FIELD PERFORMANCE OF HIGH VOLUME FLY ASH CONCRETE
- THE INDIAN EXPERIENCE

by T.P.SINGH

Synopsis: Fly Ash in concrete is now generally well accepted in the Indian Industry. However, there are strong apprehensions regarding the performance of concretes with fly ash replacements above 30 - 35%.This paper presents the properties of HVFAC with 50% Fly ash used on two demonstration projects in New Delhi, India. These demonstration projects were aimed to make Indian professionals comfortable with this type of concrete made with local materials and Indian site conditions. Several engineering parameters were monitored for nearly a year on samples collected at the time of casting as well as field cores from the site.
The results show that HVFAC is indeed an excellent material with later age properties superior to conventional concrete, namely - compressive strength, flexural strength, elastic modulus, abrasion resistance and permeability. From the viewpoint of sustainable development, it is a strongly viable solution as a building material in the years ahead.

Keywords: Compressive strength, MCD, DMRC, Flexural Strength, HVFAC, Permeability, Durability

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INTRODUCTION

HVFAC – a term coined by V.M. Malhotra of *CANMET* in late 1980s refers to a concrete having a low water content and in which at least 50% of the Portland cement is replaced by a good quality fly ash. This concrete also contains a superplasticizer which helps reduce water while providing the needed workability. Lately, HVFAC has found use in high-performance structural concrete in several projects in Canada and the U.S.

HVFAC has excellent workability, low heat of hydration, adequate early-age and high later-age strengths, reduced drying shrinkage, reduced micro cracking, excellent durability characteristics while being more economical and environment-friendly when compared to conventional concrete. Due to its superior performance and engineering properties the development of HVFAC has opened new doors to sustainability of modern concrete construction.

PRESENT SCENARIO & HVFAC - PROJECT IN INDIA

Presently in India, most ready-mixed concrete for private industry has fly ash between 20 to 30 % of the cementitious material in it while many government departments still have reservations towards its use. Batching plants on large construction sites are comfortable with fly ash upto about 25 – 30%. Much of the concrete mixed on-site with tilting drum mixers does not use fly ash as a separate additive but blended cement use is common.. As regards cement, nearly 60 to 70% of it being manufactured and sold is blended cement with 22 to 32 % of fly ash.

Unfortunately, many specifiers are unaware of the benefits that addition of fly ash brings to concrete. It is still considered a cheap, low grade replacement of cement. Often, a higher cement content is associated with good concrete. Awareness about High volume fly ash concrete (HVFAC) is still very dismal. It is imperative to improve this situation as the threats of climate change and non sustainable construction practices get stronger.

CANMET-MTL in partnership with CII and other organizations in India had taken up the HVFAC technology transfer project funded through Canadian International Development Agency. The aim was to develop India’s ability to reduce GHG emissions, promote sustainable development of the construction industry by increasing use of fly ash as cement replacement in concrete. In order to familiarize Indian practitioners with HVFAC, several demonstration projects in the form of real life structures were taken up all over India and the concrete performance closely monitored. Two such demonstration projects have been described with results in the following pages.

MCD ROAD PROJECT, NEW DELHI

The municipal corporation of Delhi (*MCD*) decided to construct a 100-m stretch of road pavement - 7m wide at Fatehpur Beri, Mehrauli, New Delhi in HVFAC. The road stretch carries heavy traffic including overloaded trucks during day as well as night. The new concrete pavement was designed as a 270-mm thick slab in 30 Mpa grade concrete, laid on the existing asphalt pavement. With the purpose of comparing the performance of HVFAC against that of plain concrete (without fly ash), the stretch was divided into 3 parts – each 33 m long and executed with 3 different mixes as follows:

1. 30 Mpa Plain concrete
2. 40 Mpa HVFAC
3. 30 Mpa HVFAC

Materials used:

Cement OPC 43 grade and fly ash from Dadri thermal power station. were used in this project. Their physical and chemical properties are presented in Table 1. Gradings for river Sand and crushed angular aggregates (20 mm and 10 mm) are presented in Table 2.

The concrete (mix proportions in Table 3) was supplied by an RMC facility in Faridabad in $6m^3$ transit mixers, and placed manually. It was compacted by poker vibrators and finished using a vibrating screed along with hand floats. A few hours later a broom finish was given followed by curing with wet gunny bags and ponding.

