S-H gel interrupts refinement of pore structure, making the concrete susceptible to deterioration. Also, the drying of concrete surface causes shrinkage cracks leading to faster deterioration concrete. Hence, internal curing is an inevitable solution to concrete [15]. Significant durability and strength characteristics such sulphate resistance, water absorption, and sorptivity are provided by SCC with LWAs [16]. The another method in water retaining technique is the use of poly-ethylene glycol (PEG) or super absorbent polymers (SAP) which lessen the migration of water from the concrete surface and helps in water preservation. Compared to normal cured concrete, the internal curing agents improve the concrete's ability to retain water and decrease evaporation-related water loss [17]. Water curing period of 3 days drastically enhanced the recital of the internal curing mixtures compared to conventional water cured control concrete at 28 days [18]. The pores presented in lightweight aggregates absorb water during 24 hrs immersion in water and later releases the water under elevated temperature and lower relative humidity conditions. Hence, outside surface water curing is not needed [19]. Internal curing mixtures showed enhanced microstructure growth as well as durability characteristics compared to those of the ambient cured control mix [20]. The strength and long-term durability of regular concrete mixtures can be enhanced by internal curing. The capacity of lightweight aggregate to reduce drying shrinkage in concrete may be enhanced by longer wetting times [21]. The substitution of fine aggregates maximum of 50% replacement by recycled concrete aggregates also can use as the water supplements material to offer internal curing [22]. The concrete subjected to hot climate condition, its compressive strength and durability related to acid and sulfate attack is majorly influenced by the different curing methods. The optimal period for developing an improved compressive strength was seven days of curing followed by maturation in a warm environment, irrespective of the type of binder and W/B ratio. For neglecting the cracks development in high performance concrete and eliminating the shrinkages, mainly at the early ages, the use of LWAs is effectively use as internal curing agent [23]. Concrete that has a low water/cement ratio and a higher cement concentration performs better when internal curing [24]. For enhanced strength and durability performance, the utilization of internal curing agents in self compacting mortars in most favorable amount promoted self compacting mortars [25]. Water integrated in the pore system of presoaked LWA is separated via capillary suction, enhancing supplementary hydration that keeps on well after conventional curing process have ceased. Internal curing permits for a compact and dense paste microstructure to form in concrete, resulting in lesser permeability, enhanced durability, and in some cases, more strength [26]. Optimizing concrete mix designs for achieving enhanced mechanical properties, micro structural and long-term structural sustainability are attained by incorporating the lightweight aggregates in the mix [27].

Curing and compaction of concrete are atmost important processes to make the concrete to achieve designed strength and durability. The conventional compaction methods requires more labour, time and also may not be effective in compacting in congested reinforcement area. Several efforts have already been made to impart self compaction to concrete by using suitable materials and mix design. Also, attempts have been already initiated to find alternative to conventional methods of curing to improve the performance of concrete. More so, significant research work has already been done in the area of curing compounds to be used in concrete to impart self curing. Further, chemical admixtures have also come into existence in the field of concrete technology. Also, the materials such as LECA and FAA were used to partially replace aggregates to make light weight self compacting concrete. Concrete based on LECA as coarse aggregate showed improved workability but decreased density and mechanical strength [28]. The blend of 10% FAA with 10% LECA the best percentage to use in place of the coarse aggregate [29]. However, not much attention has been focused on suitability of LECA and FAA as internal curing agents and also their effect on strength, durability and flexural behavior of SCC. Accordingly, the present studies carry out the strength and durability features of SCC with presoaked LECA and FAA light weight aggregates.

2. MATERIALS

2.1. Cementitious materials

OPC 53 grade cement was utilized as binding substance in concrete conforming to IS 12269-1987 [30] and its specific gravity value is 3.15. Fly ash was acts as mineral admixture in SCC to enhance the durability as well as for making fly ash aggregate pellets. The class ‘F’ fly ash collected from Mettur thermal power station and its specific gravity found as 2.27.

2.2. Sand & coarse aggregate

River sand that is readily available is used as a fine aggregate that complies with IS: 383-1970 [31] aggregate grading zone III. In SCC, coarse aggregate with a specific gravity of 2.73 and particle size range of 10 to 12 mm was utilized.

2.3. Fly Ash Aggregate (FAA)

The artificial FAA was prepared by blending of cement and class ‘F’ fly ash in assorted proportions like 5:95, 10:90, 15:85, 20:80, 25:75 with water. These materials are properly dry hand mix and put in to the mix-

Figure 2: Fly ash aggregate.

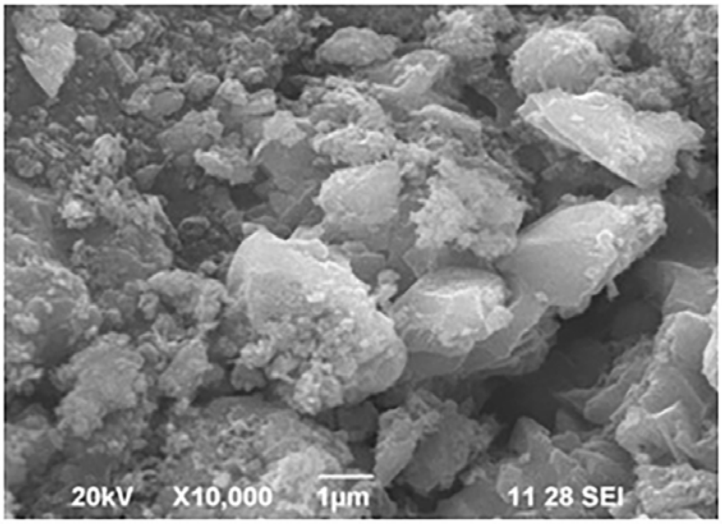

Figure 3: SEM image of FAA.

ture drum. The contents are adjusting angle of the mixture drum as 35º to 55º. After starts running of drum sprinkle the water automatically the FAA is formed. That process is called pelletisation. The prepared aggregate pellets are sieved in 4.75 mm sieve and dry it properly for 24 hours. The dried pellets water cured for 7 days to attain sufficient strength. This type of aggregate are called cold bonded aggregates shown Figure 2. In this five various proportions 15:85 with 0.3 w/c ratio gives higher compressive strength [32, 33]. So for this study 15:75 proportions was used for making FAA. FAA absorbs water by 20% on 24 hrs immersion. The bulk density of FAA found as 1050 kg/m^3. The Scanning Electron Microscopy (SEM) image of FAA is shown in Figure 3.

