Impact of Micro Silica on the properties of High Volume Fly Ash Concrete (HVFA)

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Abstract. In the current situation, to overcome the difficulties of feasible construction, concrete made with various mixtures of Ordinary Portland Cement (OPC) and diverse mineral admixtures, is the wise choice for engineering construction. Mineral admixtures viz. Ground Granulated Blast Furnace Slag (GGBS), Meta kaolin (MK), Fly Ash (FA) and Silica Fume (SF) etc. are used as Supplementary Cementitious Materials (SCM) in binary and ternary blend cement system to enhance the mechanical and durability properties. Investigation on the effect of different replacement levels of OPC in M25 grade with FA + SF in ternary cement blend on the strength characteristics and beam behavior was studied. The OPC was partially replaced (by weight) with different combinations of SF (5%, 10%, 15%, 20% and 25%) and FA as 50% (High Volume Fly Ash - HVFA). The amount of FA addition is kept constant at 50% for all combinations. The compressive strength and tensile strength tests on cube and cylinder specimens, at 7 and 28 days were carried out. Based on the compressive strength results, optimum mix proportion was found out and flexural behaviour was studied for the optimum mix. It was found that all the mixes (FA + SF) showed improvement in compressive strength over that of the control mix and the mix with 50% FA + 10% SF has 20% increase over the control mix. The tensile strength was also increased over the control mix. Flexural behaviour also showed a significant improvement in the mix with FA and SF over the control mix.

1. Introduction

In the current scenario to bulldoze the difficulties of feasible construction, concrete made with various mixtures of Ordinary Portland Cement (OPC) and diverse mineral admixtures, is the wise choice for engineering and construction. Mineral admixtures like Ground Granulated Blast Furnace Slag (GGBS), Meta kaolin (MK),Fly Ash (FA) and silica fume (SF) etc. are generally used Supplementary Cementitious Materials (SCMs). Any concrete containing Fly Ash (FA) content as 50 percent and above by mass of the total cementitious materials is considered as High Volume Fly Ash (HVFA) concrete. The concrete containing high volumes of class F fly ash was investigated for its mix proportion and its mechanical properties [1]. Past study on this subject reported that the characteristics of concrete containing HVFA ash up to 50% level of cement replacement in concrete proved efficient for reinforced concrete construction. The tests results of HVFA concrete showed that remarkable strength gain from 7 to 28 days and from 28 to 56, 91, 182, and 365 days. The durability properties of high performance concrete viz., drying shrinkage, water sorptivity were studied to ascertain the effect of fly ash. Also the chloride ion penetration of high strength concrete having Class F fly as was investigated [2]. The OPC concrete was compared with concrete containing 30% and 40% fly ash after thorough investigation. The abrasion resistance of concrete was influenced by the presence of High-Volumes of Class F Fly Ash and its effect was investigated [3]. From the test results, it was understood that, irrespective of fly ash content, there was an increase in abrasion resistance with the increase in age for all mixtures. The effect of compressive strength and abrasion resistance of HVFA containing 70% FA and remaining SF was investigated for the influence of SF in HVFA [4]. In this work the concrete contained 70% HVFA with modification of 10% and 20% of FA by SF, GGBS and their equal combinations. At all ages, the compressive strength and abrasion resistance showed highest value due to the incorporation of 20% of silica and slag [4]. The possible use of SF along with slag in HVFA concrete exposed to elevated temperatures was studied. The weight loss and residual strength properties of Plain Cement Concrete (PCC), HVFA concrete, and HVFA concretes incorporating SF and slag after being exposed to temperatures from 400°C to1000°C in step of 200°C was investigated. The mix combinations in which a proportion part of PCC was partially replaced with the mineral admixtures viz., binary (PCC+FA), ternary (PCC+FA+SF, PCC+FA+GGBS) and quaternary (PCC+FA+SF +GGBS) cementitious blends were incorporated and investigated [5]. For the SF modified high-volume fly ash concrete, the strength and durability studies was investigated [6] The effect of variation of the cement replacement by SF in HVFA concrete on the mechanical and durability properties of concrete was studied by conducting various tests in the laboratory. The various properties of HVFA concrete incorporating Nano Silica (NS) was investigated for its durability [7]. Due to the formation of refined microstructure and smaller pores, the chloride ion penetration was reduced by the addition of SF in combination with NS in concrete mixture. By the addition of NS with HVFA or GGBS, reduction in setting time and increase in early gain of strength of concrete was achieved [8]. The alteration in compressive strength value of HVFA mortars and concrete due to the addition of NS was studied [9].

