Study Effect of Polyester Fibres on Engineering and Durability Properties of High Volume Fly Ash Concrete

Prof. Indrajit Patel
Applied Mechanics Department, B & B Institute of Technology, Vallabh Vidya Nagar, Gujarat, 388120, India
+91-2692-231322 Fax +91-2692-236493, 237057
E-mail: inpatel34@gmail.com

DR.C D Modhera
Professor, Department of Applied Mechanics, SVNIT, Surat, Gujarat, 395007, India
+91-261-2201533
E-mail: cdmodhera2gmail.com

ABSTRACT

Need and Growth of infrastructural facilities has been tremendously increased during last two decades across the world and hence the construction industry. In construction industry concrete of various kinds is the key material because of its potential benefits, low inherent energy and recycle values. On the earth concrete is the most consumed material after water; which needs to give due consideration towards the sustainability of concrete industries in particular.

The sustainability issue for concrete construction industry is not arrived due to one or more reasons related to the material or the technology itself. This includes it consumes large quantities of virgin materials; the principal binder in concrete is cement, a major contributor to greenhouse gas emissions that are implicated in global warming and climate change. Cement on other hand also utilizes natural resource in form of lime stone. Huge amount of energy is consumed in mining, blasting, crushing and transportation of these raw materials. Concrete structures suffer from durability issues which have an adverse effect on the resource productivity of the industry. Potential and optimize utilization of cementing material in concrete will definitely lead towards sustainable concrete construction. Use of industry waste and by products like fly ash, silica fume, grounded granular slag to partly replace cementing material to concrete system addresses all three sustainability issues, its adoption will enable the concrete construction industry to become more sustainable.

High Volume Fly Ash (HVFA) concrete is one of the solutions in this context of sustainable concrete construction. Though HVFA concrete technology has been developed way back and being proven technology for construction industries with potential benefits over regular concrete, it has been not become popular in developing countries due to one or other limitations like ductility, impact and abrasion resistance. Authors in this article will describe effect of polyester fibres on engineering properties Impact Strength and Abrasion Resistance of High Volume Fly Ash Concrete design mix M25, M30, M35 and M40. Test samples include replacement of cement by 50%, 55% and 60% class F fly ash. Paper contains test results of key material like fly ash, fibre, mix design for all grade, 60 min. slump comparison, comparative study of impact and abrasion resistance for plain and fibre reinforced HVFA at 28 and 56 days age. Comparative studies of economic gain with HVFA over conventional mix will also be presented to address sustainability issue.

Key words: Sustainability, High volume, Fly Ash, Fibre, Impact, Abrasion Resistance.

1. Introduction

Use of supplementary cementing material in form industrial waste or by product contributes the sustainability issue for concrete technology. Fly ash being major product of thermal power station and possesses the required specifications it is widely use as supplement to cement. The pozzolanic action of fly ash is due to the significant amount of glassy material in particular and mineralogical composition in general. The particle size also governs the properties of fresh and hardens concrete. Particle size shape and texture along with chemical composition affect the water demand, workability, particle size distribution, particle packing effect and smoothness o surface texture of concrete. Finer size particle generally less than 10u and physic-chemical effect due to presence of pozzolanic cementitious reaction causes pre size and grain size reduction phenomenon which ultimately results in improvement in mechanical and durability properties as well.

Scope of the present work as a part of Ph.D. research work includes preparing trial and final design mix for HVFA containing 50,55,60% fly ash for M25,M30,M35 and M40 grade of concrete. For improving the engineering and durability properties of HVFA concrete 12 mm triangular shaped polyester fibre were added in proportion of 0.25 of cementing material by mass. Literature review has also been made for use of polyester fibre in normal concrete in terms of improvement in compressive and flexural strength, impact and abrasion resistance and resistance to alkaline condition as well. The paper includes final mix composition, test results special concrete additives like fly ash and polyester fibre. The work presented in this paper also includes comparative studies of engineering property through impact and Abrasion resistance of all designated mixes with and without fibres. All the ingredients were procured from local sources tested as per relevant standard and confirmed the same meeting relevant standards BIS or ASTM.

2. Material

2.1Ingredients for HVFA concrete

All the ingredients for concrete were procured form local sources and tested as per the relevant BIS/ASTM; properties are presented in Table I.

