11-3 High performance, high volume fly ash concrete

It should be obvious that large scale cement replacement in concrete with these industrial by-products will be highly advantageous from the stand point of cost, economy, energy efficiency, durability, and overall ecological and environmental benefits.

Chapter1: Role of Fly ash in sustainable development

- Introduction
- With the beginning of the 21st century, the public focus is shifting in favor of an era of sustainable development.
- We would be able to meet the projected cement demand in the near future without any increase in the installed capacity of portland cement production that is already there.

Obstacles preventing high rates of utilization of fly ash in the cement and concrete industries

- The obstacles as well as some of the emerging technologies to overcome these obstacles are discussed below.
- Variable quality of fly ash
- Large variation in the chemical composition of fly ashes is natural.
- Fortunately, however, the the pozzolanic properties of fly ash are not governed so much by the chemistry but by the mineralogy and particle sizes of the ash

Effect of fly ash on strengthening and durability of concrete

- The ultimate compressive and tensile strength of concrete mixture made with partial replacement of cement with fly ash are almost always higher than those of plain portland cement concrete.
- The recent development of super plasticized concrete mixtures containing 50-60% fly ash by mass of the total cementious material, but give high strength and durability at relatively early ages.
- Well cured concrete containing large amounts of fly ash not only gives very low permeability and fewer cracks due to thermal and drying shrinkage effects, but also provides excellent protection against expansive chemical reactions, such as sulfate attack and the alkalis-silica reaction.

Specifications and codes

- In most countries, the specifications for blended cement are “perspective” in the sense that a maximum permissible limit of the blending component material is specified in the blended portland cement.
- Obviously after the advent of the “super-plasticized high volume fly ash concrete system” that is able to produce concrete products of high early and high durability, the specifications and codes restricting the amount of fly ash in concrete do not make sense.

Environmental impact of toxic metals in fly ash

- All fly ashes contain very small amount of toxic metals that are leach able.
- (Arsenic (As), chromium (Cr), selenium (Se), titanium (Ti) and vanadium (Va))
- However, incorporation of fly ash into concrete solves this problem because hydration products of both portland cement and blended cement can form complexes that permeability tie up the toxic cations released by fly ash.

Chapter 2: what is fly ash? How does it work to improve properties of concrete?

- The source:
- Depending upon the grade of coal, substantial amount of non-combustible impurities from 10-40% are usually present in fly ash in the form of clay, shale, quartz, feld spar, dolomite, and limestone.

- As the fuel travels through the high temperature zone in the furnace, the volatile matter and carbons are burnt off, whereas most of the mineral impurities are carried away by the flue gas in the form of ash.
- The ash particles get fused in the combustion zone of the furnace.
- Upon leaving the combustion zone, the molten ash is cooled rapidly (e.g. from 1500C to 200C in a few seconds) and solidifies as spherical

- Some of the fused matter agglomerates to form bottom ash, but most of it flies out with the flue gas stream and is, therefore called fly ash.
- Typically the ratio of fly ash to bottom ash is 70:30 in wet bottom boilers or 85:15 in dry bottom boilers.
- The fly ash from modern thermal plants generally does not need any processing before use as a mineral admixture for concrete.

Chemical composition

- Typical oxide analyses of some North American fly ash are shown in Table 2.1.
- There are considerable differences in the chemistry of fly ashes.
- In general, fly ashes from the combustion of bituminous coals contain a low amount of calcium; on the other hand, sub-bituminous and lignite coal ashes typically contain more than 10% CaO.