Sampling

All sampling for measuring the desired properties was done as *per IS 516.* Concrete was taken from the freshly unloaded pile in Tasla's (steel pans) and placed with due compaction in the various moulds, neatly arranged in a pick-up truck. The filled up moulds were covered with a poly sheet and transported to the testing lab (4 km from the site) within half an hour for proper storage.

Fresh Properties of Concrete

Slump -- The slumps were measured as per prescribed standard practice, for every truck load. The averages are shown in Table 4.

Setting time -- Fresh concrete was sieved at the placement location & three - 15 cm cubes were filled with the concrete fraction finer than 4.75mm,(Fig.8). The penetrometer as per IS 8142 was used every ½ hr and the penetrating resistance noted in kg. This was plotted against time and the setting times – initial and final were read corresponding to a penetrating resistance of 35 kg/cm2 & 275 kg/cm2 respectively. These are presented in Table 4.

Hardened Concrete properties

Cube Compressive Strength -- Concrete samples for various ages were taken from the same batch of concrete. The cube strengths obtained starting from 3 days upto 270 days are reported in Table 5 along with a plot in Fig.1. To check the variation in different batches, 3 more samples were taken from 3 subsequent batches (transit mixer trucks) & compressive strengths measured at 28 days. These results are shown in Table 6.

- As expected, the early strengths upto14 days of the plain concrete are higher than the HVFAC concrete. At 28 days approximately the strength curves cross and then HVFAC surpasses that of plain concrete.
- The batch-to-batch strength variations measured on consecutive batches for each mix are rather high for HVFAC, and all the three mixes seem to fall short of their desired 28 day strengths.

Flexure Testing -- Un-reinforced concrete beams of size 10cm x 10cm x 50cm were cast & subjected to flexure using a symmetrical third-point loading, until failure occurred. The flexural tensile strengths for the 3 mixes in the form of MOR (*modulus of rupture)* are given in Table 5.

Chloride-Ion permeability -- The RCP test was conducted as per the ASTM 1202 on cast moulds as well as on core specimens extracted from the concrete pavement . The total charge passed in coulombs is shown in Table 5.

Core testing : Cylindrical core specimens of 100 mm dia. were extracted from in-situ concrete and tested as per standard practice after epoxy capping . The equivalent cube strengths are given in Table 5 and plotted in Fig.3.

- The core strengths are unexpectedly low for the plain concrete.
- The HVFAC cores show good strengths close to the cast cube strengths.

All cores exhibited a smooth surface texture, well distributed coarse aggregates and air pockets / blow holes from 1mm – 8 mm moderately distributed.

Abrasion resistance : To measure this property, specifically important to pavement concrete, the apparatus used consists of a ring of ball bearings which is allowed to run over the wet concrete surface for 1000 revolutions of a motor driven shaft (Fig. 4). The tests were conducted on two faces of a 10 cm cube and the indentation measured is given in Table-5. .

Modulus of Elasticity : This was determined by running a load deflection measurement on 150 mm dia. X 300 mm cylinders after clamping a compressometer on it. The straight line slope of the graph expressed in kg/cm2 is the Modulus of Elasticity presented in Table 5. The results indicate that:

- The values are in close vicinity to the predicted values given by the codal empirical formula – 5700 x √characteristic cube compressive strength.

- The values for HVFAC are higher than predicted as well as higher than the plain concrete.

Splitting Tensile Strength -- A concrete cube specimen is placed between the platens of a compression testing machine and the load applied through 2 loading pieces (12 mm dia. bars welded to flat plates) on two opposite faces. The tensile stress generated in the perpendicular plane causes a splitting failure along the center line of the specimen. The results are presented in Table 5.

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DELHI METRO RAIL CORPORATION PROJECT

The Delhi Metro Rail Corporation (DMRC) started in 1995 is running a mass rapid transport system connecting various parts of Delhi through a network of Metro rail routes. The DMRC agreed to use HVFAC in the construction of South East entrance subway at Rajiv Chowk – in the heart of Delhi. The underground facility here is nearly 14 m deep and is an interchange station where two rail routes cross each other. Nearly 3500 m3 of HVFAC was used in this subway structure which consists of 800-mm thick base slab, 500-mm thick external walls and 800-mm thick roof slab - all in RCC .