Table 1: Concrete Ingredients and specifications

Material	*Description*	*Specific Gravity*	*Standards*
Cement	*53 Grade OPC*	*3.15*	*IS 12269-1987*
Fly Ash	*Class F from WTPS Gujarat*	*2.16*	*IS -3812 2003*
Fibre	*12 mm Triangular Polyester and denier 11.2Um*	*0.91*	*ASTM C 1116*
Fine Aggregate (sand)	*River Sand Zone-II*	*2.66*	*IS-383 1970*
Coarse Aggregate -I	*Black Trap 10mm Down*	*2.84*	*IS-383 1970*
Coarse Aggregate -II	*Black Trap 20mm Down*	*2.82*	*IS-383 ,IS 2430*

2.2 Test Results of Fly ash and Polyester Fibre

Pulverized class F fly ash and 12 mm Triangular shaped fibre were tested as per BIS -1727 2004 and ASTM C: 1116 respectively. Test results are indicated in *Table 2 and Table 3* respectively, Scanning Electron Microscopic views for fly ash and fibre are shown in *Figure 1 and Figure 2*respectively.

Table 2: Chemical and physical properties of fly ash

Sr. No	*Characteristic*	*Result in %*	*Requirement as IS 3812-Part-1-2003*	
			Siliceous Pulverized Fuel Ash	*Calcareous Pulverized Fuel Ash*
1	*Total oxides.*	*95*	*70*	*50*
2	*Silicon Dioxide (SiO2), Percent by mass, min.*	*62*	*35*	*25*
3	*Reactive silica in percent by mass, min.*	*--*	*20*	*20*
4	*Magnesium Oxide (MgO), percent by mass, max.*	*0.50*	*5.0*	*5.0*
5	*Total Sulphur as Sulphur Trioxide (SO3). Percent by mass, max.*	*0.30*	*3.0*	*3.0*
6	*Available Alkalis as sodium oxide (Na2O) in percent by mass, max.*	*0.90*	*1.5*	*1.5*
7	*Total chlorides in percent by mass max.*	*0.035*	*0.05*	*0.05*
8	*Loss on ignition, in percent by mass, max.*	*1.20*	*5.0*	*5.0*
9	*Calcium Oxide.*	*22.15*	*--*	*--*
10	*Moisture content.*	*01.30*	*--*	*--*

Sr. No.	*Property*	*Result*
01	*Fineness - Specific Surface in m2/kg.*	*395*
02	*Lime Reactivity, N/mm2.*	*2.50*
03	*Compressive Strength, N/mm2.*	*79.00*
04	*Drying Shrinkage.*	*0.21*
05	*Soundness.*	*0.33*

Table 3: Test results of polyester fibre

Material	*Polyester*
Denier (Approximate)	*11.7*
Shape(Cross-section)	*Triangular –Trilobal*
Cut Length	*12.1 mm*
Diameter	*30-35u*
Specific Gravity	*0.91*
Dispersion	*Excellent*
Melt Point	*160-165 0*
Elastic Modulus, psi (ACI)	*500-700*
pH	*7.3 ± 0.5*
Colour	*Colourless & White*
Solubility in Water	*Not Soluble in Water*
Water Absorption (% by Wt.)	*Nil*
Alkaline Resistance	*Conforms to Test Procedure laid by ICBO AC 32*
UV Stability	*Higher UV Resistance*

