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Investigations on self compacting concrete using fly ash and light expanded clay aggregates

ABSTRACT

Compaction and curing both are equally important to achieve the desired strength and durability of concrete. In order to make concrete with better surface finish, improved strength and durability, it is essential to impart self compacting ability to concrete. Curing at early age is to reduce the plastic shrinkage, to ensure adequate surface strength and surface zone durability. This study examines self-compacting concrete (SCC) that contains saturated light expanded clay aggregate (LECA) and fly ash aggregate (FAA). The effects of LECA and FAA on SCC were examined with flow properties, microstructure, compressive strength, acid resistance (HCl), sulphate resistance ($MgSO_4$), and salt resistance (Nacl). The replacement of fine aggregate in the mixtures ranged from 0% to 25% with 5% interval by volume basis. Water filled LECA and FAA were also combined to produce SCC mixes. The findings demonstrate that substituting saturated lightweight aggregates for fine aggregate in SCC satisfied the filling ability, passing ability and segregation resistance. The compressive strength of SCC with 15% LECA & FAA, under internal curing is higher by 1.84% & 13.35% higher than that of the control concrete (CM_{wc}) at age of 28 days. F_{15} mix exhibited less weight loss and lesser strength loss in acid & sulphate. Also less weight gain and lesser strength loss in salt resistance. SCC made with LECA & FAA blends to promote internal curing offers technical and cost benefits in the construction industry.

Keywords: *Self compacting concrete, light expanded clay aggregate, fly ash aggregate, internal curing*

1. INTRODUCTION

Concrete is a common material in construction projects all over the world, but it has never been promoted as green because of its increased use of natural resources. Although a lot of progress has been made over the years, the emphasis has recently switched to making it more environmentally responsible. In addition, natural aggregates have been specifically extracted from natural resources due to the enormous volume required for the manufacture of concrete. Around 2.5 tonnes of concrete will be produced in 2025, while the global need for natural aggregates will rise to 12.5 billion tonnes. Each year, India already uses over 3,000 metric tonnes of natural aggregates. Repercussions of removing natural aggregates include wastelands, deforestation, air pollution, and land degradation.

SCC is a special type of concrete that can fill all the nooks and crannies of formwork and congested reinforcement with its self-weight and has a high flowability without segregation. When mechanical or manual vibrator compaction is challenging to execute, SCC is suitable. Specifically, the aforementioned compaction methods are not applicable to underwater concreting. This difficult issue can now be resolved with self-compacting concrete [1, 2]. Although SCC does not vibrate, it is poured or laid similarly to ordinary concrete. Because of its extreme fluidity, it can fill all the nooks and crevices and avoid segregation. At the same time, air cannot become trapped in concrete due to its self-compaction [3].

Concrete must be cured in addition to being compacted in order to get the appropriate strength and durability. The process of curing involves causing the cement in concrete paste to hydrate. Techniques like coating with saturated materials, ponding, fogging, and spraying are frequently used during the curing process. These methods are rarely expensive, time-consuming, or labour-intensive. The need for internal curing concrete is being

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driven by curing faults, water scarcity in arid places, contaminants, and inaccessible constructions. Nevertheless, cost-effective ways to enable concrete to self-cure must be discovered [4].

Concrete's strength and durability are influenced by the cement's hydration, which is greatly impacted by curing. Due to a lack of hydration, inadequate curing, especially at a young age, decreases the performance of concrete. When the relative humidity within capillary pores is less than 80%, cement hydration is practically complete [5]. If the water curing procedure is successful, the relative humidity must be maintained at or above 80% to keep the cement hydrated and ensure the development of enough calcium silicate hydrate gel (C-S-H). This gel formation is the main cement hydration reaction product that provides strength. In addition, it lowers porosity, resulting in a dense microstructure in concrete. Inadequate C-S-H gel prevents pore structure refinement, leaving the concrete vulnerable to degradation. Furthermore, as the concrete surface dries, shrinkage cracks appear, resulting in faster concrete deterioration. As a result, it's critical to give concrete the ability to cure itself [6].

Recently, internal curing has been recognised as a unique approach that improves durability and resistance to initial cracking. Concrete qualities like strength, shrinkage, cracking, and durability are all impacted by internal water curing, which also changes hydration and humidity mobility. Water can cure from the inside out thanks to internal curing. Superabsorbent polymers, lightweight fine aggregates, and superabsorbent polymers can all be utilised as internal water reservoirs [7].

In comparison, the compressive strength of the SCC prepared with smaller LWAs is higher than that of the SCC prepared with bigger LWAs. Generally speaking, smaller LWAs are stronger than larger ones, which results in an increase in strength. Furthermore, artificially manufactured LWAs with greater sizes typically has large pores, which reduces its strength. In multiple investigations, a comparable increase in concrete strength employing smaller size LWAs was noted. Therefore, the usage of smaller size LWAs may have beneficial impacts on the strength characteristics of SCC [8].

The purpose of this study is to evaluate the fresh, mechanical, microstructural, and durability properties of SCC by partially substituting fine aggregate with saturated LECA and FAA.

2. MATERIALS & METHODS

As per IS: 12269-1987 [9], OPC 53 Grade was utilised for the study. Fine aggregate with a specific gravity of 2.61 and aggregate grading zone III according to IS: 383 [10] were obtained from locally accessible river sand. Coarse aggregate with a maximum size of 12.5 mm and a specific gravity of 2.73 was employed in this experiment. Mettur thermal power plant Class 'F' fly ash, which has a specific gravity of 2.27, was used as a mineral addition. In addition to mineral admixture, it was used to produce fly ash aggregate through the pelletisation process. The aggregate of fly ash had a specific gravity of 1.85 and water absorption of 20% (Fig. 1). LECA was employed with a low density value of 442 kg/m^3 and water absorption of 38% (Fig. 2).

