IJSRD - International Journal for Scientific Research & Development| Vol. 6, Issue 04, 2018 | ISSN (online): 2321-0613

An Experimental Investigation of High Volume Fly Ash Concrete (HVFAC)

J. Ashok Kumar[1] K. Sita Hemanth[2]
[1]PG Scholar [2]Assistant Professor
[1,2]Department of Civil Engineering
[1,2]Chirala Engineering College, Chirala 523157, India

Abstract— Fly ash a byproduct of the coal fired power plants is regarded as a good pozzolanic material making it an eligible material to be used as partial replacement in ordinary Portland cement concretes. In normal RCC construction the usage of fly ash is limited to 10-25% of weight of ordinary Portland cement. This type of cement is known as Portland pozzolona cement or blended cement. Usually, this amount has a beneect on the workability and cost economy of concrete but it may not be enough to sufficiently improve the durability to sulphate attack, alkali-silica expansion, and thermal cracking. But a concrete to be classified as High Volume Fly Ash Concrete and to take care of sulphate attack and to improve durability of structure, shall have fly ash content about 50% of the total binder content. The intent of this project is to develop different mixes with varying fly ash content and to study to their properties. The objective of the present investigation is HVFAC to the Indian context using Indian materials. The specific goal of the project is to determine the optimum fly ash content in concretes made with Ordinary Portland Cement (OPC) and Portland-Pozzolona Cement (PPC) designed to meet the requirements of concrete grades M20, M40.

Key words: High Volume Fly Ash Concrete, fly ash, Ordinary Portland Cement, Portland Pozzolona Cement, Portland Cement Concrete

I. INTRODUCTION

Portland cement is an essential component of concrete, and India currently produces about 150 million tons of this material annually; the manufacturing of Portland cement in India directly results in the emission of over 80 million tons of CO_2 annually.

Without the introduction of new technologies and practices to use larger proportions of supplementary cementing materials (SCMs) such as fly ash, either directly in concrete production, or through the increased use of blended cements incorporating significant percentages of SCMs, the production of ordinary Portland cement, will increase significantly in India to meet the rapidly increasing demand from the concrete industry. Consequently, this would translate into a significant increase of CO_2 emissions.

The High-Volume Fly Ash Concrete (HVFAC) technology developed at CANMET, Canada utilizes proper mixture proportioning and judicious selection of locally available materials and chemical admixtures to minimize the amount of ordinary Portland cement required producing high-quality concrete for different types of applications, while continuing to meet requirements for performance, cost and practicability.

The high-volume fly ash concrete is one specific type of fly ash concrete with higher fly ash contents, lower water-to-cementitious materials ratio (W/CM), and lower cement contents. This is to take full advantages of the increased workability and durability provided by fly ash and the low W/CM, and to produce a more environmentally friendly concrete by reducing its cement content.

The main difference between the High Volume Fly Ash Concrete (HVFAC) and the usual fly ash concrete is that in the former concrete, the amount of ordinary Portland cement is minimized through proper mixture proportioning using large amounts of fly ash and judicious selection of materials and chemical admixtures while maintaining, and often improving its performance as compared to conventional concrete. There is no fixed percentage of Ordinary Portland Cement replacement by fly ash in this type of concrete, but in many cases, percentages of 50 to 55% were found to be achievable. To obtain the superior performance of this type of concrete, it is recommended that the W/CM of the HVFAC be kept well below 0.40 and, preferably of the order of 0.35 or less. To produce a workable concrete at such low W/CM, the use of super-plasticizer is most of the time, essential.

The HVFAC, defined as a concrete with more than 50% fly ash and low W/CM, was developed at CANMET, Natural Resources Canada in the mid-80s under the guidance of Dr. V.M. Malhotra, and has been studied extensively by the same organization for about 15 years. The purpose of the early development of the HVFAC was to design concrete for a massive application that required very low heat of hydration in order to minimize the thermal stress, and relatively high compressive strength and modulus of elasticity. The concrete element was made of the newly developed HVFAC, and its performance exceeded expectations. It appeared then that the concept of HVFAC could be used for a large number of applications. Following this, extensive investigation programs were undertaken to determine the mechanical and durability properties of the HVFAC made with cement and fly ash from numerous sources and covering a wide range of physical properties and chemical compositions. In parallel to the laboratory investigations, the HVFAC has been used in a number of structures in Eastern Canada since the late 80's. It was found from those investigations and field applications that properly designed and cured, HVFAC can demonstrate excellent performance, both in mechanical as well as in durability aspects, and this when it is made with a wide range of materials.