Table 2.4 - Chemical Requirements for Fly Ash for Use in Portland-Cement Concrete

	Canada CSA-A23.5		U.S. ASTM C 618	
	Type F	Type C	Class F	Class C
Free moisture, max. %	*	*	3.0	3.0
Loss on ignition, max. %	12.0	6.0	6.0^{+}	6.0
(SiO_2+Al_2O_3+Fe_2O_3), min. %	–	–	70	50
CaO, max. %	–	–	–	–
SO_3, max. %	5.0	5.0	5.0	5.0

Mineralogical composition

- The pozzolanic activity of a fly ash is greatly influenced by the amount and composition of the grassy phase present.
- Fly ashes from super-thermal stations typically contain 60-90% glass.
- Low calcium fly ashes from bituminous coals contain alumino-silicate glass that seems to be somewhat less active than the calcium-alumino-silicate glass present in the high-calcium fly ashes.
- The high calcium fly ashes exhibit both cementitious and pozzolanic properties, and some show a rapid set unless it is retarded by gypsum or other additions

Particle characteristics

- In general, the mechanisms are dependent more on the size, shape, and texture of the particles than on the chemical composition.
- For instance, the water demand and workability are controlled by particles size distribution, particles packing effect, and smoothness of surface texture.
- Typically the pozzolanic activity of a fly ash is proportional to the amount of particles under 10um whereas particles larger than 45um show a little or no pozzolanic property.

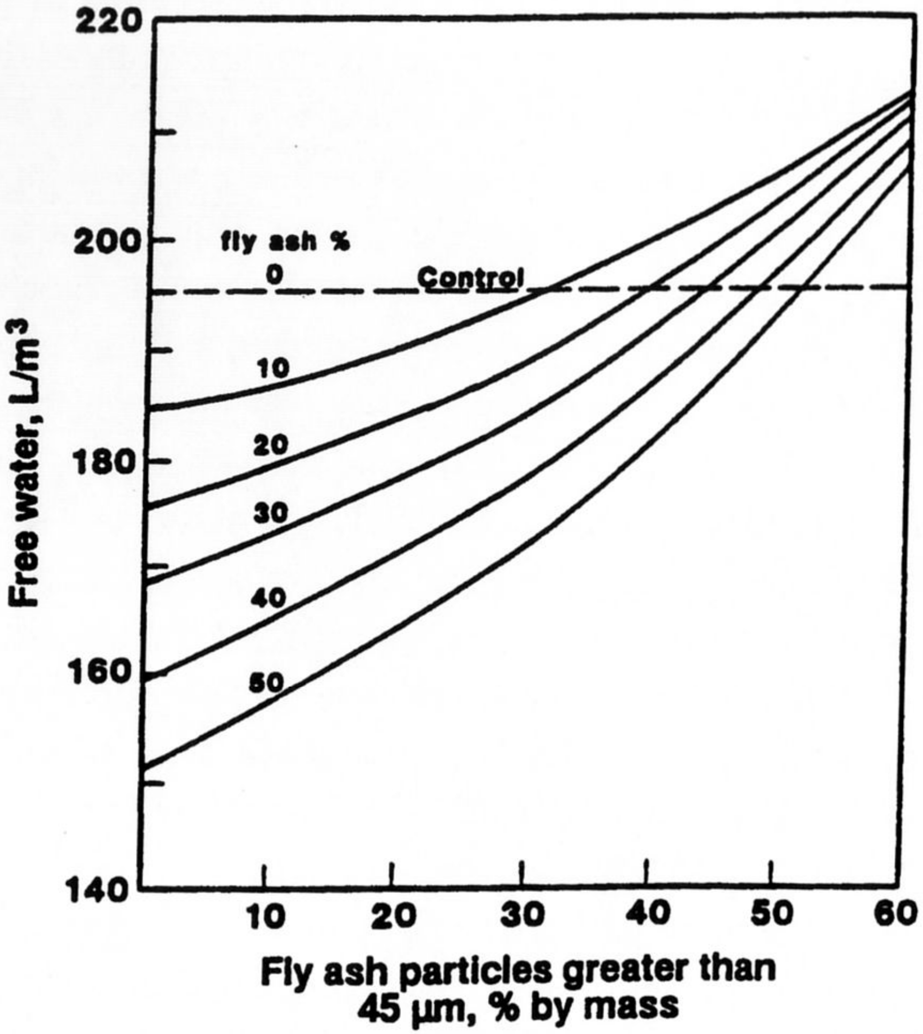

Fig. 2.3. Influence of coarse particulate content of fly ash on the water required for equal workability in concrete.
From: Owen, P.L., "Fly Ash and Its Usage in Concrete"; Journal, Concrete Society, U.K., Vol. 13, No. 7, pp. 21-26, 1979.