Figure 1. FAA aggregate

Figure 2. LECA aggregate

2.1 Fly ash aggregates

Shanmugasundaram et al. [11] states that fly ash aggregate is made by mixing fly ash and cement in a 15:85 ratio. The ratio of water to binder is set at 0.3. Dry fly ash and cement were combined in a concrete mixer. Until the fly ash aggregate formation process was finished, water was gradually added to the dry mix in the drum at an inclination angle of 35° to 55°. The aggregates produced by this process are known as cold bonded fly ash aggregate. The machine's various fly ash aggregate (FAA) sizes were taken out and allowed to dry for a day. The prepared aggregates were stored in a curing tank for seven days after being packed in gunny bags. The FAA were taken out of the gunny bags after seven days and let to dry completely. The appropriate sieves are then used to filter the aggregates. According to Figures

1 & 2, aggregates of size from 1.18 mm to 4.75 mm are considered as fine aggregate in this study. Fly ash lightweight aggregate based concrete has vast potential for its application in construction to obtain benefits such as reduction in self weight, improved thermal comfort and reduction in carbon footprint to the environment [12].

2.2 Mix proportions

EFNARC's specifications were followed in the design of the SCC [3]. The combined weight of fly ash and cement was 573.9 kg/m^3. A coarse aggregate volume of 50% of the mortar's dry rodded unit weight (774.2 kg/m^3) and a fine aggregate content of 45% (819.6 kg/m^3) are the established values. At 2% air concentration, the weight-to-particle ratio is maintained at 0.31. The dosage of superplasticizer is set at 0.7 percent of cementitious materials. In the initial two sets of mixes, fine aggregate was added in amounts ranging from 0% to 25% at intervals of 5% volume. The various mix proportions are shown in Table 1. A mixture of LECA and FAA was also used to produce SCC mixes. As shown in Table 2, LECA/FAA was used to substitute fine aggregate in the mix to the highest level of 20% by volume with a 5% increase.

Table 1. SCC Mix proportion

Mix Id	Cement (kg/m^3)	Fly Ash (kg/m^3)	LECA (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)	Super plasticizer (kg/m^3)
CM_{wc}	439.5	134.4	0	819.6	774.2	177.7	4.02
CM_{rt}			0	819.6			
L_5			12.62	778.62			
L_{10}			25.24	737.64			
L_{15}			37.87	696.66			
L_{20}			50.49	655.68			
L_{25}			63.09	614.70			
F_5			29.96	778.62			
F_{10}			59.97	737.64			
F_{15}			89.88	696.66			
F_{20}			119.94	655.68			
F_{25}			149.87	614.70			

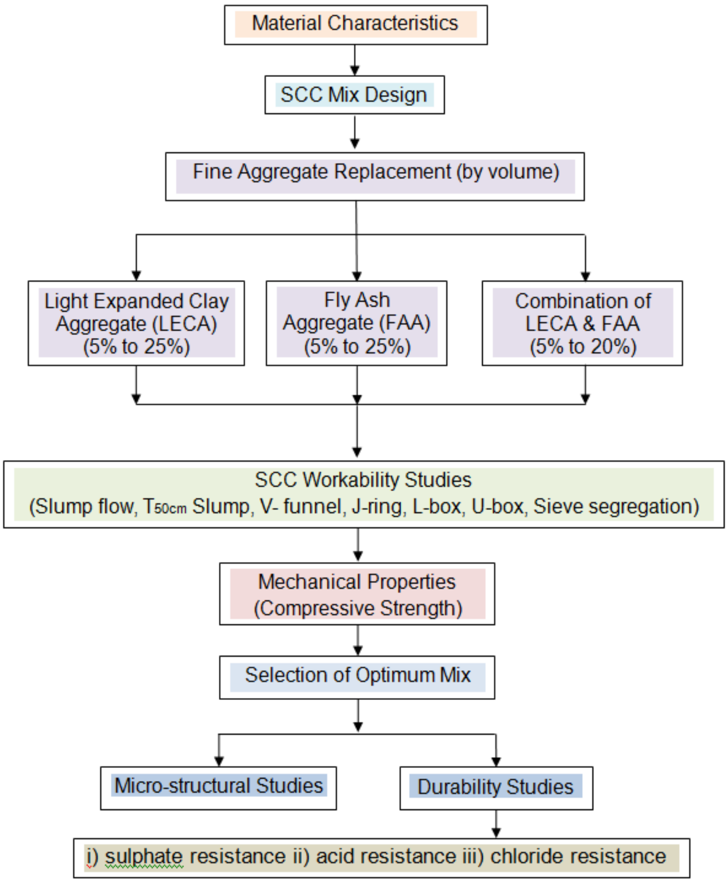
Table 2. SCC Mix proportion with blend of FAA & LECA aggregates

Mix Id	Cement (kg/m^3)	Fly Ash (kg/m^3)	FAA (kg/m^3)	LECA (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)	Super plasticizer (kg/m^3)
F_5L_5	439.5	134.4	29.99	12.62	737.64	774.2	177.7	4.02
F_5L_{10}			29.99	25.24	696.66			
F_5L_{15}			29.99	37.87	655.68			
F_5L_{20}			29.99	50.49	614.70			
$F_{10}L_5$			59.97	12.62	696.66			
$F_{10}L_{10}$			59.97	25.24	655.68			
$F_{10}L_{15}$			59.97	37.87	614.70			
$F_{10}L_{20}$			59.97	50.49	573.72			
$F_{15}L_5$			89.96	12.62	655.68			
$F_{15}L_{10}$			89.96	25.24	614.70			
$F_{15}L_{15}$			89.96	37.87	573.72			
$F_{15}L_{20}$			89.96	50.49	532.74			
$F_{20}L_5$			119.94	12.62	614.70			
$F_{20}L_{10}$			119.94	25.24	573.72			
$F_{20}L_{15}$			119.94	37.87	532.74			
$F_{20}L_{20}$			119.94	50.49	491.76			

