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Self compacting self curing concrete with lightweight aggregates

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Preliminary report

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Self compacting self curing concrete with lightweight aggregates

The self compacting self curing concrete made by partially replacing fine aggregate with the light expanded clay aggregate and fly ash aggregate is described in the paper. At that, maximum 25 % of fine aggregate (measured by volume) was replaced. Fresh concrete properties and mechanical properties of self compacting self curing concrete were analysed. Test results indicate that all mixes satisfied the self compacting properties of concrete. Furthermore, the concrete mix with 15 % of expanded clay and the mix with 15 % of fly ash exhibited greater strength under self curing conditions, when compared to the control mix and other mixes.

Key words:
self compacting concrete, lightweight aggregate, expanded clay, fly ash, self curing

Prethodno priopćenje

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Samozbijajući beton s unutarnjom njegom i lakim agregatom

U radu je opisan samozbijajući beton s unutarnjom njegom proizveden djelomičnom zamjenom sitnozrnatog agregata laganim agregatom od ekspandirane gline i agregatom od letećeg pepela. Ispitana su svojstva betona u svježem stanju i mehanička svojstva samozbijajućeg betona, pri čemu je najviše 25 % agregata (volumenski) zamijenjeno. Rezultati ispitivanja pokazuju da su sve mješavine zadovoljile zahtjeve za samozbijajući beton. Osim toga, mješavina s 15 % agregata od ekspandirane gline i mješavina s 15 % agregata od letećeg pepela postižu veću čvrstoću pri uvjetima unutarnje njege u usporedbi s čvrstoćama koje su postigle kontrolna mješavina i ostale mješavine.

Ključne riječi:
samozbijajući beton, lagani agregat, ekspandirana glina, leteći pepeo, unutarnja njega

Vorherige Mitteilung

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Selbstverdichtender selbsthärtender Beton mit leichter Gesteinskörnung

In dieser Arbeit wird selbstverdichtender selbsthärtender Beton, hergestellt mit teilweise durch leichte Gesteinskörnung aus expandiertem Ton und Aggregat aus Flugasche ersetztem feinkörnigem Aggregat. Die Eigenschaften des Betons in frischem Zustand sowie die mechanischen Eigenschaften des selbstverdichtenden Betons wurden untersucht, wobei höchstens 25 % des Volumenanteils des Aggregats ersetzt wurden. Ergebnisse der Versuche zeigen, dass alle Mischungen die Anforderungen für selbstverdichtenden Beton erfüllen konnten. Außerdem erzielten Mischungen mit 15 % Aggregat aus expandiertem Ton und Mischungen mit 15 % Aggregat aus Flugasche eine größere Festigkeit unter Bedingungen der Selbsthärtung als die Kontrollmischung und andere Mischungen.

Schlüsselwörter:
selbstverdichtender Beton, leichte Gesteinskörnung, expandierter Ton, Flugasche, Selbsthärtung

