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Original Research Paper

Industrial and Environmental Application of High Volume Fly Ash in Concrete Production

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ABSTRACT

A large number of structural properties of plain concrete are improved with addition of admixtures to concrete. It is well known that the addition of fly ash to plain concrete improves workability, strength, durability, less permeable and more stable. In conventional concrete the flexural strength reaches a maximum value between 14 and 28 days. In high volume fly ash (HVFA) concrete the strength keeps on increasing with age because of pozzolanic reaction of fly ash and strengthening of the interfacial bond between cement paste and aggregate. The use of fly ash as a partial replacement for Portland cement will usually reduce water demand and bleeding of HVFA concrete ranges from negligible to very low. Only few research works have been carried out earlier on flexural study on R C conventional beams without fly ash. Therefore in this investigation an attempt has been made to study any likely improvement on the effect of fly ash on the properties of HVFA concrete in R C beam elements with confinement of stirrups in compression zone. It has been suggested that the effective use of fly ash minimizes the disposal of fly ash, which also solves an environmental problem. This HVFA concrete is easy to pump, consolidate and finish the surface, free from cracks, reduces carbon-dioxide emissions, superior environmental friendliness, reduction in stone mining since it consumes less volume of Portland cement. The methodology adopted above improves ductility and improves the rotation capacity of the joints of framed structure, thus, improving the ultimate load carrying capacity. An attempt is also made to compare the load versus deflection of the HVFA concrete beams with conventional RCC beams and evaluated the performances of the proposed method of confinement. The results indicated that the confinement in the form of stirrups improves the ultimate strength and ductile behaviour of the concrete (IS 3812-1981). An attempt has been made in the present paper to highlight the utilization of fly ash in construction.

INTRODUCTION

Each year more than 100 million tons of fly ash is being generated annually in India with 65000 acres land being occupied by ash ponds. Globally, the level of utilization of fly ash was estimated to be less than 25%. By 2015, disposal of coal ash would require almost one square metre of land per person. The use of fly ash in cement and concrete production is less than 15%, and with a view to increase its utilization further in concrete industry, concretes were developed using high volume fly ash (Mehta 2004, Reiner & Kevins 2006, Malhotra & Mehta 2002, Malhotra 1999, Philip 2006, Wilbert et al. 1989). Fly ash disposal is a major issue in many countries. It requires a huge disposal area and creates environmental problems and water pollution. To overcome this issue, fly ash as a safe construction material can be utilized in construction. This will result in a considerable saving of cement, lower cost of production and increase the knowledge of performance of such materials. Concrete is typically the most massive individual material element in the built environment (Bhanumathidas & Kalidas 2003). Fly ash is used to improve the workability of fresh concrete, to reduce the hydration, to improve economy, to decrease permeability and alkali aggregate reaction and to increase durability and strength of concrete. According to generally accepted definition, HVFA concrete is constituted by a minimum of 50% fly ash, a low water content (130 kg/m^3), less than 200 kg/m^3 cement content and a low water-cement ratio (0.4) (IS 516-1959) (BIS 1991). The fresh concrete mixtures containing HVFA are very easy to pump, consolidate, free from honey combs and cracks, gain in strength, impermeability and durability. For many reasons the concrete construction industry is not sustainable as it consumes huge amount of Portland cement, natural source materials and structures suffer from lack of durability. HVFA concrete mixtures are sustainable because they consume less Portland cement, large volumes of an industrial waste and produce a highly durable product (Ravina & Mehta 1986).

The use of confinement to enhance the ductility and the strength of concrete is widely accepted, and when the compression zone is confined with closed stirrups which did not extend down the full depth of the beam and resulting in diagonal failure has been prevented in the beams (Dhir et al.

1988). Use of fly ash creates significant benefits for our environment. Fly ash use conserves natural resources and avoids landfill disposal of ash products. By making concrete more durable, life cycle costs of roads and structures are reduced. Furthermore, fly ash use partially displaces production of other concrete ingredients, resulting in significant energy savings and reduction in green house emissions.