Presaturated lightweight aggregates, sand, fly ash, cement, and coarse aggregate were among the materials that were combined in a dry setting. Then, before being utilized to cast specimens, a polycarboxylate ether-based superplasticizer was thoroughly combined with water. After one day of casting, the specimens were demoulded and covered with plastic sheets to prevent moisture loss. To develop 26 SCC mixes, a combination of LECA and FAA was used to partially replace fine aggregate. After a 24-hour presaturation period, these aggregates were used in SCC mixtures in a soaked surface-dried state (SSD). A mix that has no LWAs is utilised as a control (CM). The first mix was cured in water (CM_{wc}), whereas the second was cured at ambient temperature (CM_{rt}). The mixes with the letters 'L' and 'F' stand for LECA and FAA, respectively. The subscript (number) in the mix designation is the percentage of sand replaced by LECA/FAA by volume.

2.3. Methodology

The methodology adopted in the work is presented in the following flow chart.



Flow Chart – Work Methodology

The workability properties of the SCC were assessed for each mixture in order to ascertain the self-compactabilty properties. The 'V' funnel test, slump flow, and T50 cm slump flow were used to measure the concrete's filling ability in accordance with EFNARC guidelines. 'J' ring, 'U' box, and 'L' box passing tests were also administered. Segregation resistance was assessed using the sieve stability test. Each mix's compressive strength was determined using three 150 mm cube specimens after 3, 7, 28, 56, and 90 days curing, according to IS:516-2018 [13]. 100 mm cubes were utilised for resistance to sulphate, acid, and chloride resistance. According to ASTM C267-2012 [14], the specimen was tested for durability later than 28 days of curing in the appropriate chemical solution. The change in weight and strength of the specimens are calculated.

2.4. Fresh concrete properties

The fresh concrete workability test results are provided in Table 3. The workability requirements established by EFNARC are met when the SCC is mixed with lower than 20% saturated LECA and FAA. Addition of fly ash to SCC improves the flowability in all of the mixtures [15,16]. Additionally, the spherical shape of LECA improves the concrete's flow characteristics [17,18]. FAA's spherical shape also improves the flow properties of SCC mixtures. The weight of the concrete mix has been reduced, resulting in a small reduction in passing ability. However, it has been found that use of saturated lightweight aggregate with a lower self weight yields satisfactory results in concrete [19]. Additionally, limiting the coarse aggregate size to 12.5 mm produces an obstruction-free, homogenous mix that does not segregate [20]. Increasing the amount of the saturated lightweight aggregate will increase the flowability and passing ability as shown in the slump flow and J-Ring test, but still in the recommended limit [21]. Fresh concrete's rheological behaviour is more stable when pre-wetted light weight aggregate is used, and cement matrix foaming is easier to manage. The compressive strength increased as the w/c decrease in w/c, and increased with increase in binder amount [22].

Table 3. SCC workability properties

S. No	Mix ID	Slump flow (mm)	T_{50} cm Slump (sec)	V-funnel (sec)	J-ring (mm)	L-box H_2/H_1	U-box (h_2-h_1) (mm)	Sieve segregation (%)
SCC with LECA								
1.	CM_{wc}	700	3.1	9.7	6.5	0.81	29	12.51
2.	CM_{rt}	700	3.1	9.7	6.5	0.81	29	12.51
3.	L_5	680	3.4	9.6	6.6	0.94	30	10.5
4.	L_{10}	697	3.2	8.5	6.1	0.91	27	9.75
5.	L_{15}	708	2.9	7.8	5.9	0.88	26	8.75
6.	L_{20}	702	3.1	8.1	6.2	0.92	31	7.50
7.	L_{25}	700	3.2	8.0	6.2	0.95	35	4.25
SCC with FAA								
8.	F_5	686	3.1	9.5	6.8	0.93	30	11.15
9.	F_{10}	699	3.2	8.4	6.4	0.89	28	10.15
10.	F_{15}	710	2.8	7.9	6	0.86	27	9.55
11.	F_{20}	705	3.3	7.9	6.3	0.9	28	8.25
12.	F_{25}	703	3.2	8.1	6.3	0.96	33	5.75
SCC with LECA and FAA								
13.	F_5L_5	705	3.0	8.6	6.3	0.86	24	12.15
14.	F_5L_{10}	693	3.2	8.9	6.5	0.89	25	10.36
15.	F_5L_{15}	678	3.6	9.4	6.9	0.93	27	8.78
16.	F_5L_{20}	665	4.1	10.3	7.5	0.98	29	7.05
17.	$F_{10}L_5$	696	3.2	8.8	6.6	0.84	25	11.74
18.	$F_{10}L_{10}$	687	3.4	9.3	6.9	0.87	26	10.05
19.	$F_{10}L_{15}$	674	3.7	9.8	7.5	0.92	28	8.17
20.	$F_{10}L_{20}$	660	4.3	10.7	8.0	0.95	30	6.45
21.	$F_{15}L_5$	690	3.4	9.1	6.9	0.83	27	10.68
22.	$F_{15}L_{10}$	681	3.7	9.5	7.2	0.88	28	9.32
23.	$F_{15}L_{15}$	665	4.1	10.3	7.8	0.91	29	7.67
24.	$F_{15}L_{20}$	653	4.6	11.1	8.5	0.93	31	6.25
25.	$F_{20}L_5$	684	3.7	9.4	7.1	0.81	28	9.87
26.	$F_{20}L_{10}$	673	4.1	9.9	7.5	0.84	29	8.20
27.	$F_{20}L_{15}$	662	4.4	10.8	8.1	0.87	30	6.08
28.	$F_{20}L_{20}$	650	4.8	11.6	8.7	0.90	33	5.12