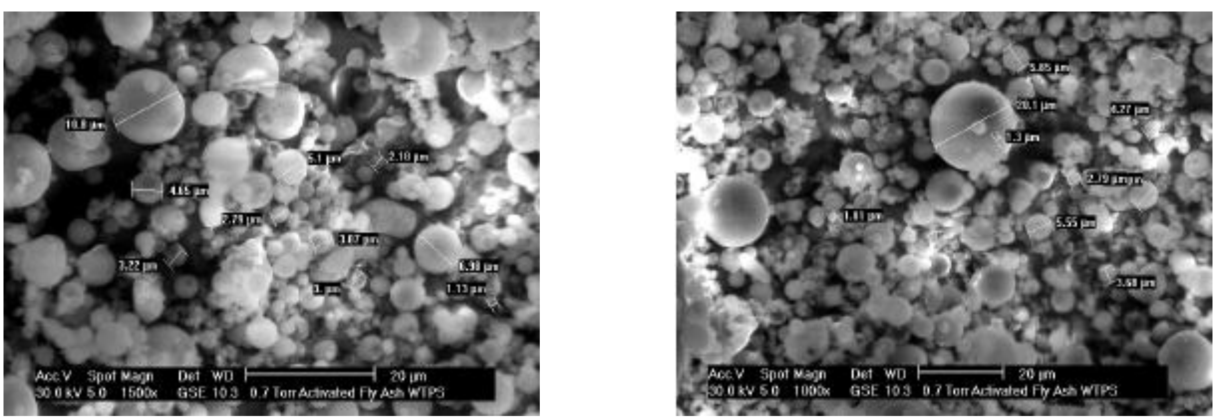


Figure 1: SEM view of fly ash

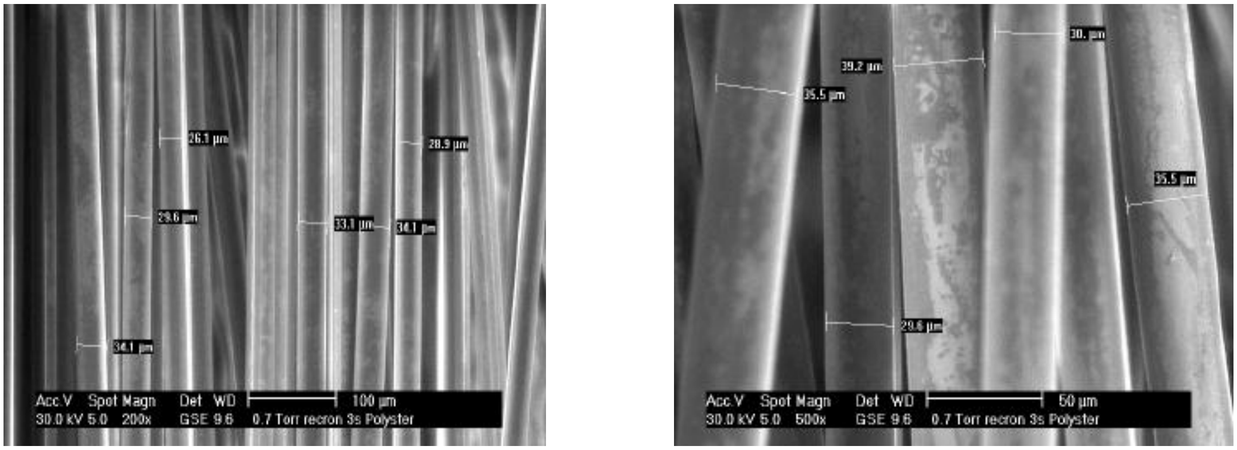


Figure 2: SEM view of polyester fibre

3.Mix Design

Based on guide lines laid down by P K Mehta and V M Malhotra as well as British Standard Method after repetition of trial final mix design was arrived for designated mix M25, M30, M35 and M40. For each grade of concrete the cement was replaced by 50%, 55% and 60% class F fly ash. The water to cementing material ration was kept between 0.25 to 0.39 with limited dose of water as per CANMET guidelines for all grade of concrete. The proportion of super plasticizer was adjusted based on amount of fly ash and richness of concrete. Typical mix design for all grades is tabulated in Table 4 below.

Table 4: HVFA Design Mix

M25

SAMPLE	*C*	*Fa*	*C+Fa*	*W*	*SP*	*W/C+FA*	*FA*	*20mm*	*10mm*	*Slump mm*	*Density KG/M3*
A10	*195*	*195*	*390*	*120*	*2.40*	*0.31*	*642*	*761*	*441*	*90*	*2394.4*
A20	*202*	*248*	*450*	*125*	*3.6*	*0.28*	*600*	*853*	*379*	*75*	*2410.6*
A30	*180*	*270*	*450*	*140*	*3.6*	*0.31*	*591*	*839*	*373*	*110*	*2396.60*

M30

SAMPLE	*C*	*Fa*	*C+Fa*	*W*	*SP*	*W/ C+Fa*	*FA*	*20 mm*	*10 mm*	*Slump mm*	*Density KG/M3*
B10	*225*	*225*	*450*	*130*	*3.4*	*0.29*	*554*	*757*	*432*	*95*	*2326.4*
B20	*225*	*275*	*500*	*130*	*4.00*	*0.26*	*585*	*850*	*351*	*90*	*2417.0*
B30	*200*	*300*	*500*	*145*	*4.00*	*0.30*	*568*	*825*	*341*	*110*	*2383.0*

