UNITED KINGDOM QUALITY ASH ASSOCIATION

Technical Datasheet

High Volume Fly Ash Concrete (HVFA)

Introduction

The most important challenge facing the cement and concrete industry is how best to meet the housing and infrastructural needs of society in a sustainable manner. HVFA can address the environmental concerns by minimising the proportion of Portland cement (CEM I) in a concrete mix and maximising the proportion of fly ash, thereby reducing the overall CO_2 emissions associated with producing concretes.

Figure 1 - HFCC laid at Didcot Power Station in 1981
Apologies for lack of Health and Safety equipment

Concrete containing a high percentage of fly ash by mass of total cement content has been used in the UK and elsewhere for around 35 years. This type of concrete has become known as high volume fly ash content concrete with various terms, notably including, High Fly Ash Content Concrete (HFCC) and High Volume Fly Ash concrete (HVFA).

From the literature available[i], it has been found that the cementitious proportion containing fly ash in HVFA can vary from 30 to 85% for different applications. It is generally accepted that the definition of "high volume fly ash" concrete is that which has a minimum of 50% fly ash by mass of the cementitious materials. Because of the low water content requirement of HVFA, a high-range water reducer is also used to achieve appropriate consistency (workability).

The Benefits of Using HVFA Concrete

There are many benefits to using HVFA concrete for appropriate applications:

- Improved workability.
- Reduced bleeding, heat of hydration, and permeability.
- Higher ultimate strength.
- Increased durability.
- Lower CO_2 emissions and greater sustainability.

Examples of the use of HVFA

There are numerous examples of HVFA concretes being used for a considerable numbers of years. In the UK a series of trials using HVFA, then called HFCC, took place at Didcot Power Station (1981) – see Figure 1, slipways at the Mumbles(1983), Grangetown Link (completed 1988) and Wincanton Sewage Works (1984)[ii]. These were subjected to a series of tests after ten years of service including compressive strength, depth of carbonation, permeability and chloride and sulphate penetration profile. The researchers concluded that HFCC could be used in structural concrete applications exposed to sulfate and chloride attack. Some thirty years on these concretes are still there and performing well.

Malhotra and Mehta[iii] report on over 20 projects in the USA, Canada and India where HVFA concrete has been used successfully. The concretes used span a wide range of applications, e.g. 50MPa columns, piles, shotcrete, slabs, etc covering the full range of structural elements. As an example, Figure 2 shows the Hindu Temple on Kauai Island, Hawaii where the massive structural slab contained 57% fly ash, with the peak temperature of 40C being recorded producing an homogenous crack free microstructure concrete being reported.

Using Fly Ash in HVFA

There are three main ways of using fly ash within a HVFA concrete mix:

- **Using pre-blended cement:** Pre-blended CEM II and CEM IV/B-V can be obtained complying with BS EN197-1: Common cements (Table 1). They are available from cement suppliers either in bulk tankers or in bags. However, this will only take you to 55% of cementitious content and just within the HVFA range.
- **Mixing cement and fly ash in a mixer:** Blending cement and fly ash together in a mixer when making concrete based on designed mix proportions. Fly ash to EN 450 and cements to EN 197-1 are widely used throughout the UK and a wide range of proportions are possible in this manner.

- **Using fly ash as filler aggregate or sand:** Fly ash can be obtained from various fly ash producers complying with EN13055-1, Lightweight aggregates for concrete, which as a Type II addition can be used as a filler aggregate in concrete. This is an alternative method of using fly ash without the compliance requirements associated with EN450 or EN197-1. However, this filler material cannot be counted towards the cementitious content of the mix, but it will still be effective in giving the benefits as indicated above.

Admixtures: Two main types of admixture are commonly used with HVFA, namely super plasticisers and air-entrainers. Super plasticisers are used to achieve the desired consistency (workability) at a low water binder ratio. They include sulphonated, naphthalene-formaldehyde condensate super plasticisers or polycarboxylate based high-range water reducers. The dosage of these admixtures varies noticeably depending on the type of fly ash used. A synthetic resin-type air entraining admixture is also widely used with HVFA at a dosage determined by various factors, such as cement fineness and fly ash quality, in particular its loss-on ignition value.

Placing, bleeding, shrinkage, etc: Whilst it should be feasible to design HVFAC mixes to comply with required performance, there can be some limitations to this. In general, due to the high volume of fines and low water content, fresh mixes of HVFA concrete are very cohesive and show little or no bleeding and segregation. They show excellent flowability and pumpability. Consequently, the surface finish is usually smooth and without honeycombing. To avoid possible plastic shrinkage cracking as well as autogenous shrinkage cracking, HVFA surfaces must be protected from any water loss during placement. It was found, during field trials, that HVFA concrete could be produced and placed successfully using normal concreting techniques including pumping.

Types of common cement	Notation	Fly Ash composition, % by mass of cement
Portland fly ash cement	CEM II/A-V	6 to 20%
	CEM II/B-V	21 to 35%
Portland composite cement	CEM II/A-M	6 to 20%
	CEM II/B-M	21 to 35%
Pozzolanic cement	CEM IV/A	11 to 35%
	CEM IV/B	36 to 55%*
Composite cement	CEM V/A	18 to 30%
	CEM V/B	31 to 50%*
	High Volume Fly Ash formulation	
High Volume Fly Ash (HVFA)*	CEM IV/B + fly ash as filler aggregate	>55 to 85% of total binder including filler content
* Defined as HVFA concrete when ≥50% fly ash incorporated		

Table A - Cement types conforming to EN197-1

Curing: The need for adequate curing cannot be over-emphasized for HVFA concrete. A relatively longer moist-curing or leaving the form work in place for at least a week is essential to achieve the optimum strength and durability characteristics that are possible from HVFA concrete.

