INFLUENCE OF PRESATURATED LIGHT EXPANDED CLAY AND FLY ASH AGGREGATE IN SELF COMPACTING CONCRETE

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This paper presents the finding of an experimental study on strength and durability performances of self compacting concrete (SCC) with pre-saturated light expanded clay aggregate (LECA) and fly ash aggregate (FAA). The fine aggregate was replaced in the mixes in the range of 0% to 25% with 5% interval on volume basis. Also, the blend of LECA and FAA was used to make Self Compacting Self Curing Concrete (SCSCC) mixes. The influence of LECA and FAA on the fresh properties, strength, acid resistance (HCl) and sulphate resistance ($MgSO_4$) on SCC and SCSCC were studied. From the results it was observed that replacement of fine aggregate by presaturated LECA and FAA as self curing agent to SCC mixes gives cost-effective and technical benefits.

Keywords: *Self compacting concrete, Curing, Strength, Micro structure, Durability*

1. Introduction

Compaction is the process of removal of entrapped air in the concrete and to make concrete into dense and homogeneous material. Generally, compaction of concrete is being done using conventional methods such as hand rodding and mechanical vibration/ spinning of high pressure shock. These methods may not be effective in structures with congested reinforcement. Also, they require more man power and time for construction. In order to make concrete with better surface finish, improved strength and durability, it is essential to impart self compacting ability to concrete. Okamura [1] discovered Self compacting concrete (SCC) is a special type of concrete with much higher fluidity without segregation and capable of filling every nook and corner of form work and congested reinforcement under its own weight only. SCC is found suitable where compaction by manual or by mechanical vibrators is very difficult to execute. Particularly, underwater concreting cannot be done using aforementioned compaction methods. This difficult, can now be solved with self compacting concrete. SCC is placed or poured in the same way as ordinary concrete but without vibration. It is very fluid and can pass around obstructions and fill all the nooks and corners without the risk of either mortar or other ingredients of concrete separating out. At the same time, the self compacting ability of concrete ensures that air is not entrapped. Okamura&Ouchi [2] explained that this type of concrete mixture does not require any compaction and thereby it saves time, labour and energy. The surface finish produced by self compacting concrete is exceptionally good and patching is not necessary.

Apart from compaction, curing is also equally important to attain the designed strength and durability of concrete. Curing is the process of promoting the hydration of cement in the paste of concrete. Generally, curing is being done using conventional methods such as ponding, fogging, sprinkling and covering with saturated materials etc. These methods are seldom labour intensive, time consuming and expensive. Also, negligence in curing, paucity of water in arid areas, inaccessibility of structure and presence of contaminant are some of the reasons for promoting self curing concrete. Curing compounds such as wax emulsion, acrylic emulsion, and chlorinated rubber based compounds; hydro carbon resins and polyvinyl acetate based compounds can also be used in the concrete to promote self curing. These chemical compounds absorb water from atmosphere to promote hydration in concrete. However, there is a need to search for cost effective solutions to impart self curing ability to concrete.

In the recent years, self curing has been recognized as a novel methodology which assures improved protection against early-age cracking and as well provides better durability. Moreover, internal water curing has a significant effect on the hydration and moisture movement and thus manipulate the concrete properties including strength, shrinkage, cracking, and durability. The ACI-308 [3] code states that "internal curing refers to the process by which the hydration of cement occurs due to the availability of extra internal water that is not part of the mixing water." 'Internal curing' allows water for curing from inside to outside through the internal water reservoirs. This can be accomplished in the form of lightweight fine aggregates, superabsorbent polymers, or saturated wood fibers.

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Fig 1 -Fly ash aggregate.

Fig 2 -LECA aggregate.

Hence, an attempt is made in this paper to determine the effect of incorporation of prewetted LECA and FAA as a partial replacement of fine aggregate in fresh, mechanical, micro-structural and durability properties of SCSCC.

2.Materials

Ordinary Portland cement (OPC) 53 Grade conforming to IS: 12269 [4] was used for the study. Locally available river sand having specific gravity of 2.61 conforming to grading zone-III was used as natural fine aggregate. Coarse aggregate of maximum 12.5 mm size and specific gravity 2.73 was used in this study. Class ‘F’ fly ash having specific gravity of 2.27 as obtained from Mettur thermal power plant was used as a mineral admixture. Apart from mineral admixture, it was used to make fly ash aggregate by pelletization method. The specific gravity and water absorption of fly ash aggregate were 1.85 and 20% respectively (Fig.1). LECA with a specific gravity of 1.42 was obtained from GBC India, Ahmadabad to partially replace the fine aggregate in the concrete. The LECA aggregate has water absorption as high as 38% with density of 442 kg/m^3. The polycarboxylate ether based superplasticizer was also used to attain good workability in SCC.

