



EFFECT OF HIGH VOLUME FLY ASH CONCRETE IN SELF-CURING ENGINEERED CEMENTITIOUS COMPOSITE (ECC)

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ABSTRACT

Engineered Cementitious Composites (ECC) is a special type of high performance fibre reinforced cementitious composite having uniquely high ductile and tensile properties. Reducing the usage of cement in ECC by using less energy intensive binders is a step in the attainment of sustainable development to reduce greenhouse gases. River sand is also becoming a scarce commodity and hence exploring alternatives to it has become important. This paper focuses on characterizing the mechanical properties of an Eco – friendly ECC with High Volume Fly Ash (HVFA) content, manufactured sand and Polyvinyl Alcohol (PVA) Fibre. Experiments were conducted for finding the mechanical properties of ECC by the influence of HVFA (60%, 70% & 80%) content, Self-curing Agent (Polyethylene Glycol 600) and Calcium Carbonate. The results show that the mechanical properties of HVFA-ECC having fly ash up to 70% are comparable with those of ECC without fly ash. Addition of CaCO₃ and self-curing agent contributed for the early strength development and an alternative for water curing in HVFA-ECC.

Keywords: Calcium Carbonate, Eco- Friendly, Engineered Cementitious Composite, High Volume Fly Ash, PVA fibre, Self-curing agent, M sand

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1. INTRODUCTION

Despite cement concrete is being a widely used construction material with high compressive strength, the presence of coarse aggregate such as gravel or crushed stones makes it brittle with low tensile strength. An approach was made on Engineered Cementitious Composite (ECC), for the creation of synergistic interaction between fibers, matrix and interface, for maximizing

the tensile ductility by the development of closely spaced multiple microcracks while minimizing the fiber content (Li, V.C., 2008) [1]. Considerable increase in load carrying capacity and ductility could be achieved in concrete beams containing ECC with polyvinyl alcohol fibre than with polypropylene fibre (Ismail et al., 2018; Shanour et al., 2018) [2], [3]. The compressive strength and flexural strength of ECC increased with the addition of 1 - 2% PVA fibre content (Joseph et al., 2017) [4]. ECC beams with PVA fibres could sustain significantly greater shear forces than conventional concrete (Kang et al. 2017) [5]. The crack width and deflection at the serviceability limit state of ECC beams were much smaller than those of RC beams (Meng et al., 2017) [6]. Self-compacting and strain hardening ECC could be developed by adding Fly Ash (Lin et al., 2017) [7] and Nano silica (Mohammed et al., 2017) [8]. High volume fly ash concrete showed delayed setting time and increased temperature sensitivity. This could be effectively moderated by the replacement of a portion of fly ash with Calcium Carbonate (CaCO_3) powder (Dale, 2014) [9]. CaCO_3 is a natural material, which has a finer particle size compared to cement. Replacement of 10% cement by CaCO_3 improves particle packing of concrete which increases workability. CaCO_3 helps increase in the early strength, arising as a result of the accelerator effect and high rate of hydration which harden the concrete quicker (Ali et al., 2015) [10]. Curing process protects the loss of moisture required for hydration, increases the strength and decreases the permeability of hardened concrete. But, curing is not always feasible, and the addition of Polyethylene glycol (PEG) acts as an internal curing agent. It traps the moisture within the structure and prevents it from evaporation (Thiru Chelvi et al., 2017) [11]. Literature on the behaviour of HVFA-ECC with manufactured sand, self-curing agent and CaCO_3 is not available. Hence, in this study, experiments were conducted to find the mechanical properties ECC with HVFA (60%, 70% & 80%) content, M sand, self-curing agent (Polyethylene Glycol 600) and calcium carbonate.

2. EXPERIMENTAL PROGRAM

2.1. Materials

Engineered Cementitious Composite (ECC) was incorporated with fine manufactured sand with maximum grain size of 300 μm and a mean size of 110 μm for the various mixtures. Sand to binder ratio (S/B) was kept 0.6 and water to binder (w/b) ratio was kept in between 0.35 to 0.44 in order to attain a good balance between fresh and hardened properties (Jia et al., 2017) [12]. The binder system is defined as the total amount of cementitious material, i.e. cement and fly ash (Type C) in ECC. For locating the improvement in the early strength of ECC with 50% fly ash as replacement to cement, 10% CaCO_3 was added to the cementitious composite (Wongkeo, 2017) [13]. 1% PVA fibre was used in the ECC (Pan et al., 2015) [14]. Properties of PVA fibres are shown Table 1.

