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LIGHT EXPANDED CLAY AGGREGATE AND FLY ASH AGGREGATE AS SELF CURING AGENTS IN SELF COMPACTING CONCRETE

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ABSTRACT

In the present study, light expanded clay aggregate (LECA) and fly ash aggregate (FAA) were used as self-curing agents in self-compacting concrete (SCC). FAA and LECA were used as an internal water reservoir. The coarse aggregate was replaced by 5% LECA and the fine aggregate was replaced by the various proportions of FAA from 0% to 50% by weight of fine aggregate. Test results showed that SCC mix with 40% FAA attained higher strength under conventional water curing. Besides, SCC mix with 30% FAA showed higher strength under self-curing. It is concluded that SCC with LECA and FAA could be successfully used as self curing agents where conventional curing is not effective.

Keywords: Self-compacting concrete; light weight aggregate; fly ash aggregate; light weight expanded clay aggregate; self-curing.

1. INTRODUCTION

Self-compacting concrete (SCC), is the one which does not need any mechanical vibration after placing as it flows into formwork under its own weight [1]. SCC has several advantages compared to conventional vibrated concrete, promoting faster construction times, easy flow around congested reinforcement and avoids vibration equipment noise. SCC achieves high-quality durable finishes; simply and effectively. SCC technology has wide spread acceptance in in-situ construction as well in precast concrete products. Such concrete is made by using high powder content with mineral and chemical admixture, lower w/c ratio and lower coarse aggregate content. To enhance the flow of SCC, the mineral admixture such as fly ash, silica fume, GGBS and super plasticizer should be used. SCC properties are greatly influenced by admixture type, its dosage and filler. Aggregate gradation plays a major role for thriving production of SCC when paste content is increased

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with higher volume of paste. It will have unfavorable effects on mechanical properties, and cracking vulnerability [2]. The finer size fraction of fine aggregate reduces the flowablity and increases the viscosity. However the size of fine aggregate does not have remarkable influence on compressive strength of mortar for SCC [3]. From the results of SCC with different sizes of coarse aggregate such as 20 mm, 16 mm, 12.5 mm and 10 mm, it is understood that flow properties were reduced with increase in size of coarse aggregate and increase in strength is directly proportional to the size of the coarse aggregate [4].

For any concrete, curing is an essential process to attain desirable strength and durability properties. Often, it is not easily possible to provide curing water from the top surface at the required rate to achieve concrete with desired properties. In this respect, self curing can be provided by the gradual release of water from aggregate, in which it was absorbed before mixing, to the cement particle to allow continued hydration to achieve desired properties. Self curing can be possible by using pre-soaked lightweight aggregates as self-curing agents. Self curing can be carried out with less quantity of saturated light weight aggregate [5]. This gives additional water to the concrete which is not the part of mixing water [6]. High water absorption lightweight aggregate may have the beneficial effect of supplying curing water internally [7]. Self-curing refers to the use of prewetted lightweight aggregate that can provide curing water throughout the cross section of the concrete. This differs from conventional curing where water is provided after placement and where the water is applied only at the surface of the concrete [8]. Different such as bentonite clay, super absorbent polymers, natural and artificial lightweight aggregates (LWA) such as leca, expanded shale, and diatomaceous earth could be used as self curing agents in concrete [9]. In this LECA concrete can be used in making structural elements and save money, especially, in high-rise building, building on a low strength soil and also where there is a not sufficient coarse aggregate mine. Famili et al (2012) investigated self-curing of high strength SCC with leca. They found a moderate reduction of compressive strength [10]. However, Kovler and his associate (2007), Weber and his associate (1997) observed increase in compressive strength by incorporating LWA [5, 11]. Besides, Durán-Herrera et al (2007) reported self-cured concrete has no effect on the compressive strength due to the inclusion of LWA [12]. Therefore it is suggested by various authors to use self-curing where external curing is impractical. Further, while combining LWA as self-curing agent in SCC improves workability due to high water absorption of aggregate. A.A. Maghsoudi et.al. (2011) reported that the spherical shape of leca enhances rheological properties of fresh concrete mix and it was expected to increase the compressive strength of SCSCC [13]. Mehmet Gesoglu et.al. (2014) investigated Self-consolidating characteristics of concrete using rounded fine and coarse fly ash lightweight aggregates. Due to the spherical shape of FAA provides ease in flow of the aggregate particles. Also, due to the increase in the content of FAA, there was a gradual decrease in the compressive strength irrespective of the testing age. This is because of weakness of FAA compared to natural aggregate [14]. Several researchers studied the effects of the particle size, specific gravity, density, strength, moisture content, and absorption of the FAA on the properties of Light Weight Concrete (LWC). Consequently, there are only a few studies on utilization of FAA in the manufacture of SCC. Erhan Güneyisi et.al. (2012) studied fresh properties of self-compacting cold bonded fly ash lightweight aggregate concrete. They found that the use of FAA with silica fume together decreases the slump value time and V-funnel flow time. On the other hand L-