2.1.Preparation of fly ash aggregates

Cement and fly ash are taken in the ratio of 15:85 to make fly ash aggregate as suggested by Shanmugasundaram et al [5]. Water/binder ratio is fixed at 0.3. Cement and fly ash were mixed thoroughly in a dry state in a concrete mixer. Then the water was added to the dry mix and thoroughly mixed in the drum with 35 to 55° angle of inclination, until the process of formation of fly ash aggregates was completed. The aggregates produced using this process is called as cold bonded fly ash aggregate.

The fly ash aggregates (FAA) having different sizes were taken out from the mixer machine and allowed to dry for a day. The aggregates were packed in gunny bags and immersed in curing tank for 7 days. After 7 days, the FAA were taken out from gunny bags and dried completely. Then aggregates are subjected to sieving by using appropriate sieves. Gopi et.al [6] suggested that aggregates having size in the range of 1.18 mm to 4.75 mm are considered as fine aggregates (Fig.2).

3.Mix design for scc

SCC mix design was done as per the guidelines prescribed by EFNARC [7]. The total powder content to 573.9 kg/m^3 (cement + fly ash). Coarse aggregate content is fixed at 50% of its dry rodded unit weight and fine aggregate content at 45% by mortar volume. The W/P ratio is kept at 0.31 by weight, with air content 2%. Super plasticizer dosage is fixed at 0.7% of cementitious materials. The fine aggregate was replaced in the mixes in the range of 0% to 25% with 5% interval on volume basis in first two set of mixes. The mix

Table 1

Mix proportion for SCSCC with LECA/FAA aggregate

S. No	Mix Id	Cement (kg/m^3)	Fly Ash (kg/m^3)	LECA/FAA (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)	Super plasticizer (kg/m^3)
1.	CM_{wc}	439.5	134.4	0	819.6	774.2	177.7	4.02
2.	CM_{rt}			0	819.6			
3.	L_5			12.62	778.62			
4.	L_{10}			25.24	737.64			
5.	L_{15}			37.87	696.66			
6.	L_{20}			50.49	655.68			
7.	L_{25}			63.09	614.70			
8.	F_5			29.96	778.62			
9.	F_{10}			59.97	737.64			
10.	F_{15}			89.88	696.66			
11.	F_{20}			119.94	655.68			
12.	F_{25}			149.87	614.70			

Table 2

Mix proportion for SCSCC with FAA and LECA aggregates

S. No	Mix Id	Cement (kg/m³)	Fly Ash (kg/m³)	FAA (kg/m³)	LECA (kg/m³)	Fine Aggregate (kg/m³)	Coarse Aggregate (kg/m³)	Water (kg/m³)	Super plasticizer (kg/m³)
1.	F_5L_5	439.5	134.4	29.99	12.62	737.64	774.2	177.7	4.02
2.	F_5L_{10}			29.99	25.24	696.66			
3.	F_5L_{15}			29.99	37.87	655.68			
4.	F_5L_{20}			29.99	50.49	614.70			
5.	$F_{10}L_5$			59.97	12.62	696.66			
6.	$F_{10}L_{10}$			59.97	25.24	655.68			
7.	$F_{10}L_{15}$			59.97	37.87	614.70			
8.	$F_{10}L_{20}$			59.97	50.49	573.72			
9.	$F_{15}L_5$			89.96	12.62	655.68			
10.	$F_{15}L_{10}$			89.96	25.24	614.70			
11.	$F_{15}L_{15}$			89.96	37.87	573.72			
12.	$F_{15}L_{20}$			89.96	50.49	532.74			
13.	$F_{20}L_5$			119.94	12.62	614.70			
14.	$F_{20}L_{10}$			119.94	25.24	573.72			
15.	$F_{20}L_{15}$			119.94	37.87	532.74			
16.	$F_{20}L_{20}$			119.94	50.49	491.76			

proportions are presented in Table.1. Also, the blend of LECA and FAA was used to make SCSCC mixes. The fine aggregate was replaced in the mix by LECA/FAA to the maximum extent of 20% by volume with 5% increment as shown in Table.2.

