Application of High Volume Fly Ash Concrete in Road Sector

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Synopsis

The original work on development of High Volume Fly Ash Concrete (HVFAC) was done at Canada Centre for Mineral and Energy Technology (CANMET) in 1985. The Ordinary Portland Cement (OPC) was replaced upto 55% by fly ash in structural concrete of grade M-30. The HVFAC was used in construction of some buildings and roads in Canada and US on experimental basis. Nearly 20 years after completion, these buildings have performed admirably and have shown better durability characteristics as compared to the constructions carried out with OPC.

The development of HVFAC technology in India took practical shape on the initiative of CANMET in 2002. A technology transfer project, funded by the Canada Climate Change Development Fund and administrated by Canadian International Development Agency (CIDA) was started in partnership with CANMET and CII, as the Indian Lead Agency. The project comprised numerous activities such as awareness creation through seminars, literature distribution, case studies and participating in execution of demonstration projects. The demonstration projects mainly in the road sector created confidence in India that cement could be replaced upto 50% and even more in structural grade concrete without any compromise on quality. On the contrary, HVFAC exhibited better quality parameters especially in respect of flexural strength, impermeability and gain of strength over a long period.

HVFAC has special significance in Indian context. Firstly, India is one of the largest producers of fly ash in the world, nearly 250 million tons per year which is likely to increase to 300 million tons by the year 2025. Disposal of such large quantity of fly ash is posing serious environmental and ecological problems. Secondly, more than 90% road network in a tropical country like India is based on bituminous flexible pavement technology. Concrete roads could not make appreciable headway due to higher initial cost of construction. HVFAC provides a viable solution to both these problems and therefore has very high potential for adoption and use in India.

In this paper a HVFAC demonstration concrete road project is discussed with respect to its technical and performance parameters.

Key Words: Fly ash, concrete, high volume, cement, environment, pavements, quantity, performance.

Introduction:

Maintenance and repair of bitumen roads in India is a perpetual problem. The conventional concrete pavements involve higher initial expenditure as compared to bitumen roads and therefore have not found much favor with most of the owners, in spite of lower life cycle cost. A solution, which meets both technical and financial requirements is required to be found out and adopted on priority as major road projects are under execution in the country.

High Volume Fly ash (HVFA) Technology provides a viable solution to resolve both the problems of economy and durability. This technology is more suitable for countries like India where adequate quantity of fly ash, cement and good quality stone aggregates are locally available while bitumen production is very limited and large quantities are required to be imported. In addition, high rainfall and tropical climate are not conducive to bitumen roads.

This paper presents details of a demonstration project executed with HVFA technology under the guidance of CANMET and CII. The performance parameters have also been compared with the conventional concrete as some panels were casted with controlled concrete in this demonstration project.

Details of Demonstration Project:

An approach road of about 135 m long was constructed at Hyderabad in an industrial unit. The road is subjected to heavy traffic, each vehicle carrying about 30T load, and around 150 vehicles transit on this road daily.

Salient Features:

a)	The length of the road	136.5 m
b)	The width of the road	7.2 m
c)	Thickness of Pavement Quality Concrete (PQC)	260 mm
d)	Grade of Concrete	M-40
e)	Total Volume of HVFA Concrete used	238 m^3

For Comparison purposes three different concrete mixes were used, mix having 40 mm maximum size of aggregate, mix having 20 mm maximum size of aggregate and controlled mix. These mixes incorporated 50% fly ash as replacement of cement. Mix was also made for normal conventional concrete based on OPC of same grade as controlled concrete. All these 3 mixes were used in the demonstration project for comparison purpose.

Material Characterization

a) Cement and fly ash:

In this study cement OPC 43 grade and fly ash from Vijaywada thermal power station (field III) were used. The physical and chemical properties are presented in Table 1.

Table 1 - Physical Properties and Chemical Analysis of the Materials Used

	OPC 43 Grade	**VTPS fly ash**
Physical Tests		
Specific gravity	3.15	2.66
Specific surface, Blaine, m^2/kg	273	312
Compressive strength of **150** mm cubes, MPa		
3-day	35.00	
7-day	47.00	
28-day	58.00	
Strength Activity Index, %		87
Lime activity, MPa		4
Soundness by autoclave expansion, %		0.01
Drying shrinkage, %		0.01
Chemical Analysis, %		
Silicon dioxide (SiO_2) %		61.0
Magnesium oxide (MgO) %	1.16	0.67
Total Alkalis as (Na_2O) %	0.40	1.16
Sulphur trioxide (SO_3) %		0.04
Loss on ignition %	1.57	1.47

b) Aggregates:

River Sand meeting the requirement of IS: 383 of Zone II and crushed angular aggregates (40 mm, 20 mm and 10 mm) were used. The details are given in Table – 2.