2.5. Compressive strength

As illustrated in Fig. 3, the water cured concrete mix's (CM_{wc}) compressive strength was 38 MPa at 7 days and 44.1 MPa at 28 days. Concrete cured at room temperature (CM_{rt}) only achieved 35.56 MPa and 41.25 MPa at 7 and 28 days, respectively. The CM_{wc} mix's compressive strength at 28 days is 6.90 percent higher than that of the CM_{rt} mix. Concrete strength decreases as a result of room temperature curing, which leaves less water accessible for the hydration process [23, 24]. The reason for this is that the saturated LECA aggregate contains the necessary amount of moisture for the hydration process [25]. The LECA aggregate ensures a complete hydration process by allowing moisture to go from the concrete's interior to its exterior [26, 27]. The use of saturated lightweight aggregate promotes self-curing and ensures concrete's strength [28, 29]. Lightweight aggregates are mainly responsible for variation in strength and bulk density of concrete [30].

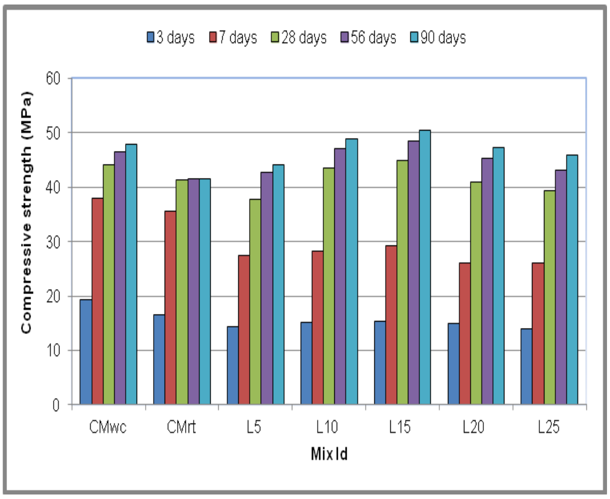


Figure 3. Compressive strength of SCC with LECA

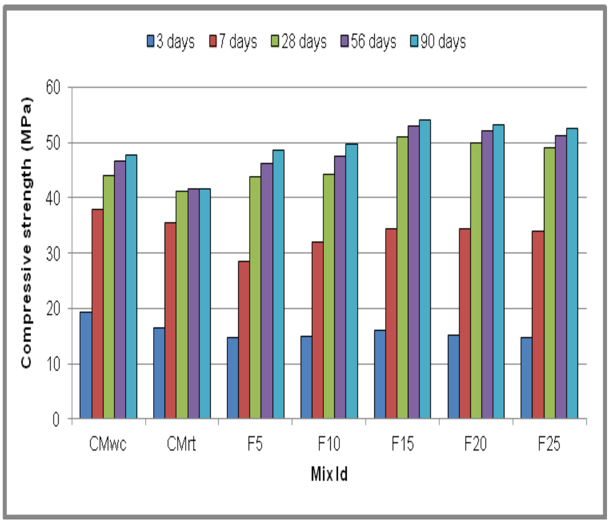


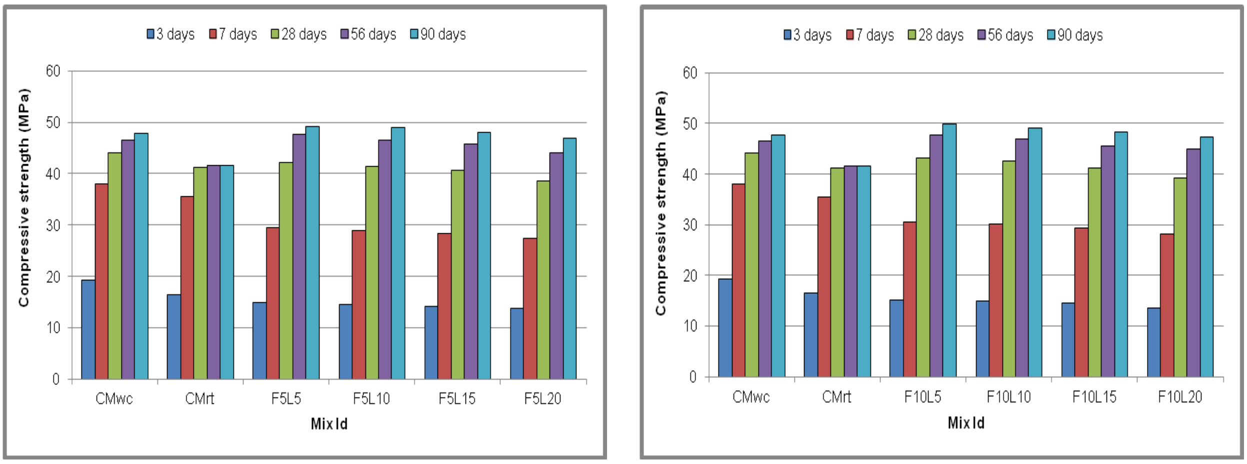
Figure 4. Compressive strength of SCC with FAA

SCC with FAA at different ages exhibits a very identical pattern in compressive strength to SCC with LECA (Fig. 4). The FAA-included SCC had a higher compressive strength than SCC with LECA at ages 7, 28, 56, and 90 days. The potency of all the SCC mixes containing FAA was also greater than that of the control at later ages. In order to attain the optimum compressive strength, it is also clear that the best percentage to replace natural sand in SCC is 15% FAA. At 28 days, 56 days, and 90 days, the SCC with FAA shown a 15.42%, 13.72%, and 13.37% increase in compressive strength compared to the control mix and control concrete (CM_{wc}). However, compressive strength was lost when FAA was added in excess of 15%. However, the strength of SCC with 20 and 25% FAA is superior to control concrete.