The ingredient such prewetted LWAs, river sand, fly ash, cement and coarse aggregate were mixed thoroughly in dry condition. Then, the polycarboxylate ether-based superplasticizer mixed in water was added to the mix and later thoroughly mixed to cast specimens. After 24 hours of casting, the specimens were demoulded and covered with plastic sheets to minimize moisture loss.Twenty six SCC mixes were made with combination of LECA & FAA by partially replacing fine aggregate. These aggregates were presaturated for 24 hrs and used at saturated surface dried condition (SSD) while making the SCSCC mixes. The mix without LECA and FAA are taken as control mix (CM). One mix was cured with water (CM_{wc}) and the other in room temperature (CM_{rt}). The mixes coded with letter 'L' and 'F' designates mixes with LECA and FAA respectively. The numeral in the mix code (subscript) designates the percentage of replacement of natural fine aggregate by volume with LECA/FAA.

4.Testing methods

Fresh concrete properties of the SCSCC, i.e. the filling ability, passing ability, and segregation resistance, were measured for all mixes in order to determine self-compactabilty properties. Slump flow, T_{50}cm slump flow, and the 'V' funnel test, were conducted so as to measure the filling ability of fresh concrete. The passing ability tests such as the 'J' ring, 'U' box, and 'L' box, were also carried out. The sieve stability test was performed to test segregation resistance as per EFNARC [7] guidelines.

Three cube specimens of size 150 mm were tested after 3, 7, 28, 56 and 90 days for each mix to determine the compressive strength of concrete as per IS:516 [8]. For sulphate and acid resistance, 100 mm cubes were used. Durability test was performed after 28 days of curing the specimen in the respective chemical solution. For each test change in weight and strength loss was calculated.

4.1.Fresh SCSCC Properties

The concrete workability tests such as slump flow, T_{50} cm slump flow, V-funnel test, J-Ring test, L-Box test, U-Box test and sieve segregation test were conducted for all SCSCC mixes made with prewetted LECA and FAA and the results are presented in Table 3.

The SCSCC mixes with less than 20% of pre-wetted LECA and FAA satisfies the workability requirements as specified by EFNARC [7]. Sood et al [9] and Chowdhury et al [10] identified that the incorporation of fly ash in SCC increases the spread of the flow in all the mixes. Also, the spherical shape of LECA improves the flow characteristics of fresh concrete found by Maghsoudi et al [11] & Bogas et al [12]. Similarly, Gopi & Revathi [13] proved the spherical shape of FAA enhances flow characteristics of SCSCC mixes. Choi et al [14] indicated that the weight of the concrete mix was reduced and thereby passing ability is slightly decreased. However, it has been reported that reduced self weight of the concrete with prewetted lightweight aggregate, gives satisfactory results. Further, Krishna et al [15] revealed that limiting the coarse aggregate size to 12.5 mm achieves homogenous and non segregating mix without blockage.

4.2.Compressive strength

It is evident from Fig.3 the compressive strength of water cured control concrete mix (CM_{wc}) reached 38 MPa and 44.1 MPa at 7 and 28 days respectively. Whereas, concrete cured at the room temperature (CM_{rt}) attained only 35.56 MPa and 41.25 MPa at 7 and 28 days, respectively. It

Table 3

Properties of fresh SCSCC mixes

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 (%)
SCSCC 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
SCSCC 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	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
SCSCC 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
EFNARC Acceptance criteria		650 -800	2 - 5	6 - 12	0 - 10	0.8 -1	0 - 30	0 - 15

shows that the compressive strength of CM_{wc} mix is 6.90 % higher than CM_{rt} mix at 28 days. It is due to insufficient water available for hydration process due to curing at room temperature, leading to reduction in the strength of concrete point out by Jensen & Pietro [16] and Evangeline [17]. The SCSCC with 15% of LECA has exhibited 1.88%, 4.06% and 5.73% higher compressive strength than the control concrete (CM_{wc}) at age of 28 days, 56 days and 90 days respectively. It is due to the presence of required moisture content available in the pre saturated LECA aggregate for hydration process. The LECA aggregate allows moisture content to move from inside to outside to ensure complete hydration process in concrete. Recent results (Dayalan&Buellah [18] and Golias et al [19] expressed that the prewetted lightweight aggregate is used in the concrete promote self curing and to ensure the compressive strength of concrete The results obtained are in agreement with the results reported by Mousa et al [20 ,21].