M35

SAMPLE	*C*	*Fa*	*C+Fa*	*W*	*SP*	*W/ C+Fa*	*FA*	*20 mm*	*10 Mm*	*Slump mm*	*Density KG/M3*
C10	*250*	*250*	*500*	*140*	*4.0*	*0.28*	*554*	*757*	*432*	*100*	*2387.00*
C20	*247*	*303*	*550*	*138*	*3.80*	*0.28*	*525*	*848*	*336*	*95*	*2400.90*
C30	*220*	*330*	*550*	*137.50*	*3.80*	*0.25*	*514*	*826*	*327*	*90*	*2358.30*

M40

SAMPLE	*C*	*Fa*	*C+Fa*	*W*	*SP*	*W/ C+FA*	*FA*	*10 mm*	*20 Mm*	*Slump mm*	*Density KG/M3*
D10	*280*	*280*	*560*	*150*	*5.6*	*0.27*	*501*	*761*	*415*	*110*	*2392.60*
D20	*270*	*330*	*600*	*150*	*4.2*	*0.25*	*485*	*820*	*318*	*110*	*2377.60*
D30	*240*	*360*	*600*	*144.00*	*4.20*	*0.35*	*471*	*839*	*319*	*100*	*2377.20*

Mix: A –M25 B-M30, C –M35, D-M40 Fly ash Content: 1=50% 2=55% 3=60% Fibre Content: 0=0%, 1=0.15%, 2=0.25%

4. Experimental Set up

4.1 Impact Test

According to the current recommendations of ACI Committee 544, the test is to be carried out by dropping a hammer weighing 44.7 N from a height of 457 mm repeatedly on a 63.5 mm-diameter hardened steel ball that is placed on the top of the centre of a 150 x 63.5 mm cylindrical concrete specimen (disc), as shown in Fig. 3 The steel ball is free to move vertically within a 63.5 mm cylindrical sleeve.

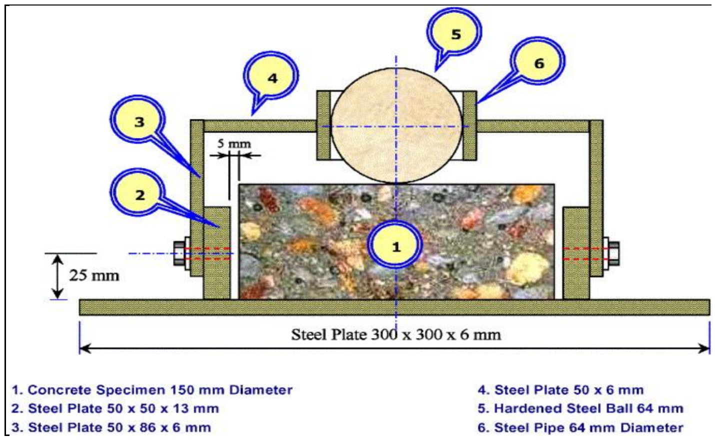


Figure 3: Test setup for measuring Impact Resistance

For each specimen, two values have been recorded corresponding to initial and ultimate failure. The initial failure is identified by the appearance of a visible crack and, therefore, the first-crack impact resistance (FC) is measured by the total number of blows required to initiate a visible crack. The test should continue until complete failure, which occurs when sufficient impact energy is supplied to spread the cracks enough so that the test specimen touches the steel lugs, which are located at a distance of 5 mm from the specimen. Therefore, the ultimate impact resistance (UR) is represented by the total number of blows required to initiate and propagate cracks until ultimate failure.

Energy Absorbed by Specimen per blow = mxgxh in N-m

4.2 Abrasion Resistance Measurement

Abrasion test was carried out as per IS 1237-2000 recommended for concrete tile abrasion and sample confirming to ACI committee 201. Sample size with 70.6 x 70.6 mm surface, properly dries in oven at temperature of 1100C was placed on disc rotating at 30 rpm with constant load of 300N and 20 gram abrasive powder uniformly spread over disc at end of predefined constant revolution 22 and repeated for total 220 revolutions with 9 breaks. The wear shall be determined from the difference in readings obtained by the measuring instrument before and after the abrasion of the specimen. The value shall be checked up with the average loss in thickness of the specimen obtained by the following formula:

$$t = \frac{(W1 - W2)\,V1}{W1 \times A}$$

Where, t = average loss in thickness in mm,

W1 = initial mass of the specimen in g,

W2 = final mass of the abraded specimen in g

V1 = initial volume of the specimen in mm^3

A = surface area of the specimen in mm2

5.Test results

5.1 Slump

For all the design mix slump was measured at 60 minutes retention period using standard practice laid down in BIS 456-2000. Initial slump values for all samples found of collapse in nature and the values at 60 minutes retention is tabulate in *Table 5.*

Table 5: 60 minutes retention slump measured in mm.