Table 1 Properties of PVA fibers

Fibre	Density	Initial modulus	Specification	Oil agent content
PVA	1.29	280 cN/dtex	12 mm	0.2%

A high range water reducing admixture with a chemical composition containing polycarboxylate was found to be the most effective in maintaining the desired fresh property of ECC during mixing and placing (Pan et al., 2015). High Range Water Reducer (HRWR) used in the study was CONXL PCE RHEOPLUS 2635 with a solid content of 40 ± 2 and a specific gravity of 1.09.

2.2. Specimen Preparation

The mix proportions of ECC are shown in Table 2. Nine HVFA - ECC mixes were proportioned by using three variables: fly ash (60%, 70% and 80%) by mass of total cementitious materials, PEG 600 as a self-curing compound and Calcium Carbonate as the early strength contributor. For the purpose of comparative study, plain mortar mixture with and without fibres were produced. The ECC mixtures are referred to as ECC-%, ECC-%P or ECC-%PC, where ‘%’ is the percentage of fly ash content, ‘P’ is the ECC mix with PEG 600 and ‘PC’ is the ECC mix having PEG 600 and CaCO₃.

All the solid components without fibres were first placed in to the Pan mixer and dry mixed for 5 minutes. Then water with dissolved HRWR was gradually added and mixed for 10-15 min. After attaining minimum slump flow value, the PVA fibers were added to the mixture without any lumps while the mixer was running. Mix 1, 2, 3, 6 and 9 were water cured and Mix 4, 5, 7, 8, 10 and 11 were air cured as self-curing component was added to it.

Table 2 Mix Proportion of ECC

Mix	Description	Cement to Binder (B)	Fly Ash to B	Msand to B	Water to B	HRWR to B	Fiber to B	PEG to B	CaCO ₃ to B
1	CM	1	0	0.6	0.35	0.005	0	0	0
2	ECC-0	1	0	0.6	0.35	0.005	0.01	0	0
3	ECC-60	0.4	0.6	0.6	0.37	0.005	0.01	0	0
4	ECC-60P	0.4	0.6	0.6	0.37	0.005	0.01	0.02	0
5	ECC-60PC	0.4	0.6	0.6	0.37	0.005	0.01	0.02	0.1
6	ECC-70	0.3	0.7	0.6	0.4	0.005	0.01	0	0
7	ECC-70P	0.3	0.7	0.6	0.4	0.005	0.01	0.02	0
8	ECC-70PC	0.3	0.7	0.6	0.4	0.005	0.01	0.02	0.1
9	ECC-80	0.2	0.8	0.6	0.44	0.005	0.01	0	0
10	ECC-80P	0.2	0.8	0.6	0.44	0.005	0.01	0.02	0
11	ECC-80PC	0.2	0.8	0.6	0.44	0.005	0.01	0.02	0.1

2.3. Rheological Tests

2.3.1. Mini – Slump Flow Test

Mini Slump flow test is a method of measuring the workability of ECC mortar without any fibre. Mini slump cone is 30 mm high and its spread flow is shown in fig 1 (a). The spread values are the approximate diameter of the circle formed during slump flow.

2.3.2. Standard Slump Flow Test

Workability test of the final mix was done on a 300mm height slump cone for indicating the flowability of Fresh mixtures. The typical standard slump flow test is shown in fig 1 (b) according to ASTM C1611.