MATERIALS AND METHODS

Ordinary Portland cement 53 grade confirming to (IS 12269 -1987) (BIS 1987) was used in this investigation. The fine aggregate (sand) confirming to zone II of IS 383-1970 (BIS 1970) and crushed stone of 20mm size were used for making concrete. Potable water was used for mixing concrete and curing of cast specimens. The fly ash (IS 3812-1981) (BIS 1981) of class 'F' used was obtained from Mettur thermal power station to cast and test the cube and beam specimens. The reinforcement consisted of main bars 10mm dia RTS, and 8mm 2 legged vertical stirrups were used for beam specimens.

Concrete grade M25 was proportioned by adopting I.S. method of mix designing with water cement ratio of 0.4 (BIS 2009). The mixing of cement and aggregate was done manually. Weigh batching was used and compaction was achieved using poking rods. The cement and fly ash were thoroughly mixed in the dry state in a large size tray and poured over the fine aggregate. This mixer was thoroughly mixed and gently poured over the coarse aggregate and mixed again. Measured quantity of water was then added to the dry mixture. The entire mixing (IS 10262:2009) (BIS 2009) was carried in a large size tray. Slump test was conducted and the results are given in Table 1.

For the experimental work casting of concrete cubes of 150mm × 150mm × 150mm size in the pre oiled mould was used. The test specimens were divided into three groups. Each group consisted of partial replacement of cement by fly ash at 0, 50 and 55 % at 7, 14 and 28 days curing period. Such that 9 numbers of plain concrete and 72 numbers of HVFA concrete cubes were casted. Cylinder specimens were also casted for 28 days curing period. Super plasticizer SP 430 of 0, 1, 1.5 and 2% was added during casting the above specimens. All the specimens were demoulded after 24 hours and cured in water.

The specimens were dried in air for one day before testing. The results of compression strength of cubes, splitting tensile strength **(f_{sp})** and flexural strength (f_t) of HVFAC specimens (IS 516-1959) (BIS 1991) are summarized and given in Table 2. The results are comparable with conventional concrete which further indicates the suitability for 50% fly ash partial replacement for cement with 1.5% dosage of plasticizer, which gives the maximum compressive, splitting tensile and flexural strength to concrete.

Table 1: Test results of fresh concrete 50% and 55% replacement of fly ash.

Grade of Concrete	% of Plasticizer	Slump Value (mm) 50%	Slump Value (mm) 55%
M25	0.0	30	26
M25	1.0	33	29
M25	1.5	37	34
M25	2.0	41	38

Table 2: Test results of hardened concrete.

Cube ID	% of Fly ash Replaced	Dosage of Plasticizer	Compressive Strength (MPa)			f_{sp} (MPa)	f_t (MPa)
			7 Days	14 Days	28 Days	28 Days	28 Days
A0	50	0	11.05	13.71	17.83	2.70	1.85
B0	55	0	11.64	14.67	16.45	2.65	1.81
C0	0	0	17.50	19.56	25.38	2.80	1.91
A1	50	1	13.46	15.70	22.44	2.51	1.69
B1	55	1	10.43	12.16	17.38	2.24	1.51
A1.5	50	1.5	14.53	17.95	24.22	3.12	1.99
B1.5	55	1.5	10.66	12.00	16.88	2.98	1.82
A2	50	2	11.85	13.95	19.85	3.28	2.36
B2	55	2	09.89	11.53	16.48	3.05	2.52

For casting the beam specimens, steel moulds of internal dimensions 100 mm × 150mm × 1500mm were used. For easy removal of mould oil was smeared on the inner sides of the mould. Six of 10mm dia RTS bars were used as longitudinal reinforcement out of which two each at top and bottom and another two were provided at the middle to hold the confined hoops at 'd/2' depth.

For profile-1(P1) 8mm dia 2-legged stirrups at a spacing of 0.75 d was used at full depth. According to confinement same stirrups were provided with hoops alternatively at half of 0.75d spacing for profile-2 (P2) and 0.75d spacing for profile-3 (P3) respectively. The reinforcement after fabrication was placed in the mould and plain cement concrete was placed layer after layer up to the bottom of the confining hoops and carefully compacted by poking rods uniformly to avoid honeycombing. The specimens were removed after 24 hours and cured in water tanks and dried in air for one day before testing.