1. Introduction

Self compacting concrete (SCC) has gained in significance over the past three decades due to its inherent properties. The SCC plays an important role in cases when compaction is found to be difficult. It was developed in the 1980s for the purpose of obtaining durable concrete structures [1]. The SCC is made by using high powder content with mineral and chemical admixtures, and a lower w/c ratio and coarse aggregate content [2]. The mix composition of the SCC should be checked by its filling ability, passing ability, and segregation resistance. To enhance the flow of SCC, mineral admixtures such as the fly ash, silica fume, and GGBS, should be used along with cement. Apart from mineral admixtures, the use of superplasticizer is mandatory as a means to reduce water content and increase workability of the SCC. Adequate viscosity can be obtained by applying powdered materials and viscosity modifying agents [3]. Its properties are greatly influenced by the type of admixture, by filler, and by dosage of these components. Furthermore, appropriate selection of aggregate size and gradation is important for successful production of the SCC [3, 4]. Compared to angular aggregate, rounded aggregate generally enhances flowability and reduces blocking in SCC [5, 6]. Adjustments are to be made to the content of coarse aggregate, fine aggregate and powder material to achieve the desired flow properties [2, 7, 8]. Furthermore, it is understood that flow properties of the SCC reduce with an increase in the size of coarse aggregate [9]. Finer fractions of fine aggregate reduce flowability and increase viscosity. However, the size of fine aggregate does not have a considerable influence on the compressive strength of mortar [10]. The SCC mix is more expensive than conventional concrete due to higher powder content. To reduce the cost of SCC, filler materials such as limestone/chalk powder and dolomite fines can be used. When used as filler, limestone powder improves the particle packing and compressive strength of the SCC. This is due to the chemical interaction between the cement and limestone powder [11].
The lightweight aggregate (LWA) in the SCC improves its flowability while increasing at the same time the material segregation [12]. The LWA does not have a sufficient internal energy of motion compared to normal aggregate concrete. The light expanded clay aggregate (LECA) with a higher water absorption capacity, and the ball shaped fly ash aggregate (FAA), exert a strong influence on the rheology of concrete [13]. The self compacting lightweight concrete (SCLWC) not only reduces the self weight of concrete, but it also facilitates the self curing of concrete.
Self curing can be imparted to concrete by using saturated lightweight aggregates, super absorbent polymers, and polyethylene-glycol in concrete [14]. Both natural and artificial lightweight aggregates exhibiting a considerable internal porosity may be used as reservoirs for self curing water in concrete. Self curing can be carried out by partially replacing conventional fine aggregate with saturated lightweight aggregate and water soluble chemicals [15, 20]. The water soluble chemicals enhance the self curing by reducing water evaporation during hardening of concrete. The saturated lightweight aggregate in concrete acts as an internal reservoir and allows water for curing to pass from inside to outside. The self curing is an effective mitigation strategy for self-desiccation and autogenous shrinkage in the self compacting self curing concrete (SCSCC) [16, 17]. Strength properties were not affected by self curing when adequate amounts of pre-wetted LWA were used [18, 19]. However, the use of a weaker LWA as self curing agent resulted in a lower compressive strength [20]. Being spherical in shape, the LECA and FAA improve rheological properties of fresh concrete mixes, and can enhance mechanical properties of the SCSCC [13, 21].
An attempt is made in this paper to determine the effect of incorporation of LECA and FAA as a partial replacement of fine aggregate in fresh and hardened concrete.

2. Materials

Grade 53 Ordinary Portland cement conforming to IS: 12269 – 1987 [22] was used for the program. Locally available river sand (RS), with a specific gravity of 2.61 conforming to grading zone III, was used as natural fine aggregate. Natural crushed coarse aggregate, 12 mm in grain size, with a specific gravity of 2.73, was used in this study. The class "F" fly ash, with a specific gravity of 2.27, as obtained from Mettur Thermal Power Plant, was used as mineral admixture. It was also used to make fly ash aggregate using the pelletisation method [23, 24]. The specific gravity of fly ash aggregate and water absorption are 1.85 and 20 %, respectively (Figure1).

Figure 1. Fly ash aggregate (FAA)

Also, the LECA with a specific gravity of 0.42 was obtained from GBC India, Ahmadabad, as a partial replacement of fine aggregate in concrete (Figure 2). The LECA aggregate exhibits the water absorption as high as 38 %. Natural crushed coarse aggregate 12 mm in maximum size, conforming to Indian Standard specifications IS: 383-1970 [25], was used in this paper. The Glenium B233 (polycarboxylate ether-based) superplasticizer was also used to obtain a achieve workability in the SCSCC.

Figure 2. Light expanded clay aggregate (LECA)

3. Mix design for self compacting self curing concrete

The SCSCC mix design was prepared as per guidelines prescribed by EFNARC [3]. Two sets of SCSCC mixes were made separately by partially replacing fine aggregate with lightweight aggregates (LWA), i.e. with the saturated LECA and FAA. These aggregates were pre-wetted for 24 hours and used in the saturated surface dried condition [SSD] while making the mixes. To enhance the stability of the SCC with the prewetted LECA, the river sand, fly ash, cement, and coarse aggregate, were mixed thoroughly in dry condition, and then the polycarboxylate ether-based superplasticizer mixed in water was added to the mix [13]. The replacement of fine aggregate was made from 0 % to 25 % by volume, at 5 % intervals. The mix without the LECA and FAA was used as control mix (CM). Mix proportions of all mixes are shown in Table 1. Mixes are marked with letters "L" and "F", standing for the LECA and FAA, respectively. The subscript designates the percent of replacement of fine aggregate by volume.

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-compactability properties. Slump flow, T_{50cm} 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 guidelines [3]. A total of 66 cubes of 150 mm for compressive strength, 66 cylinders of 150 mm x 300 mm for split tensile strength, 66 prisms of 500 mm x 100 mm x 100 mm for flexural strength, and 66 cylinders of 150 mm x 300 mm for modulus of elasticity, were cast to measure properties of hardened concrete. After 24 hours of casting, the specimens were demoulded and covered with plastic sheets to minimize moisture loss. Demoulded control mix specimens [CM_{wc}] were cured in water for 7 and 28 days. The specimens were tested for compressive strength, split tensile strength, flexural strength, and modulus of elasticity at 7 & 28 days as per IS: 516:1959 [26]. Three specimens were tested for each mix to determine various properties of hardened concrete.