The strength of the concrete is enhanced by the increased pozzolanic activation of the fly ash and cement [31, 32]. The compressive strength of the SCC mixes increased, after a curing time of 90 days compared to the control concrete (CM_{wc}) confirmed that the incorporation of saturated LWAs improves their mechanical characteristics [33].

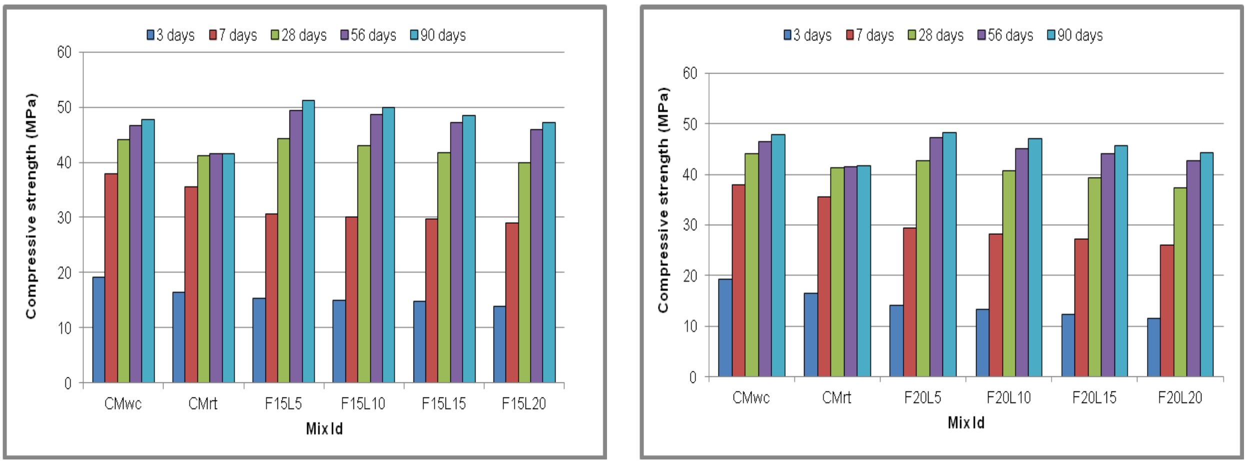
As self-curing agents, different concentrations of LECA and FAA were used to measure the compressive strength of SCC; the results are displayed in Figures. 5a-d. While the FAA content is constant, the compressive strength of SCC falls when the LECA level increases. With an increase in LECA content, there may be more internal water accessible for the hydration process in SCC. SCC with LECA and FAA has a lower early compressive strength than CM_{wc}, which is similar to SCC with LECA and also FAA. SCC mix ($F_{15}L_5$) outperformed the other mixes in terms of compressive strength. At the age of 28 days, this mix exhibited compressive strength comparable to the control mix. $F_{15}L_5$ strength is somewhat higher than control mix at later ages. At the ages of 28, 56, and 90 days, the $F_{15}L_5$ mix outperformed the CM_{wc} mix by 0.31 percent, 5.90 percent, and 7.11 percent, respectively. In SCC, saturated lightweight aggregates such as LECA and FAA continuously release the necessary volume of water for hydration in order to achieve maximum strength [4]. The inclusion of FA and LSP greatly enhanced the microstructure and strength at all ages [34].

Better strength was achieved with a 15% replacement ratio and a about 10% less weight than regular weight self-compacted concrete. It also shown that it is feasible to produce structural lightweight concrete. Because of its moderate cost and satisfactory strength, it can be utilised for building and precast concrete elements [7].



a) 5% FAA with LECA

b) 10% FAA with LECA



c) 15% FAA with LECA

d) 20% FAA with LECA

Figure 5. a-d Compressive strength of SCC with LECA and FAA blend

3. MICRO-STRUCTURAL STUDIES

SEM microstructural investigations were performed on all SCC mixes to investigate the effect of self-curing on the degree of hydration, generation of hydration products, elemental content, and other factors. Figures 6-9 show the SEM pictures.

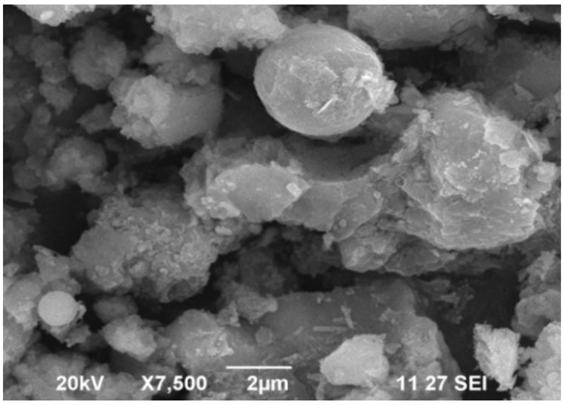


Figure 6. SEM image of CM$_{wc}$ Mix

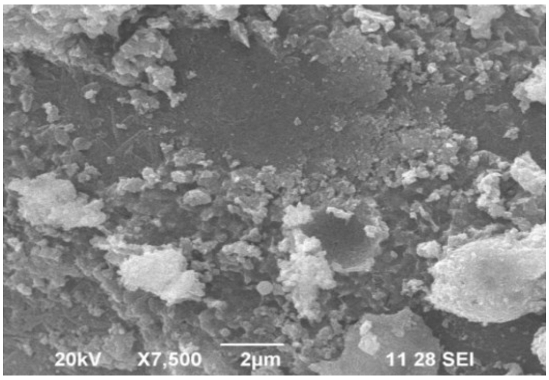


Figure 7. SEM image of L$_{15}$ Mix

The SEM images of each mix show the existence of C-S-H, C-A-S-H, and a trace amount of CH. The pozzolanic activity of the fly ash used in all of the mixes may be connected to the reduced CH. Additionally, no signs of ettringite, which appears at 28 days of age, are present. Furthermore, the shot showed portion of the unreacted spherical shape of the fly ash. Additionally, the images show that the microstructure of all SCC mixtures is denser than that of the control. This is most likely due to the use of saturated lightweight aggregates as self-curing agents, which ensured full hydration of the cement paste and produced a denser microstructure. Also, the F_{15} mix has a denser microstructure than the other two SCC mixes, according to SEM images. Microstructure densification results from the chemical reaction of reactive silica in fly ash aggregate with calcium hydroxide, which yields more cementitious material [25].