From the above test results it has been observed that the optimum strength was obtained by adding 50% replacement of cement by fly ash and 1.5 % of plasticizer mix. Accordingly 18 numbers of RC beams were casted for the above profiles out of which 9 beams were confined closely spaced rectangular hoops by holding 2 main bars at middle. Fig. 1 shows the details of the beam cross section without confine-

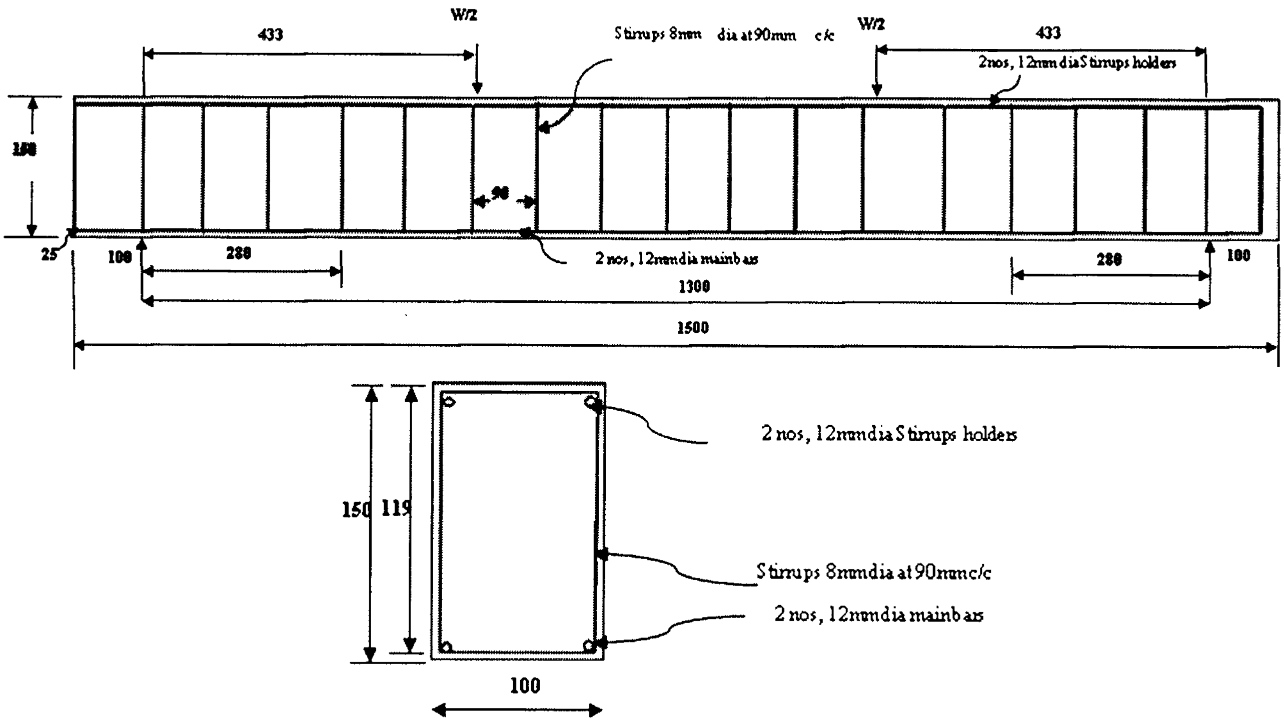
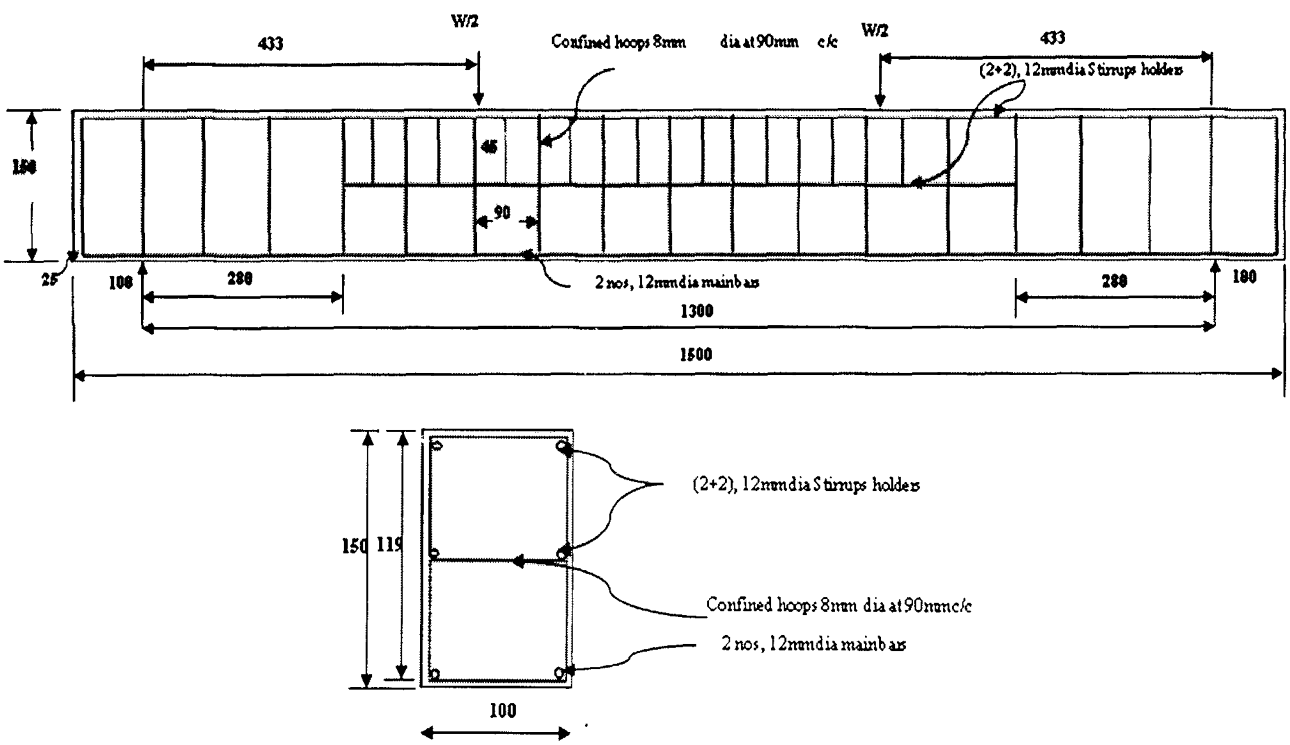