2.4. LECA

LECA is produced by firing natural clay mixed with water to make it pellets in ball mill and this pellets heat in a furnace. Heating process pellets got air voids and it got the light weight as shown in Figure 4. LECA absorbs water by 38% on 24 hrs immersion, because of large pores in the structure. Bulk density of LECA found as 442 kg/m^3. The SEM image of LECA is shown in Figure 5, which shows that LECA has huge and large pore size. Because of it superior characteristics of absorption and desorption it is consider as good internal curing agent.

Figure 4: Light expanded clay aggregate.

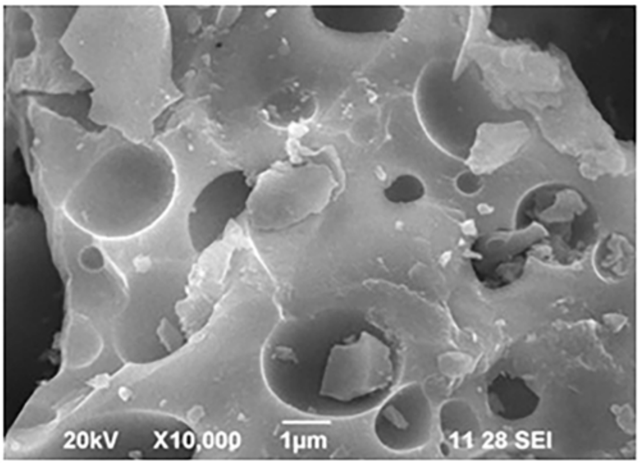

Figure 5: SEM image of LECA.

2.5. Chemical admixture

Superplastcizer is a necessary component of SCC to obtain desired fresh concrete workability without increasing water content. Glenium B233 (polycarboxylate ether based) superplastcizer was used to achieve significant workability and its quantity is fixed based on mini slump cone test. The problem of segregation and bleeding can be reduced by the addition of Glenium B233.

3. METHODOLOGY

The mix proportion shall assure all recital criteria for SCC. In this study, EFNARC procedure and Okamura suggested method were followed for SCC mix design [34]. SCC. Presoaked LECA and FAA were used to partially replace the river sand in two sets of mixes. These aggregates were presoaked in water for one day and utilized in saturated surface dried condition [SSD]. To develop the significant properties with presoaked LWA, cement, fly ash, river sand and coarse aggregate were mixed based on the proportion and then Glenium B233 superplastcizer diluted in water and then mixed. The river sand was partially replaced by LWAs at 0% to 25% at 5% interval based on volume. The mix containing no LWAs is referred to as the control mix (CM). One set of control mix cured with conventional water immersion method (CM_{wc}). Another set of control mix cured are kept in room temperature (CM_{rt}). The mix proportions for all the SCC mixes are presented in Table 1. SCC mixes were designated with letter 'L' and 'F' with subscript assigns LECA and FAA and percentage of replacement of river sand. Internal curing was performed for the mixes with one day presoaking the LECA and FAA. The remolded specimens after one day sealed with polythene covers to reduce the wetness loss from the specimens. The lightweight aggregates' pores absorbed water, which was utilised for internal curing to promote complete hydration. Internal curing water is not the component of mixing water for making of SCC [35]. From the hardened SCC results, durability performance for instance HCl attack, Magnesium sulphate attack, bond strength and accelerated corrosion were carried out.

Table 1: Mix composition of SCC mixes.

MIX CATEGORY		CM	LECA MIXES					FAA MIXES				
S. NO	MIX ID COMPOSITION		L_5	L_{10}	L_{15}	L_{20}	L_{25}	F_5	F_{10}	F_{15}	F_{20}	F_{25}
1.	Cement [kg/m³]	439						439				
2.	Fly ash [kg/m³]	134						134				
3.	Fine aggregate [kg/m³]	820	778	737	696	655	614	778	737	696	655	614
4.	LECA/FAA [kg/m³]	–	12.6	25.2	37.8	50.4	63.0	29.9	59.9	89.8	120	150
5.	Coarse Aggregate [kg/m³]	774						774				
6.	Water [lit/m³]	177						177				
7.	Super plasticizer	0.5						0.5				
8.	w/b ratio	0.31						0.31				

4. RESULTS AND DISCUSSIONS

4.1. Fresh concrete workability studies

SCC workability tests for all the proportions prepared with presoaked LWAs and the outcomes are presented in Table 2. The results are within the acceptable value which prescribed in EFNARC guidelines [1]. The various workability test are shown in the Figures 6–10.

4.2. Hardened concrete studies

The hardened concrete compressive strength of SCC are tested for both 7 days and 28 days as per IS: 516 – 2018 [36]. The water physically held in the presoaked lightweight aggregates effectively used for hydration purpose of cement paste in the interfacial transition zone (ITZ). The hardened SCC, 15% substitution of river sand by LECA and 15% substitution of river sand by FAA shows significant enhance in compressive strength than other mixes which shown in Figures 11 & 12.

Table 2: Fresh SCC mixes-workability.

S. NO	MIX ID	SLUMP FLOW (mm)	T50 CM SLUMP (sec)	V- FUNNEL (sec)	J-RING (mm)	L-BOX H_2/H_1	U-BOX $(H_2\sim H_1)$ (mm)	SIEVE SEGREGATION (%)
1.	CM_{wc}	700	3.2	9.7	6.6	0.81	29	12.51
2.	CM_{rt}	700	3.2	9.7	6.5	0.81	29	12.51
SCC with LECA								
3.	L_5	682	3.3	9.7	6.7	0.94	30	10.5
4.	L_{10}	695	3.1	8.6	6.2	0.91	27	9.76
5.	L_{15}	705	2.8	7.9	6.0	0.88	26	8.76
6.	L_{20}	704	3.0	8.2	6.3	0.92	31	7.51
7.	L_{25}	702	3.1	8.1	6.3	0.95	35	4.26
SCC with FAA								
8.	F_5	685	3.2	9.6	6.9	0.93	30	11.16
9.	F_{10}	698	3.3	8.5	6.5	0.89	28	10.16
10.	F_{15}	712	2.9	8.0	6.0	0.86	27	9.55
11.	F_{20}	706	3.4	8.0	6.2	0.9	28	8.25
12.	F_{25}	703	3.3	8.2	6.3	0.96	33	5.75
EFNARC Acceptance range		650 – 800	2 – 5	6 – 12	0 – 10	0.8 – 1	0 – 30	0 – 15

Figure 6: Slump flow test.