MIX	*Fly Ash 50%*						*55 %*						*60%*					
	Fibre 0.00%		*0.25%*		*0.50%*		*0.00%*		*0.25%*		*0.50%*		*0.00%*		*0.25%*		*0.50%*	
	w/c	*S*	*w/c*	*S*	*w/c*	*S*	*w/c*	*S*	*w/c*	*S*	*w/c*	*S*	*w/c*	*S*	*w/c*	*S*	*w/c*	*S*
M25	*.30*	*90*	*.40*	*95*	*.44*	*110*	*.28*	*90*	*.32*	*90*	*.32*	*95*	*.31*	*90*	*.42*	*110*	*.35*	*115*
M30	*.29*	*95*	*.34*	*90*	*.44*	*115*	*.28*	*100*	*.30*	*85*	*.32*	*90*	*.30*	*100*	*.36*	*90*	*.32*	*105*
M35	*.28*	*100*	*.34*	*90*	*.34*	*95*	*.26*	*100*	*.28*	*80*	*.28*	*85*	*.25*	*110*	*.30*	*85*	*.32*	*100*
M40	*.27*	*110*	*.30*	*85*	*.39*	*100*	*.26*	*110*	*.28*	*80*	*.28*	*85*	*.35*	*110*	*.28*	*80*	*.30*	*95*

5.2 Impact Resistance

As per ACI committee 544 report the number of blows were measured at the instance of first cracking and ultimate cracking for all the test specimens at the age of 26 and s6 days. The results are shown in Table 6(a) to 6(c) for different proportion of fly ash 50%, 55% and 60% respectively.

Table-6(a): Impact Strength with 50% Fly ash Content

Mix	28 Days				56 Days			
	0.0 Fibre		0.25% Fibre		0.0 Fibre		0.25% Fibre	
	Ave. Blows	Energy Absorbed N-m	Ave. Blows	Energy Absorbed N-m	Ave. Blows	Energy Absorbed N-m	Ave. Blows	Energy Absorbed N-m
25	271	6034.8	447	9954.1	329	7326.3	427	9610.3
30	317	7059.2	513	11423.8	378	8417.4	485	10915.6
35	289	6435,6	484	10778.0	336	7562.2	467	10510.6
40	314	6992.4	499	11112.8	370	8327.4	468	10533.1

Table-6(b) :Impact Strength with 55% Fly ash Content

Mix	*28 Days*				*56 Days*			
	0.0 Fibre		*0.25% Fibre*		*0.0 Fibre*		*0.25% Fibre*	
	Ave. Blows	*Energy Absorbed N-m*	*Ave. Blows*	*Energy Absorbed N-m*	*Ave. Blows*	*Energy Absorbed N-m*	*Ave. Blows*	*Energy Absorbed N-m*
25	*307*	*6836.5*	*518*	*11535.2*	*367*	*8260.0*	*456*	*10154.5*
30	*368*	*8194.9*	*601*	*13383.5*	*433*	*9745.3*	*535*	*11913.7*
35	*313*	*6970.1*	*522*	*11624.3*	*362*	*8147.4*	*468*	*10421.7*
40	*317*	*7059.2*	*519*	*11557.5*	*374*	*8417.4*	*471*	*10488.5*

Table-6(c): Impact Strength with 60% Fly ash Content

Mix	*28 Days*				*56 Days*			
	0.0 Fibre		*0.25% Fibre*		*0.0 Fibre*		*0.25% Fibre*	
	Ave. Blows	*Energy Absorbed N-m*	*Ave. Blows*	*Energy Absorbed N-m*	*Ave. Blows*	*Energy Absorbed N-m*	*Ave. Blows*	*Energy Absorbed N-m*
25	*234*	*5210.8*	*378*	*8417.6*	*270*	*6012.5*	*330*	*7348.7*
30	*266*	*5923.5*	*438*	*9753.7*	*310*	*6903.3*	*393*	*8751.5*
35	*254*	*5656.2*	*405*	*9018.8*	*302*	*6725.1*	*385*	*8573.5*
40	*264*	*5858.9*	*427*	*9508.7*	*328*	*7304.1*	*401*	*8929.7*

5.3 Abrasion Resistance

Abrasion resistance in terms of loss of thickness after application of specified abrasive charge for given duration was measured for plain and fibre reinforced HVFA test specimens at age of 28 and 56 days with different inclusion of fly ash and fibre dose of 0.15% & 0.25% by mass of cementitious material. The results are laid down in *Table 7*.