Box height ratio improved significantly [15]. Harilal.B and his associate (2013) evaluated that the cold bonded fly ash aggregate concrete gained more compressive strength than other types of cold bonded aggregates such as quarry dust and cement [16]. Furthermore, the researchers showed that FAA with spherical shape makes easier the mobility of fresh SCC.

As SCC with self curing agents is emerged as new innovation in construction industry, it will receive attention in near future. The remarkable development of infrastructure urges the need of pioneering concrete which fulfill the requirements. Flowability of SCC with self curing agents improves while the segregation resistance tends to decrease [17&18]. Also, compressive strength of SCSCC is comparable to the water cured SCC. Leca as self curing agent is attempted by several researchers. However, as the cost of Leca is high, the present study proposes to use fly ash aggregate (FAA) as partial replacement for fine aggregate with Leca as partial replacement for coarse aggregate and to evaluate the fresh and hardened properties of self compacting self curing concrete (SCSCC).

2. MATERIALS

2.1 Cementitious materials

Ordinary Portland cement of 53 grade conforming to IS: 12269-1987 [19] is used. The specific gravity of cement is found to be 3.15. The class ‘F’ fly ash obtained from Mettur thermal power plant is used as a mineral admixture and also for manufacturing the FAA. The specific gravity of fly ash is 2.27. The chemical properties of the cementitious materials are shown in Table 2.1.

Table 1: Chemical properties of cementitious materials

Chemical Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O
Cement (%)	19.4	5.28	6.0	62.3	1.16	2.21	0.23	0.97
Fly ash (%)	50.68	26.9	11.24	5.24	1.82	1.72	0.5	0.81

2.2 Fine aggregate and coarse aggregate

Locally available river sand is used as natural fine aggregate. River sand conforms to aggregate grading zone III. Naturally crushed coarse aggregate of size 12 mm is used in this study. It is tested as per IS: 383-1970 [20]. The properties of fine & coarse aggregate are presented in Table 2.2.

2.3 Fly ash aggregate (FAA)

The artificially made fly ash aggregate was prepared by mixing cement and fly ash in various proportions of water. The contents were thoroughly mixed in the drum until the complete formation of FAA. This method of formation of FAA is called as pelletisation. The parameters such as adjusting the angle of the mixer drum as 35° to 55° and speed of revolution of mixer drum kept as 35 to 55 rpm need to be considered for the efficiency of the production of pellet [21]. The prepared FAA were sieved at 4.75 mm sieve and allowed to dry for a day. The dried FAA was cured in a water tank for 7 days. This is called as cold bonded fly ash aggregate. In the mix proportion, cement and fly ash were added in the ratio of 15:85 with w/c 0.3 for FAA preparation [22]. In the present work FAA is used as partial replacement for fine aggregate. Fine aggregate was replaced from 10% to 50% by FAA in increment of 10%. The properties of FAA are shown in Table 2.2.

2.4 LECA

Light weight expanded clay (LECA) is produced by firing natural clay, which swells at 1000-1200 °C due to the action of the gases generated inside the mass. In the present study leca was obtained from GBC India, Ahmadabad, Gujarat. The coarse aggregate is replaced by 5% leca. The properties of leca are shown in Table 2.2.