Figure 7: V- funnel test.

Figure 8: J-ring test.

Figure 9: L-box test.

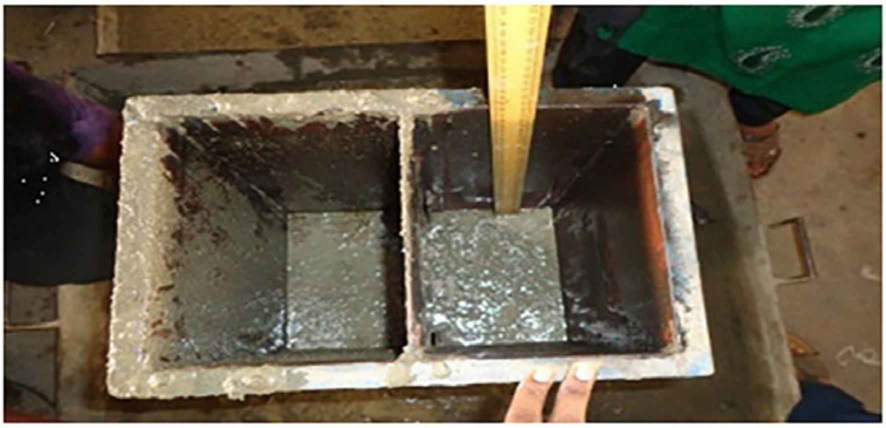

Figure 10: U- box test.

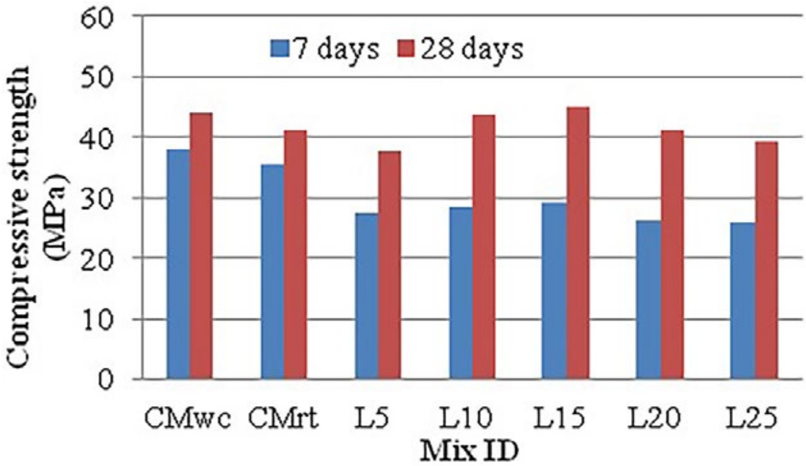

Figure 11: Compressive strength for SCC with LECA.

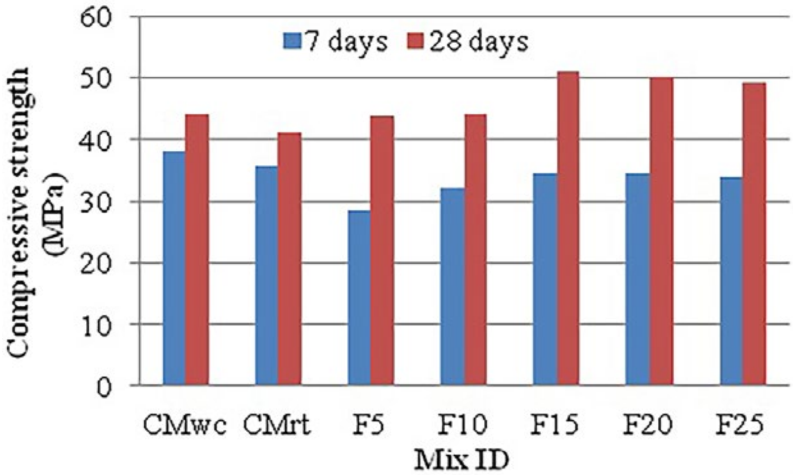

Figure 12: Compressive strength for SCC with FAA.

Compressive strength test for water cured (CM_{wc}) and room temperature cured (CM_{rt}) control mix concrete for 7 days and 28 days are 38 MPa, 44.10 MPa and 35.56 MPa, 41.25 MPa respectively. The highest compressive strength for LECA mix and FAA mix proportion in 7 days 28 days attained at 15% replacement. According to the compressive strength results the subsequent durability studies are performed for the optimum strength mixes.

4.3. Micro-structural studies

The micro-structural analyses are carried out by SEM for optimum SCC mixes according to compressive strength results. The effects of presoaked LWAs in SCC are studied in this SEM analysis. The SEM images are shown in Figures 13–15.

The SEM images prove the occurrence of C-S-H, C-A-S-H and very little quantity of CH. There is no evidence of occurrence of ettringite formation. The un-reacted round and spherical forms of fly ash are presented. SCC mixes have shown comparatively denser microstructure than the conventional. The presence of presoaked LWAs as internal curing materials, it ensures entire hydration of cement paste between the aggregates, so enough bonds between paste and aggregate was achieved. The F_{15} mix shows comparatively small porosity such as 7.85%, 5.95%, and 4.05% at 7, 28 and 90 days respectively. It follows that the F_{15} blend produced a more compact microstructure. Current results showed that the the chemical interactions between the reactive silica found in FAA and calcium hydroxide were demonstrated to create additional cementitious material, which resulted in a dense microstructure of SCC.

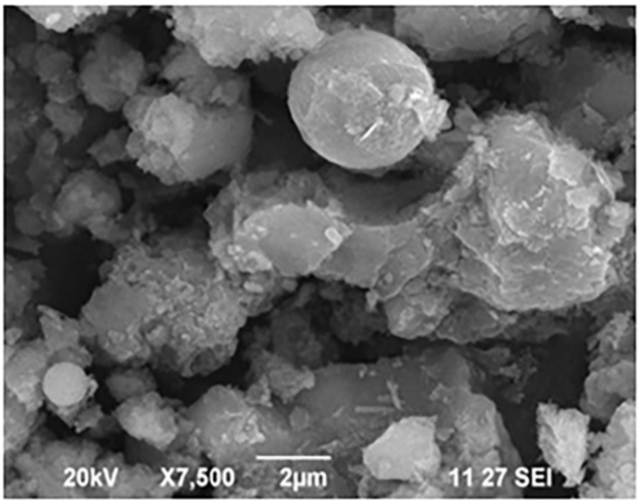

Figure 13: SEM image of CM_{rt} mix.