Table 7: Abrasion Resistance for plain and fibre reinforced HVFA (wear in mm.)

Mix	*Days/*	*50% Fly Ash*			*55% Fly ash*			*60% Fly Ash*		
	Fiber	*0%*	*0.15%*	*0.25%*	*0%*	*0.15%*	*0.25%*	*0%*	*0.15%*	*0.25%*
25	*28*	*1.14*	*0.67*	*0.66*	*1.17*	*0.67*	*0.66*	*1.18*	*0.69*	*0.67*
	56	*0.929*	*0.55*	*0.50*	*0.98*	*0.59*	*0.56*	*1.05*	*0.6*	*0.59*
30	*28*	*0.87*	*0.59*	*0.57*	*0.87*	*0.62*	*0.59*	*0.9*	*0.63*	*0.6*
	56	*0.82*	*0.51*	*0.49*	*0.85*	*0.55*	*0.54*	*0.87*	*0.59*	*0.56*
35	*28*	*0.77*	*0.57*	*0.55*	*0.78*	*0.59*	*0.56*	*0.79*	*0.6*	*0.57*
	56	*0.72*	*0.48*	*0.45*	*0.77*	*0.48*	*0.46*	*0.8*	*0.58*	*0.54*
40	*28*	*0.69*	*0.53*	*0.53*	*0.77*	*0.54*	*0.53*	*0.78*	*0.58*	*0.55*
	56	*0.69*	*0.45*	*0.42*	*0.76*	*0.47*	*0.43*	*0.78*	*0.56*	*0.52*

6.Result Analysis

Comparative study of plain and fibre reinforced HVFA samples for impact resistance and abrasion resistance are shown below with graphical representation.

Table 8(a): Percentage increase in impact resistance at 28 days age

Grade	*50%*	*55%*	*60%*
25	*64.90*	*68.72*	*61.63*
30	*61.80*	*63.31*	*60.66*
35	*59.74*	*62.73*	*59.45*
40	*58.90*	*62.69*	*61.74*

Table 8(b): Percentage increase in impact resistance at 56 days age

Grade	*50%*	*55%*	*60%*
25	*30.00*	*24.25*	*22.22*
30	*28.30*	*23.55*	*26.77*
35	*28.98*	*22.82*	*27.48*