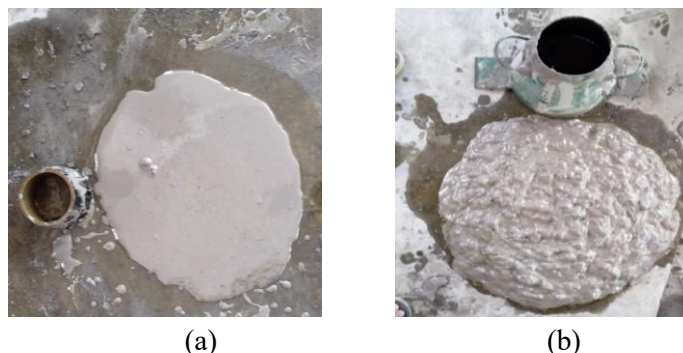


Figure 1 Slump without fibre (a) and Slump with fibre (b)

2.4. Experimental Investigation

2.4.1. Compressive Strength Test

The compressive strength values of the hardened concrete of ten different mixes along with conventional mortar were cast in 50 mm cube. Three cubes were tested accordingly at the end of the 7th and 28th days for each mixture. The test was done using a universal testing machine for obtaining the ultimate load carrying capacity of the cube and the average values were taken as the compressive strength of the specimen. Similarly, cylinder specimens with a diameter of 100mm and a height of 200mm were also tested on a universal testing machine for determining split tensile strength.

2.4.2. Direct tensile Strength Test

Direct tensile strength was done on a dog bone shaped specimen as shown in fig 2(a). use of SHIMADZU (100kN) universal testing machine as shown in fig 2 (b) as per ASTM C1273. The specimens were tested at the displacement rate of 0.1 mm/min until the failure of the specimen. Three Dog-bone shaped specimens of each mixture were prepared for direct tensile testing as shown in fig. 2 (a). On 28th day the direct tensile testing was conducted using SHIMADZU (100 KN) universal testing machine as shown in fig. 2 (b) and average values were taken. By using displacement control, the loading rate was kept as 0.1mm/min until the specimen gets failed.

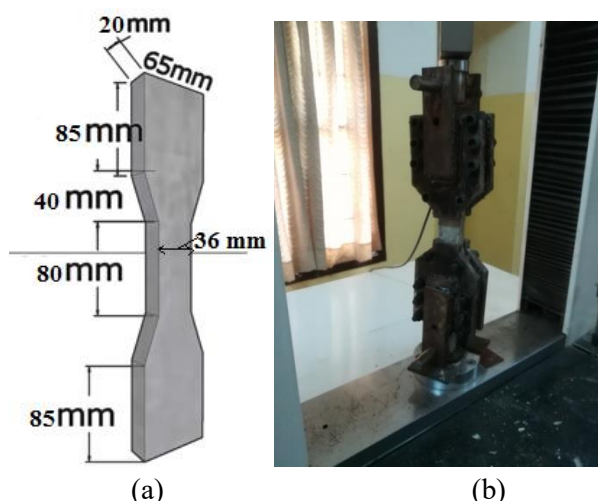


Figure 2 Dog-Bone shape specimen (a), Direct tensile testing (b)

2.4.3. Flexural Strength Test

Flexural strength test was done on a short span beam of 500mm and a cross section of 100mm square. Three specimens were cast for each mixture and tested as single point loading at the centre with the setup of a simply supported beam was conducted. The average value was taken as the ultimate load.

3. RESULTS AND DISCUSSION

3.1. Workability

All the mixtures were designed to have mini slump spread value ranging from 270mm to 300mm and standard slump spread value ranging from 450mm to 540mm as shown in Table 3. The increase in fly ash content was found decreasing decreased the slump value of ECC mix and required a large water content.