Table 2 - Grading of Coarse and Fine Aggregate

Coarse Aggregate				**Fine Aggregate**		**Limits Zone II**
Sieve Size, mm	**40 mm Passing, %**	**20 mm Passing, %**	**10 mm Passing, %**	**Sieve Size, mm**	**Passing, %**	**Passing, %**
40	85.4	-	-			
25	-	100	-	4.75	100	90-100
20	1.8	90.2	100	2.36	92.4	75-100
16	-	41.9	-	1.18	75.6	55-90
12.5	-	9.1	100	0.60	44.1	35-59
10	-	3.8	94.3	0.30	14.1	8-30
6.3	-	-	15.9	0.15	0	0-10
4.75	-	0	4			

c) Admixtures:

Sulphonated Naphthalene Condensate (SNF) superplasticiser with a solid content of about 42% and a relative density of 1.23 was used. However, it would be desirable to use PC based admixture of any reputed chemical admixture manufacturer especially for HVFA concrete mixes as w/b ratio is generally low in such mixes.

d) Trial Mixes:

Nine trial concrete mixes were prepared with fly ash content ranging from 37% to 50% and total weight of cementitious materials ranging from 400 to 450 kg/m^3. The w/b ratio and plasticizer dose varied for different mixes in order to achieve certain workability. The results of trial mixes are presented in table 3.

Table 3 - Trial Mixes

Trial No. & Date	**Cementitious Material kg/m^3**	**Cement kg/m^3**	**Fly ash kg/m^3**	**Sand kg/m^3**	**10mm kg/m^3**	**20mm kg/m^3**	**40mm kg/m^3**	**Water l/m^3**	**w/b**	**Density kg/m^3**	**Admixture l/m^3**	**Initial Slump mm**	**Comp. Str. in N/mm^2**		**Remarks**
													7 days	**28 days**	
Trial – 1	400	400	-	704	328	770	-	155	0.38	2388	3.2	40	40.0	53	Normal SP 430, admixture was used
Trial – 2	450	225	225	708	320	373	373	136	0.30	2360	7	50	-		Normal SP 430, Mix was very sticky & not workable, Not set even after 36 hrs.
Trial – 3	450	250	200	650	325	275	600	155	0.39	2405	4.2	70	34	49	Normal SP 430, Well set Workable

															mix
Trial – 4	450	270	180	716	537	537	-	135	0.30	2375	5.4	30	40	49	Superior admix. SP430 used but Very less workability
Trial – 5	450	225	225	708	530	530	-	158	0.35	2376	4.20	80	28	43	Superior admix. SP430 used High workable mix
Trial – 6	450	225	225	708	424	636	-	140	0.31	2358	5.8	60	31	46	Superior admix. SP430 used Workable mix
Trial – 7	450	225	225	708	636	424	-	146	0.32	2364	5.4	70	32	46	Superior admix. SP430 used Workable mix
Trial – 8	450	225	225	708	265	265	530	120	0.27	2338	7.5	80	36	47	Superior admix. SP430 used, high workability
Trial – 9	450	225	225	708	424	636	-	132	0.29	2350	6.54	80	35	51	Superior admix. SP430 used Workable mix

The concrete mix at serial 9 was selected for workability, compressive strength and cost of concrete. The mixes with 40 mm and 20 mm MSA were also developed along with control mix with OPC alone for comparison purposes. The details of three mixes, which have been actually used in the construction of approach road for purposes of performance evaluation, are presented in Table 4.

Table 4 - Selected Concrete Mixes for the Projects

MATERIAL	**Mix with 40 mm MSA (Trial – 3) I**	**Mix with 20 mm MSA (Trial – 9) II**	**CONTROL MIX (Trial – 1) III**
	Kg / m^3	**Kg / m^3**	**Kg / m^3**
CEMENT (OPC 43 GRADE)	250	225	400
FLYASH	200	225	-
RIVER SAND	650	708	704
40MM	600	-	-
10MM	325	424	328
20MM	275	636	770
WATER	155	132	155
DENSITY	2405	2350	2388
w/b RATIO	0.39	0.29	0.38
ADMIXTURE (SNF)	4.2	6.54	3.2
Slump in mm	70-80	80-90	40-50

e) Replacement of cement by 50% fly ash:

In this project, trial mix at serial 9 has been adopted replacing fly ash by 50%. However, some panels were casted with mixes at Trial-1 and Trial-3 for comparison purpose. The performance of concrete with 50% fly ash was found well comparable to control mix (without any replacement).

f) Construction Features:

The construction methodology and the equipment used for the construction of high volume fly ash concrete road were generally similar to those used for OPC concrete roads, placing concrete in panels of 3.5m x 4.0m size and using needle vibrator as means of compaction. The concrete was produced in a batching plant.