40	*26.48*	*21.93*	*22.25*

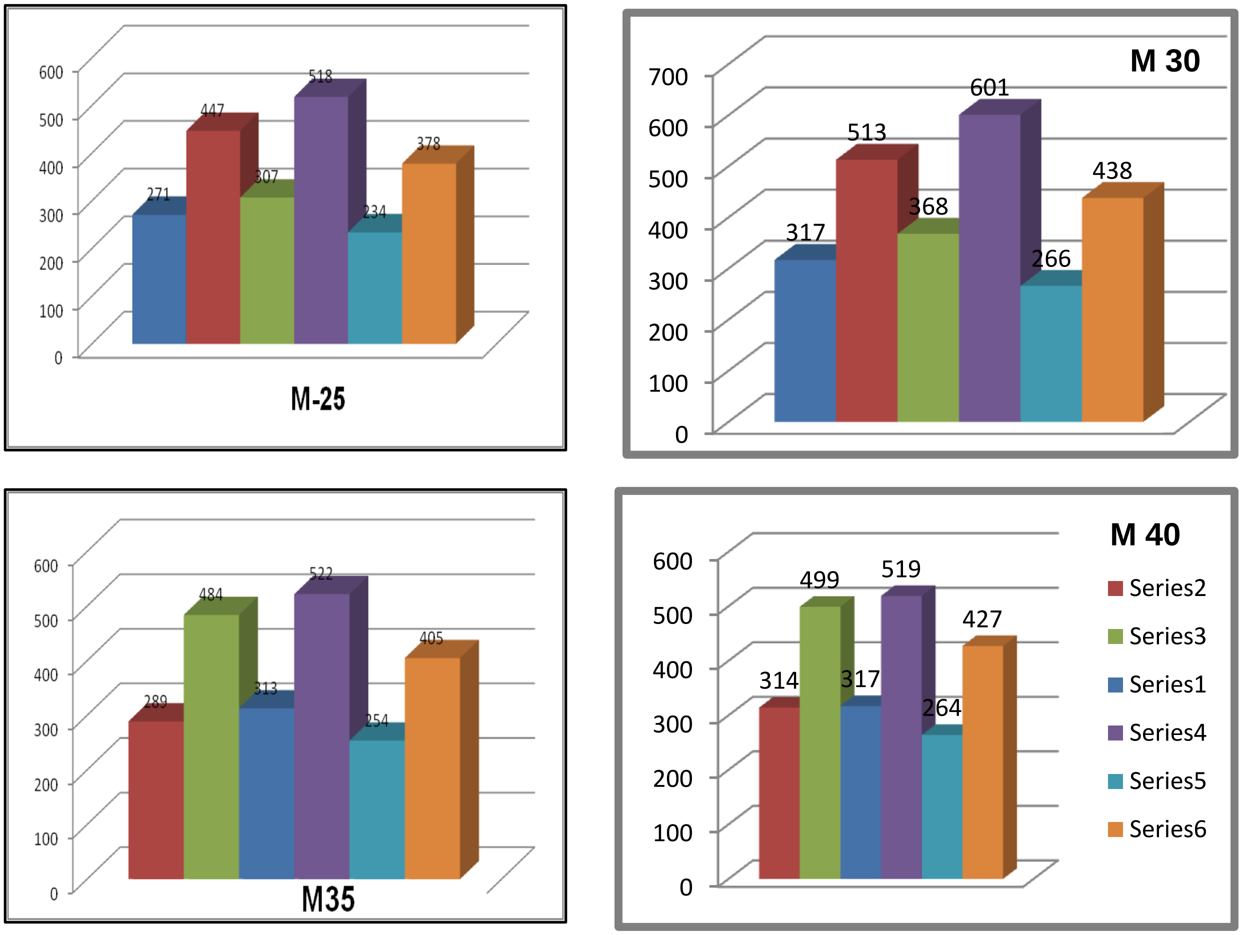
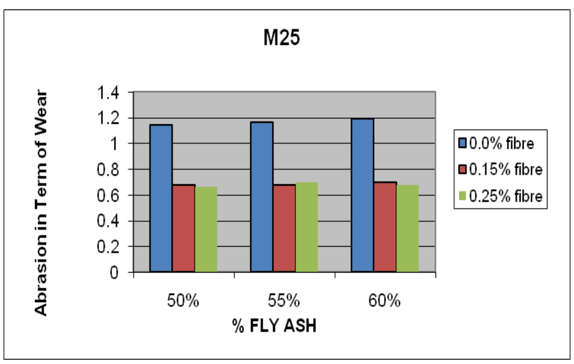
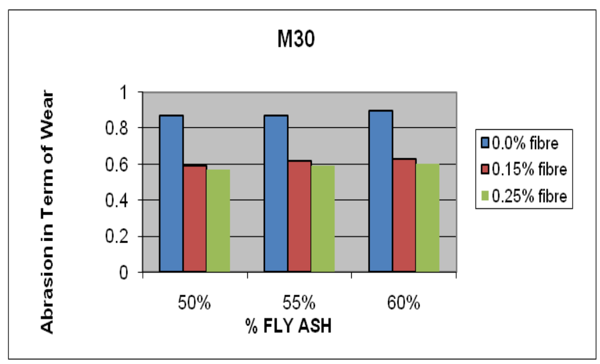


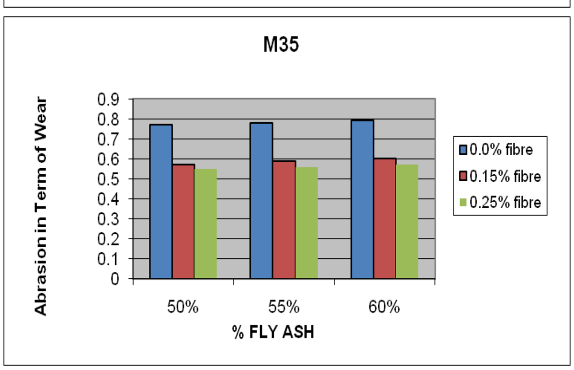
Figure 4: Comparative study at 28 days Impact Resistance

Table 10 (b) 28 Days Abrasion Comparison (in terms of wear in mm)