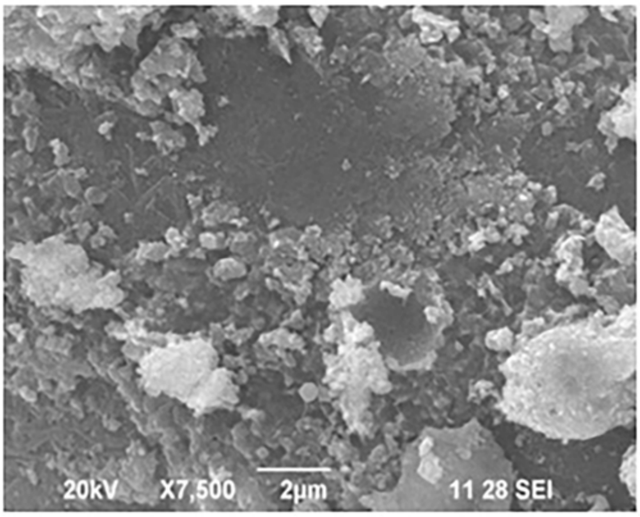

Figure 14: SEM image of L_{15} mix.

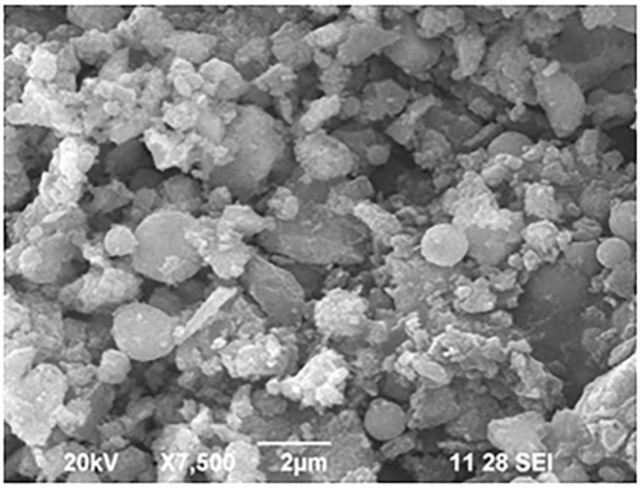

Figure 15: SEM image of F_{15} mix.

4.4 Durability tests on SCC

4.4.1. Acid attack

SCC specimens of size 100 mm cubes are casted for acid attack as per ASTM C267-01 [37]. The casted cubes are preserved for internal curing up to 28 days. Then the cubes are immersed in 3% of Hydrochloric acid (HCl) solution, to make the specimens are in extreme exposure condition. The solutions are changed at a regular duration for to maintain the pH. The cubes are tested in 7, 28, 56, 90 and 180 days interval. Figure 16 shows the visual appearnce of the cubes after 180 days submergence in HCl solution. Weight reduction and compressive strength loss results were observed. Table 3, Figures 17 & 18 presents the results of acid attack test of SCC control mix with LECA and FAA mix.

The weight loss percentage in acid attack for control mix (CMwc), LECA (L15) and FAA (F15) for 7 days 2.04%, 1.67%, & 1.38%, for 28 days 3.11% 2.39%, & 1.89%, for 56 days 4.55%, 3.71%, 2.91% for 90 days 5.23%, 4.66%, 3.83% and for 180 days 5.62%, 4.96%, 4.16%. As well as strength loss concern for 7 days 2.77%, 2.03%, 1.58%, for 28 days 3.91%, 3.25%, 2.55%, for 56 days 4.87%, 3.97%, 3.35%, for 90 days 5.43%,

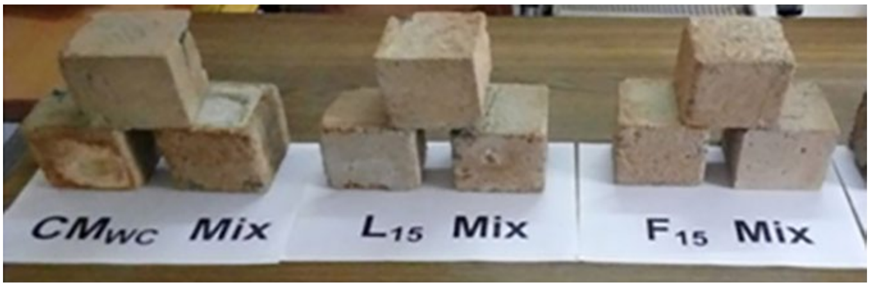

Figure 16: Visual appearance of the cubes after 180 days submergence in HCL acid solution.

Table 3: Durability with 3% of HCl.

S.NO	PERIOD OF IMMERSION (DAYS)	WEIGHT LOSS (%)			STRENGTH LOSS (%)		
		CM_{WC}	L_{15}	F_{15}	CM_{WC}	L_{15}	F_{15}
1	7	2.04	1.67	1.38	2.77	2.03	1.58
2	28	3.11	2.39	1.89	3.91	3.25	2.55
3	56	4.55	3.71	2.91	4.87	3.97	3.35
4	90	5.23	4.66	3.83	5.43	4.62	3.93
5	180	5.62	4.96	4.16	5.67	4.92	4.32

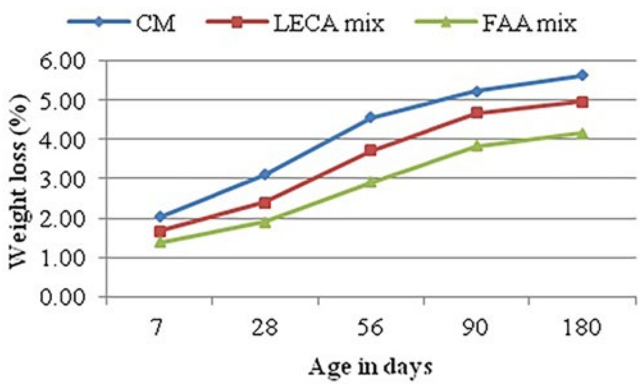

Figure 17: Weight loss (%).