More recently, this technology has been used in Western Canada (British Columbia and Alberta) and Toronto, where case studies were documented, and which again, demonstrated the potential for a greater use of this type of concrete. However, there are limitations to its use in Canada related to the climatic conditions. Cold weather conditions in late autumn, winter and early spring in Canada limit the percentage of fly ash that can be used in concrete due to potential retardation in setting and slow strength development. Also, the HVFAC is not suitable for some applications that are subjected to high levels of deicing salts such as sidewalks during winter in northern countries.

In principle, it should be easier to apply the HVFAC technology in India than it is in Canada due to the favorable climatic conditions. The hot, humid climatic condition in India should be ideal for HVFAC. Literature review and experimental studies performed in this project have also indicated that there are plenty of sources of good-quality fly ash in India that could be used for HVFAC. However, in any cases, the project includes activities for adapting the technology to the Indian context.

II. EXPERIMENTAL INVESTIGATION

A. *Test Programme*

Concrete of grades M20, M40 and M60 (nominally 20, 40 and 60 MPa) using fly ash with OPC and PPC were investigated in this project. For each grade of concrete made with OPC, four concrete mixtures were made, a control concrete without fly ash, and concrete incorporating 30, 40 and 50% fly ash. For each grade of concrete made with PPC, three concrete mixtures were made, one made with PPC only, one with the cementitious materials incorporating 40% fly ash, and one with the cementitious materials incorporating 50% fly ash. In addition to this, for grade M40, both for concretes made with OPC and PPC, mixtures with the cementitious materials incorporating 55% fly ash were made. For each concrete mixture, the compressive strength at 1, 3, 7, 28, 56 and 91 days, splitting tensile strength, flexural strength were determined.

B. *Materials*

The properties and specifications of various materials used in the preparation of test specimens are as follows:

1) *Cement*

Two types of cements were used i.e. 53 grade ordinary Portland cement (OPC), as per IS 12269, manufactured by Ambuja Cement and Portland-pozzolona cement (PPC), as per IS 1489, manufactured by Ambuja cement, containing approximately 30% fly ash from Garden Reach. Their physical properties and chemical analysis are given in Table I.

2) *Fly Ash*

Class F Fly Ash used in the study. Fly ash was used is the form VTPS, Ibrahimpatnam, Vijayawada.

3) *Aggregates*

Two sizes of coarse aggregates were used in this project i.e. 20-mm graded aggregate as per IS 383 was used for grade M20 concrete, and 16-mm graded aggregate as per IS 383 was used for grades M40 and M60 concretes. River sand, (Grading zone-II conforming to IS 383) was used as fine aggregates in all grades of concrete investigated. The physical properties of the aggregates are given in Table II.

4) *Admixtures*

ASTM Type-A, lignosulfonated based water reducing admixture, manufactured by Pidilite Industries Ltd, India, was used for M20 grade of concrete, and ASTM Type-F (naphthalene formaldehyde based super plasticizer) manufactured by FOSROC India Ltd, was used for grades M40 and M60 concretes. Super plasticizer CONPLAST SP 430A2 is used.

5) *Water*

Ordinary potable water which is free from organic matter of any type as specified in IS 456 code is used for mixing.

Description	Ordinary Portland Cement (OPC)	Portland Pozzolona Cement (PPC)	Fly Ash
Physical Tests			
Specific Gravity	3.17	3.12	2.03
Fineness			
-passing 45 micron	84	92	88
-specific surface, Blaine, cm2/g	3294	3402	4892
Compressive strength of 70.7 mm cubes, Mpa			
3-day	30.12	27.91	-
7-day	37.22	37.49	-
28-day	42.83	47.44	-
Chemical Analysis (%)			
Silicon dioxide (SiO2)	18.67	-	57.1
Aluminum oxide (AI2O3)	6.07	-	27.1
Ferric oxide (Fe2O3)	4.96	-	7.4
Calcium oxide (CaO)	60.12	-	2.1
Magnesium oxide (MgO)	2.13	2.93	1.2
Alkalis equivalent	-	-	2.42
Titanium oxide (TiO2)	-	-	1.2
Sulphur trioxide (SO3)	2.57	2.68	0.1
Loss on ignition	1.98	1.95	1.3
Bogue Potential Compound Composition			
Tricalcium silicate C3S	47.6	-	-
Dicalcium silicate C2S	17.9	-	-
Tricalcium aluminate C3A	7.7	-	-
Tretracalcium aluminoferrite C4AF	15.1	-	-