Grade	*Fly Ash Content in %*	*Fiber Content*			*Percentage increase in abrasion resistance for 0.25% fibre content*
		0.0	*0.15*	*0.25*	
M25	*50*	*1.140*	*0.673*	*0.660*	*42.10*
	55	*1.170*	*0.675*	*0.665*	*43.16*
	60	*1.180*	*0.690*	*0.675*	*42.79*
M30	*50*	*0.870*	*0.590*	*0.570*	*34.48*
	55	*0.870*	*0.620*	*0.590*	*32.18*
	60	*0.900*	*0.630*	*0.600*	*33.33*
M35	*50*	*0.770*	*0.570*	*0.550*	*28.57*
	55	*0.780*	*0.590*	*0.560*	*28.75*
	60	*0.790*	*0.600*	*0.570*	*27.85*
M40	*50*	*0.690*	*0.530*	*0.530*	*23.18*
	55	*0.680*	*0.540*	*0.530*	*23.05*
	60	*0.680*	*0.580*	*0.530*	*23.05*







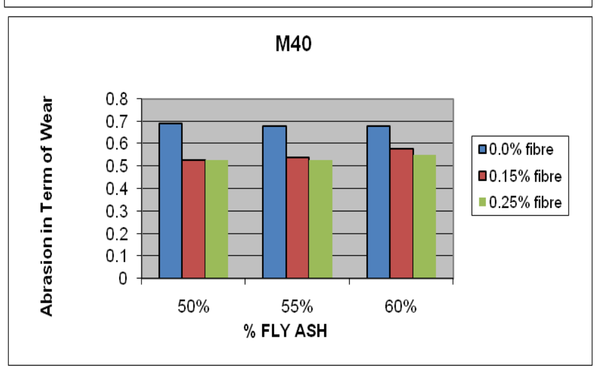


Figure 5 Comparative study of 28 days Reduction in wear

Table 11(a): Percentage increase in abrasion resistance at 28 days age

Grade	*50%*	*55%*	*60%*
25	*42.10*	*43.16*	*42.79*
30	*34.48*	*32.18*	*33.33*
35	*28.57*	*28.75*	*27.85*
40	*23.10*	*23.05*	*23.05*

Table 11(b): Percentage increase in abrasion resistance at 56 days age

Grade	*50%*	*55%*	*60%*
25	*46.23*	*42.85*	*43.80*
30	*40.24*	*36.70*	*35.63*
35	*37.50*	*40.25*	*32.50*
40	*39.13*	*43.21*	*33.33*

Table 12: Percentage saving in unit cost of convention cement concrete

Grade/Fly Ash	*Percentage Saving in unit cost of concrete*		
	50%	*55%*	*60%*
25	*17.04*	*17.66*	*18.80*
30	*18.10*	*22.60*	*20.91*
35	*18.80*	*21.10*	*23.50*
40	*19.41*	*23.57*	*25.30*

7.Conclusions

Based on experimental work, analysis and comparative studies following conclusion are drawn.

1. **Rheological Properties:**
   a. Mix are observed workable, homogenous, cohesive and uniformity in matrix with and without fibre. No significant segregation and bleeding observed.

   b. It is observed that water to cementing material ratio ranges between 0.24 to 0.39 which is within specified limits as per IS-456 2000 and slump values at 60 min retention time for all test mix is between 85 to 110mm.

2. **Impact Resistance:**

   a. Increase in Impact resistance at 28 days values ranges from 68 % to 60% for mix M25 to M40 on an average.

   b. For 56 days Impact Resistance the increase is in order of 22 to 29% over plain HVFA concrete using polyester fibre.

   c. Higher replacement of cement with fly ash reduces impact resistance of all design mix. The decrease is of order 12% to 17%.

   d. As the age of sample increases the impact resistance continues to increase. It is of order 17-21% for 50% FA, 17-20% for 55% FA and 15-23% for 60% fly ash inclusion.

   e. Higher percentage of fly ash inclusion 60% shows comparatively 5.5 to 10% lower values towards impact resistance compared to lower content of fly ash.

3. **Abrasion Resistance:**

   a. Inclusion of 0.15 and 0.25% 12mm triangular polyester fibre leads to reduction in wear of all samples.

   b. At 28 days for M25, M30, M35, M40 grade of concrete increase in abrasion resistance is of order 42.50, 33.00, 28.20 and 23.00% respectively.

   c. Gain in abrasion resistance beyond 28 to 56 days age is of order 10.50 to 14.00%.

   d. It is observed that higher content of fly ash increases wear and richer mix shows lesser wear.

4. Using high volume fly ash there is 17%-26% reduction in cost of concrete for different grade and replacement of cement with fly ash.

5. Considerable contribution can be made in reduction of green house gases CO_2 depending on strength requirement and percentage replacement of cement.

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