Figure 2 – HVFA was used for a massive, monolithic foundation slab at the Hindu Temple, Kauai Island, Hawaii, 1999

It has been generally considered that HVFA has a considerably greater susceptibility to poor curing than Portland cement concrete. Dry ambient conditions greatly reduce the strength potential of fly ash as pozzolanic reactions fail to contribute to the development of strength. The provision of moist curing is beneficial from the standpoint of gradual gain in strength, as well as reduction of plastic shrinkage and drying shrinkage-cracking. The setting and hardening rates of HVFA concrete at early age are slower, especially under cold weather conditions. An extended hydration period makes the material more sensitive to curing conditions. The steam curing appears to decrease significantly the expansion of fly ash mortars (all FA percentages), due to the reaction of free lime with water.

Mix Design Considerations and Constructions

Table B shows typical mix proportions for different strength levels along with a typical range of component materials for different levels of strength in high-performance HVFA concrete. Embodied CO_2 estimates are given, excluding the aggregates and admixtures these would indicate a typical reduction in embodied CO_2 of ~50% in comparison with equivalent concretes containing 100% CEM I.

Strength (MPa)	Low (20MPa @28 days)	Moderate (30MPa @ 28 days)	High (40MPa @ 28days)
28 days	20	30	40
90 days to 1 year	40	50	60
Typical mix proportions			
Water	120-130	115-125	100-120
Cement (CEM I)	100-130	150-160	180-200
Fly ash (EN450 or filler)	125-150	180-200	200-225
Water/binder ratio	0.40 – 0.45	0.33 – 0.35	0.30 – 0.32
Embodied CO_2 from binders (See Datasheet 8.3 and 8.4)	108 kg CO_2/m^3	145 kg CO_2/m^3	178 kg CO_2/m^3
Super-plasticiser*	As required to achieve W/C ratio and as recommended by the manufacturer. Typically dosages of ~3l/m^3 or more will be required.		
* The environmental impact of super plasticiser is ~0.72 kg CO_2/kg, or typically between 2 and 4 kg CO_2 per m^3 of HVFA concrete. See **http://www.admixtures.org.uk/** for more detailed information and environmental performance declarations.			

Table B - Typical cementitious contents of HVFA concretes

Performance and durability: To obtain the high performance of HVFA concrete, it is recommended that the water to binder ratio be kept low. At low water to binder ratio, workable HVFAC is achieved by using a combination of methods, such as taking advantage of the super plasticising effect of fly ash itself when used in a large volume, the use of a chemical super plasticiser, and a judicious aggregate grading. Consequently, properly cured high-volume concrete products are very homogenous in microstructure, virtually crack-free, and highly durable.

Durable concretes can be made with high volume fly ash and in some respects the potential durability is greater than for normal Portland cement concretes of the same grade. This is due to both, continued hydration of the fly ash which subsequently reduces the porosity and permeability characteristics of the paste structure and modified chemistry of the cement matrix. However, carbonation of HVFA concrete is an issue with conflicting results being found in the literature and indeed carbonation depths could be substantially higher than the corresponding Portland cement concrete. Extended moist curing seems to be the key to minimise permeability and reduce any carbonation problems, but an increase in carbonation depth will need to be allowed for in the design in comparison with Portland cement concrete.

Typical Characteristics of HVFAC

Based on the literature survey[i], compared to conventional Portland cement concrete, typical properties of HVFA concrete can be summarized as follows:

- Improved flowability, pumpability, and compactability, leading to smoother surface finish and quicker finishing time.
- Total amount of bleed water is low or negligible for high volume fly ash concrete. The setting time of HVFA concrete, in general, is longer than that of a conventional concrete made using Portland cement alone. This is due to the low cement content, the slower reaction process of fly ash, and the high dosage of super plasticiser required.
- Due to low cement content, autogenous temperature rise in high volume fly ash concrete is rather low.
- The need for adequate curing is crucial for high-volume fly ash concrete to ensure satisfactory early and later-age strength development, low permeability, and long term resistance to aggressive media. It is essential that the HVFA concrete be protected from premature drying.
- Early-strength up to 7 days can be accelerated with suitable changes in the mix design when earlier removal of formwork or early structural loading is desired.
- Later strength gain between 28 days and 90 days and beyond is due to pozzolanic reaction.

- Good dimensional stability and resistance to cracking from autogenous shrinkage, and drying shrinkage. However, in unprotected concrete there is a higher tendency for plastic shrinkage cracking.
- Very high durability in terms of reinforcement corrosion, alkali-silica expansion, and sulfate attack.
- Superior environmental advantages due to ecological utilization of large quantities of fly ash, reduced CO_2 emissions, and enhancement of resource productivity of the concrete construction industry.

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[i] High Volume Fly Ash: Literature Search, Applying Concrete Knowledge & J. Bai, Senior Lecturer, University of Glamorgan, UK. 18 June 2011 on behalf of the UKQAA.

[ii] Investigation into the Long-Term In-Situ Performance of High Fly Ash Content Concrete Used for Structural Applications by M.R.H. Dunstan, M.D.A. Thomas, J.B. Cripwell, and D.J. Harrison, Volume 1, ACI SP-132, 1993

[iii] High Performance, High Volume Fly Ash Concrete for building sustainable and durable structures, V M Malhotra and P K Mehta, Third Edition, 2008, Published by Supplementary Cementing Materials for Sustainable Development Inc., Ottawa, Canada