Table 3 Slump Test Values

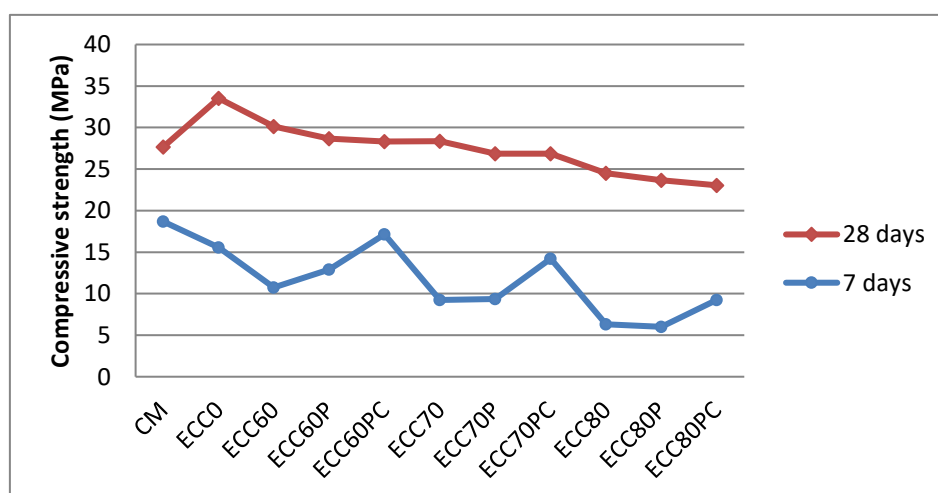
Mix Description	Slump without PVA fibre (dia)	Slump with PVA fibre (dia)
CM	270mm	470 mm
ECC-0	280 mm	450 mm
ECC-60	270 mm	480 mm
ECC-60P	290 mm	500 mm
ECC-60PC	280 mm	480 mm
ECC-70	250 mm	520 mm
ECC-70P	280 mm	540 mm
ECC-70PC	260 mm	530 mm
ECC-80	260 mm	500 mm
ECC-80P	300 mm	530 mm
ECC-80PC	280 mm	510mm

3.2. Compressive Strength Test

The compressive strength of the different mixtures is shown in Table 4. Compressive strength of ECC without fly ash was seen as 21% more than the Conventional mortar. The compressive strength of water cured ECC with 60%, 70% and 80% of fly ash content is 10%, 15% and 27% respectively less than ECC without fly ash at 28 days. Only 5% reduction in compressive strength was noticed when self-curing agent was added in HVFA-ECC instead of water curing. An increase of 50% early strength was attained in the HVFA-ECC by the addition of CaCO_3 , but it was not contributing to the increase in strength development at 28 days. The comparison of compressive strength of different mixtures is shown in fig. 3.

Table 4 Compressive strength test results

Mix Description	7 days testing (MPa)	28 days testing (MPa)
CM	18.68	27.67
ECC-0	15.56	33.52
ECC-60	10.76	30.12
ECC-60P	12.92	28.65
ECC-60PC	17.16	28.32
ECC-70	9.24	28.36
ECC-70P	9.36	26.86
ECC-70PC	14.20	26.85
ECC-80	6.32	24.52
ECC-80P	6.01	23.65
ECC-80PC	9.24	23.05

**Figure 3** Compressive Strength of HVFA-ECC

3.3. Split Tensile Strength

Details of the Split tensile strength of various ECC mix are shown in table 5. Split tensile strength of ECC without fly ash was 20% more than the conventional mortar. The split tensile strength of water cured ECC with 60%, 70% and 80% were 10%, 18% and 23% respectively less than ECC without fly ash at 28 days. Only 2% reduction in split tensile strength was noticed when the HVFA-ECC mixtures were added with self-curing agent. Addition of CaCO₃ increased only the early split strength of ECC with 60%, 70% and 80% of fly ash by 16%, 9% and 3% respectively. The comparison of Split tensile strength of different mixtures is shown in fig. 4.

Comparison of Split tensile strength of different mixtures is shown in fig. 4.

Table 5 Split tensile strength test result

Mix Description	7 days testing (MPa)	28 days testing (MPa)
CM	3.1036	3.903
ECC-0	3.903	4.684
ECC-60	3.284	4.208
ECC-60P	3.308	4.192
ECC-60PC	3.840	4.124
ECC-70	3.191	3.825
ECC-70P	3.147	3.725
ECC-70PC	3.485	3.704
ECC-80	3.012	3.586
ECC-80P	2.890	3.521
ECC-80PC	3.12	3.450