- Fly ash particles are spherical in shape, and this has a positive effect on the water requirement and workability of concrete mixtures.
- Mechanisms by which fly ash improves the properties of concrete
- Among the properties that are favorably affected are the rheological behaviors of fresh concrete mixtures.
- Resistance to chemical attack and thermal cracking are the two major benefits in concrete durability of hardened concrete.

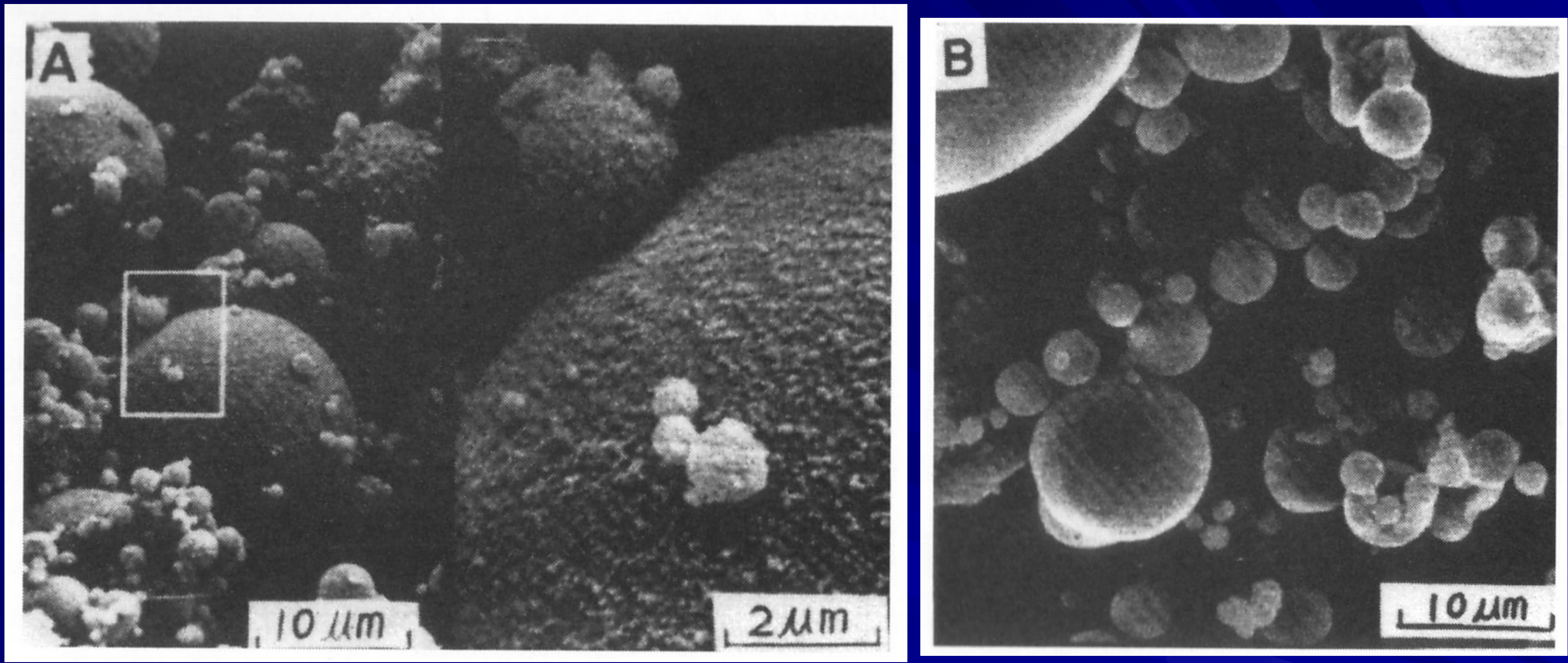

Fig. 2.1. Scanning electron micrograph: (A) ASTM Class C, (B) ASTM Class F fly ash.