The mix proportions used in this project are given in Table 3. The HVFAC was delivered between April 2005 to Sept. 2005, placements ranging from 40 m3 to 870 m3. The concrete mix designated as Mix 1 was used from April to June and then changed to Mix 2 in July apparently due to problems from variability in fly ash quality. As a result of prior acquaintance with the special features of HVFAC, the client agreed to provide a wet curing of 14 days as against the usual 7 days for conventional concrete.

Properties of Fresh Concrete

The concrete manufacturing facility felt that due to the high content of fly ash, the mix was exceptionally sticky and not very pumpable below a slump of 180 mm. It was designed therefore to have a slump in the range of 220 to 240 at the plant, reduced to 180 – 200 at the point of delivery. The mix designers managed a good control over the workability – maintaining the slumps in a narrow range just past the threshold of pumpability. However the concrete had an excessively slow setting time – mostly beyond 48 hours, often as high as 72 hrs. This was probably due to the dosage and the type of superplasticizer used. Fortunately, the client accepted the slow setting time .

Sampling

The concrete samples were taken in wheel barrows just at the entrance of the site from the transit mixer. Since the clients did not want any holes in the structure from in-situ coring later, a separate block of concrete roughly 500 x 500 x 400 mm was cast close to the site office at the entrance. Cores were extracted from this block for testing at 28, 91 and 270 days. Unfortunately this isolated block did not receive much attention at site in terms of curing, giving the engineer a chance to study the properties of an inadequately cured HVFAC.

Properties of Hardened Concrete

Compressive Strength -- Although the client had agreed to raise the 28-day time limit to 56 days for achieving the required strength, the concrete which was designed for 35 Mpa strength, gave an average 7-day strength of 23.9 Mpa. This strength doubled in 28 days to an average of 47.7 Mpa. The highest strength achieved was 58 Mpa, while the lowest was 40 Mpa – safely above the requirement. The strengths increased remarkably over the next few months as seen in Table 7 and Fig. 5, reaching an average of above 75 Mpa in 9 months – more than double the characteristic strength.

The strengths from cylindrical cores lag behind a little as expected, due to the neglected curing on the in situ block. The minimum 28-day strength from the cores is 37 Mpa. In 91 days this increased to 47 Mpa and in 270 days an impressive 76 Mpa – same as that of cast cubes.

Permeability -- The RCPT values from *cast moulds* at 28 days fall in the range of 580 to 1200 coulombs – indicative of very low penetrability. These values, presented in Table 8 and Fig. 6, further reduced to less than 50% in 91 days and to a very low range of 130 to 400 in 270 days.

The values of RCPT from *cores* start in the range of 1500-2300 coulombs at 28 days (indicating low to moderate penetrability) and approach 1000 (threshold of 'Low to Very Low' penetrability according to ASTM 1202) in 91 days. These cores were taken from the cast block on the site which did not receive much curing. Hence the relatively higher values. However at 270 days the penetrability is 'very low' as seen from the coulomb value. Conventional concrete on the other hand usually has values ranging from 2500 to 4000 coulombs.

Flexural Strength -- The flexural strength was measured by testing 10 cm x 10 cm x 50 cm beams cast on site with the sample concrete and determining the modulus of rupture. The flexural strength (Table 9) was found to be between 5 to 6 Mpa at 28 days and between 7 to 7.5 Mpa at 91 days. The increase of nearly 30 % over the 28day strength is a special feature of HVFAC in contrast to conventional concrete in which the strengths increase negligibly after 28 days. Structural members like pavements where the flexural strength governs design can particularly benefit from the use of HVFAC.

Young's Modulus of Elasticity -- The Young's Modulus of elasticity determined by the IS-516 method gave values in the vicinity of 2.5 GPa at 28 days (Table 9). This increased by nearly 40 % to a value of 3.6 GPa at 91 days. The increase is attributed to an improved transition zone (interface of coarse aggregates and paste) from the pozzolonic reaction products as well as some of the fly ash particles acting as filler in the voids.