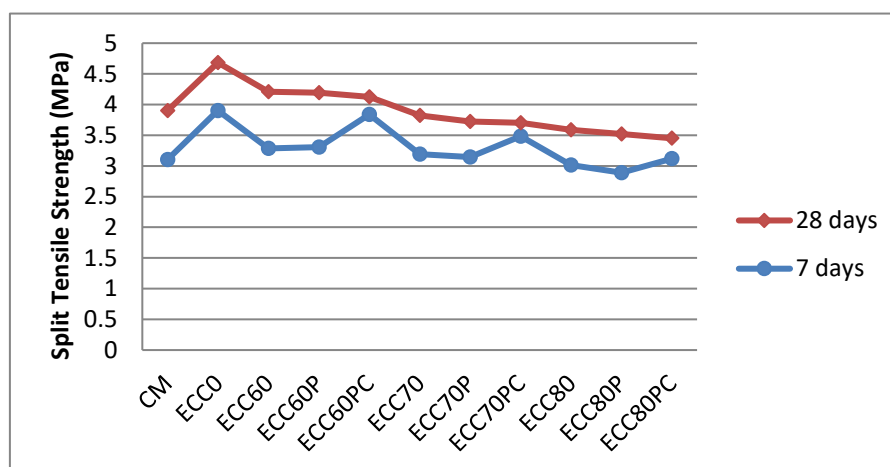


Figure 4 Split Tensile Strength of HVFA-ECC

3.4. Direct Tensile Strength Test

The Direct tensile test results of the Dog bone shaped specimens are shown in Table 6. During the loading process, propagation of cracks caused fluctuations in the stress strain curves of ECC with and without fly ash. The initial and ultimate strength for conventional mortar was 3.53 Mpa, but for ECC without fly ash, the initial crack strength was 4.4 MPa and ultimate tensile strength was 4.8 MPa. The ultimate tensile strength of water cured ECC with 60%, 70% and 80% was 4%, 7% and 9% respectively less than ECC without fly ash. Only 3% reduction in direct tensile strength was noticed in HVFA-ECC specimens with self-curing compound. An average of 3% reduction was seen in HVFA-ECC specimens with self-curing were added to

CaCO₃. The ultimate tensile strain of ECC was 6 times higher than the conventional mortar. The tensile strain of water cured ECC with 60%, 70% and 80% is 3%, 8% and 10% was less than that of ECC without fly ash. An average of 14% reduction in the ultimate tensile strain was noticed on HVFA-ECC than on water cured HVFA-ECC. The use of CaCO₃ in HVFA-ECC decreases the ultimate tensile strain by 24%. The Direct tensile stress-strain curve of HVFA-ECC Dog-bone shaped specimens tested at 28 days is shown in fig. 5.

Days is shown in fig. 5.

Table 6 Direct Tensile Test results

Mix Description	Mix	Tensile Stress (MPa)		Tensile Strain (%)
		Initial Crack	Ultimate	Ultimate
CM	1	3.53	3.53	0.2
ECC-0	2	4.4	4.7965	1.215
ECC-60	3	4.22	4.5	1.175
ECC-60P	4	4.1	4.3	0.965
ECC-60PC	5	3.9	4.26	0.84
ECC-70	6	4.1	4.28	1.115
ECC-70P	7	4.05	4.15	0.97
ECC-70PC	8	3.9	4.072	0.94
ECC-80	9	4.01	4.1	1.095
ECC-80P	10	3.9	3.98	0.97
ECC-80PC	11	3.78	3.84	0.795