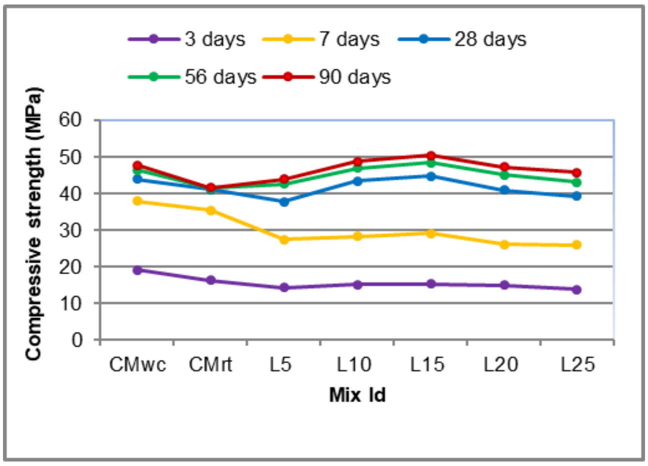


Fig. 3 - Compressive strength of SCSCC with LECA

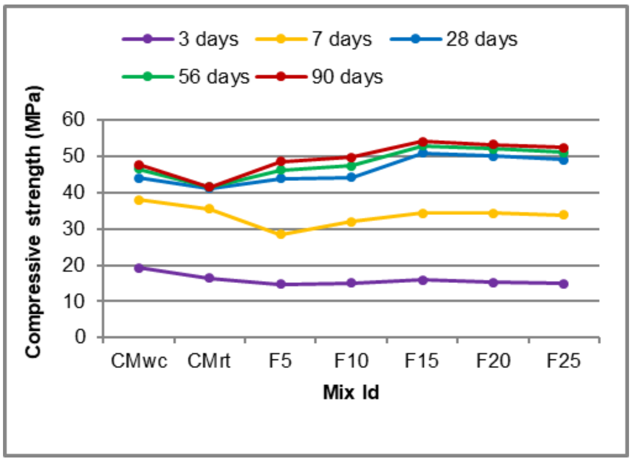
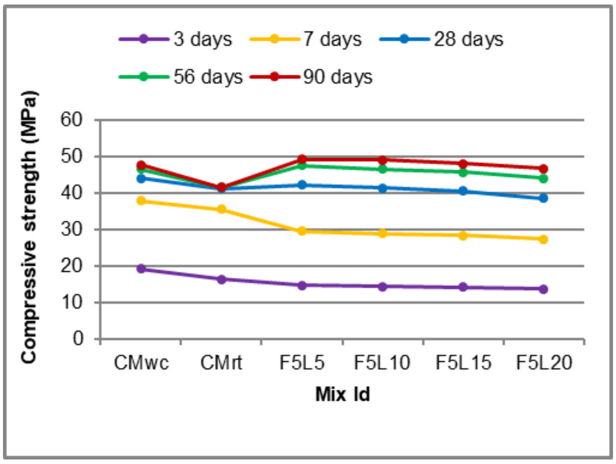


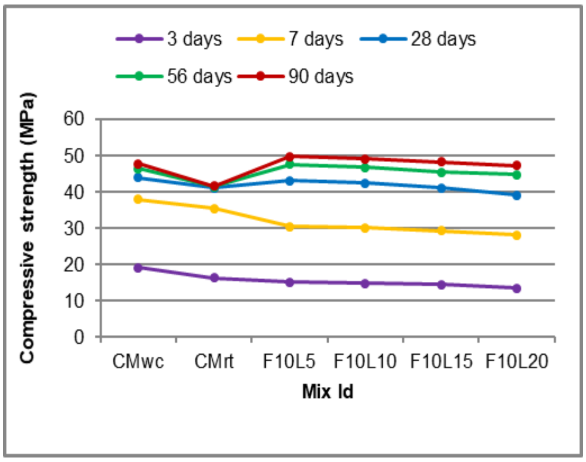
Fig. 4 - Compressive strength of SCSCC with FAA

The trend observed in compressive strength of SCSCC with FAA at different ages is almost similar to that of the SCSCC with LECA (Fig.4). However, the compressive strength of FAA incorporated SCSCC is appreciably higher at 7, 28, 56 and 90 days than the SCSCC with LECA. Further, all the SCSCC mixes with FAA have exhibited high strength than control at later ages. Also, it is clear that 15% of FAA is the optimum percentage to replace natural fine aggregate to impart maximum compressive strength to SCSCC. The SCSCC with FAA has shown 15.42%, 13.72% and 13.37% more compressive strength than control mix at the age of 28 days, 56 days and 90 days respectively than the control concrete (CM_{wc}) compressive strength. However, incorporation of FAA beyond 15% found to reduction in compressive strength of SCSCC. But, the strength of SCSCC with 20 and 25% of FAA is higher than control concrete. It is due to the enhanced pozzolanic activation between the cement and fly ash improves the strength of concrete mentioned by Guneyisi et al [22, 23]. Also, the self curing ability of SCSCC with fly ash aggregate as self curing agent improves the strength of concrete.