Table 1: Physical Properties & Chemical Analysis of the Cements & Fly Ash

C. *Mixture Proportions*

The proportions of the concrete mixtures are summarized in Table III to VIII. For the concrete mixtures of grade M20, a total weight of cementitious materials of approximately 350 kg/m^3 was used. For concretes of grade M40 and grade M60, total weights of cementitious materials of approximately 400 kg/m^3, and 450 kg/m^3 were used, respectively. Different proportions of fly ash were used in the concrete mixtures. For the different grades of concretes made with OPC, control concrete without fly ash, and mixtures incorporating 30, 40 and 50% fly ash as replacement for OPC were produced. For the M40 concrete, an additional mixture incorporating 55% fly ash was also made. This particular mixture is more similar to the typical high-volume fly ash concrete (HVFAC) mixture developed by CANMET. For the different grades of concrete made with PPC, a mixture was made using the PPC as is, and mixtures were made with partly replacing PPC with fly ash to bring the total proportion of fly ash in the cementitious materials content of the mixtures to 40, and 50%. Again an additional mixture was made with the total proportion of fly ash in the cementitious materials content of the mixture at 55%. To determine the percentage of replacement of PPC by fly ash in the mixtures made with the PPC to achieve the specific proportions of fly ash in the cementitious materials content (40, 50 and 55%), it was assumed that the PPC incorporated 30% fly ash.

The cementitious materials content was kept approximately constant for each grade of concrete. However, the water content, and to some extent, the dosage of admixture (either water reducer or super-plasticizer) were adjusted to get the target slump and similar strengths for all the concrete mixtures of the same grade. Consequently, the water-to-cementitious materials ratios of the mixtures varied depending on the percentage of fly ash used.

D. Preparation & Casting of Test Specimens

All the concrete mixtures were mixed in a laboratory drum concrete mixer. From each concrete mixture, a number of 150x150x150-mm cubes, 100x200-mm cylinders and 100x100x500-mm prisms were cast for the determination of the compressive, flexural and splitting tensile strengths. Two batches of the same concrete mixture were needed to make all the samples. The specimens were cast in two layers and were compacted using an internal vibrator. They were demolded after 24 hours, and were transferred to a water tank until required for testing.

E. Testing of the Specimens

The slump and the compressive, splitting tensile and flexural strengths were determined according to the Indian standard procedures.

III. RESULTS & DISCUSSION

A. Grade M20 Concrete Made with OPC

Table III shows the properties of fresh concrete of grade M20 concrete made with OPC and Garden Reach fly ash (30, 40 and 50% as replacement of cement by mass). The results show that the unit weight and slump of concrete ranged from 2445 to 2505 kg/m^3, and from 75 to 105 mm, respectively.

For similar total weight of cementing materials (350 kg/m^3) and similar range of slump, the increase of fly ash content from 30 to 50% decreased the water content from 165 to 149 kg/m^3, and the w/cm from 0.48 to 0.43 (Mix. 2 to 4), whereas the corresponding values for the control mixture without fly ash are 174 kg/m^3 and 0.50 respectively (Mix. 1).

B. Grade M40 Concrete Made with OPC

Table IV shows that the unit weight and initial slump of the concrete mixtures of grade M40 concrete ranged from 2405 to 2480 kg/m^{3}and from 105 to 120 mm, respectively.

The results show that for similar total weight of cementitious materials and similar range of slump, the increase of fly ash content decreases the water content and the w/cm of the concrete. For example, for concrete mixtures made with 400 kg/m^3 of cementitious materials, the increase of fly ash content from 30 to 50% decreased the w/cm from 0.36 to 0.32 to obtain a slump of about 100 mm (Mix. 6 to 8). The higher slump registered for HVFAC (Mix. 9) is mainly due to the higher dosage of the super-plasticizer.

The slump was reduced significantly after 30 minutes, and the reduction was similar for all mixtures. The high ambient temperature (around 30ºC) must have had a strong effect on the slump loss with time.