In this research work, the influence of partial replacement of OPC by FA (50%) and SF (5%, 10% and 15%) by weight in M25 grade concrete with Super Plasticizer (SP) was studied. Compressive strength at the end of 7 and 28 days was carried out on cubes of various mix proportions of SF and FA as partial substitution of cement with Water-Binder (w/b) ratio of 0.35. Beams were cast for the optimum mix proportion to determine flexural behaviour. It was found that all the mixes with the inclusion of FA and SF had improvement in strength over that of the control mix. From the experiment it was found that the mix (FA+SF)-2 had remarkable increase in strength by 20% over the control mix for M25 grade. Thus it became very important to improve the desired characteristics in HVFA by appropriate addition of mineral admixtures.

2. Experimental Program

2.1. Materials

Ordinary Portland Cement of 43 grade confirming to IS 8112:2013 [10] was used for this experimental work. Crushed granite of size ranging 20 mm – 10 mm was used and specific gravity was found to be 2.74 confirming to IS 2386 (part III) [11]. Natural river sand passing through IS sieve 4.75 mm of specific gravity 2.65 confirming to gradation Zone-III was used. Potable tap water available in the laboratory was used for mixing of concrete and curing. Conplast SP430 which is a chemical admixture complies with IS 9103 [12] and ASTM-C 496 [13] Type 'F' as a high range water reducing admixture was used to improve the workability and reduce the water content. SF and FA which are used as SCMs were obtained from ASTRRA chemicals, Chennai and Neyveli Lignite Corporation (NLC), Tamilnadu respectively. The physical and chemical properties of OPC, FA and SF are given in Table 1.

Table 1. Physical properties and Chemical composition of OPC, FA and SF

Description	OPC	FA	SF
Color	Grey	Light Grey	Light Grey
Specific gravity	3.1	2.7	2.63
CaO (%)	62.8	1.07	0.52
SiO_2 (%)	20.3	92.83	99.886
Al_2O_3 (%)	5.4	0.53	0.043
Fe_2O_3 (%)	3.9	3.97	0.040
MgO (%)	2.7	0.42	0.000
Na_2O (%)	0.14	0.16	0.003
K_2O (%)	0.53	1.02	0.001

2.2. Mix proportions

The proportion of materials for the M25 grade of concrete was ascertained by design mix and the proportion was 1:1.71:2.87 (by weight) respectively [14,15]. To study the effect of FA and SF blend as a partial substitution of cement, specimens were cast for reference and other mixes with different replacement levels of FA and SF (by weight) as given in Table 2 with w/b ratio of 0.35.

Table 2. Mix Proportions with various replacement levels of FA and SF

Mix	Replacement level (%)	
	FA	SF
Control (C)	0	0
(FA+SF)-1	50	5
(FA+SF)-2	50	10
(FA+SF)-3	50	15
(FA+SF)-4	50	20
(FA+SF)-5	50	25

2.3. Specimen casting and curing

To examine the consequence of addition of FA and SF combination (as partial replacement of cement), 150 mm cubes and 150 mm diameter, 300 mm height cylinders were cast for control mix and the other mixes comprising different mix combinations of FA and SF. Conplast SP 430 is added in all the mixes as it gives better results and good workability. Specimens were placed in the well lubricated mould and compacted and the specimens were left at room temperature for 24 hrs and after that specimens were placed in curing tank till the end of designated curing period (7 days and 28 days).

2.4. Specimen testing

The compressive strength of different mixes were found out after 7 and 28 days curing and the tensile strength were found out after 28 days curing in a compression testing machine of capacity 3000 kN confirming to IS 516:1959 [16]. The load rate adopted was 10 kN/min. Based on the test results of compressive and tensile strength, 100 mm × 150 mm × 1200 mm size beam specimens were cast for optimum mix proportion obtained for M25 grade of concrete.