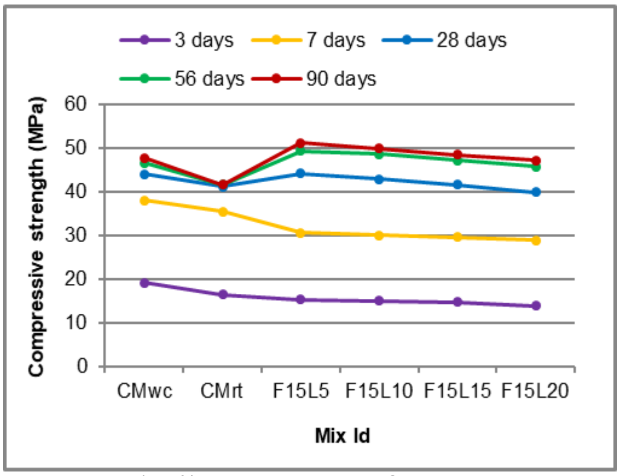
The compressive strength of SCSCC with different proportions of both LECA and FAA as self curing agents was measured and the results are presented in Fig.5a-d. The compressive strength of SCSCC is decreasing with increase in LECA content, while keeping FAA content constant. Gopi et al [24] specified that it may be due to the presence of more internal water available for hydration process in SCSCC with increase in LECA content. Similar to SCSCC with LECA and also with FAA, the early compressive strength of SCSCC with blend of LECA and FAA is less than CM_{wc}. Out of all the combinations, SCSCC mix ($F_{15}L_5$) achieved higher compressive strength than other mixes. This mix has shown compressive strength on par with control mix at the age of 28 days. However, at later age, the strength of $F_{15}L_5$ is marginally higher than control mix. The $F_{15}L_5$ mix has exhibited 0.31%, 5.90% and 7.11% higher strength than CM_{wc} mix at the age of 28, 56 and 90 days respectively. The prewetted light weight aggregate such as LECA and FAA in SCSCC release the required amount of water for hydration continuously to gain maximum strength as stated by Famili et al [25].



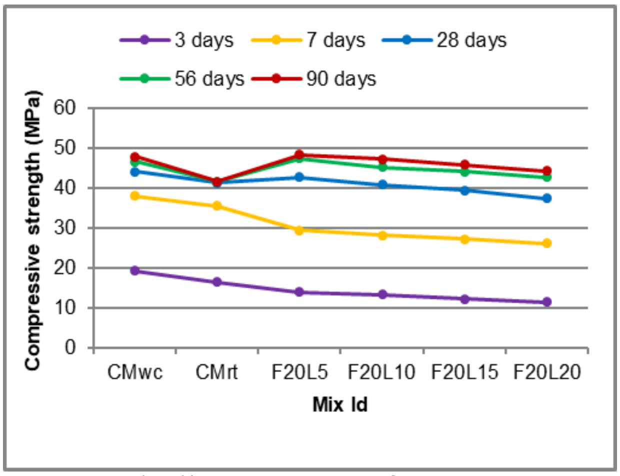
a) 5% FAA with varied LECA content



b) 10% FAA with varied LECA content



c) 15% FAA with varied LECA content



d) 20% FAA with varied LECA content

Fig. 5 a-d - Compressive strength of SCSCC with blend of LECA and FAA.