C. Grade M20 Concrete Made with PPC

Table VI presents the properties of the fresh concrete of grade M20 concrete made with PPC and different percentages of Garden Reach fly ash. The results show that the unit weight and initial slump ranged from 2370 to 2420 kg/m^3 and from 80 to 110 mm, respectively. As it was observed for the concrete made with OPC, the increase in the proportion of fly ash in the cementitious materials content reduced the water demand and the w/cm of the mixtures. However, to achieve similar slump, these concretes required higher water demand (higher w/cm) than the corresponding mixtures made with OPC (Table III). This is possibly due to the fact that the fly ash incorporated in the blended cement gets finer during the production of the PPC because of the intergrinding process with the clinker, which results in increased water demand compared to fly ash used as separate ingredient in the concrete mixer. Another possibility could be that the cement part itself of the PPC is slightly finer than that of the OPC; this would also result in higher water demand. A third possibility could also be that the percentage of fly ash in the PPC is a bit less than 30%. The value of 30% was based on information from the cement producer, and was used for the calculation of the percentage of replacement to achieve specific fly ash contents in the mixtures. In spite of the good control from the cement producer, there are probably some slight variations in the actual percentage of fly ash in the PPC. This would also influence the water demand of the cement. A combination of all the above factors is also possible.

Similarly to the OPC mixtures, all concretes showed significant slump loss after 30 minutes.

D. Grade M40 Concrete Made with PPC

Table XII shows the properties of the fresh concrete of grade M40 concrete made with PPC and different percentages of Garden Reach fly ash. The results show that the unit weight and initial slump of these concretes ranged from 2420 to 2480 kg/m^3 and from 95 to 125 mm, respectively. As observed for grade M20 concrete, these concrete mixtures required higher dosage of super-plasticizer and higher water demand to achieve similar slump as the corresponding mixtures made with OPC cement (Table IV). Once again, a significant slump reduction was observed after 30 minutes.

E. Grade M20 Concrete Made with OPC

1) Compressive Strength

Table IX shows that the 28 days compressive strength of the concrete of Grade M20 made with OPC ranged from 38.1 to 45.7 MPa. This shows that most of these concretes were over-designed, performing as Grade M35 or M40 concretes. The cementitious materials content could probably have been around 300 kg/m^3 instead of 350 kg/m^3, and still meet the M20 requirements.

The results show that the mixtures incorporating 30 and 40% fly ash as cement replacement, developed 28-day strength slightly higher than that of the control. The relatively high strength of these fly ash mixtures is partly due to their lower w/cm compared to that of the control mixture, resulting from the reduced water demand. The high strength level of the fly ash mixtures indicates also that the Garden Reach fly ash used in this project is quite reactive. At 91 days, these two fly ash mixtures showed strength values significantly higher than the control concrete. However both fly ash concretes had significantly lower compressive strength at early ages than the control. This was expected because it is well known that the reaction of fly ash is a slower process than the hydration of cement, resulting in a slower strength development of fly ash concrete compared to OPC concrete at early ages but faster at later ages. The concrete made with 50% fly ash showed a compressive strength somewhat lower than that of the control at 28 days and even at 91 days, and of course significantly lower at early ages. This indicates that the 50% fly ash mix was not properly designed to achieve the same 28-day strength as that of the control. However, the 50% fly ash concrete did meet the M20 requirement as well. Both the 40 and 50% fly ash mixtures had not set yet at one day. This is probably due to the retarding effect of the water-reducing admixture. The dosage of the admixture was probably too high for the amount of OPC in those two mixtures; it is mainly the amount of OPC that controls the setting time since the fly ash contribution to strength development at one day is negligible. Some results cannot be explained, for example the higher 56-day strength of the control mix compared to its 91-day strength; these are probably due to some experimental errors.

In general, the results show that it is possible to replace up to 50% of cement by fly ash and still develop adequate early age strength (3 days), 28-d compressive strength well above grade M20 requirements, and relatively high long-term strengths.

2) *Splitting Tensile & Flexural Strength*

Table X shows that the control and the 30% fly ash concretes developed similar splitting tensile and flexural strength at 28 and 91 days. The 40% fly ash concrete showed similar strengths at 28 days but higher strengths at 91 days when compared to the splitting tensile and flexural strength developed by the control concrete. On the other hand, the 50% fly ash concrete developed lower strengths at 28 days but similar strengths at 91 days as those of the control concrete.

F. *Grade M40 Concrete Made with OPC*

1) *Compressive Strength*

Table XI presents the compressive strength at 1, 3, 7, 28, 56 and 91 days of concrete of grade M40 made with OPC and Garden Reach fly ash. The table shows that the 28-day compressive strength of the concretes ranged from 48.8 to 58.9 MPa, which is above the requirements for grade M40 concrete.

The results show the same trend as that observed for concrete mixtures of Grade M20; the fly ash concretes developed lower early ages strengths, and generally higher strengths at later ages compared to those of the control concrete. The results also show that the 30 and 40% fly ash concretes developed significantly higher strengths at 28 days and beyond, while the 50% fly ash and the HVFAC (typical CANMET mix) developed similar strengths at 28 days and beyond, when compared to the strength values of the control concrete. This shows that it is possible to substitute up to 55% ordinary portland cement by Garden Reach fly ash and still obtain a concrete that develops acceptable early age strength, and similar or higher strengths at 28 days and at later ages compared to those of a concrete of grade M40 made with portland cement only.