5. Results and discussion

5.1. Fresh properties of self compacting self curing concrete

Properties of fresh SCSCC concrete made with LECA & FAA as partial replacement for fine aggregate are presented in Table 2. It is evident from the results that the filling ability, passing ability & segregation resistance of all mixes are in conformity with EFNARC [3]. However, U-Box test results of L_{25} and F_{25} mixes slightly exceed the desirable maximum limit.

Table 1. Mix proportion for various SCSCC mixes

Mix Composition	CM	L_5	L_{10}	L_{15}	L_{20}	L_{25}	F_5	F_{10}	F_{15}	F_{20}	F_{25}
Cement [kg/m³]	439.5						439.5				
Fly ash [kg/m³]	134.4						134.4				
Fine aggregate [kg/m³]	819.6	778.4	737.4	696.4	655.5	614.5	778.4	737.4	696.4	655.5	614.5
LECA/FAA [kg/m³]	-	12.6	25.2	37.8	50.4	63.0	29.9	59.9	89.8	119.9	149.8
Coarse aggregate [kg/m³]	774.2						774.2				
Water [kg/m³]	177.7						177.7				
Super plasticizer (% by weight of powder content)	0.7						0.7				
w/c ratio	0.31						0.31				

Table 2. Properties of fresh self compacting self curing concrete

Mix ID	Slump flow [mm]	T_{50cm} Slump flow [s]	V-funnel [s]	J-ring [mm]	U-box (h_2-h_1) [mm]	L-box h_2/h_1	Sieve stability test [%]
CM	700	3.1	9.7	6.5	29	0.81	12.51
L_5	680	3.4	9.6	6.6	31	0.94	10.50
L_{10}	697	3.2	8.5	6.1	27	0.91	9.75
L_{15}	708	2.9	7.8	5.9	26	0.88	8.75
L_{20}	702	3.1	8.1	6.2	31	0.92	7.50
L_{25}	700	3.2	8.0	6.2	35	0.95	4.25
F_5	686	3.1	9.5	6.8	31	0.93	11.15
F_{10}	699	3.2	8.4	6.4	28	0.89	10.15
F_{15}	710	2.8	7.9	6.0	27	0.86	9.55
F_{20}	705	3.3	7.9	6.3	28	0.90	8.25
F_{25}	703	3.2	8.1	6.3	33	0.96	5.75

5.2. Properties of hardened SCSCC

The hardened concrete properties such as the compressive strength, split tensile strength, flexural strength, and modulus of elasticity, were measured as per IS: 516:1959 [26] at 7 and 28 days. Statistical analyses performed for all mixes are presented in Table 3.

The compressive strength values of CM_{wc} at 7 and 28 days amount to 38 MPa and 44.1 MPa, respectively. The control concrete mix, CM_{rt}, cured at room temperature yields only 35.56 MPa and 41.25 MPa at 7 and 28 days, respectively. The reduction in compressive strength of CM_{rt} is about 6.46 % compared to the CM_{wc} mix at 28 days. It is quite obvious that, for a low w/c ratio, concrete without water curing does not have enough water for hydration and, hence, the strength of concrete is reduced [17, 27, 28].

It is evident from Figure 3.a that the early compressive strength of the LECA incorporated SCSCC concrete is significantly lower at 7 days than that of the control concrete. However, a remarkable improvement in compressive strength is registered at 28 days. The compressive strength of SCSCC improves under self curing with an increase in LECA content of up to 15 %. Beyond 15 % of LECA content, the compressive strength reduces, which is probable due to either weaker nature or very prounced water absorption characteristics of the LECA aggregate. For SCSCC with 15 % of LECA, the compressive strength under self curing is by 1.84 % higher compared to that of the control concrete. It is due to the presence of adequate moisture content in the LECA aggregate contained in the concrete. The LECA aggregate allows moisture content to move from inside to outside to complete the hydration process in concrete. The results obtained are in conformity with the results published by Maghsoudi et.al and Magda et.al [13, 14]. The compressive strength will not be affected by self curing when the required amount of pre-wetted lightweight aggregate is used in the concrete [18, 19]. However, weaker LWA as self curing agent in concrete might reduce the strength [20].