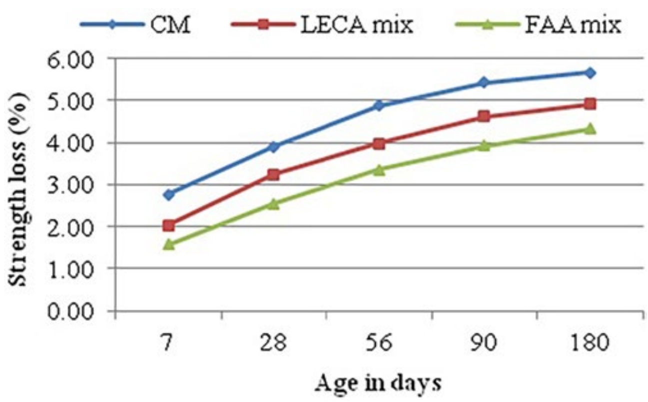

Figure 18: Strength loss (%).

4.62%, 3.93% and for 180 days 5.67%, 4.92% & 4.32% respectively. Compared to the other two mixes, FAA mix achieved less weight and strength loss in acid attack test. Due to internal water curing by LWAs in SCC, the concrete's homogeneity and permeability have increased. Because of the chemical reaction between the reactive silica in the fly ash aggregate and calcium hyroxide, which produces more cementitious material and densifies the microstructure, the F_{15} mix performs the best [38, 39].

4.4.2. Sulphate attack

SCC cube specimens 100 mm × 100 mm × 100 mm are prepared for sulphate attack as per ASTM C452-02 [40]. The casted cubes are kept and sealed for internal curing up to 28 days. Then the cubes are submerged in 5% of magnesium sulphate ($MgSO_4$) solution, to make the specimens are in severe exposure condition. The solutions are changed at a regular duration for to maintain the pH. The cubes are tested in 7, 28, 56, 90 and 180 days interval. Figure 19 shows the visual look of the cubes after 180 days submergence in $MgSO_4$ solution. Loss in weight and compressive strength loss results were observed. Table 4 and Figures 20 & 21 shows the results of sulphate attack test of SCC control mix with LECA and FAA mix.

Figure 19: Visual appearance of the cubes after 180 days submergence in $MgSO_4$ solution.

Table 4: Durability with 5% of magnesium sulphate solution.

S. NO	PERIOD OF IMMERSION (DAYS)	WEIGHT LOSS (%)			STRENGTH LOSS (%)		
		CM_{WC}	L_{15}	F_{15}	CM_{WC}	L_{15}	F_{15}
1	7	0.83	0.68	0.42	1.87	1.33	1.18
2	28	1.24	1.11	0.94	2.15	1.90	1.64
3	56	1.88	1.67	1.46	3.45	3.13	2.75
4	90	2.56	2.33	2.13	4.24	3.92	3.65
5	180	3.23	2.91	2.68	4.87	4.57	4.23

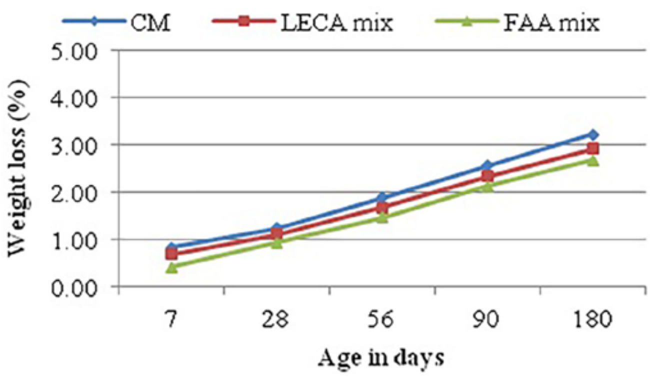

Figure 20: Weight loss (%).

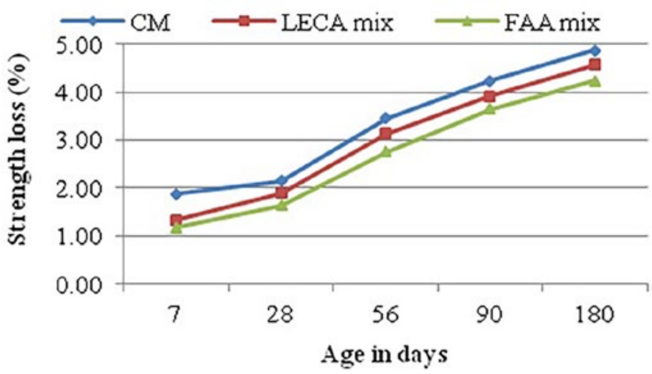

Figure 21: Strength loss (%).

The weight loss percentage in sulphate attack for control mix (CM_{wc}), LECA (L_{15}) and FAA (F_{15}) for 7 days 0.83%, 068%, 0.42%, for 28 days 1.24%, 1.11%, 0.94%, for 56 days 1.88%, 1.67% & 1.46%, for 90 days 2.56%, 2.33%, 2.13% and for 180 days 3.23%, 2.91% & 2.68%. In addition to strength loss concern for 7 days 1.87%, 1.33%,1.18%, for 28 days 2.15%, 1.90%, 1.64%, for 56 days 3.45%, 3.13%, 2.75%, for 90 days 4.24%, 3.92%, 3.65% and for 180 days 4.87%, 4.57% & 4.23% respectively. Compared to the other two mixes, FAA mix gives less weight and strength loss in sulphate attack test. When fly ash is added, the leachable calcium hydroxide is changed into calcium silicate hydrate. Therefore, the concrete resists sulphate assault due to the lack of calcium hydroxide [41]. The reactive silica present in Fly ash aggregates might have reacted with calcium hydroxide leading to the formation of additional cementitious compounds in F_{15} mix. The development of additional cementitious imparts denser microstructure to F_{15} mix making it more resistant to sulphate attack.

4.4.3. Bond strength

SCC specimens of size 100 mm cubes are casted with 12 mm diameter Thermo Mechanically Treated (TMT) bar is kept at center of cube mold. The casted cubes are internally cured up to 28 days. The cured cubes are tested in Universal Testing Machine (UTM). Figure 22 provides the pull-out test setup. The load was gradually applied

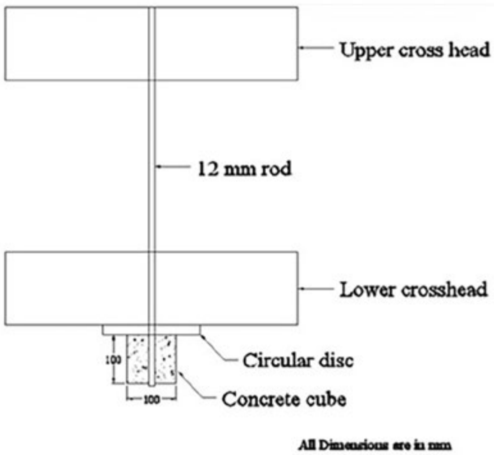

Figure 22: Pull out test setup.