CONCLUSIONS AND DISCUSSION :

From the performance of HVFAC used in these projects, it can be concluded that :

1. The HVFAC could achieve better performance than expected using only half of the conventional OPC thus saving GHG emissions of nearly 200 kg for every m3 of concrete used.
2. Compared to conventional concrete, HVFAC has lower early compressive strength but very good later age strength which continues to increase over several months. Due to this property, acceptance criterion for HVFAC should be made 60 or 90 days wherever the structure is to be loaded at a later age. HVFAC has also performed better in terms of its elastic modulus, flexural, tensile and abrasion strengths.
3. The permeability and hence the durability characteristics of HVFAC are far more superior than plain concrete.
4. The setting time at DMRC project was unduly long while at MCD was quite like plain concrete suggesting the importance of choosing the correct type of plasticizer.
5. Quality Control is as important in HVFAC as in conventional concrete. In fact the MCD project results show that HVFAC has a greater cushion in achieving the designed target properties due to its prolonged pozzolonic reaction.

Having achieved such an excellent performance on both projects from local materials used by local practitioners in local working conditions, the use of HVFAC should be widely promoted. Due to its economy as well as environmental advantages also, HVFAC instead of plain concrete, should be the obvious immediate choice on construction projects.

CODES AND REFERENCES

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Table 1 -- Physical and chemical properties of the materials used at MCD project

	Description	OPC Cement Grade 43	ASTM class F Flyash
Physical Properties	Specific gravity	3.15	
	Specific surface ,Blaine ,m2/kg	315	404
	Particle retained on 45 µm Sieve		15%
	Compressive strength of 51 mm cubes ,Mpa		
	3-day	38.0	
	7-day	47.5	
	28-day	58.5	
	Lime reactivity ,Mpa		4.7
Chemical Properties	Strength activity index at 28d		0.85
	Magnesium oxide (MgO) %	4.2	0.44
	Total Alkalis as (Na2O) %	0.4	0.79
	Sulphur trioxide (SO3) %	1.9	traces
	Loss on iginition %	1.6 %	0.6 %

Table 2 -- Grading of Coarse and fine aggregates used at MCD Project

Coarse Aggregate					**Fine Aggregate**		**Zone II**
Sieve size (mm)	20 mm Passing %	Desirable Limits	10 mm Passing %	Desirable Limits	Sieve size (mm)	Passing %	Desirable Limits
25	100	100			**4.75**	97	90 -100
20	99.5	85-100			**2.36**	82.2	75 -100
12.5			100	100	**1.18**	66.1	55 – 90
10	8.1	0-20	89.4	85 -100	**0.6**	52.4	35 – 59
4.75		0-5	14.5	0 -20	**0.3**	14.2	8 -30
					0.15	2.5	0 -10

Table 3 -- Mix Proportions used for MCD and DMRC projects in Kg /m3

	MCD Project			**DMRC Project**	
	M-30 Plain Reference mix	M-40 HVFAC	M-30 HVFAC	Mix 1	Mix 2
	C	F	G		
OPC Cement 43 grade	360	220	190	225	235
Fly Ash ASTM class F	-	220	190	225	210
Water	170	138	136	140	147
W / cm	0.47	0.31	0.36	0.31	0.33
Coarse Aggregate 20 mm	570	612	633	712	698
Coarse Aggregate 10 mm	570	500	517	475	474
Fine Aggregate	700	681	705	569	567
Superplasticizer	2.5 - 3.6	2.2 - 2.6	1.5 - 2.3	5.4	3.1

Table 4 -- Properties of Fresh concrete - MCD Project

Mix	*Desig-nation*	*Date*	*Slump range min - max*	*Avg. Slump mm*	*Avg. Temp.*	*Initial Setting Hr.*	*Final Setting Hr.*
M 30 PLAIN (Reference)	C	22.02.05	100 - 35	50	27ºC	08.00	10.00
M 40 HVFAC	F	23.02.05	85 - 35	50	27ºC	09.00	12.30
M 30 HVFAC	G	25.02.05	65 - 50	60	26ºC	09.30	13.00