Fig. 1: Sectional details of non confinement of RC beam (profile-1, spacing, s = 0.75d).



Cross Section At Mid Span (Profile-2)

Fig. 2: Sectional details of confinement of RC beam (profile-2, spacing, s = 0.75d/2).

ment as profile 1, and Fig. 2 shows the details of the beam in compression zone as profile 2.

Testing and Behaviour of Beam Specimens

A 100 ton capacity reaction frame mounted over strong floor was used to test the beams. The beams were simply supported over an effectively span of 1.3 meter. Two point loads were applied at one fourth distances from each support. The load was applied gradually and in increments. The test was continued until the load dropped about 80% of ultimate load for both confined and unconfined concrete specimens. All the beams were tested till it reaches their full flexural capacity.

The behaviour of the beam was keenly observed from the beginning to till collapse. The dial gauges with a least count of 0.01mm having a travel of 50mm was used to record the vertical deflection at the bottom of the beam.

Large deflections are observed in confined beams which indicate the ductile behaviour of beams. The confined beam failure took place either due to crushing or shear failure in compression zone and failed with sufficient warning before collapse.

The introduction of stirrups resisted load considerably even at the maximum load. It has been observed that hairline cracks developed in the lower part of beam and as loading continues, cracks widened and extended upwards towards neutral axis. At this stage shear cracks were noticed.

In all the beams when the load increases, cracks appeared in the flexural span. Further increase of load caused additional cracks on either side of the crack which occurred in the initial stages. The cracks have been propagate and at this stage some shear cracks also developed. In case of confined beams, the failure took place either due to crushing of concrete in compression zone or shear compression failure.

These beams were failed all of a sudden as and when peak load is reached. In case of confined RC beams it has been noticed that the formation of cracks are also similar to unconfined beams; these beams resisted the load considerably even during post peak load. Also large deflections were observed which indicate the ductile behaviour of these beams.

RESULTS AND DISCUSSION

The results of the study are given in Tables 1-3 and Figs. 3-8. The load was increased gradually in the initial stages up to 80% of the peak load and then increased at slower rate until the peak load was reached such that the beam was just at the verge of collapse. In the case of specimen with confined stirrups it was observed that the lateral expansion was small at the beginning stages of loading, when axial stress is increased further, the specimen began to crush and lateral expansion increased rapidly. As the confined stress was very large it was observed that vertical cracks appeared on the surface at this stage. As the load on the specimen increased, the number of cracks also increased and started widening. At about 90% of the peak load, spalling of concrete was noticed and it was severe after the crossing of peak load. In general, the values of ultimate load were found to increase as the confinement increases.