G. *Splitting Tensile & Flexural Strength*

Table X shows that, in general, the control and the fly ash concretes developed similar 28-d splitting tensile strengths. At 91 days, the fly ash concretes developed higher splitting tensile strength. The flexural strength followed the same trend as that observed for splitting tensile strength, except that the 40% fly ash developed significantly higher 28-d flexural strength, and for some reasons, the HVFAC developed relatively lower 28 and 91-d flexural strengths than those of the control concrete.

H. *Grade M20 Concrete Made with PPC*

1) *Compressive Strength*

Table XI presents the 1, 3, 7, 28, 56 and 91-d compressive strength test results of grade M20 concrete mixtures made with PPC and Garden Reach fly ash. The results show that the 1-d compressive strength decreased significantly with increasing fly ash content. However, at 3 days and beyond, the increase in fly ash content did not significantly decrease the compressive strength. In fact, at 28 days all concretes developed similar compressive strength of about 40 MPa. As it was the case for grade M20 concrete made with OPC, this shows that these mixtures were over-designed for a concrete of grade M20, and the total cementitious materials could have been reduced.

It was already mentioned that the PPC used in this study contains about 30% fly ash from the same source at Garden Reach, Kolkata. When comparing the results of concretes made with PPC with those of similar grade of concrete but made with OPC (Table IX), it can be seen that in general, the use of PPC increased the early age strength (up to 7 days), and reduced the strength at 28 days and beyond. The slightly higher early-age strength up to 7 days of the PPC concrete is probably explained by the same possible reasons stated previously for the water demand: finer fly ash due to intergrading process, finer cement part of the PPC, slightly lower percentage of fly ash in the PPC than what was assumed, or a combination of those factors.

The results clearly show that it is possible to increase the proportion of fly ash in a given amount of cementitious materials by replacing part of PPC, and produce concrete having a performance comparable to that of a concrete that would incorporate the same amount of cementitious materials and the same proportion of fly ash as partial replacement for OPC.

2) *Splitting Tensile & Flexural Strength*

Splitting tensile and flexural strength of grade M20 concretes made with PPC (Table X) were found similar to the corresponding concretes made with OPC (Table X) both at 28 days and 91 days. However, there is a tendency of showing slightly higher values for samples made with PPC but that variation may be within the range of experimental deviations.

I. Grade M40 Concrete Made with PPC

1) Compressive strength

Table XI shows that the concrete mixtures of Grade M40 made with PPC developed 1, 28, and 91-d compressive strengths ranging from 11.6 to 20.8, 46.2 to 52.9, and from 55.5 to 61.3 MPa, respectively. These concretes comfortably met the strength requirement of grade M40. When comparing these results to those of corresponding concretes made with OPC (Table XI), it again appears that the use of PPC resulted in higher early-age strength (up to 7 days) and lower later-age strength. The increase in the early-age strength is again probably due to the reasons stated above. The decrease in the strength at later age is mainly due to the increased w/cm of the concretes made with PPC compared to that of the concrete made with OPC.

For the HVFAC that was made with similar w/cm of 0.32 in both cases (using OPC and PPC), it was observed that the use of PPC resulted in increased early-age strength and similar later-age strength.

2) Splitting Tensile & Flexural Strength

Table XI shows that the splitting tensile strength of the concrete was about 4 MPa at 28 days and about 4.5 MPa at 91 days. The 28 and 91-d flexural strengths ranged from 5.3 to 6.5 and from 6.5 to 8.0 MPa, respectively. When comparing these values to those of concretes made with OPC (Table XI), it appears that they are, in general, similar, except the 91-d flexural strength of the 40 and 50% fly ash concretes that were slightly higher for the concretes made with PPC.