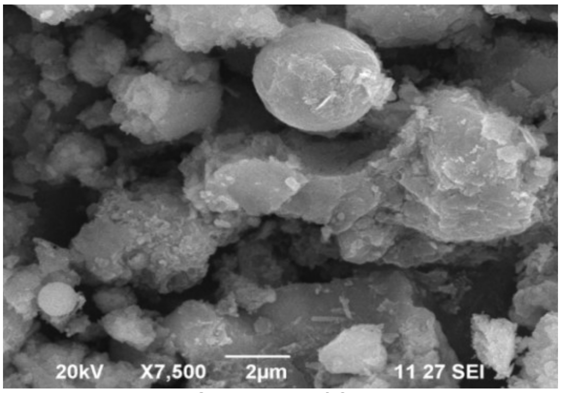


Fig.6 - SEM image of CM_{wc} Mix

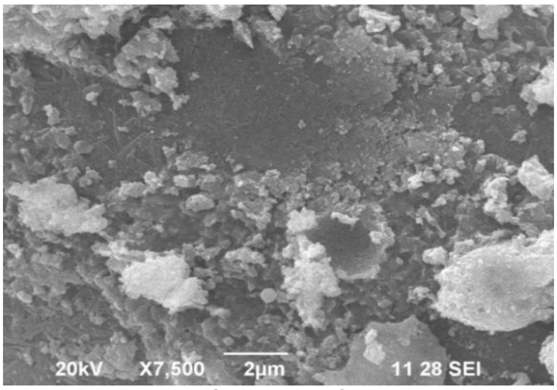


Fig.7 - SEM image of L_{15} Mix

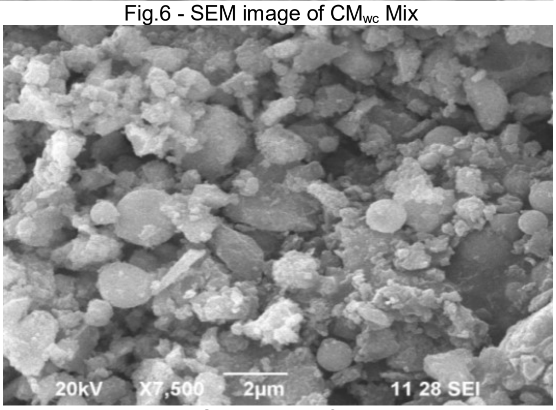


Fig.8 - SEM image of F_{15} Mix

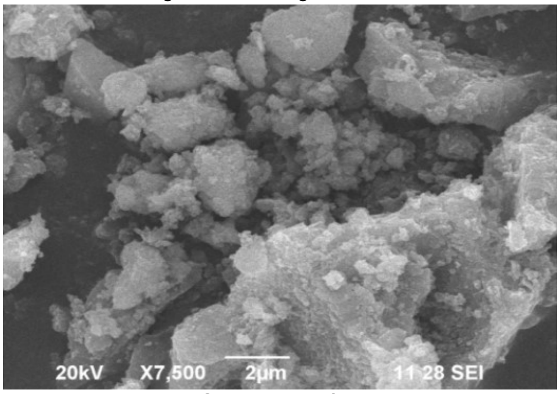


Fig.9 - SEM image of $F_{15}L_5$ Mix

Further, among all SCSCC mixes, SCSCC with 15% of FAA mix has yielded highest compressive strength followed by L_{15} and $F_{15}L_5$ mixes. For micro-structural and durability studies these mixes are considered.

4.3.Micro-structural studies

Scanning Electron Microscopy (SEM) for micro-structural analyses were made for all SCSCC mixes to study the effect of self curing on the degree of hydration, formation of hydration products, Adhesion to aggregate, Homogeneity etc. The SEM images are shown in Fig.6-9.

The SEM images of all the mixes shows the presence of C-S-H, C-A-S-H and also small amount of CH. The reduced CH could be due to pozzolanic activity of fly ash used in all the mixes. Also, there is no evidence of presence of ettringite as it is appears at the age of 28 days. Further, some of the un-reacted spherical shape of fly ash could be seen in the image. It is also evident from the images that all SCSCC mixes have shown relatively denser microstructure than the control. It must be due to the incorporation of prewetted lightweight aggregates as self curing agents to ensure complete hydration of cement paste importing denser microstructure. Also, the F_{15} mix shows relatively very less porosity such as 7.85%, 5.95%, and 4.05% at 7, 28 and 90 days respectively. So, it is manifest that F_{15} mix having denser microstructure. Recent results from Dhiyaneshwaran et al [26] and Karthick &Basker [27] indicated that the chemical interaction between reactive silica present in fly ash aggregate and calcium hydroxide produce additional cementitious material leading to densification of microstructure.

4.4.Durability tests

4.4.1.Sulphate Resistance Test

Sulphate ions in soil, groundwater, bacterial action in sewers and sea water may induce expansion and cracking, leading to deterioration of reinforced concrete structures. In the present study, an attempt was made to find out the effect of 5% magnesium sulphate solution on the performance of SCSCC. The SCSCC cubes are immersed in 5% magnesium sulphate solution over a period of 28, 56, 90 and 180 days and tested for loss in weight as well as compressive strength.The visual observations shows the precipitation of white salt over CM_{wc} and $F_{15}L_5$ specimens. But, concrete cubes representing L_{15} and F_{15} mixes are relatively free from white salt preciptation. It must be due to relatively low permeability of L_{15} and F_{15} mixes than control and $F_{15}L_5$ mixes. The precipatation of white salt over the concrete is because of magnesium taking part in the reactions replacing calcium in the solid faces with the formation of Brucite (magnisum hydoxide) and magnisum silicate hydrates (Fig.10). Brucite on the concrete surface, lowers the pH of the pore solution and then decomposes the calcium silicate hydrates. The displaced calcium is precipated as gypsum in the form of white precipatation over the specimens as stated by Lee [28]. However, the SCSCC is free from manifestations of sulphate attack such as cracking, crumbling and softening.