Fly ash as a water reducer

- Too much mixing water is probably the most important cause for many problems.
- Why typical concrete mixtures contain too much mixing water?
- Firstly, typical mixtures do not have an optimum particle size distribution, and this accounts for the undesirably high water contents.
- Secondly, much larger amount of water than necessary for the hydration of cement have to be used because portland cement particles, due to the presence of electric charges on the surface, tend to form flocks that trap large volumes of the mixing water.

- It is generally observed that a partial substitution of portland cement by fly ash in a mortar or concrete mixture reduces the water requirement for obtaining a given consistency.
- Up to 20% reduction can be achieved.
- Firstly, fine particles of fly ash get adsorbed in the oppositely charged surfaces of cement particles and prevent them from flocculation.
- Secondly, the spherical shape and smooth surface help to reduce.
- Thirdly, the “particle packing effect” is also responsible for reduced water demand. Due to its lower density and higher volume per unit mass, fly ash is a more efficient void filler than portland cement.

Drying shrinkage

- Perhaps the greatest disadvantage associated with the use of portland cement concrete is cracking due to drying shrinkage.
- Due to a significant reduction in the water requirement, the total volume of the cement paste in the HVFA concrete is 25% as compared to 29.6% for the conventional portland cement concrete which represents a 16% reduction in the cement paste volume.

Water-tightness and durability

- HVFA concrete mixtures, when properly cured, are able to provide excellent water tightness and durability.
- With the progress of the pozzolanic reaction, a gradual decrease occurs in both the soze of the capillary pores and the crystalline hydration products on the transition zone, thereby reducing its thickness and eliminating the weak link in the concrete microstructure.

Thermal cracking

- Further, there is considerable construction activity now in the hot-arid areas of the world where concrete temperature in excess of 60 degree are not uncommon within a few days of concrete placement.
- For instance, a 40MPa concrete mixture containing 350Kg/m3 portland cement can raise the temperature about 55-60 degree within a week if there is no heat loss to the environment.
- However, with a HVFA concrete mixture containing 50% cement replacement with a Class C fly ash, the adiabatic temperature rise is expected to be 30-35 degree.

Chapter 3: What is high performance, high-volume fly ash concrete?

- The primary aim in the use of fly ash has been to reduce the heat of hydration since 1930’s.
- In recent years, large volumes of fly ash have been incorporated into the construction of roller compacted concrete, but the low early-age strengths are not of concern.
- For structural concrete requiring high-early strength, the water content of fly ash concrete mixtures can be reduced with the help of a super-plasticizer.

Definition (high volume fly ash concrete)

- This concrete has a very low water content and at least 50% of the portland cement by mass is replaced with ASTM Class F fly ash.
- Because of the low water content, a high-range water reducer (superplasticizer) is used generally to achieve slumps ranging from 150 to 200mm.
- In the cases, where high early strength and high slump are not required, the use of a superplasticizing admixture is not necessary.

- Specifically speaking, the following characteristic define the high performance HVFA concrete.
- \- Minimum of 50% fly ash by mass of the cementitious materials must be maintained.
- \- Low water content, generally no more than 130 kg/m3 is mandatory.
- Cement content no more than 200kg/m3 is desirable.

Chapter4: Concrete mixture proportions

- Typical mixture proportions of super-plasticized high performance HVFA concrete.
- For the first trial batch the typical suggested mixture proportion are shown in table 4.1.
- High performance HVFA concrete without a super-plasticizer
- These are shown in another table4.2.