Figure 3.b shows that the trend in compressive strength for the SCSCC with FAA as self curing agent at 7 & 28 days is similar to that of the SCSCC with LECA. However, the compressive strength of the FAA incorporated SCSCC is significantly higher at 7 and 28 days compared to the SCSCC with LECA as self curing agent. Also, the compressive strength of SCSCC improves under self curing with an increase in the FAA content of up to 15 %. Nevertheless, the compressive strength reduces beyond 15 %. Unlike the LECA incorporated SCSCC, the compressive strength of SCSCC with 20 % and 25 % of FAA is higher than that of the control concrete. It is due to the fact that the water absorption of FAA is significantly lower than that of the LECA aggregate, and to the pozzolanic reaction between the cement and fly ash.

The split tensile strength (Figures 4.a and 4.b), flexural strength (Figures 5.a and 5.b), and the modulus of elasticity (Figures 6.a and 6.b) of the LECA SCSCC and FAA SCSCC are also measured and the corresponding results are presented in Table 3. It can be observed that the trends in the split tensile strength, flexural strength, and modulus of elasticity of the LECA SCSCC and FAA SCSCC are similar to those of the compressive strength.

Table 3. Properties of hardened self compacting self curing concrete

Mix ID	Age at testing	Compressive strength [MPa]			Split tensile strength [MPa]			Flexural strength [MPa]			Modulus of elasticity [GPa]		
		mean	SD	COV	mean	SD	COV	mean	SD	COV	mean	SD	COV
CM_{wc}	7	38.00	0.49	1.28	2.96	0.04	1.47	5.65	0.07	1.28	29.30	0.49	1.66
	28	44.10	0.72	1.64	3.98	0.08	2.06	6.63	0.07	0.99	34.20	0.46	1.33
CM_{rt}	7	35.56	0.61	1.72	1.85	0.03	1.43	5.04	0.04	0.79	27.00	0.38	1.41
	28	41.25	0.64	1.54	2.31	0.06	2.70	5.52	0.11	1.91	31.80	0.36	1.12
L_5	7	27.46	0.59	2.13	1.87	0.02	1.07	5.26	0.04	0.83	25.82	0.23	0.89
	28	37.79	0.41	1.09	3.37	0.09	2.59	5.77	0.11	1.83	32.20	0.35	1.10
L_{10}	7	28.33	0.59	2.10	1.91	0.01	0.52	5.39	0.05	0.85	26.00	0.59	2.26
	28	43.60	0.78	1.80	3.97	0.09	2.27	6.52	0.11	1.71	33.50	0.55	1.63
L_{15}	7	29.16	0.95	3.24	1.92	0.02	1.04	5.74	0.04	0.76	27.75	0.33	1.18
	28	44.93	0.95	2.11	4.32	0.09	1.98	7.58	0.16	2.16	34.72	0.31	0.90
L_{20}	7	26.13	0.88	3.37	1.72	0.04	2.10	5.28	0.06	1.18	26.40	0.25	0.94
	28	41.03	0.65	1.57	3.34	0.07	2.16	7.2	0.07	0.97	32.90	0.69	2.09
L_{25}	7	25.98	0.18	0.71	1.68	0.07	3.90	5.12	0.09	1.79	24.93	0.70	2.81
	28	39.30	0.63	1.61	3.14	0.03	0.84	7.15	0.04	0.56	31.7	0.46	1.45
F_5	7	28.50	0.39	1.38	1.92	0.03	1.38	5.55	0.11	1.95	25.83	1.29	4.98
	28	43.90	0.23	0.52	3.41	0.13	3.74	6.02	0.10	1.73	33.90	0.85	2.51
F_{10}	7	32.06	0.29	0.90	2.12	0.03	1.25	5.67	0.16	2.74	26.76	0.71	2.64
	28	44.26	0.80	1.80	3.65	0.07	1.80	6.65	0.22	3.31	35.21	0.62	1.77
F_{15}	7	34.40	0.27	0.78	2.89	0.05	1.83	5.83	0.10	1.79	28.22	0.32	1.13
	28	50.90	0.38	0.75	4.42	0.03	0.68	7.87	0.14	1.75	38.87	0.41	1.06
F_{20}	7	34.36	0.45	1.31	2.60	0.03	1.02	5.30	0.04	0.82	26.75	0.18	0.66
	28	50.00	0.18	0.36	3.98	0.03	0.66	7.33	0.02	0.27	38.51	0.56	1.47
F_{25}	7	33.87	0.94	2.79	2.57	0.03	1.03	5.24	0.06	1.19	25.66	0.46	1.77
	28	49.12	0.95	1.93	3.49	0.05	1.29	7.05	0.12	1.74	37.43	0.19	0.50