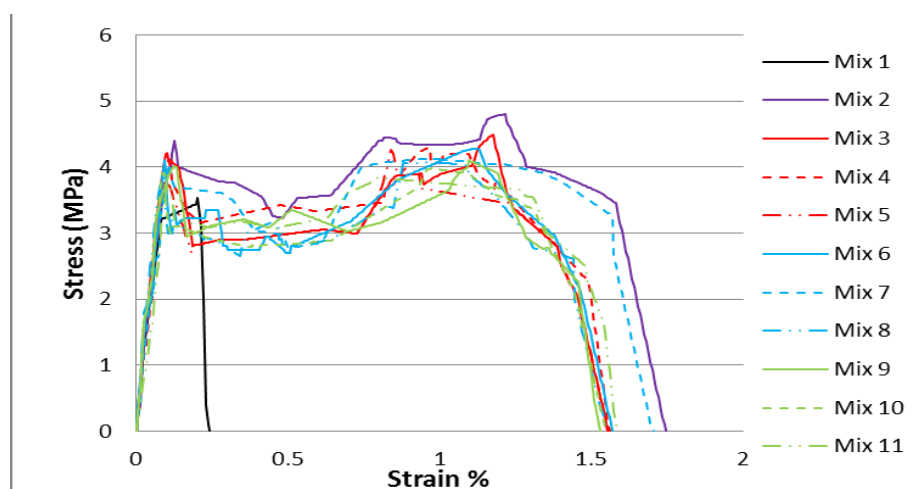


Figure 5 Direct tensile strength test

3.5. Flexural Strength

Details of flexural strength of ECC mixtures are shown in Table 7. Flexural strength of ECC without fly ash was 120% more than the Conventional mortar. The flexural strength of water cured ECC with 60%, 70% and 80% of fly ash was 20%, 30% and 39% respectively less than ECC without fly ash at 28 days. Only 1.5% reduction in flexural strength was noticed when the HVFA-ECC specimens were cured with the addition of self-curing agent. An average of 3% increase in early flexural strength was attained in the HVFA-ECC by the addition of CaCO₃, but it was not contributing for 28 days strength development. A comparison of flexural strength of different mixtures is shown in fig. 6.

Table 7 Flexural Strength results

Mix Description	7 days (Mpa)	28 days (MPa)
CM	3.2	3.75
ECC-0	6.9	8.5
ECC-60	4.8	6.8
ECC-60P	4.68	6.75
ECC-60PC	5.3	6.62
ECC-70	5.01	5.96
ECC-70P	4.86	5.82
ECC-70PC	5.42	5.78
ECC-80	3.92	5.2
ECC-80P	3.88	5.18
ECC-80PC	4.25	5.1

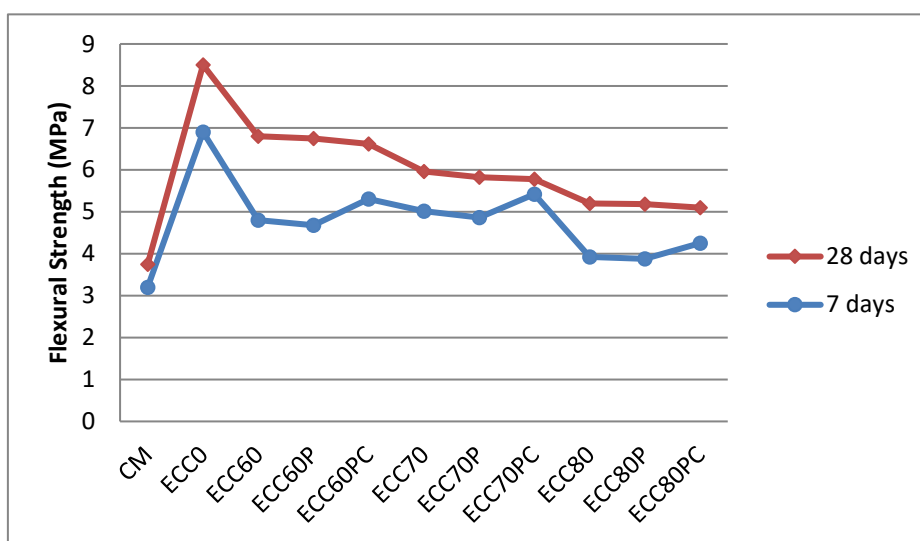


Figure 6 Flexural Strength of HVFA-ECC

4. CONCLUSION

In this paper, an experimental investigation was carried out to find the mechanical properties of ECC by the influence of HVFA (60%, 70% & 80%) content, Self-curing Agent (Polyethylene Glycol 600) and Calcium Carbonate and the following conclusions are drawn.

- HVFA-ECC having fly ash replacement up to 70% showed high compressive strength with slight strength loss compared to ECC without fly ash. Only marginal strength loss was noticed in HVFA-ECC with self-curing agent than with water cured HVFA-ECC. Addition of CaCO₃ improved only the early compressive strength.
- There is a marginal reduction in the direct tensile strength of HVFA-ECC than that of ECC without fly ash and exhibited strain hardening. Only 3% reduction in direct tensile strength was noticed in HVFA-ECC with self-curing compound than with water cured HVFA-ECC.
- The flexural strength of HVFA-ECC is also comparable with that of ECC without fly ash.

Thus the use of high volume fly ash in ECC not only enhances the mechanical properties but also leads to sustainability. Also self-curing agent could be an alternative solution for water curing.

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