Table 5 -- Properties of Hardened concrete - MCD Project

Tests		***Age in Days***							
		3	**7**	**14**	**28**	**91**	**180**	**270**	**600**
Compressive strength 150mm Cubes (Mpa)	C	17.9	24.7	29.9	33.3	37.1	41.1	43.8	
	F	8.9	14.2	20.0	30.0	45.6	53.1	55.1	
	G	12.3	16.0	23.1	32.7	46.0	58.4	62.4	
FLEXURE MOR (Mpa)	C				3.3	4.3		5.3	
	F				3.2	6.2		7.7	
	G				3.3	6.1		7.7	
RCPT (Coulombs) from Cast specimens	C				5587				
	F				1838				
	G				1749				
RCPT (Coulombs) from Cores	C				8832				4616
	F				1575				109
	G				3148				279
Abrasion Resistance Indentation in mm	C			1.22	0.84	0.82			
	F			1.34	1.30	0.98			
	G			1.44	1.30	1.05			
Young's Modulus of Elasticity (Gpa)	C				30.1	32.8			
	F				32.2	33.6			
	G				34.3	38.9			
Splitting Tensile Strength (Mpa)	C				1.7	2.3			
	F				1.5	2.5			
	G				1.6	2.8			
Compressive Strength from cores (Mpa)	C			17.9	22.0	24.3			26.3
	F			22.9	33.5	42.0			53.4
	G			22.8	30.3	42.6			42.0

Table 6 -- MCD, 28 day compr. Strengths from consecutive batches kg/cm2

Mix	TM 1	TM 2	TM 3	TM 4	Avg.
M 30 PLAIN	333	306	309	322	318
M 40 HVFAC	300	400	401	362	366
M 30 HVFAC	327	304	320	280	308

Table 7 -- DMRC, Compressive Strength from Cubes and in-situ cores in Kg/Cm2

	Date of Casting	AGE IN DAYS					
		7	28	56	91	180	270
Cube Compressive Strengh (Mpa)	8.04.05	20.4	47.6	56.2	65.1	65.6	78.3
	8.07.05	25.7	52.6	62.9	67.1	68.4	72.4
	15.07.05	25.3	41.6				
	18.07.05	25.3	52.4	59.3	60.4	63.9	67.4
	23.07.05	21.0	45.5	56.2	57.9	58.6	
	5.09.05		40.1	46.0			
	13.09.05	25.4	58.2	63.7	66.3	69.7	72.8
	26.09.05		43.1	54.8			
	avg.	**23.9**	**47.7**	**57.0**	**63.3**	**65.2**	**72.8**
Compressive Strengh from cores (Mpa)	8.04.05		43.8		47.9		
	18.07.05		37.1		46.8		76.3
	avg.		**40.4**		**47.3**		**76.3**

Table 8 -- DMRC, Rapid Chloride Ion Permeability as per ASTM 1202

	Date of Casting	AGE IN DAYS 28	91	270
RCPT from cast specimens (Coulombs) Average of 2 Specimens each	8-Apr-05	1215	286	130
	8-Jul-05	949	288	269
	18-Jul-05	900	411	381
	23-Jul-05	777	381	-
	13-Sep-05	580	387	342
	avg.	**884**	**351**	**281**
RCPT from cores (Coulombs)	8-Apr-05	2313	1067	
	18-Jul-05	1569	953	857
	avg.	**1941**	**1010**	**857**

Table 9 -- DMRC, Elastic Modulus and Modulus of Rupture

	Date of Casting	AGE IN DAYS 28	91
Yong's Modulus of Elasticity (Gpa)	8-Apr-05	26.8	40.5
	8-Jul-05	40.1	-
	18-Jul-05	25.8	32.5
	23-Jul-05	24.1	-
	13-Sep-05	24.4	21.0
	avg.	**28.2**	**36.5**
Modulus of rupture (Mpa)	8-Apr-05	3.6	5.6
	8-Jul-05	6.1	7.5
	18-Jul-05	6.0	7.1
	23-Jul-05	5.2	7.0
	13-Sep-05	5.8	7.7
	avg.	**5.3**	**7.0**