CM_{wc} – Control Mix with water curing; CMrt – Control Mix kept at room temperature; SD = Standard Deviation; COV = Coefficient of Variance [%]

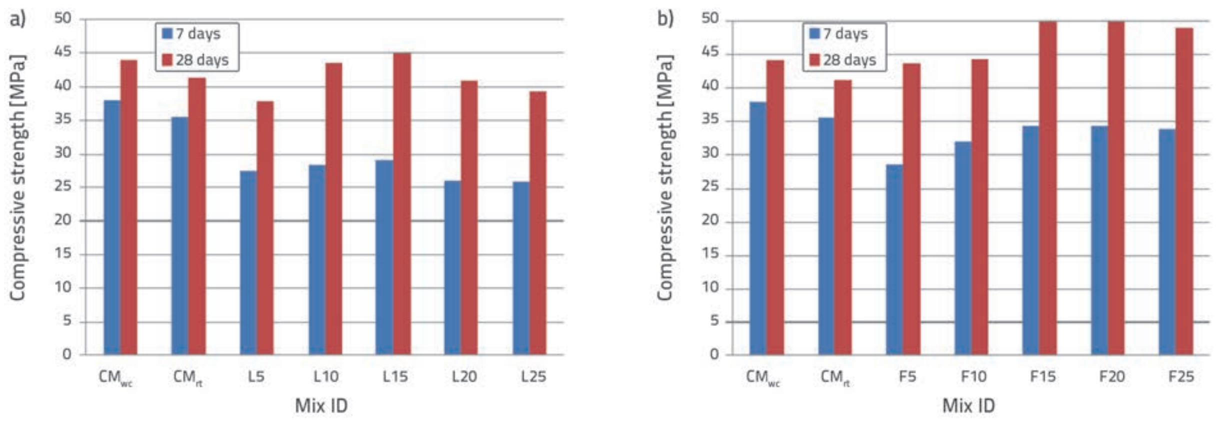

Figure 3. Compressive strength of SCSCC: a) with LECA; b) with FAA

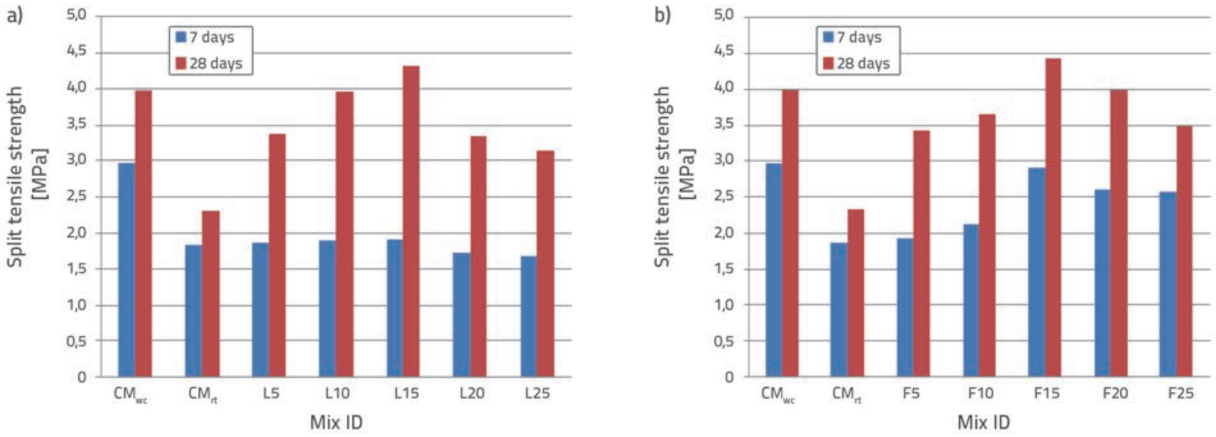

Figure 4. Split tensile strength of SCSCC: a) with LECA; b) with FAA

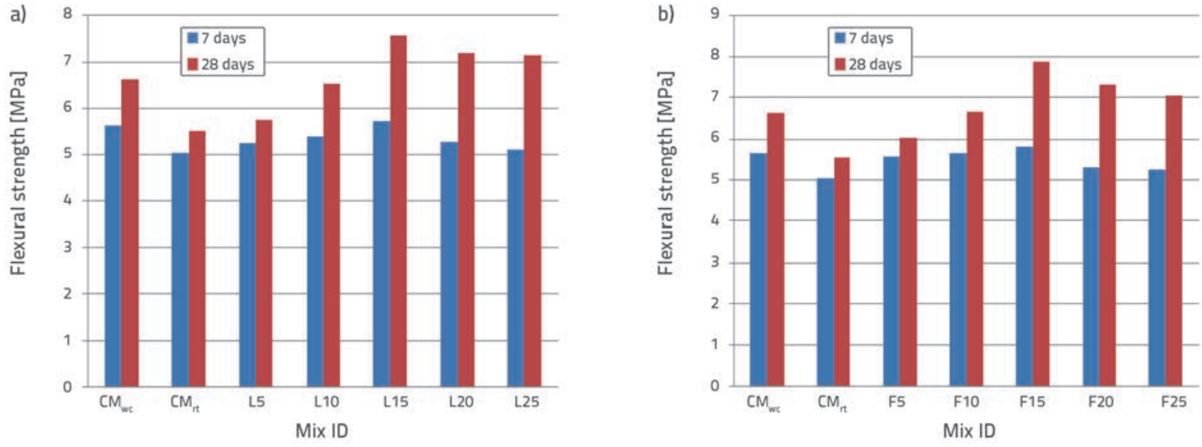

Figure 5. Flexural strength of SCSCC: a) with LECA; b) with FAA

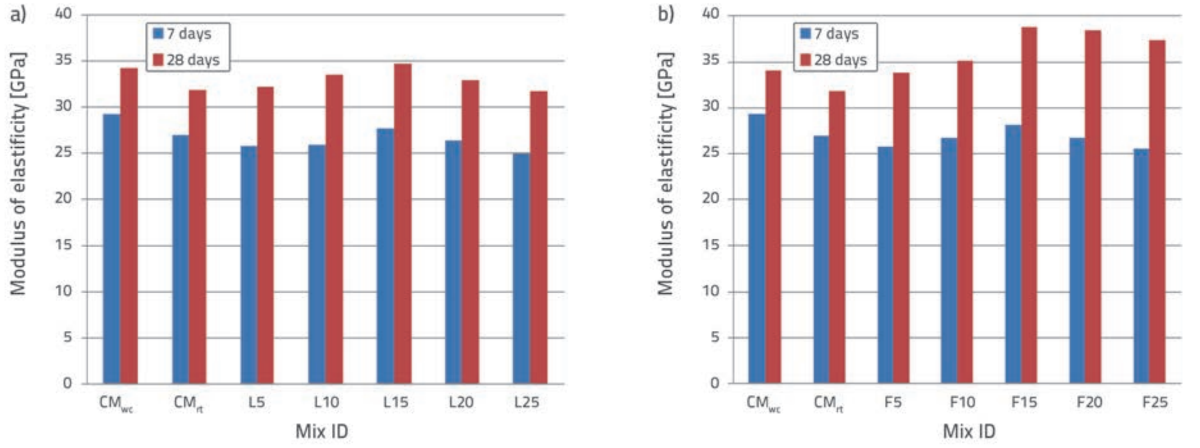

Figure 6. Modulus of elasticity of SCSCC: a) with LECA; b) with FAA

6. Conclusion

The filling ability, passing ability, and segregation resistance of all SCSCC mixes with LECA and FAA are in conformity with EFNARC standards. The spherical shape of LECA and FAA has significantly improved rheological properties of the fresh concrete mix.

The early compressive strength of the LECA and FAA incorporated SCSCC concrete is significantly lower than that of the control concrete. However, a significant improvement in compressive strength has been noted at 28 days.

For the SCSCC with 15 % of LECA, the compressive strength under self curing is by 1.84 % higher compared to that of the control concrete. If the LECA content is higher than 15 % the compressive strength reduces due to either weaker nature or very high water absorption of LECA aggregate.

The SCSCC concrete with FAA as self curing agent exhibits a significantly higher compressive strength at 7 and 28 days compared to that of the SCSCC with LECA as self curing agent. Also, the compressive strength of SCSCC with 20 % and 25 % of FAA is higher than that of the control concrete, unlike the LECA incorporated SCSCC.

The SCSCC with 15 % of LWA exhibits the maximum tensile strength, flexural strength and modulus of elasticity values.

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