Table 5: Bond strength of SCC mixes.

S.NO	MIX ID	LOAD AT 0.25 mm SLIP (kN)	AREA OF EMBEDED BAR πdl (mm²)	BOND STRENGTH (MPa)
1.	CM_{wc}	29.40	3770	7.79
2.	L_{15}	32.80	3770	8.70
3.	F_{15}	35.05	3770	9.29

to the embedded rod at a rate not greater than 2250 kg/min according to IS 2770 (Part 1) – 1967 [42]. The load at a slip of 0.25 mm at the unsupported end of the bar was recorded. The load applied at the designated slip is divided by the surface area of the implanted rod length to determine the bond stress.

According to IS 2770–1967, the load at slips of 0.25 mm are taken for evaluating bond stress. Table 5 shows the bond strength results. Bond Strength = P/πdl MPa, where, P – Bond Stress (MPa), d – dia of rod (mm), l = embedded length of rod (mm). Bond strength of control mix (CM_{WC}), LECA (L_{15}) and FAA (F_{15}) for 28 days are 7.79 MPa, 8.70 MPa & 9.29 MPa and its shown in Table 5. Generally, enhanced filling and passing ability of SCC within the reinforcement impart an excellent bond between reinforcement and concrete. Also, it is obvious from the output that the SCC with FAA offered highest bond strength. It is due to additional cementitious compounds produced due to pozzolanic activity of fly ash aggregate in SCC mix [43]. As well, incorporation of saturated LWAs as internal curing material in SCC ensured entire hydration of cement paste resulting in higher bond strength.

4.4.4. Accelerated corrosion

SCC specimens 200 mm height and 100 mm diameter are casted with 12 mm diameter TMT rod as per ASTM C 876 – 1991 [44] is kept at center of mould. Before casting, rod is weighed. The cylinders are kept in internal curing state for 28 days. The cured cylinders are kept in 5% NaCl with water and that solution also keep bottom of electrodes, so both electrodes are kept it on a wooden pieces. The solution does not allow directly on the rod, so keep the solution 10 mm below of the top surface of the specimens. The cased specimen's rods are act as anode. The stainless steel plate also immersed in that solution act as a cathode. The electrodes connect the AC to DC pack 12 volt current passed to the electrode. Every one hour the specimens are took out of the solution and takes the multimeter readings of amps. The readings should be tabulated. After completion of test the weight of the rod is measured. This test also called as half-cell potential.

Half-cell potential testing is an indirect method to measure the corrosion activity in reinforcing steel in concrete. A half-cell potential measurement setup consists of a voltmeter with positive lead connected to a reference electrode placed on the surface of the concrete and a negative lead connecting the voltmeter to the reinforcing steel. The schematic diagram is shown in Figure 23.

The accelerated corrosion test of control mix (CM_{WC}), LECA (L_{15}) and FAA (F_{15}) specimens are casted and cured for 28 days. Then specimens are kept in 5% NaCl solution and passed 12 volt current on each specimen. The Half-cell potential reading was taken at each 1 hr interval. Up to 500 Hrs the readings are taken for each specimen.

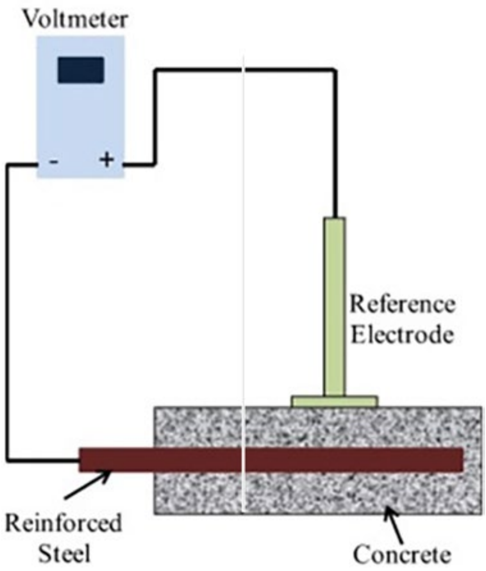

Figure 23: Schematic diagram of accelerated corrosion test.

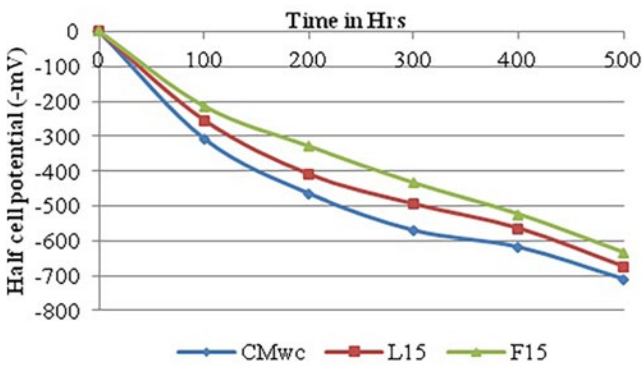

Figure 24: Half cell potential – time (sec) vs potential (mv).

From the Figure 24 shows the half cell potential readings are in millivolt (mv) time by time the potential are reduces control mix of SCC 50% corrosion shows at the time of 1770 seconds. The LECA mix of SCC shows 50% corrosion at the time of 2280 min and the FAA mix of SCC shows 50% corrosion at the time of 2340 min. It is obvious that internal curing ability of SCC mixes improve corrosion resistance by reducing permeability through the use of presoaked lightweight aggregates. The higher resistance to corrosion of F_{15} is due to the positive effect of its filling in the tiny pores. Additionally, the chemical reaction between calcium hydroxide and reactive silica found in fly ash aggregate produces cementitious material and microstructure densification.

5. CONCLUSION

From the investigation on presoaked LECA and FAA in self compacting concrete, the subsequent conclusions are arrived.