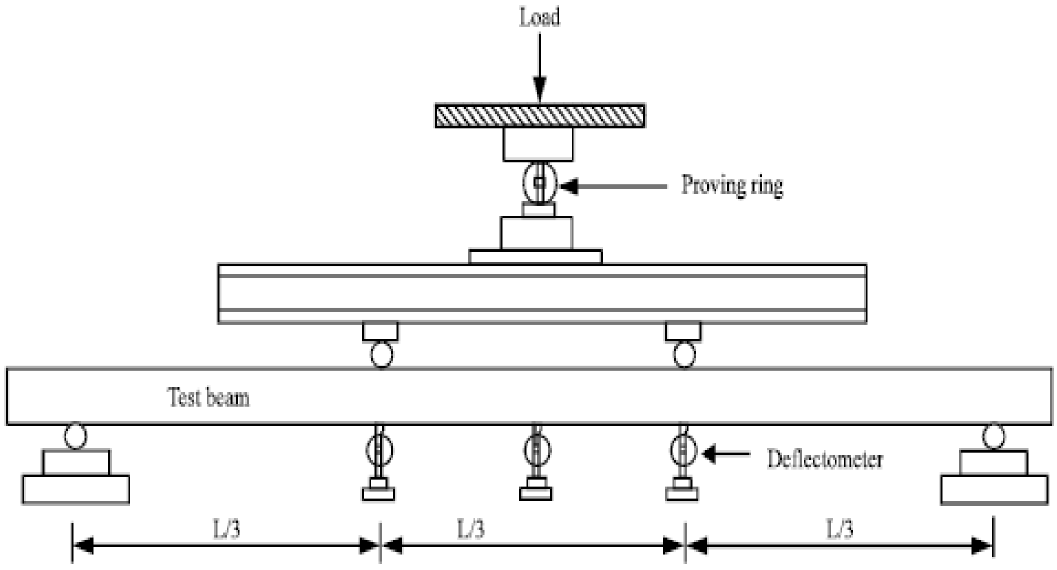


Figure 1. Test set up for flexure

3. Results and Discussion

3.1. Compressive strength

From the test results of compressive strength for concrete, it was found that the mix (FA+SF)-2 ie., 50% FA and 10% SF had higher compressive strength than that of the other mixes both in seven days and twenty eight days curing. When SF was added to concrete, initially it remained inert and then started hydrating, which produced two chemical compounds: Calcium Silicate Hydrate (CSH), formed as crystalline structure, which was responsible for the strength development and Calcium Hydroxide (CH), a by-product also called as free lime which was responsible for lining the available pores within concrete as a filler.