Fig.10 - Visual appearance of the specimens after 180 days immersion in $MgSO_4$ solution

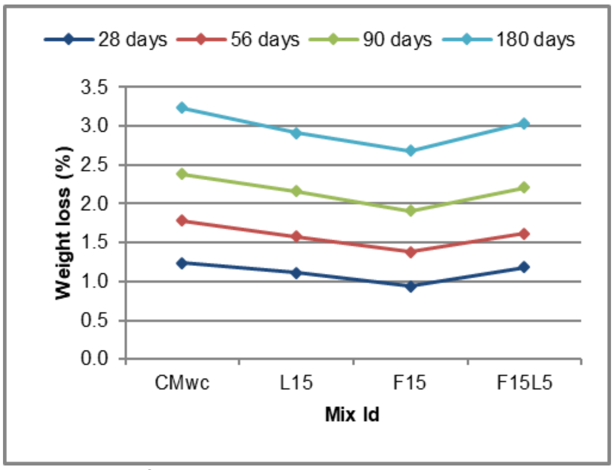


Fig.11 - Loss of weight due to sulphate attack

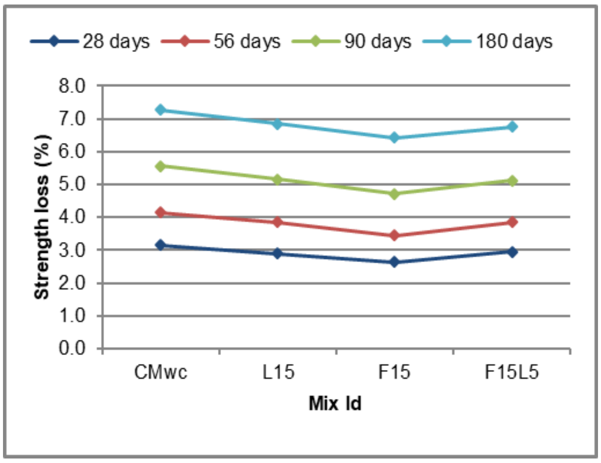


Fig.12 - Loss of strength due to sulphate attack

The loss in weight and compressive strength of SCSCC specimens due to sulphate attack is shown in Fig.11 and in Fig.12 respectively. All SCSCC mixes have shown relatively low weight loss and compressive strength than CM_{wc}. The enhanced sulphate resistance of SCSCC mixes is mainly due to self curing of LWA which imparts relatively low permeability. Also, F_{15} mix has exhibited best performance, followed by L_{15} and $F_{15}L_5$ SCSCC mixes respectively. The F_{15} mix has shown 2.64%, 3.45%, 4.72% and 6.43% less compressive strength loss than CM_{wc} at the age of 28, 56, 90 and 180 days respectively. Further, the weight loss of F_{15} mix is relatively less than the other SCSCC mixes. The incorporation of fly ash converts the leachable calcium hydroxide to calcium silicate hydrate. Thus, the non-availabilty of calcium hydroxide make the concrete to resist sulphate attack.

4.4.2.Acid Resistance Test

Acid generally attack the calcium hydroxide vigorously, although all the Portland cement compounds are susceptible to degradation. It cannot cause deterioration in the interior of the specimen without the cement paste on the outer portion being completely destroyed. The rate of penetration is thus inversely proportional to the quantity of acid neutralizing material, such as the calcium hydroxide, C-S-H gel. Nirmalkumar & Sivakumar [29] point out the rate of attack also depends on the ability of hydrogen ions to be diffused through the cement gel (C-S-H) after calcium hydroxide $Ca(OH)_2$ has been dissolved and leached out.

An attempt has been made in the present work to study the acid resistance of concrete using 3% hydrochloric acid solution (Fig.13). It is evident from the Fig.14 and Fig.15 that all the SCSCC

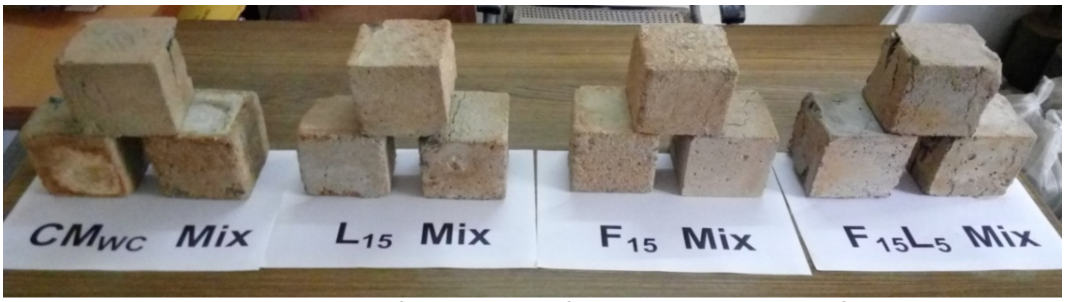


Fig.13 - Visual appearance of the specimens after 180 days immersion in HCl solution.