Table 2: Properties of Aggregates

S.No	Properties	Fine Aggregate	Coarse Aggregate	FAA	LECA
1.	Specific Gravity	2.61	2.73	1.85	0.42
2.	Bulk Density (kg/m^3)	1635	1571	1050	442
3.	Fineness Modulus	2.18	6.36	3.28	6.51
4.	Water Absorption (%)	0.52	0.45	20	39

2.5 Chemical admixtures

Superplastcizer or high range water reducing admixtures are an essential component of SCC. Glenium B233 (polycarboxylate ether based) superplastcizer was used to attain good workability in SCC and their dosage is 0.5% of cementitious material. Glenium Stream 2 admixture was used as viscosity modifying admixture to attain good flowability in SCC and their dosage is 0.2% of cementitious material.

2.6 Water

Mixing water used in the study satisfied the quality standards of drinking water and it was taken from KSR college campus.

3. METHODOLOGY

3.1 Mix design

SCC mix design was done as per modified Nan-Su method for M30 grade [23]. Initially, a number of trial mixes were made and finally the coarse aggregate was partially replaced by 5% leca and the fine aggregate is partially replaced from 10% to 50% by FAA. The mix without LECA and FAA is taken as control mix. The mix proportion for all the mixes are shown in Table 3.1.

3.2 Curing

Both water curing and self curing was attempted for all the mixes. LECA and FAA were pre wetted for 24 hours and surface dried (SSD condition) before concreting to achieve self curing. In case of water curing, LECA and FAA were added in dry state and conventional curing was carried out externally.

3.3 Properties of SCSCC

The fresh concrete properties of SCC were carried out for all the mixes in order to ensure the self compactabilty. The hardened SCSCC properties such as compressive strength using 150 mm cubes, split tensile strength with 150 mm x 300 mm cylinder and flexural strength with 500 mm x 100 mm x 100 mm prisms were carried out as per IS: 516:1959 [24] at the age of 7 and 28 days (Fig 3.1 to 3.3). At each age, three specimens were casted and tested.

Figure 1. Compressive strength

Figure 2. Split tensile strength

Figure 3. Flexural strength

Table 3: Mix Proportion of SCSCC

Ingredients	Quantity (kg/m^3)					
	CM	L_5FAA_{10}	L_5FAA_{20}	L_5FAA_{30}	L_5FAA_{40}	L_5FAA_{50}
Cement [kg/m^3]	375	375	375	375	375	375
Fly ash [kg/m^3]	80.47	80.47	80.47	80.47	80.47	80.47
Water [lit/m^3]	178	178	178	178	178	178
Fine Aggregate [kg/m^3]	890.96	801.86	712.77	663.68	534.57	445.48
Fly Ash Aggregate [kg/m^3]	-	89.09	178.19	227.28	356.38	445.48
LECA [kg/m^3]	-	37.43	37.43	37.43	37.43	37.43
Coarse Aggregate [kg/m^3]	748.62	711.18	711.18	711.18	711.18	711.18
Superplastcizer [kg/m^3]	2.27	2.27	2.27	2.27	2.27	2.27
VMA [kg/m^3]	0.91	0.91	0.91	0.91	0.91	0.91

Note: L – Leca; FAA - Fly Ash Aggregate; CM - Control SCC Mix

4. RESULT AND DISCUSSIONS

4.1. Fresh concrete properties of SCSCC

The fresh concrete properties of SCSCC made with LECA as partial replacement for coarse aggregate and FAA as partial replacement for fine aggregate is shown in Table 4.1. The slump flow is a measure of the ability of concrete to flow under its own weight. The slump flow is in the range of 680mm to 725mm. The maximum slump flow is achieved by 725mm. T50cm slump flow is between 3.1sec to 4.5sec. It is in the desirable value. V-funnel test is performed for to measure the filling ability with out any external force. The value obtained is 8.12sec to 11sec which is in the recommended value of 6sec to 12 sec. J-ring, L-box, U-box tests is the measure of passing ability of SCC in congested reinforcement. The results reported that 6mm to 9mm for J-ring, 0.83 to 0.95 for L-box and 13mm to 25mm for U-box test. All the passing tests results show that incorporating LWA in SCC gives satisfactory results as per EFNARC [25] guidelines.