- The workability characteristics of SCC blends meet the EFNARC minimum standards. Due to the concrete's decreased weight, SCC with more than 15% LECA and FAA has an adverse effect on passing ability.
- In comparison to the ambient cured control mix, 15% river sand replacement with LECA and 15% river sand replacement with FAA show 8.92% and 23.4% greater compressive strengths, respectively, based on SCC's compressive strength performance with LECA and FAA.
- Based on durability studies, the percentage of weight and strength loss with 5% HCL and 5% $MgSO_4$ indicates that LECA and FAA mixes show lesser weight and strength losses than the control mix.
- The substitution of river sand by LECA and FAA gives good bond strength. The strength levels attained are greater than the least grade specified for even the extreme exposure condition given in IS 456: 2000.

- In comparison to the control mix and FAA mix of SCC, the half-cell potential readings of LECA and FAA mixes of SCC require more time to complete 50% corrosion, according to the accelerated corrosion test. The LECA mix of SCC takes longer to reach 50% corrosion than the FAA mix of SCC in the accelerated corrosion test, when cement is the primary component implicated in the corrosion. The SCC sample's control mix corroded more quickly than the FAA and LECA mixes because of insufficient curing.
- Internal curing is the most effective method for preventing early age shrinkage, as well as insufficient curing in today's water-scarce world. Internal curing concrete may have a higher strength than concrete that has been cured under regular conditions. Concrete strength development due to presoaked LWA's, which contributes to a better hydration process and thus increased strength. Due to the absorbed water, cement paste surrounded by presoaked LWA's becomes denser and harder.

6. BIBLIOGRAPHY

[1] EFNARC, *Specifications and guidelines for self-compacting concrete*, Switzerland, European Federation of National Trade Associations Representing Producers and Applicators of Specialist Building Products, 2002.

[2] OFUYATAN, T., OLUTOGE, F.A., OLOWOFOYEKU, A., "Durability properties of palm oil fuel ash self compacting concrete", *Engineering, Technology & Applied Scientific Research*, v. 5, n. 1, pp. 753–756, 2015. doi: http://doi.org/10.48084/etasr.524.

[3] SUPEKAR, V.R., KUMBHAR, P.D., "Properties of concrete by replacement of natural sand with artificial sand", *International Journal of Engineering Research & Technology (Ahmedabad)*, v. 1, n. 7, pp. 6, 2012.

[4] GOPI, R., REVATHI, V., KANAGARAJ, D., "Light expanded clay aggregate and fly ash aggregate as self curing agents in self compacting concrete", *Asian Journal of Civil Engineering*, v. 16, n. 7, pp. 1025–1035, 2015.

[5] MAHALINGAM, B., NAGAMANI, K., "Effect of processed fly ash on fresh and hardened properties of self compacting concrete", *International Journal of Earth Sciences and Engineering*, v. 4, n. 5, pp. 930–940, 2011.

[6] XIE, T.Y., ELCHALAKANI, M., ALI, M.M., *et al*., "Mechanical and durability properties of self-compacting concrete with blended binders", *Computers and Concrete, An International Journal*, v. 22, n. 4, pp. 407–417, 2018.

[7] BAUCHKAR, S.D., CHORE, H.S., "Experimental study on rheology, strength and durability proper ties of high strength self-compacting concrete", *Computers and Concrete*, v. 22, n. 2, pp. 183–196, 2018. doi: http://doi.org/10.12989/cac.2018.22.2.183.

[8] ABISHA, Y., NALANTH, N., "Pineapple fibre as an additive to self-compacting concrete", *Matéria (Rio de Janeiro)*, v. 28, n. 1, pp. e20220315, 2023. doi: http://doi.org/10.1590/1517-7076-rmat-2022-0315.

[9] VIJAPUR, V., NOORULLA, M., "An experimental investigation on the behavior of self curing concrete under acidic attack", *International Journal of Engineering Research-online*, v. 1, n. 3, pp. 385–394, 2013.

[10] NAS, M., KURBETCI, S., "Durability properties of concrete containing metakaolin", *Advances in Concrete Construction*, v. 6, n. 2, pp. 159, 2018.

[11] GOPI, R., HARIHANANDH, M., SARAVANAN, M., *et al*., "Influence of presaturated sugarcane bagasse ash pellets in concrete", *Journal of Critical Reviews*, v. 7, n. 7, pp. 648–652, 2020. doi: http://doi.org/10.31838/JCR.07.07.117.

[12] GOPI, R., REVATHI, V., "Influence of presaturated light expanded clay and fly ash aggregate in Self compacting concrete", *Romanian Journal of Materials*, v. 49, n. 3, pp. 370–378, 2019.

[13] ARAB MOHAMMED, A., ABDEL-AZIZ METWALY, A., MAHMOUD FATMA, R., "Effect of self curing agent on the properties and durability of normal and high strength self-compacted concrete properties", *International Journal of Advanced Science and Technology*, v. 29, n. 6, pp. 3393–3404, 2020.

[14] HENKENSIEFKEN, R., CASTRO, J., BENTZ, D., *et al*., "Water absorption in internally cured mortar made with water-filled lightweight aggregate", *Cement and Concrete Research*, v. 39, n. 10, pp. 883–892, 2009. doi: http://doi.org/10.1016/j.cemconres.2009.06.009.

[15] RAJAMANICKAM, G., RAMASAMY, S., SOUNDARARAJAN, E.K., *et al*., "Influence of presaturated coconut fibre ash pellets in concrete", *Matéria (Rio de Janeiro)*, v. 28, n. 3, pp. e20230190, 2023. doi: http://doi.org/10.1590/1517-7076-rmat-2023-0190.

[16] POORNIMA BHARATHI, S., GOPI, R., REVATHI, V., "Strength and durability studies of self compacting self curing concrete using lightweight aggregates", *Integrated Journal of Engineering Research and Technology*, v. 2, n. 2, pp. 178–185, 2015.

[17] TYAGI, S., "An experimental investigation of self-curing concrete incorporated with polyethylene glycol as self-curing agent", *International Research Journal of Engineering and Technology*, v. 2, n. 6, pp. 129–132, 2015.

[18] EL-DIEB, A.S., EL-MAADDAWY, T.A., "Performance of self-curing concrete as affected by different curing regimes", *Advances in Concrete Construction*, v. 9, n. 1, pp. 33–41, 2020.

[19] ZOU, D., LI, K., LI, W., *et al*., "Effects of pore structure and water absorption on internal curing efficiency of porous aggregates", *Construction & Building Materials*, v. 163, pp. 949–959, 2018. doi: http://doi.org/10.1016/j.conbuildmat.2017.12.170.