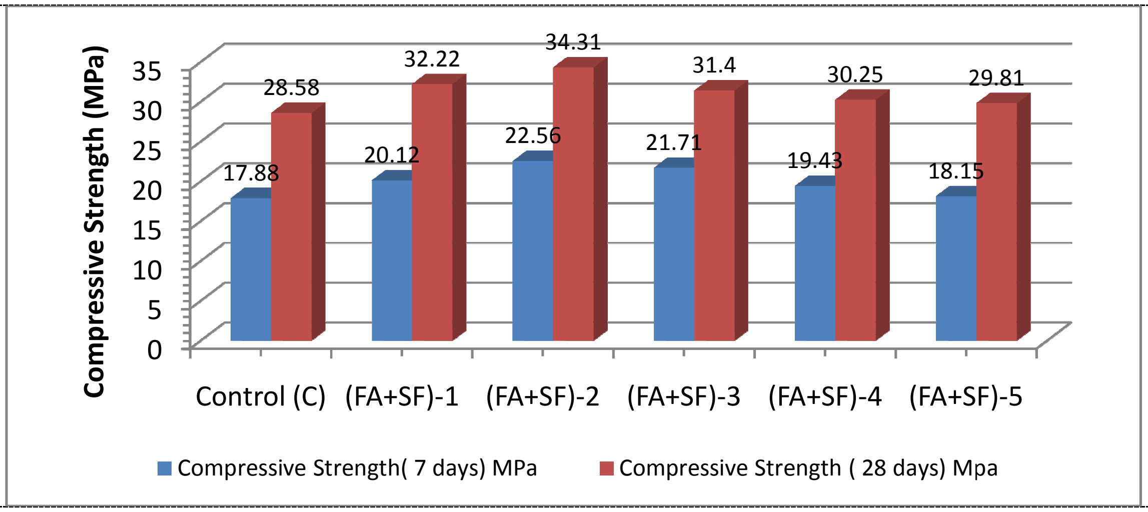


Figure 2. 7 days & 28 days Compressive strength of concrete

Pozzolanic reaction occurred between SF and the CH, producing additional CSH in many of the voids around hydrated cement particles which induced much denser matrix which was in turn improved the compressive, flexural and bond strength. Hence, less CH with increasing binding (cemen) compounds produced good strength concrete. However, in concrete with SF and FA, the interfacial zone became stronger, more homogeneous and denser. Hence, the cracks usually traverse around the coarse aggregates during the test on controlled specimens.

3.2. Split tensile strength

The findings in tensile strength gave the similar results as that of compressive strength. For FA and SF replacements there was s significant increase the split tensile strength with that of control specimen. It was noticed that the rate of mean increase of tensile strength (6.2%) was found to be low when compared with that of compressive strength (14.06%). There was an increase in tensile strength for the mix (FA+SF)-2 by 9.8% when compared with that of control mix.

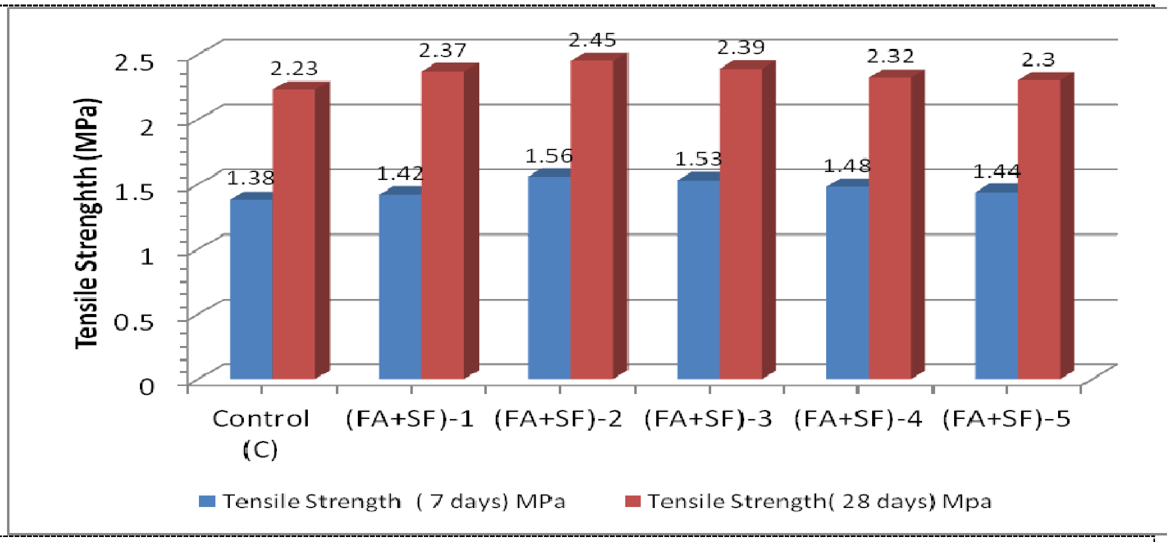
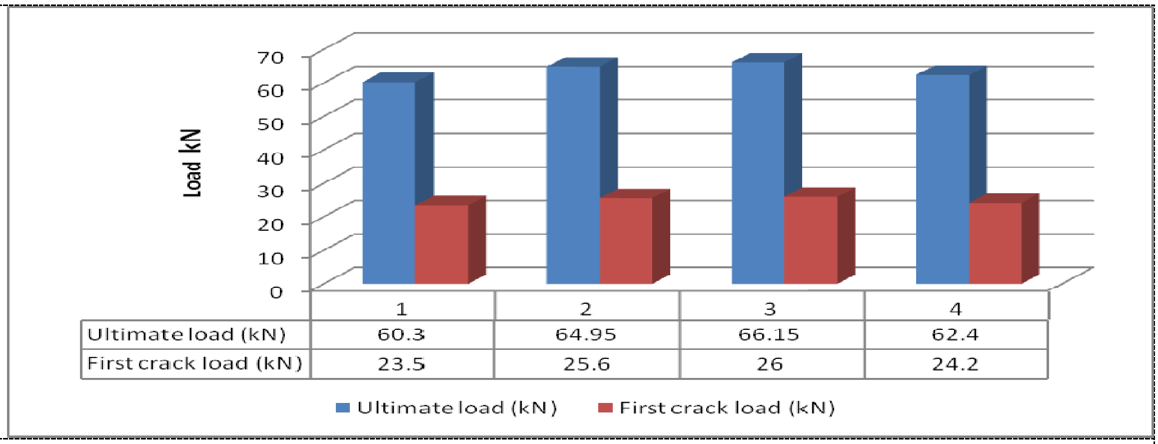