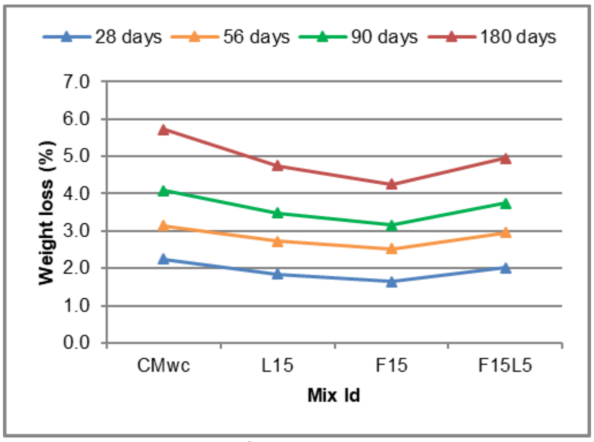


Fig.14 - Loss of weight due to acid attack

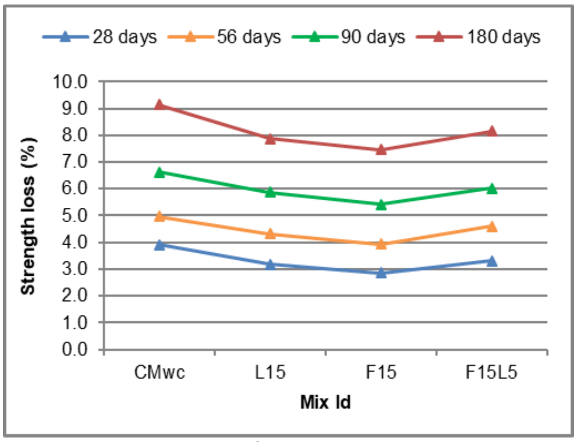


Fig.15 - Loss of strength due to acid attack

mixes have exhibited relatively less weight loss and compressive strength loss than control mix. Also F_{15} mix has exhibited best performance, followed by L_{15} and $F_{15}L_5$ mixes respectively. The F_{15} mix has demonstrated 2.85%, 3.94%, 5.43% and 7.47% less compressive strength loss than control at the age of 28 days, 56 days, 90 days and 180 days respectively. It must be due to better homogeneity and permeability of the concrete because of self curing of SCSCC (Fig.15). The best performance of F_{15} must be due to chemical interaction between reactive silica present in fly ash aggregate used in concrete and calcium hyroxide producing additional cementitious material and thereby densification of microstructure.

5.Conclusion

The following conclusions can be made based on the test results of this study:

1. The use of saturated LECA & FAA in SCC mixes improves the compressive strength of concrete under ambient curing regime which may be attributed to a better water retention and cause continuous hydration process of cement paste resulting in less voids and pores which leads higher compressive strength compared to control mix.
2. The 15% of LECA or FAA is the optimum doses to replace natural fine aggregate to impart highest compressive strength to SCSCC. In the case of blended material, the blend of 15% of FAA and 5% LECA is the optimum doses to replace the fine aggregate in SCSCC to achieve maximum compressive strength.
3. The SCSCC mixes have illustrated relatively better resistance against sulphate attack. These mixes have shown relatively less compressive strength loss than CMwc due to self curing of LWA imparting relatively low permeability. Also, F_{15} mix has exhibited best performance, followed by L_{15} and F15L5 SCSCC mixes respectively. The F_{15} mix has shown 2.64%, 3.45%, 4.72% and 6.43% less compressive strength loss than CM_{wc} at the age of 28, 56, 90 and 180 days respectively.
4. Besides, all the SCSCC mixes have shown relatively low weight than CM_{wc} due to the formation of additional cementitious compounds.
5. The SCSCC mixes have exhibited relatively better resistance against the acid. These mixes have demonstrated relatively less compressive strength loss than control mix due to their improved microstructure. Also F_{15} mix has exhibited best performance, followed by L_{15} and $F_{15}L_5$ mixes respectively. The F_{15} mix has demonstrated 2.85%, 3.94%, 5.43% and 7.47% less compressive strength loss than control at the age of 28 days, 56 days, 90 days and 180 days respectively.

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