Mix. No.	W/CM	Water, kg/m3	Cement, %	kg/m3	Fly Ash %	Coarse kg/m3	Agg, kg/m3	Fine Agg. kg/m3	W.R., * L/m3	Ambiant Temp., °C	Temp of Fresh Concrete, °C	Weight, kg/m3	Unit Initial	Slump, After 30 min.
1	0.50	174	100	348	0	0	1206	739	3.0	27.0	28.0	2465	75	40
2	0.48	165	70	241	30	103	1200	735	1.8	26.0	27.0	2445	105	70
3	0.46	162	60	212	40	141	1233	755	3.1	25.5	27.0	2505	105	50
4	0.43	149	50	174	50	174	1208	739	3.8	26.0	26.0	2445	95	90

Table 2: Mixture Proportions & Properties of Fresh Concrete of Grade M20 Concrete Made with OPC and Different Percentages of Fly Ash

* Water-reducing admixture

Mix. No.	W/CM	Water, kg/m3	Cement, %	Cement, kg/m3	Fly Ash %	Fly Ash kg/m3	Coarse Agg, kg/m3	Fine Agg. kg/m3	SP,* L/m3	Ambient Temp., °C	Temp of Fresh Concrete, °C	Unit Weight, kg/m3	Slump, Initial	After 30 min.
5	0.40	152	100	379	0	0	1117	759	5.5	29.5	31.0	2405	120	65
6	0.36	139	70	271	30	116	1144	773	4.9	30.0	31.0	2445	110	60
7	0.34	132	60	233	40	155	1148	775	4.6	30.0	31.0	2445	105	40
8	0.32	126	50	197	50	197	1168	789	4.6	30.0	31.0	2480	120	70
9	0.32	125	45	176	55	215	1148	779	4.9	30.0	31.0	2445	150	80

Table 3: Mixture Proportions & Properties of fresh Concrete of Grade M40 Concrete Made with OPC and Different Percentages of fly ash

* Superplasticizer

Mix. No.	W/CM	Water, kg/m3	Cement, %	Cement, kg/m3	Fly Ash %	Fly Ash kg/m3	Fly Ash * In total CM, %	Coarse Agg., kg/m3	Fine Agg. kg/m3	SP,** L/m3	Ambiant Temp., °C	Temp of Fresh Concrete, °C	Unit Weight, kg/m3	Slump, Initial	After 30 min.
14	0.52	172	100	332	0	0	30	1158	709	3.6	26.0	27.0	2370	80	45
15	0.48	164	86	293	14	48	40	1187	727	2.7	26.0	27.0	2420	95	60
16	0.46	158	71	244	29	99	50	1190	729	3.7	24.5	27.0	2420	110	65

Table 4: Mixture Proportions and Properties of Fresh Concrete of Grade M20 Concrete made with PPC and Different Percentages of fly ash

* Based on the assumption that the PPC contains 30% of fly Ash ** Super-plasticizer

Mix. No.	W/CM	Water, kg/m3	Cement,		Fly Ash		Fly Ash* In total CM, %	Coarse Agg., kg/m3	Fine Agg. kg/m3	SP,** L/m3	Ambiant Temp., °C	Temp of Fresh Concrete, °C	Unit Weight, kg/m3	Slump, Initial After 30 min.	
			%	kg/m3	%	kg/m3									
17	0.42	160	100	383	0	0	30	1134	765	6.8	30.0	31.5	2445	95	30
18	0.38	146	86	329	14	54	40	1136	767	5.7	31.0	32.5	2430	125	65
19	0.36	138	71	273	29	110	50	1133	766	5.5	30.0	31.0	2420	115	55
20	0.32	126	64	253	36	142	55	1166	792	5.8	24.5	27.0	2480	95	60

Table 5: Mixture Proportions And Properties of Fresh Concrete of Grade M40 Concrete Made With PPC And Different Percentages Of Fly Ash.

* Based on the assumption that the PPC contains 30% of fly ash ** superplasticizer

Mix No.	Cement, %	Fly Ash %	Fly ash in total CM, %	W/CM	Compressive Strength, MPa					
					1 day	3 days	7 days	28 days	56 days	91days
1	100	0	0	0.50	13.3	31.1	38.6	40.7	52.0	45.3
2	70	30	30	0.48	7.6	17.0	26.1	45.7	50.0	53.9
3	60	40	40	0.46	-	15.3	23.6	44.1	59.5	54.7
4	50	50	50	0.43	-	14.1	21.5	38.1	42.8	40.5

Table 6: Compressive Strength of grade M20 concrete made with OPC and different percentages of fly ash

Mix. No.	Cement, %	Fly Ash, %	Fly ash in total CM, %	W/CM	Splitting Tensile Strength MPa		Flexural Strength MPa	
					28 days	91 days	28 days	91 days
1	100	0	0	0.50	3.6	4.0	5.2	5.2
2	70	30	30	0.48	3.4	3.9	5.5	5.6
3	60	40	40	0.46	3.5	4.3	5.6	7.9
4	50	50	50	0.43	2.6	3.9	4.5	6.0