[20] AL SAFFAR, D.M., AL SAAD, A.J., TAYEH, B.A., "Effect of internal curing on behavior of high performance concrete: An overview", *Case Studies in Construction Materials*, v. 10, pp. e00229, 2019. doi: http://doi.org/10.1016/j.cscm.2019.e00229.

[21] JONES, C., GOAD, D., HALE, W.M., "Examining soaking duration of coarse clay and shale lightweight aggregates for internal curing in conventional concrete", *Construction & Building Materials*, v. 249, pp. 118754, 2020. doi: http://doi.org/10.1016/j.conbuildmat.2020.118754.

[22] EL-HAWARY, M., AL-SULILY, A., "Internal curing of recycled aggregates concrete", *Journal of Cleaner Production*, v. 275, n. 1, pp. 122911, 2020. doi: http://doi.org/10.1016/j.jclepro.2020.122911.

[23] ALASKAR, A., ALSHANNAG, M., HIGAZEY, M., "Mechanical properties and durability of high performance concrete internally cured using lightweight aggregates", *Construction & Building Materials*, v. 288, n. 21, pp. 122998, 2021. doi: http://doi.org/10.1016/j.conbuildmat.2021.122998.

[24] MOUSA, M.I., MAHDY, M.G., ABDEL-REHEEM, A.H., *et al*., "Physical properties of self curing concrete (SCUC)", *HBRC Journal*, v. 11, n. 2, pp. 167–175, 2015. doi: http://doi.org/10.1016/j.hbrcj.2014.05.001.

[25] CHAND, M.S.R., GIRI, P.S.N.R., KUMAR, P.R., *et al*., "Effect of self curing chemicals in self compacting mortars", *Construction & Building Materials*, v. 107, pp. 356–364, 2016. doi: http://doi.org/10.1016/j.conbuildmat.2016.01.018.

[26] AKHNOUKH, A.K., "Internal curing of concrete using lightweight aggregates", *Particulate Science and Technology*, v. 36, n. 3, pp. 362–367, 2018. doi: http://doi.org/10.1080/02726351.2016.1256360.

[27] KADHAR, S.A., GOPAL, E., SIVAKUMAR, V., *et al*., "Optimizing flow, strength, and durability in high-strength self-compacting and self-curing concrete utilizing lightweight aggregates", *Matéria (Rio de Janeiro)*, v. 29, n. 1, pp. e20230336, 2024. doi: http://doi.org/10.1590/1517-7076-rmat-2023-0336.

[28] RAJALEKSHMI, P., JOSE, P.A., "Influence of eco-friendly lightweight aggregates in mechanical and durability properties of geopolymer concrete", *Matéria (Rio de Janeiro)*, v. 28, n. 4, pp. e20230209, 2023. doi: http://doi.org/10.1590/1517-7076-rmat-2023-0209.

[29] KADHAR, S.A., GOPAL, E., SIVAKUMAR, V., "An experimental study on strength and durability properties of self-compacting and self-curing concrete using light weight aggregates", *Matéria (Rio de Janeiro)*, v. 28, n. 3, pp. e20230156, 2023. doi: http://doi.org/10.1590/1517-7076-rmat-2023-0156.

[30] BUREAU OF INDIAN STANDARDS, *IS 12269: Specification for 53 grade ordinary Portland cement*, New Delhi, India, Bureau of Indian Standards, 1987.

[31] BUREAU OF INDIAN STANDARDS, *IS 383, "Specifications for coarse aggregates from natural sources for concrete*, New Delhi, India, Bureau of Indian Standards, 2016.

[32] GOPI, R., REVATHI, V., RAMYA, R., *et al*., "Saturated light expanded clay aggregate and fly ash aggregate as internal curing agents in self compacting concrete", *Australian Journal of Basic and Applied Sciences*, v. 9, n. 31, pp. 226–233, 2015.

[33] SHANMUGASUNDARAM, S., JAYANTHI, R., SUNDARARAJAN, C., *et al*., "Study on utilization of fly ash aggregates in concrete", *Modern Applied Science*, v. 4, n. 5, pp. 44–57, 2010. doi: http://doi.org/10.5539/mas.v4n5p44.

[34] OKAMURA, H., OZAWA, K., "Mix design for self compacting concrete", *Concrete Library of Japanese Society of Civil Engineers*, pp. 107–120, 1995.

[35] GOPI, R., REVATHI, V., "Self compacting self curing concrete with lightweight aggregates", *Gradevinar*, v. 68, n. 4, pp. 279–285, 2016.

[36] BUREAU OF INDIAN STANDARDS, IS 516, “Methods of test for strength for strength of concrete, New Delhi, India, Bureau of Indian Standards, 2018.

[37] ASTM INTERNATIONAL, *ASTM C267-01: Standard Test Methods for Chemical Resistance of Mortars, Grouts and Monolithic Surfacing and Polymer Concretes*, West Conshohocken, PA, ASTM International, 2001.

[38] DHIYANESHWARAN, S., RAMANATHAN, P., BASKER, I., *et al*., “Study on durability characteristics of self-compacting concrete with fly ash”, *Jordan Journal of Civil Engineering*, v. 7, n. 3, pp. 342–353, 2013.

[39] NIRMALKUMAR, K., SIVAKUMAR, V., “Acid resistance behavior of concrete made using untreated and treated tannery effluent”, *Modern Applied Science*, v. 3, n. 1, pp. 139–143, 2009. doi: http://doi.org/10.5539/mas.v3n1p139.

[40] ASTM INTERNATIONAL, *ASTM C452-02, “Standard test method for potential expansion of portland-cement mortars exposed to sulfate*, West Conshohocken, PA, ASTM International, 1995.

[41] KARTHIK, V., BASKAR, G., “Study on durability properties of self compacting concrete with copper slag partially replaced for fine aggregate”, *International Journal of Civil Engineering and Technology*, v. 6, n. 9, pp. 20–30, 2015.

[42] BUREAU OF INDIAN STANDARDS, IS 2770: Part-1, “Indian standard code of practice - Methods of testing bond strength in reinforced concrete, New Delhi, India, Bureau of Indian Standards, 1967.

[43] RAJAMANE, N.P., NATARAJA, M.C., LAKSHMANAN, N., *et al*., “Pull-out tests for bond strengths of geopolymer concretes”, *Indian Concrete Journal*, v. 86, n. 10, pp. 25–38, 2012.

[44] ASTM INTERNATIONAL, *ASTM, C876: Standard test method for half-cell potentials of uncoated reinforcing steel in concrete*, West Conshohocken, ASTM International, 1991.