Table 4: Fresh concrete properties of SCSCC

Test Methods	Recommended Values	CM	L_5FAA_{10}	L_5FAA_{20}	L_5FAA_{30}	L_5FAA_{40}	L_5FAA_{50}
Slump flow	650 to 800 mm	680	700	710	725	710	702
T50 cm slump flow	2 to 5 sec	4.5	4.2	4	3.1	3.4	3.7
V – funnel	6 to 12 sec	11	10	9.45	8.12	8.55	9.34
J –ring	< 10 mm	9	8	8	7	7	6
L – Box	0.8 to 1	0.83	0.85	0.88	0.90	0.92	0.95
U – Box	0 to 30 mm	25	22	20	13	15	18

4.2 Hardened concrete properties of SCSCC

The hardened concrete properties were obtained at 7 days and at 28 days according to Indian Standard Specifications IS:516:1959 [24].

4.2.1 Compressive strength

Table 5: Compressive Strength of SCSCC

Mix id	7 days Compressive strength (MPa)		28 days Compressive strength (MPa)	
	Water curing	Self curing	Water curing	Self curing
CM	17.92	15.60	36.50	23.75
L_5FAA_{10}	25.18	20.44	39.78	37.75
L_5FAA_{20}	28.59	24.71	41.00	39.18
L_5FAA_{30}	32.07	29.00	43.25	40.12
L_5FAA_{40}	35.45	27.11	45.85	37.58
L_5FAA_{50}	34.28	25.90	44.45	35.64

The compressive strength test results of SCSCC are furnished in Table 4.2. It is seen from the test results that addition of FAA with LECA drastically increased the compressive strength under water and self curing in comparison with CM. Also water cured mixes developed higher compressive strength than self cured corresponding mixes. The compressive strength of SCSCC mixes were increased from 25.18 MPa to 35.45 MPa for FAA content from 10% to 50% at 7 days under water curing while the compressive strength of CM was 17.92 MPa. Similar trend is noticed under self curing. In comparison with CM, the LFAA mixes reached higher compressive strength under self curing. The reason could be due to the enhanced binding of FAA with cement paste and contributed for higher compressive strength. Further, water curing provided higher compressive strength than self curing. The compressive strength of CM under water curing was 36.50 MPa at the age of 28 days. The mixes with LF increased the compressive strength from 39.78 MPa to 45.85 MPa at 28 days with the increase of FAA 10% to 40%. The compressive strength of CM under self curing was 23.75 MPa which did not attain the design compressive strength at the age of 28 days while all LFAA mixes reached the target compressive strength. In case of water cured SCC, mix L_5FAA_{40} attained highest compressive strength and it was observed as 45.85MPa whereas self cured SCC mix L_5FAA_{30} achieved maximum compressive strength which was noticed as 40.12 MPa. Furthermore, a correlation between the different SCSCC mixes with compressive strength of water curing and self curing specimens were made and found to be good with R^2 = 0.953 and R^2 = 0.878 respectively (Fig.4.1). The expression obtained for 28 days compressive strength (f_{cs}) is given below.