Figure 3. 7 days & 28 days Split tensile strength of concrete

3.3. Flexural behaviour

3.3.1. Ultimate load. The ultimate load for beams of different mix proportions were presented in Table 6. It can be seen that ultimate load of 66.15 kN has been achieved for mix (FA+SF)-2 which was 9.70% higher than M25 control beams respectively.



	1	2	3	4
Ultimate load (kN)	60.3	64.95	66.15	62.4
First crack load (kN)	23.5	25.6	26	24.2

Figure 4. Ultimate and first crack load for different mixes

3.3.2. Load – Deflection behaviour. At every load increment, it was noted that the beam with optimum mix with Super Plasticizer has taken higher deflection values in comparison to that of control beam as shown in Figure 5. This showed that the replacement of cement by SF and FA leads to ductile behaviour.

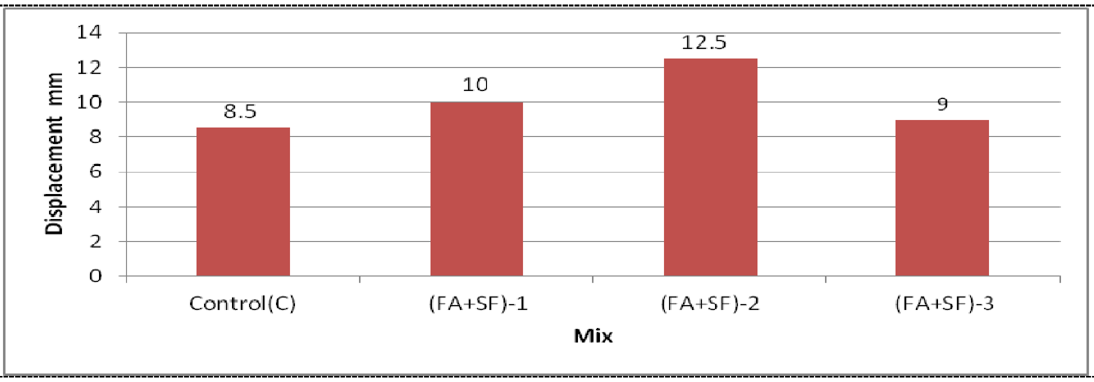


Figure 5. Maximum deflection for different mixes

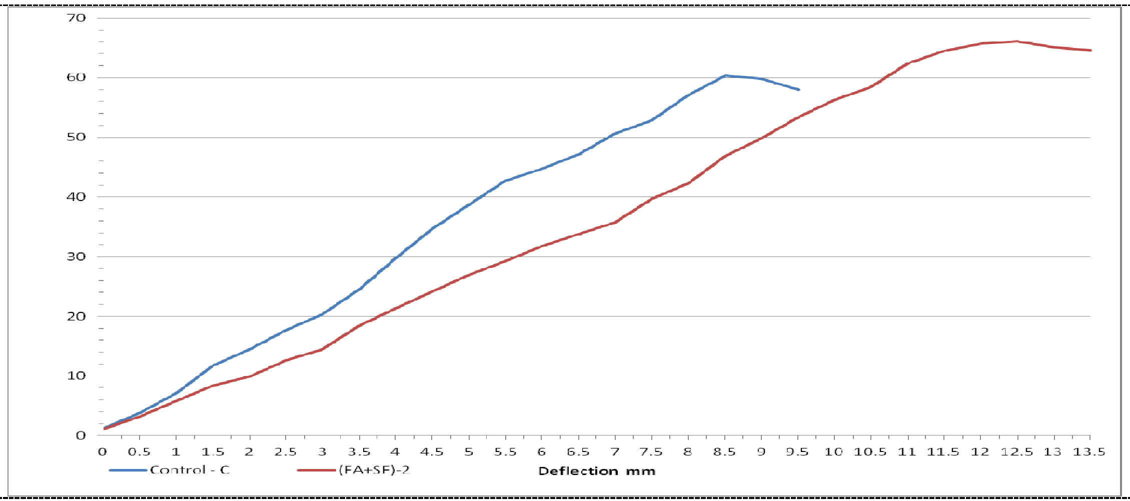
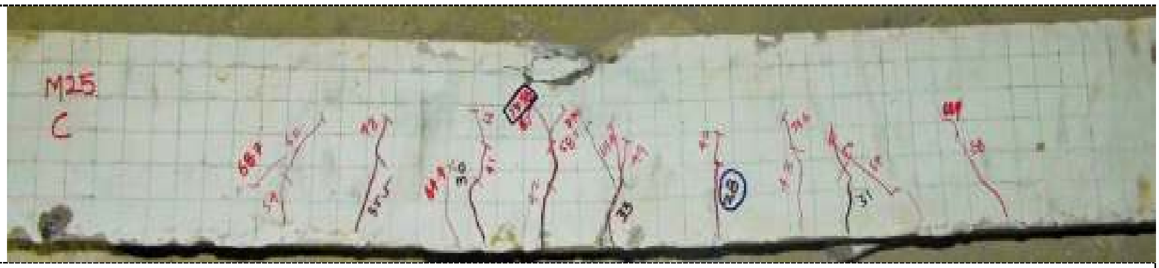


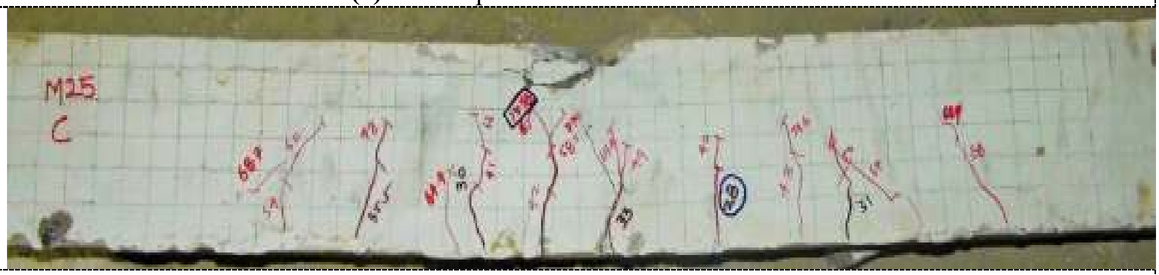
Figure 6. Load – Deflection behavior of beam

The load deflection graph (Figure 6) was plotted for the beam with control mix and for the beam with optimum mix of HVFA concrete and SF. The maximum displacement observed in control mix is 8.5 mm whereas in SF combined HVFA beam, it is 12.5 mm. From the Figure 6, it was understood that the addition of SF increased the load carrying capacity of the beam.

3.3.3. Crack pattern and failure mode. In this experimental work, the crack propagation was observed, measured and marked at every 5 kN load increment up to the failure, as shown in the Figure 7(a) and 7(b) below.



7(a). Crack pattern for M25 Control beam



7(b). Crack pattern for M25 optimum mix (FA+SF)-2 beam

Figure 7. Crack pattern and failure mode for tested beam specimens

In the constant moment zone, flexural cracks were formed first and these cracks were extended vertically upwards and developed gradually wide as the load increased. As the load increased, the extreme fibre stresses in bending increased until the tensile strength of concrete was reached. This caused flexural cracking initially in the constant moment region. The final failure of the beam was described by large strains in the steel reinforcement and considerable deflection near collapse followed by extensive cracking.