Table 4.1. Typical Mixture Proportions for High-Performance, High-Volume Fly Ash Concrete

Typical Mixture Proportions, kg/m³			
	Low Strength 20 MPa, at 28 days	Moderate Strength 30 MPa, at 28 days	High-Strength, 40 MPa, at 28 days
Water	120-130	115-125	115-120
ASTM Type I/Type II Cement*	125-130	155-160	180-200
ASTM Class F Fly Ash	125-130	215-220	220-225
Coarse Aggregate (19 mm max.)	1170±10	1200±10	1110±10
Fine Aggregate	800±10	750±10	750±10
Air-Entraining Admixture	**	**	**
Superplasticizer	***	***	***

Table 4.2. Mixture Proportions and Strength Development Rates of Pumpable, HVFA Concretes without a Superplasticizer, kg/m^3

	#1	#2	#3	#4	#5	#6	#7
ASTM Type I Portland Cement	150	160	160	180	195	195	170
ASTM Class F Fly Ash	150	160	217*	180	195	195	170
Total Water Content	133	120	141	136	133	130+	135
Water/Binder	0.44	0.37	0.37	0.38	0.34	0.33+	0.40
Coarse Aggregate (25 mm MSA)	1130	1170	1179	1160	1130	1080	1110
Fine Aggregate	890	830	735	790	720	770	800
ASTM Type A, Water Reducer	√	√	√	√	√	√	√
Compressive Strength, MPa							
7-days	11	13	15	18	22	20	36
28-days	19	22	25	25	37	32	45
60-days	25	27	31	28	–	37	–
90-180 days	–	36	46	35	–	–	–

Note: Mixtures No. 1-5 were used for foundations and footings of residential and commercial buildings in the San Francisco Bay Area; Mixture No. 6 was used for the foundation of the Liu Centre at the University of British Columbia in Vancouver, and Mixture No. 7 for the Computer Science Building at York University in Toronto.

*The fly ash in Mix No. 3 is a composite of 187 kg fly ash and 30 kg rice-husk ash; thus the binder is composed of 50% fly ash, 8% rice-husk ash, and 42% Portland cement.

+Mix No. 6 contains an air-entraining admixture that has the effect of lowering the water requirement and strength.

Chapter5: Properties of fresh and hardened concrete

- Properties of fresh concrete
- Slump: The slump can be adjusted by varying the dosage of a super-plasticizer.
- It is always advisable to use only a single supplier of chemical admixtures.
- Air content:: In general, there is no difficulty. However, occasionally one may run to difficulty when the carbon content is high. In such cases, one should consider changing the source of fly ash or the brand of the air entraining admixture.
- Bleeding: Because of the low water content, the bleeding is very small. It is therefore very important that the curing of the concrete be commenced as soon as possible.
- Time-of-set: The somewhat delayed setting of the high performance HVFA concrete can be beneficial in hot weather because it allows more time for transporting and placing concrete.
- Autogenous temperature rise: The rise is smaller compared to that in OPC.

Properties of hardened concrete

- Adequate early strength and later age strength can be achieved with proper selection of the cement type and amount.
- The one day strength is of the order of 6 to 8 MPa (larger than 5MPa).
- Water permeability is very low.
- HVFA concrete can effectively reduce the expansion due to ASR.

Chapter6: HVFA concrete-construction practice, placement, consolidation, finishing, curing, and testing

- Due to the high volume of fines and low water content, HVFA concrete is generally very cohesive and no tendency for bleeding and segregation.
- As HVFA concrete shows little bleeding, the flatwork surfaces immediately after the finishing operation must be protected against water loss by covering these with a heavy plastic sheet.
- Unless these precautions are taken, HVFA concrete would be prone to plastic shrinkage cracking especially in hot and windy weather.

- It is necessary to provide proper curing, I,e. proper temperature and humidity conditions for a minimum period of 7 days.
- Due to differences in the curing temperature and humidity, the actual strength of concrete on a structure will not be the same as the strength of laboratory or even field cured cylinders.

Chapter7: Case histories of the use of HVFA concrete in Canada and the USA

- Hotels, Wharf development, Shotcrete, Building, Seismic rehabilitation, Temple

Chapter8: Summary

- The HVFA concrete offers a holistic approach to the problem of of meeting increasing demands for concrete in the future, enhancement of durability and sustainability of concrete structures at reduced or no additional cost, and ecological disposal of large quantities of the waste from coal fired power plants.