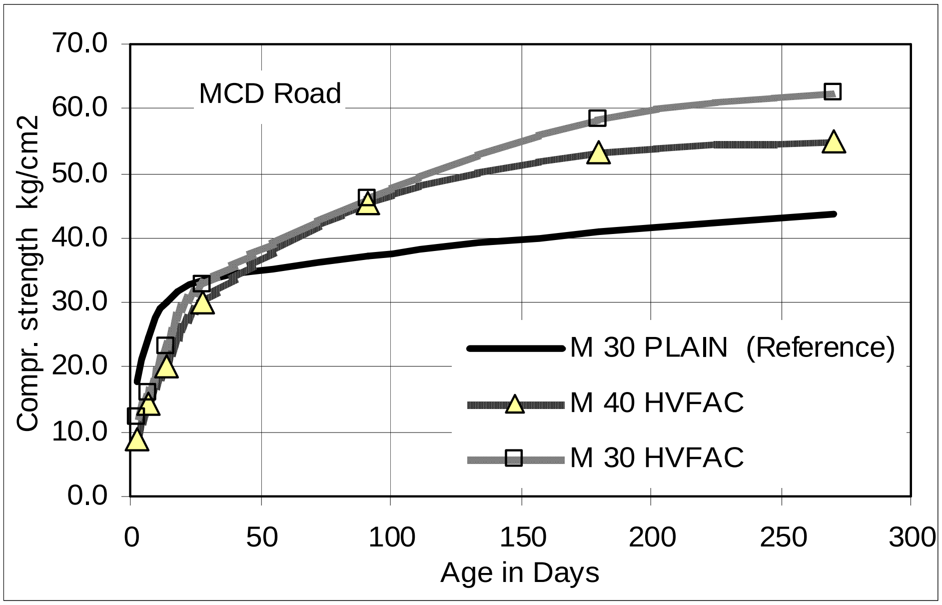

Fig. 1 Cube Compressive strengths, MCD Project

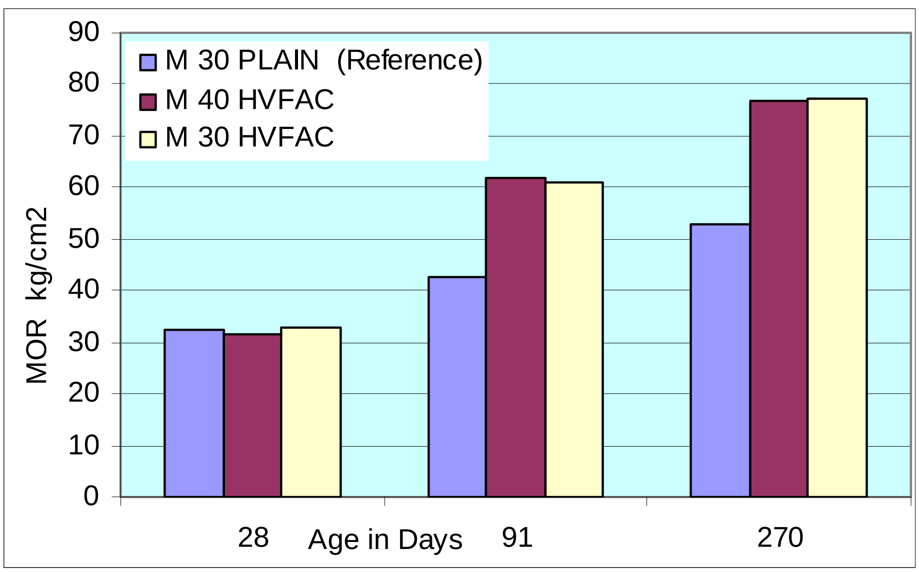

Fig. 2 Flexural strengths as MOR, MCD Project

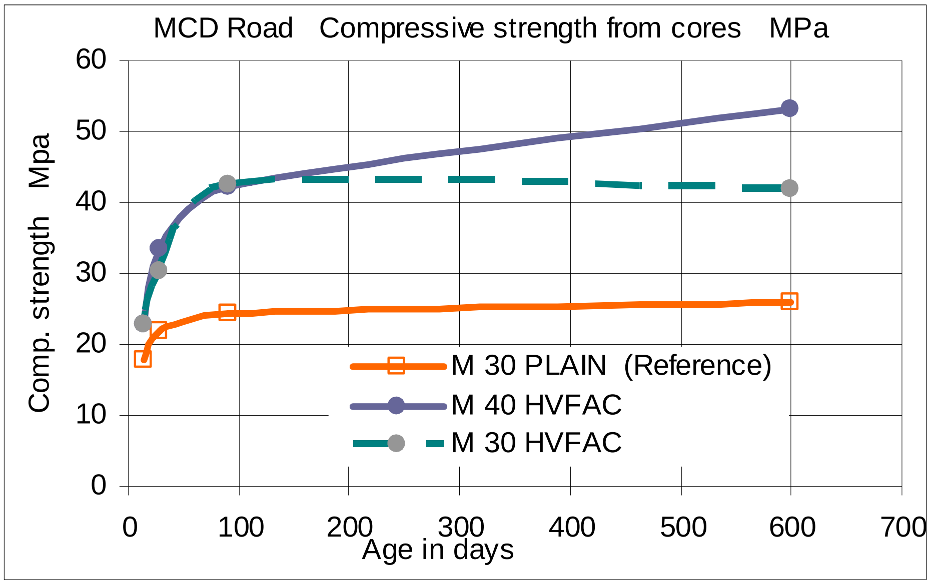

Fig. 3 Cube Compressive strengths from cores, MCD Project