4. Conclusions

From the results of experimental work carried out, the following conclusions could be drawn:

- ✓ The optimum dose of FA and SF in combination was found to be 50% and 10% (by weight) respectively as a partial replacement of binder (cement) for M25 grade of concrete for a w/b ratio of 0.35 to achieve high compressive strength at the end of seven and twenty eight days.
- ✓ The inclusion of FA and SF resulted in faster strength development of concrete at early age of curing. The average increase in Compressive strength at 7days was obtained to be 14.06% .There was an gradual increase of 20% in 28 days compressive strength for optimum mix (FA+SF)-2 over the control mix.
- ✓ The split tensile strength of concrete for all mixes using FA and SF combination as partial replacement of cement was higher than control mix.
- ✓ The ultimate load and first crack load for the beams with optimum mix was higher than that of control beam for both grades due to the immediate filler effect, and the acceleration of cement

hydration.

- ✓ Maximum deflection for the beam with mix (FA+SF)-2 was increased by 7.5% over the beam with control mix.
- ✓ These results encouraged the use of FA and SF, as pozzolanic material for partial cement replacement of binder, in producing concrete with superior engineering properties.
- ✓ This led to the reduction in pollution to the environment. Also the technical and economic issues caused by cement production could be sorted out.

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References

[1] Chung-Ho Huang Shu-Ken Lin, Chao-shun Chang, How – Ji Shen 2013 Mix proportions and mechanical properties of concrete containing very high-volume of Class F fly ash. *Constr. Build. Mater.* **46** 71-8.
[2] Nath and Sarker 2011 Effect of Fly Ash on the Durability Properties of High Strength Concrete. *Procedia Eng.* **14** 1149-56.
[3] Siddique Rafat, William Prince, Siham Kamali 2007 Influence of utilization of high-volume of Class F fly ash on the abrasion resistance of concrete. *Leonardo Electron. J. Pract. Technol.* **10** 13-28.
[4] Alaa M Rashad, H EI-D H Seleem and A F Shaheen 2014 Effect of silica fume and slag on compressive strength and abrasion resistance of HVFA Concrete, *Int. J. Concr. Struct. Mater. (IJCSM)* **8**(1) 69-81.
[5] Alaa M.Rashad 2015 Potential Use of Silica Fume Coupled with Slag in HVFA Concrete Exposed to Elevated Temperatures, *ASCE J.Mater. Civ. Eng.* Online publication.
[6] Nazeer M, Anupama P S 2014 Strength and Durability Studies on Silica Fume Modified High-Volume Fly Ash Concrete. *Int. J. Adv. Res. Eng. Technol.* **5**(10) 55-68.
[7] Steve Supit , Faiz Uddin Ahmed Shaikh 2015 Durability Properties of High Volume Fly Ash Concrete containing Nano – silica. *Mater. Struct.* **48** 2431-45.
[8] Min-Hong Zhang, Jahidul Islam, Muta Harah Zakaria 2012 Use of Nano silica to reduce setting time and increase early strength of concretes with high volumes of fly ash or slag. *Constr. Build. Mater.* **29** 573-80.
[9] Shaikh F U A, Supit S W M, and Sarker P K 2014 A study on the effect of Nano silica on compressive strength of high volume fly ash mortars and concretes. *Mater. Des.* ***60*** 433-42.
[10] IS 8112-2013, Indian standard Ordinary Portland Cement, 43 grade – specification, *Bureau of Indian Standards*, New Delhi, India.
[11] IS 2386 (Part III) – 1963, Indian Standard Methods of Test for aggregates for Concrete (Part III) Specific gravity, Density, Voids, Absorption and Bulking, *Bureau of Indian Standards*, New Delhi, India.
[12] IS 9103:1999, Specification for Concrete Admixtures, *Bureau of Indian Standards*, New Delhi, India.
[13] ASTM C496 / C496M - 11 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens.
[14] IS 10262- 2009, Indian Standard for Concrete Mix Proportioning – Guidelines, *Bureau of Indian Standards*, New Delhi, India.
[15] IS 456 – 2000, Indian Standard Plain and Reinforced Concrete - Code of Practice, *Bureau of Indian Standards*, New Delhi, India.
[16] IS 516 – 1959, Indian Standard Methods of Tests for Strength of Concrete, *Bureau of Indian Standards*, New Delhi, India.