From the test results shown in Table 2, it has been observed that the compressive strength of 55% fly ash concrete cubes at 28 days is decreased in strength to about 50% than ordinary concrete. Further observations reveal that rate of development of compressing strength at the age of 7 and 14 days is not high for fly ash based concrete. This may be due to slower pozzolanic reaction of fly ash at early ages. However, at the age of 28 days the increase in pozzolanic activity of fly ash was sufficient to contribute to the compressive strength.

From the test results shown in Table 3, it is observed that the flexural strength and deflections of the specimens confined with stirrups at 90mm C/C with 50% fly ash replacement of cement (profile-2) was almost same while comparing the test results of the specimens made in conventional concrete without fly ash at 90mm C/C stirrups (profile1). Specimens confined with stirrups show a higher increase in confined strength than unconfined specimens. It has been observed that the strength and ductility of the confined concrete specimen increase as the lateral confinement increases. These beams resisted the load considerably even during the post peak load.

CONCLUSION

It has been observed that workability of concrete decreases as the percentage of fly ash increases for the same water cementitious materials ratio (0.4). It has been concluded that the 50% fly ash replacement of cement and 1.5% super plasticizer added to the HVFA concrete achieved better compressive strength, split tensile strength and flexure strength compared to other categories. 50% fly ash replacement of cement and 1.5% super plasticizer added to the concrete designed for the same 28 days compressive strength of OPC lags behind OPC based concrete in compressive strength up to the age of 14 days. The strength values were almost similar at the age of 28 days. The flexural strength of profile-2 beam by 50% fly ash replacement of cement and 1.5% super plasticizer added to the concrete was found to be higher than ordinary Portland cement concrete beam of profile-1.

Large deflections were observed in profile-2 beams which indicate the ductile behaviour and the confinement improves both the strength and deformation characteristics of concrete.

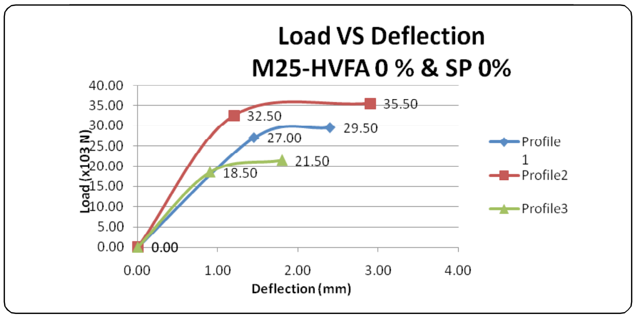


Fig. 3: Load vs. deflection curve-opcc.

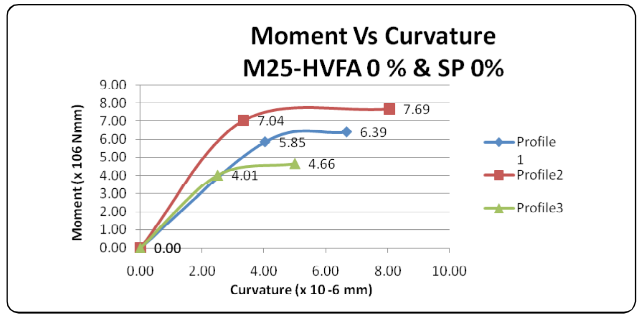


Fig. 6: Moment vs. curvature-opcc.

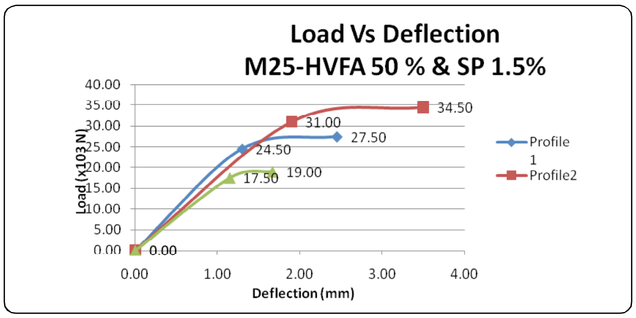


Fig. 4: Load vs. deflection curve-50% fly ash and 1.5 % sp.