Table 7: Splitting Tensile and Flexural Strengths Test Results of Grade M20 Concrete Made with OPC and Different Percentages of fly ash

Mix No.	Cement, %	Fly Ash %	Fly ash in total CM, %	W/CM	Compressive Strength, MPa					
					1 day	3 days	7 days	28 days	56 days	91days
5	100	0	0	0.40	20.1	36.0	42.1	48.8	50.8	52.9
6	70	30	30	0.36	11.5	32.7	34.3	54.9	65.8	73.2
7	60	40	40	0.34	13.0	30.6	38.6	58.9	67.5	73.6
8	50	50	50	0.32	4.6	25.4	38.1	50.4	52.5	57.7
9	45	55	55	0.32	7.8	23.3	29.7	49.6	52.7	54.3

Table 8: Compressive Strength of Grade M40 Concrete Made with OPC and Different Percentages of fly ash

Mix. No.	Cement, %	Fly Ash, %	Fly ash in total CM, %	W/CM	Splitting Tensile Strength MPa		Flexural Strength MPa	
					28 days	91 days	28 days	91 days
5	100	0	0	0.40	3.5	3.7	5.3	6.8
6	70	30	30	0.36	3.7	3.8	5.5	7.4
7	60	40	40	0.34	4.3	4.9	6.5	7.5
8	50	50	50	0.32	3.9	5.1	5.9	7.3
9	45	55	55	0.32	3.7	4.4	4.8	5.8

Table 9: Splitting Tensile and Flexural Strengths Test Results of Grade M40 Concrete with OPC and Different Percentages of fly ash

Mix No.	Cement, %	Fly Ash %	Fly ash* in total CM, %	W/CM	Compressive Strength, MPa					
					1 day	3 days	7 days	28 days	56 days	91days

14	100	0	30	0.52	9.5	21.6	27.9	40.2	48.6	51.2
15	86	14	40	0.48	2.2	18.1	26.3	40.2	49.7	55.3
16	71	29	50	0.46	1.1	17.9	21.9	40.7	51.0	49.0

Table 10: Compressive Strength of Grade M20 Concrete Made with PPC and Different Percentages of fly ash

Mix. No.	Cement, %	Fly Ash, %	Fly ash in* total CM, %	W/CM	Splitting Tensile Strength MPa		Flexural Strength MPa	
					28 days	91 days	28 days	91 days
14	100	0	30	0.52	3.6	4.5	4.9	6.5
15	86	14	40	0.48	3.5	4.4	5.7	7.1
16	71	29	50	0.46	2.6	3.6	5.8	7.0

Table 11: Splitting Tensile and Flexural Strengths Test Results of Grade M20 Concrete Made with PPC and Different Percentages of fly ash

Mix No.	Cement, %	Fly Ash %	Fly ash* in total CM, %	W/CM	Compressive Strength, MPa					
					1 day	3 days	7 days	28 days	56 days	91days
17	100	0	30	0.42	20.8	31.9	37.6	46.2	48.1	57.4
18	86	14	40	0.38	19.0	29.8	37.8	52.4	52.2	61.3
19	71	29	50	036	11.6	26.6	34.0	51.0	56.8	60.3
20	64	36	55	0.32	12.2	28.7	31.6	52.9	59.6	55.7

Table 10: Compressive Strength of Grade M40 Concrete Made with PPC and Different Percentages of fly ash

Mix. No.	Cement, %	Fly Ash, %	Fly ash in* total CM, %	W/CM	Splitting Tensile Strength MPa		Flexural Strength MPa	
					28 days	91 days	28 days	91 days
17	100	0	30	0.42	3.7	4.5	5.3	6.5
18	86	14	40	0.38	4.3	3.4	6.5	8.9
19	71	29	50	036	4.6	3.7	5.6	8.0
20	64	36	55	0.32	3.9	n.a.	n.a.	n.a.