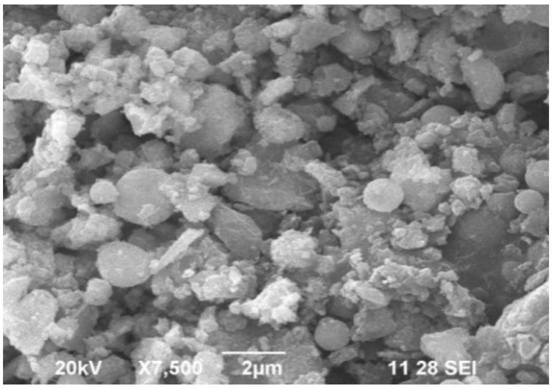


Figure 8. SEM image of F_{15} Mix

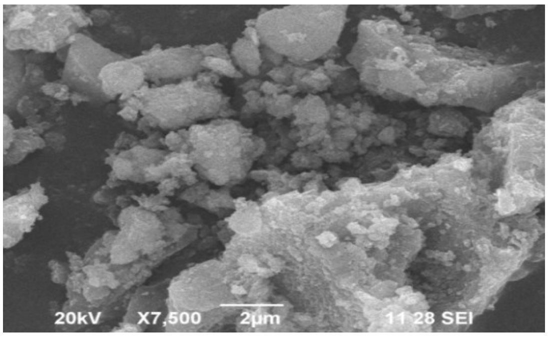


Figure 9. SEM image of $F_{15}L_5$ Mix

4. DURABILITY STUDIES

4.1 Sulphate resistance test

The degradation of reinforced concrete structures can be caused by sulphate ions in soil, groundwater, bacterial activity in sewers, and seawater. The goal of the current investigation was to determine how the performance of SCC was affected by a 5% magnesium sulphate solution. For 28, 56, 90, and 180 days, the SCC cubes are submerged in a 5% magnesium sulphate solution, and their compressive strength and weight loss are measured.

Figure 10. Specimens after 180 days submergence in $MgSO_4$ solution

White salt precipitation on CM_{wc} and $F_{15}L_5$ specimens is seen. However, white salt precipitation is minimal in concrete cubes representing L_{15} and F_{15} mixtures. It's probably because L_{15} and F_{15} mixtures have lower permeability than control and $F_{15}L_5$ mixes. The creation of Brucite (magnisum hydoxide) and magnisum silicate hydrates results in the precipitation of white salt over the concrete due to magnesium participating in processes that replace calcium in the solid faces (Fig.10). The calcium silicate hydrates are decomposed by brucite on the concrete surface, which lowers the pH of the pore solution. The displaced calcium precipitates as gypsum on the specimens in the form of white precipatation [35].

The weight loss and compressive strength loss of SCC specimens as a result of sulphate assault are shown in Figures 11 and 12, respectively. All SCC blends have demonstrated reduced compressive strength and weight loss when compared to CM_{wc}. The self-curing of LWA, which lowers permeability, is primarily responsible for the enhanced sulphate resistance of SCC mixtures. Furthermore, the F_{15} mix outperformed the L_{15} and $F_{15}L_5$ SCC mixes. In comparison to CM_{wc}, the F_{15} mix had a decrease in compressive strength of 2.64%, 3.45%, 4.72%, and 6.43% at ages of 28, 56, 90, and 180 days. Additionally, compared to the other SCC mixes, the F_{15} combination sheds less weight. The addition of fly ash transforms the leachable calcium hydroxide into calcium silicate hydrate [4].

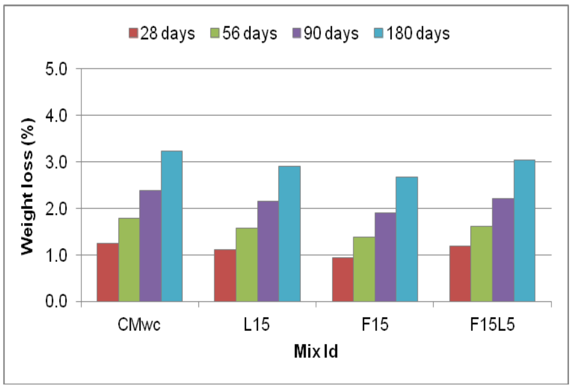


Figure 11. Weight loss due to sulphate

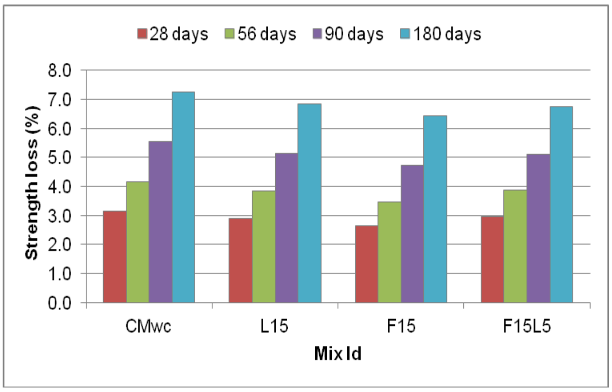


Figure12. Strength loss due to sulphate

4.2. Acid resistance test

Although all Portland cement components are subject to deterioration, acid attacks calcium hydroxide most aggressively. It is unable to degrade the specimen's interior without completely disintegrating the cement paste on the exterior. Accordingly, the rate of penetration is inversely correlated with the amount of acid neutralising material, such as calcium hydroxide or C-S-H gel. The ability of hydrogen ions to permeate the cement gel (C-S-H) following the dissolution and leaching of calcium hydroxide $(Ca(OH)_2$ also affects the attack rate [36].