$$f_{cs} = -0.3193x^2+3.9553x+32.804; \text{ (Water curing)}$$

$$f_{cs} = -1.7068x^2+13.658x+13.752; \text{ (Self curing)}$$

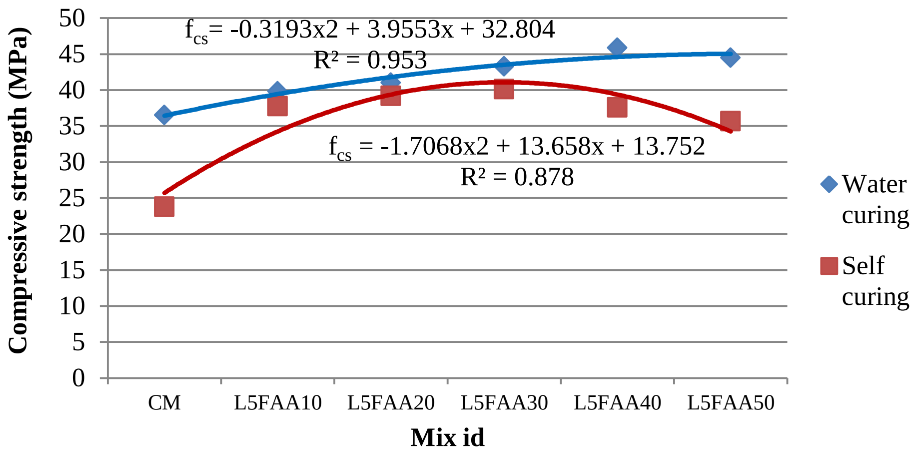

Figure 4. Regression analysis for compressive strength at 28 days

4.2.2 Split tensile strength

Table 6: Split tensile Strength of SCSCC

Mix id	7 days Split tensile strength (MPa)		28 days Split tensile strength (MPa)	
	Water curing	Self curing	Water curing	Self curing
CM	2.45	1.73	3.50	2.38
L_5FAA_{10}	3.38	2.60	3.87	3.70
L_5FAA_{20}	3.50	2.78	4.34	3.98
L_5FAA_{30}	3.64	2.95	4.76	4.20
L_5FAA_{40}	3.82	2.80	5.19	3.85
L_5FAA_{50}	3.72	2.68	4.94	3.32

The split tensile strength test results of SCSCC are given in Table 4.3. The split tensile strength of SCSCC reflects the results of compressive strength. The split tensile strength of

CM was obtained as 2.45 MPa at 7 days under water curing. With respect to LFAA mixes, the split tensile strength was varied from 3.38 MPa to 3.82 MPa at the age of 7 days under water curing whereas the split tensile strength ranged from 2.60 MPa to 2.95 MPa at 7 days under self curing. Further, split tensile strength at 28 days showed the same trend as that of 7 days. Split tensile strength of CM was obtained as 3.50 MPa at 28 days under water curing. Similarly, split tensile strength of CM was obtained as 2.38 MPa under self curing at 28 days. The split tensile strength of LFAA mixes varied from 3.87 MPa to 5.19 MPa under water curing whereas the split tensile strength ranged from 3.32 MPa to 4.20 MPa under self curing. Further, highest split tensile strength was observed as 5.19 MPa for L_5FAA_{40} mix under water curing and mix L_5FAA_{30} attained 4.2 MPa under self curing condition at 28 days. Furthermore, a correlation between the different SCSCC mixes with compressive strength of water curing and self curing specimens was made and found to good with R^2 = 0.957 and R^2 = 0.963 respectively (Fig.4.2). Also, an expression between the different SCSCC mixes with 28 days split tensile strength (f_{sp})of water curing and self curing specimens were obtained and is given below.

$$f_{sp} = -0.0582x^2+0.7384x+2.732; \text{ (Water curing)}$$
$$f_{sp} = -0.2102x^2+1.6247x+1.073; \text{ (Self curing)}$$

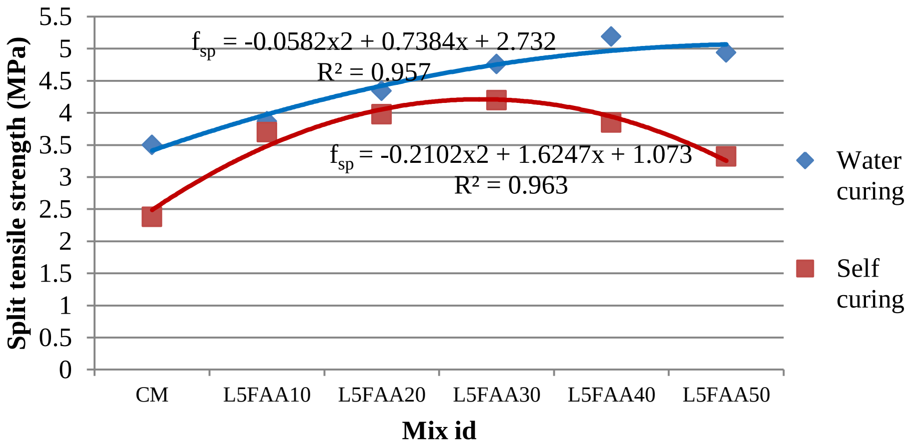

Figure 5. Regression analysis for split tensile strength 28 days

4.2.3 Flexural strength

Table 7: Flexural Strength of SCSCC

Mix id	7 days Flexural strength (MPa)		28 days Flexural strength (MPa)	
	Water curing	Self curing	Water curing	Self curing
CM	4.24	3.05	6.60	4.30
L_5FAA_{10}	4.95	4.36	7.38	6.80
L_5FAA_{20}	5.33	4.60	7.84	7.00
L_5FAA_{30}	5.60	4.96	8.26	7.53
L_5FAA_{40}	6.10	4.78	8.52	6.95
L_5FAA_{50}	5.85	4.42	8.38	6.52