No noticeable differences in placing, compacting and finishing was observed between the HVFA and OPC concretes. The only exception was that contraction joints were possible to be made for OPC concrete after 8 to 10 hours of placing, where as for HVFA concrete it was possible, only after 18 to 20 hours. This was due to the delay in the initial setting time of around 6 to 8 hours for HVFA concrete as compared to OPC concrete. HVFA concrete, however showed extended workability. Handling of concrete with 20mm (MSA) was found easier than 40mm (MSA) and it was more cohesive and easy to compact.

g) Properties of hardened Concrete:

OPC concrete as expected developed higher compressive strength at early age (7 days) and almost similar strength at 28 days as HVFA concrete. The results of compressive strength, flexural strength, tensile strength and water permeability are presented in Table – 5. The cores were also taken after 74 days from the panels using all 3 types of concretes and core results are compared in Table – 5.

Table 5 - Compressive, Flexural, Splitting tensile Strengths and Water Permeability of Concrete

Mix. Type	Compressive Strength, MPa					Flexural strength, MPa	Splitting tensile strength, MPa	Water permeability m/sec
	Lab. Specimens				Cores	Lab. Specimens		
	7-d	28-d	56-d	74-d	74-d	56-d	56-d	56-d
OPC	40.0	53.0	56.0	58.0	51.0	6.2	1.9	$3x10^{-10}$
HVFA 20 - mm (MSA)	35.0	51.0	58.0	62.7	58.5	6.9	2.4	$2x10^{-11}$
HVFA 40 - mm (MSA)	34.0	49.0	56.0	61.3	54.0	6.4	2.1	$3x10^{-11}$

In addition to above HVFA and OPC concretes were also evaluated for sulphate and acidic attacks on concrete. The results are presented in Table 6.

Table 6 - Acid and Sulphate attack of concrete

Type of concrete	Percentage weight loss in Diluted H_2SO_4 for 60 days	Percentage weight loss in Diluted HCl for 60 days	Percentage weight loss in Na_2SO_4 Solution for 60 days
HVFA concrete	4.3	1.4	2.2
OPC concrete	4.7	1.6	2.5

h) Cost comparison

HVFA concrete with about 50% replacement of cement by fly ash was found approximately 15% cheaper than OPC concrete in material cost only. The details are presented in Table – 7.

Table 7 - Cost Comparison of Raw Materials between OPC and HVFAC Mixes

MATERIALS	HVFAC		OPC	
	Kg/ m^3.	Rs. / m^3	Kg/ m^3	Rs. / m^3.
CEMENT (OPC 43 Grade)	225	1350	400	2400
Fly ash	225	360	-	
River Sand	708	850	675	810
Stone aggregate				
40 mm	-	-	-	462
10 mm	424	340	325	260
20 mm	636	508	275	220
Water	132	12	160	12
ADMIXTURE	4.2 – 6.5	150	2.8-4.2	120
Cost/ m^3		3570		4284

Note: The cost/ m^3 has been arrived based on rates of material at Hyderabad during the period.

i) Findings

- HVFA concrete retained workability for a longer period, which gave workers more time to place the concrete, compact and finish. It is helpful where construction is done through conventional means. For fully mechanized construction using slip-form pavers, mix can be modified suitably.

- HVFA achieved relatively lower strength at 7 days, similar strength at 28 days and higher compressive strength at 56 and 74 days compared to that of OPC concrete. HVFA also developed higher flexural strength.

- HVFA concrete is found more durable against sulphate and acid attack.

- HVFA concrete exhibited about 10 times less water permeability than OPC concrete.

- HVFA concrete was found about 15% cheaper than OPC concrete in raw material cost and in overall cost about 8%.

Conclusion

Based on the experience gained on various projects of similar nature, the following conclusions can be drawn;

i. HVFA concrete provides high strength, high durability and gain of strength over a long period of time. Especially very useful where re-bars are not used.

ii. HVFA concrete is about 15% cheaper in raw material cost than similar grade of conventional concrete. The cost of HVFA concrete road is almost at par with bitumen road.

iii. HVFA concrete road like the conventional concrete road has high service life without major maintenance needs, is not adversely affected by rains, allows smooth traffic flow, causes low wear and tear of vehicles, provides savings in fuel consumption and is environmental friendly as large quantity of fly ash can be used. HVFAC is a green construction material.

iv. HVFA concrete can provide a superior and economical alternative for flexible pavements and would be ideal for the countries which have problem of disposal of fly ash like India and shortage of the bitumen

The HVFA concrete technology is expected to find more acceptance by Highway authorities at the National and International organization, State and district levels in the coming years due to the numerous advantages, the technology offers. The contribution of organizations like CANMET, CIDA, CII and various Corporates in India can also promote this technology by increasing its use in industrial and housing sectors. The HVFAC can be used for conventional as well as mechanized methods of construction.

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