Figure 13. Specimens after 180 days submergence in HCl solution

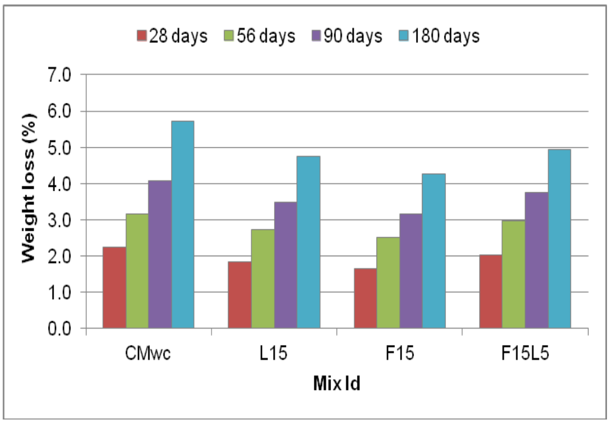


Figure 14. Weight loss due to acid

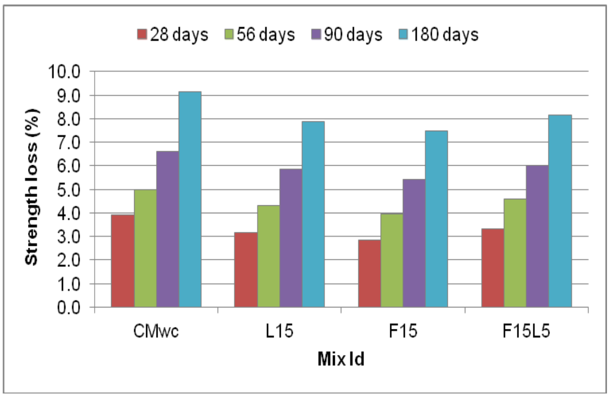


Figure 15. Strength loss due to acid

The present investigation used a 3% hydrochloric acid solution to try to find out how resistant concrete was to acid (Fig.13). As illustrated in Figures. 14 and 15, all of the SCC mixes have demonstrated less weight loss and compressive strength loss than the control mix. Furthermore, the F_{15} mix outperformed the L_{15} and $F_{15}L_5$ mixes, respectively. The F_{15} mix exhibited 2.85%, 3.94%, 5.43%, and 7.47% less loss of compressive strength than the control at 28 days, 56 days, 90 days, and 180 days. The concrete needs to have better permeability and homogeneity due to SCC's self-curing properties (Fig.15). Reactive silica in fly ash aggregate and calcium hydroxide must react chemically to produce additional cementitious material and densify the microstructure, which is responsible for F_{15}'s best performance [28]. In acidic environments, the most significant reduction in compressive strength for Leca occurred between 1 and 7 days. The acidic environment has a greater impact on the strength reduction of LECA in the early days. Furthermore, the samples' weight decreased by no more than 1% to 4% from their initial weight [37].

4.3. Chloride resistance test

Seawater, groundwater, soil, aggregates, mix water, chloride-containing air in maritime regions, and de-icing solutions all include chloride ions that shorten concrete's lifespan. The sodium chloride present in mix water is also known to have erratic effects on setting of concrete [38]. Also, it causes significant compressive strength loss in concrete [39]. According to IS: 456 (2000) [40], water with a chloride concentration of up to 500 parts per million is safe to use in concrete; nevertheless, water with even higher salt levels has been utilised with success. More so, chloride ions, CO_2, etc. destroy the defensive stable ferric oxide film around the steel rebar in alkaline environment. Concrete and rebars embedded in concrete can corrode as a result of chloride ion penetration. When calcium hydroxide in concrete reacts with chloride ions, expansive alkaline calcium chloride is produced, this causes concrete to deteriorate. During crystallization, alkaline calcium chloride expands in volume, causing concrete to crumble.