Fig. 4 – Indentation caused by revolving ball ring in the Abrasion test

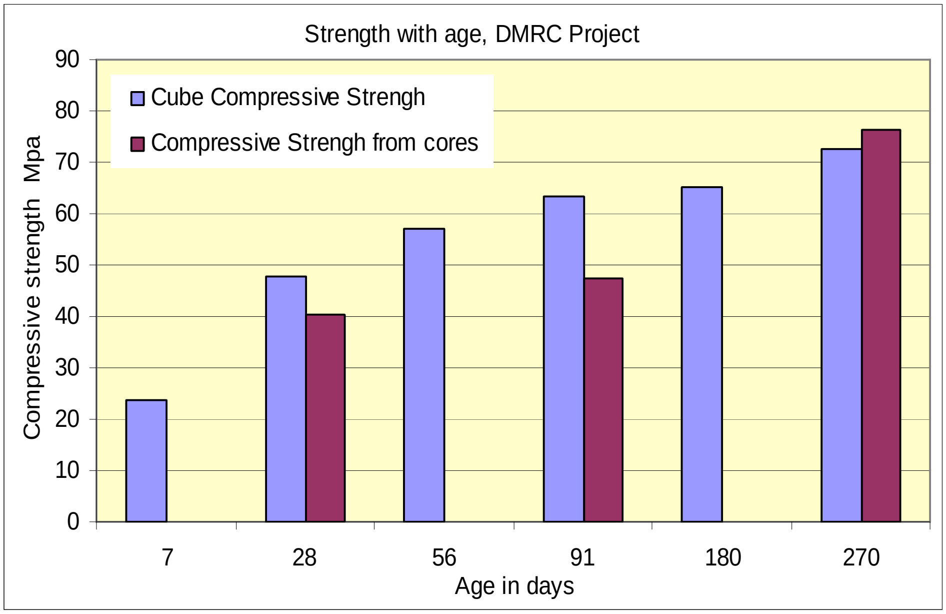

Fig. 5 Compressive Strengths Mpa, DMRC Project

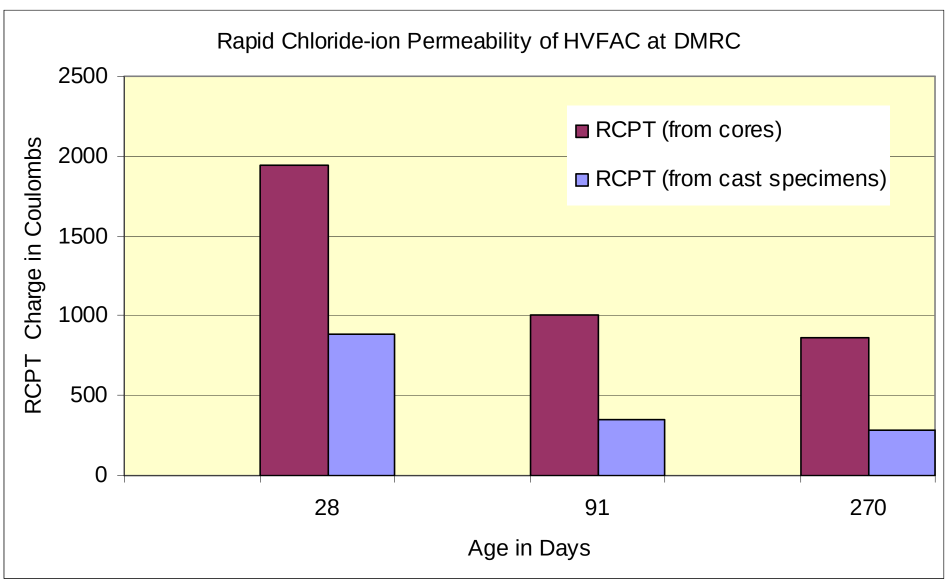

Fig. 6 RCPT in coulombs, DMRC Project