Flexural strength test results of SCSCC are presented in Table 4.4. The flexural strength of CM was obtained as 4.24 MPa at 7days under water curing. Incorporation of FAA in SCC, the flexural strength ranged from 4.95 MPa to 6.10 MPa at the age of 7 days under water curing. The flexural strength of self curing mixes varied from 4.36 MPa to 4.96 MPa at 7 days under self curing. Further, flexural strength at 28 days showed the same effect. Flexural strength of CM was obtained as 6.60 MPa at 28 days under water curing. Similarly, flexural strength of CM was obtained as 4.30 MPa under self curing at 28 days. The flexural strength of FAA mixes was varied from 7.38 MPa to 8.52 MPa under water curing whereas; the flexural strength gained was 42% at the age of 28 days under self curing. Here also, similar to compressive strength and split tensile strength test results of SCSCC, highest flexural strength was obtained for L_5FAA_{40} mix as 8.52 MPa under water curing and L_5FAA_{30} mix reached 7.53 MPa. The correlation between the different SCSCC mixes with flexural strength of water curing and self curing specimens were good with $R^2 = 0.995$ and $R^2 = 0.907$ respectively (Fig.4.3). The expression obtained for 28 days flexural strength are given below.

$$f_{fs} = -0.0964x^2+1.039x+5.656; \text{ (Water curing)}$$
$$f_{fs} = -0.3173x^2+2.5664x+2.347; \text{ (Self curing)}$$

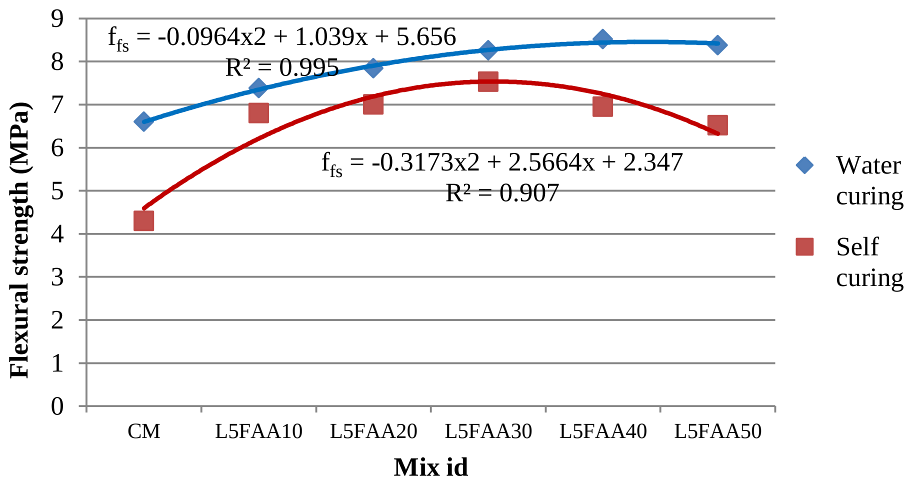

Figure 6. Regression analysis for flexural strength 28 days

5. CONCLUSION

The present study has the following conclusions.

The mix combinations of SCSCC with LECA and FAA and CM satisfied the fresh workability concrete properties as per recommended guide lines given in EFNARC standards. The SCSCC mix with LECA: FAA proportion 5:40 attained higher compressive strength, split tensile strength and flexural strength than other mixes under water curing. In case of self curing, SCSCC mix with LECA: FAA proportion 5:30 achieved higher compressive strength, split tensile strength and flexural strength than other mixes. The addition of LECA and FAA as self curing agents contributes higher strength properties than

CM. LECA and FAA facilitate a high relative humidity within the pore structure of the concrete. This extends the hydration and thereby increases the strength of concrete. Therefore, self compacting self curing concrete with LECA and FAA is recommended for field application where curing is difficult.

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