Figure 16. Specimens after 180 days immersion in NaCl solution

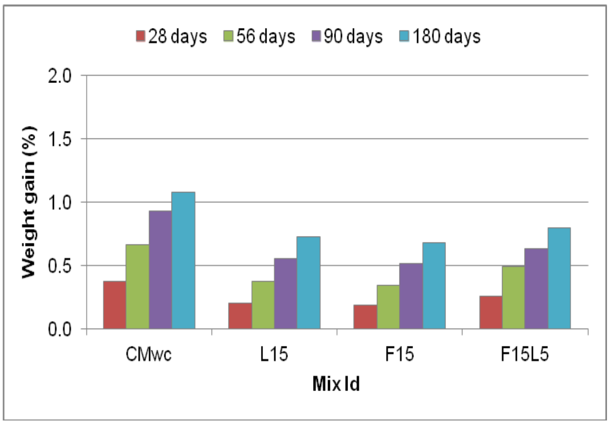


Figure 17. Weight gain due to chloride

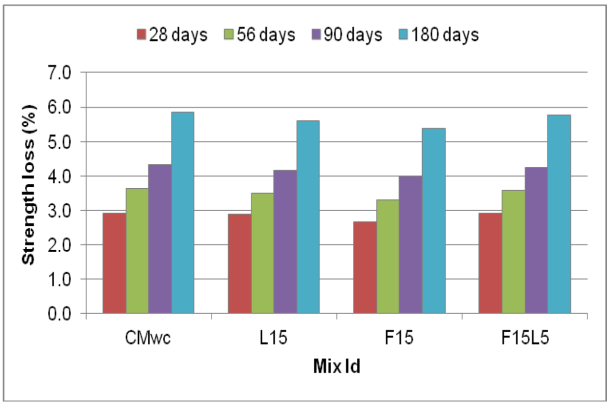


Figure 18. Strength loss due to chloride

Over the course of 28 days, 56 days, 90 days, and 180 days, SCC specimens and a control mix were continuously exposed to a 3.5% sodium chloride (NaCl) solution (Fig. 16). The specimens' weight (Fig. 17) and compressive strength (Fig. 18) were measured. All the specimens representing CM_{wc}, L_{15}, F_{15} and $F_{15}L_5$ mixes are free from cracks, crumbling and softening. It is evident from Fig. 20 that all the SCC specimens exhibited relatively less weight gain than control. The gain in weight is due to penetration and deposition of sodium chloride in the concrete [41]. The F_{15} mix has exhibited least gain in the weight, followed by L_{15} and $F_{15}L_5$ mixes respectively. This trend is same as that of compressive strength of SCC mixes. It is obvious that the SCC mixes wth higher compressive strength exhibits the low porosity and permeability and thereby greater resistance to penetration of chloride ions.

The self compaction and self curing of SCC mixes imparted low porosity as well as permeability and thereby higher resistance to NaCl [42]. In comparison to CM_{wc}, all SCC mixes have demonstrated a comparatively lower loss of compressive strength. Additionally, the F_{15} mix performed the best, followed by the L_{15} and $F_{15}L_5$ mixes. At 28 days, 56 days, 90 days, and 180 days, respectively, the F_{15} mix demonstrated a 2.67%, 3.30%, 4.00%, and 5.38% reduction in compressive strength loss compared to CM_{wc}. Concrete performs better as a result of the reaction between the amorphous silica found in fly ash aggregates (in the F_{15} mix) and calcium hydroxide produced during the hydration process, which forms dense C-S-H in the concrete [43, 44]. Also, density and thermal conductivity of concrete can be reduced using lightweight aggregate in concrete [45].

5. CONCLUSIONS

The test results of this study allow for the following deductions to be made:

- Saturated LECA and FAA in SCC mixes increase the compressive strength of concrete under ambient curing conditions by enhancing water retention and permitting the cement paste to continually hydrate. Compared to control mixtures, this produces a better compressive strength and fewer voids and pores.
- Optimum dosages of LECA or FAA to substitute natural fine aggregate in SCC are 15% in order to provide the highest compressive strength. When utilising blended

material to increase compressive strength, the ideal dosages to replace the fine aggregate in SCC are 15% FAA and 5% LECA.

- It has been shown that the SCC blends are more resilient to attacks by sulphates. These mixtures have shown less loss of compressive strength than CM_{wc} because LWA self-cures and imparts relatively low permeability. The F_{15} mix also did the best, followed by the $F_{15}L_5$ and L_{15} SCC mixes. The F_{15} mix demonstrated a decrease in compressive strength of 2.64%, 3.45%, 4.72%, and 6.43% at ages of 28, 56, 90, and 180 days in comparison to CM_{wc}. All SCC combinations are also lighter than CM_{wc} because of the formation of additional cementitious chemicals.
- Comparatively better acid resistance has been demonstrated by the SCC combinations. Because of their enhanced microstructure, these combinations have shown less loss of compressive strength than the control mix. Additionally, the F_{15} mix outperformed the L_{15} and $F_{15}L_5$ mixes, respectively. The F_{15} mix demonstrated 2.85%, 3.94%, 5.43%, and 7.47% less loss of compressive strength than the control at 28 days, 56 days, 90 days, and 180 days.
- All SCC combinations were also demonstrated to be more resistant to the effects of sodium chloride salt. The SCC mixes lose less compressive strength than the CMwc because of their low permeability. It was also shown that the F_{15} blend outperformed the L_{15} and $F_{15}L_5$ mixes. The F_{15} mix demonstrated 2.67%, 3.30 %, 4.00 %, and 5.38 % less loss of compressive strength than CM_{wc} at 28 days, 56 days, 90 days, and 180 days. However, all of the mixes have become heavier as a result of sodium chloride seeping and precipitating into the concrete.
- Lightweight SCC with LECA reduces dead load, contributing to structural efficiency in tall buildings. SCC with LECA & FAA is ideal for precast elements due to its ease of placement and minimal need for vibration. Fly ash can enhance the durability of concrete exposed to severe environmental conditions, and the lightweight nature of the mix may offer additional benefits for certain structures. The thermal and acoustic properties of lightweight SCC make it useful for soundproofing and thermal insulation purposes.

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IZVOD

ISTRAŽIVANJA SAMOZBIJAJUCEG BETONA KORIŠĆENJEM LETEĆEG PEPELA I LAGANIH EKSPANDOVANIH GLINENIH AGREGATA

Ova studija ispituje samozbijajući beton (SCC) koji sadrži zasićeni agregat letećeg pepela (FAA) i laki agregat ekspandirane gline (LECA). Zamena finog agregata u smešama se kretala od 0% do 25% na osnovu zapremine. LECA i FAA su takođe kombinovani da bi se proizvele SCC mešavine. Efekti LECA i FAA na SCC ispitivani su sa svojstvima tečenja, mikrostrukturom, čvrstoćom na pritisak, otpornošću na kiselinu (HCl), otpornošću na sulfat (MgSO4) i otpornošću na soli (Nacl). Nalazi pokazuju da zamena zasićenih lakih agregata finim agregatom u SCC mešavinama radi promovisanja unutrašnjeg očvršćavanja nudi tehničke i troškovne prednosti.

Ključne reči: *samozbijajući beton, laki ekspandirani agregat, elektrofilterski agregat, unutrašnje očvršćavanje*

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