Table 11: Splitting Tensile and Flexural Strengths Test Results of Grade M40 Concrete Made with PPC and Different Percentages of fly ash

Based on the assumption that the PPC contains 30% fly ash

IV. CONCLUSION

Based on the results obtained from this study, the following conclusions can be drawn:

1) For similar Grade of concrete, similar range of slump, and similar cementitious materials contents, the water requirement and consequently the w/cm decreased with increasing fly ash content.
2) For similar slump and similar fly ash content, the w/cm decreased with increasing total weight of cementitious materials.
3) It is possible to design a concrete incorporating up to 50% fly ash that meets the strength requirement of grades M20, M40 and M60 concrete; such concrete will develop acceptable early age's strength, higher strength at later ages, and significantly lower chloride-ion penetrability compared to control concretes of similar grade made with OPC only.
4) It is possible to increase the proportion of fly ash in a given amount of cementitious materials by replacing part of PPC, and produce concrete having a performance comparable to that of a concrete that would incorporate the same amount of cementitious materials and the same proportion of fly ash as partial replacement for OPC.
5) For the same grade of concrete, the same total amount of cementitious materials, and the same proportion of fly ash, the use of PPC in combination with fly ash resulted in increased dosages of water reducer and super-plasticizer, and/or higher w/cm in order to achieve similar workability, compared to concrete in which blends of OPC and fly ash were used. This could be explained by a finer fly ash in the PPC due to inter-grinding process, finer cement part of the PPC, slightly lower percentage of fly ash in the PPC than what was assumed, or a combination of those factors.
6) The use of PPC resulted in increased compressive strength at early ages, but lower compressive strength at later ages. These changes were more significant for higher grades of concrete. The slightly different behavior in strength development of the concrete made with PPC compared to that of concrete made with OPC could be due to the same reasons stated for the difference in the water demand of the two types of concrete.

REFERENCES

[1] V.M. Malhotra, Superplasticized Fly Ash Concrete for Structural Applications, Concrete International 8 (12) (Dec. 1986) 28-31.

[2] G.M. Giaccio, and V.M. Malhotra, Concrete Incorporating High Volumes of ASTM Class F Fly Ash, Cement, Concrete and Aggregates 10 (12) (1988) 88-95.

[3] V.M. Malhotra, and K.E. Painter, Early-Age Strength Properties and Freezing and Thawing Resistance of Concrete Incorporating High Volumes of ASTM Class F

Fly Ash, The International Journal of Cement Composites and Lightweight Concrete 11 (1) (1989) 37-46.

[4] W.S. Langley, G.G. Carette, and V.M. Malhotra, Structural Concrete Incorporating High Volumes of ASTM Class F Fly Ash, ACI Materials Journal 86 (5) (1989) 507-514.

[5] Sivasundaram, G.G. Carette, and V.M. Malhotra, Properties of Concrete Incorporating Low Quantity of Cement and High Volumes of Low Calcium Fly Ash, ACI SP-114, 1 (1989) 45-71 (ed.: V.M. Malhotra).

[6] Sivasundaram, G.G. Carette, and V.M. Malhotra, Long-Term Strength Development of High-Volume Fly Ash Concrete, Cement and Concrete Composites 12 (4) (1990) 263-270.

[7] Sivasundaram, G.G. Carette, and V.M. Malhotra, Mechanical Properties, Creep, and Resistance to Diffusion of Chloride Ions of Concrete Incorporating High Volumes of ASTM Class F Fly Ashes from Seven Different Sources, ACI Materials Journal 88 (4) (1991) 407-416.

[8] M.M. Alasali, and V.M. Malhotra, Role of Concrete Incorporating High Volumes of Fly Ash in Controlling Expansion due to Alkali-Aggregate Reaction, ACI Materials Journal 88 (2) (1991) 159-163.

[9] Bilodeau, and V.M. Malhotra, Concrete Incorporating High Volumes of ASTM Class F Fly Ashes: Mechanical Properties and Resistance to De-Icing Salt Scaling and to Chloride-Ion Penetration, ACI SP-132, 1 (1992) 319-349 (ed.: V.M. Malhotra).

[10] G.G. Carette, A. Bilodeau, R.L. Chevrier, and V.M. Malhotra, Mechanical Properties of Concrete Incorporating High Volumes of Fly Ash from Sources in the U.S., ACI Materials Journal 90 (6) (1993) 535-544.

[11] Bilodeau, V. Sivasundaram, K.E. Painter, and V.M. Malhotra, Durability of Concrete Incorporating High Volumes of Fly Ash from Sources in the U.S., ACI Materials Journal 91 (1) (1994) 3-12.

[12] Bilodeau, and V.M. Malhotra, High-Volume Fly Ash System: Concrete Solution for Sustainable Development, ACI Materials Journal 97 (1) (2000) 41-48.

[13] V.M. Malhotra, Making Concrete “Greener” With Fly Ash, Concrete International, 21 (5) (1999) 61-66.

[14] D.Lu, R. Chevrier and N. Bouzoubaa, Investigations of Fly Ash concrete using Indian Materials, Material Technology Laboratory, MTL 2004-9 (TR-R), July 2004.