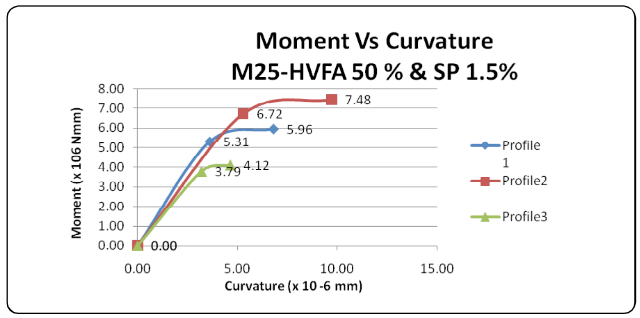


Fig. 7: Moment vs. curvature-50% fly ash and 1.5% sp.

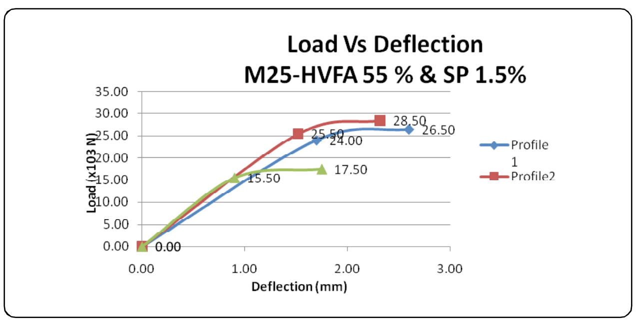


Fig. 5: Load vs. deflection curve-55% fly ash and 1.5%sp.

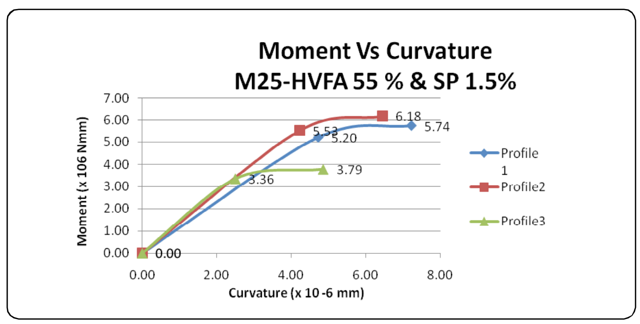


Fig. 8: Moment vs. curvature-55% fly ash and 1.5% sp.

Table 3: Test results of M25 grade beams.

Fly ash	Load-KN		Deflection-mm		Curvature-mm 1/R = M/ EI		Moment-KNmm M = Wl/6		Flexural Rigidity-KNmm²	
Profile	Yield	Ultimate	Yield	Ultimate	Yield	Ultimate	Yield	Ultimate	Yield	Ultimate
OPCC-P1	27.00	29.50	1.45	2.40	4.03	6.67	5 .85	6.39	1.45	0.96
OPCC-P2	32.50	35.50	1.20	2.90	3.33	8.06	7.04	7.69	2.11	0.95
OPCC-P3	18.50	21.50	0.90	1.80	2.50	5.00	4.01	4.66	1.60	0.93
50%-P1	24.50	27.50	1.30	2.45	3.61	6.81	5.31	5.96	1.47	0.88
50%-P2	31.00	34.50	1.90	3.50	5.28	9.72	6.72	7.48	1.27	0.77
50%-P3	17.50	19.00	1.15	1.67	3.20	4.64	3.79	4.12	1.19	0.89
55%-P1	24.00	26.50	1.70	2.60	4.72	7.22	5.20	5.74	1.10	0.79
55%-P2	25.50	28.50	1.52	2.32	4.22	6.45	5.53	6.18	1.31	0.96
55%-P3	15.50	17.50	0.90	1.75	2.50	4.86	3.36	3.79	1.34	0.78

Usage of fly ash could prevent millions of tons of the waste product from reaching landfills in addition to reducing global CO_2 emissions. Besides, usage of HVFAC is very effective in developing earthquake resistant structures which is need of the hour.

HVFAC mixtures are sustainable because they consume less Portland cement, large volume of an individual waste and produce a highly durable product. The HVFAC offers a solution to the problem of meeting the increasing demands for concrete in the future in a sustainable manner and a reduced cost and at the same time reducing the environmental impact.

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