UNITED KINGDOM QUALITY ASH ASSOCIATION

TECHNICAL DATASHEET 1.0

Fly Ash for concrete

Introduction

Fly ash has both pozzolanic and physical properties that enhance the performance of concrete. When Portland cement hydrates it produces quantities of alkali calcium hydroxide (lime). Pozzolanas like fly ash react with this lime to form stable calcium silicate and aluminate hydrates. These hydrates fill the voids within the concrete, removing some of the lime and thus reducing the permeability. This process improves the strength, durability, chloride and sulfate resistance of the concrete. The pozzolanic reaction occurs relatively slowly at normal temperatures enhancing strength in the longer term relative to normal Portland Cement (CEM I) concrete (Figure 1).

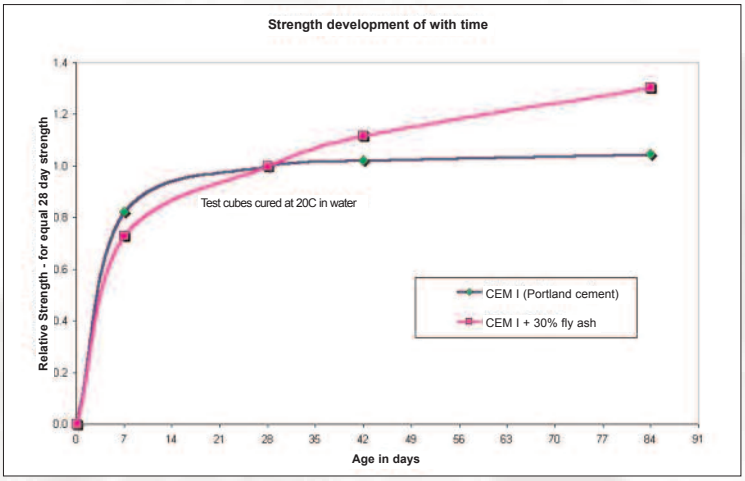


Figure 1 - The relative strength gain properties of fly ash concrete

The finer fraction of fly ash, i.e. those particles that pass the 45μm sieve, act as a solid particulate plasticiser. These particles are spherical (Figure 2) and act like ball bearings within the concrete reducing the water requirement for a given workability. A reduction in the water content lowers the permeability and increases strength and durability. In addition the concrete is more cohesive, has a lower rate of bleeding and is less prone to segregation.

Fly ash readily reacts with sodium and potassium alkalis within the concrete. If there is 25% or more of fly ash within the cement content of a mix the high alkalinity from these metal alkalis is quickly reduced. Any risks of alkali silica reaction are significantly reduced if not completely eliminated.

The advantages of using fly ash in concrete can be summarised as follows:

- ***Improves long term strength performance and durability.***
- ***Reduces permeability, which reduces shrinkage, creep and gives greater resistance to chloride ingress and sulfate attack.***
- ***Minimises the risk of alkali silica reaction.***
- ***Reduces the temperature rise in thick sections.***
- ***Makes more cohesive concrete that has a reduced rate of bleeding, is easier to compact, gives better pumping properties and improves the surface finish of the finished structure, e.g. when used in Self Compacting Concrete.***

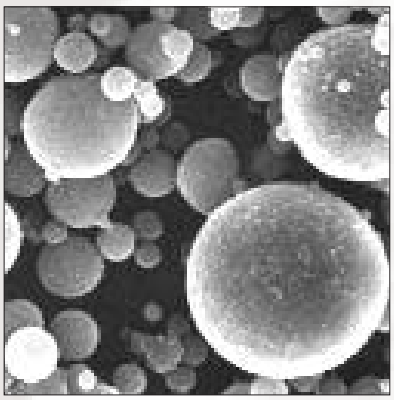


Figure 2 - Micrograph of fly ash

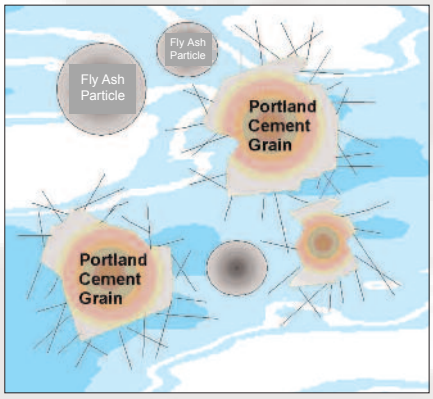
Using fly ash within your concrete

Fly ash can be used in site mixed, readymixed and pre-cast concrete. There are a number of differing ways of incorporating it within a concrete mix.

Pre-blended cement. Pre-blended CEM I and fly ash cement can be obtained complying with BS EN197-1 - Common cements. These cements are CE marked. CEM IIA-V contains between 6 to 20% fly ash, CEM IVA and VLH IVA can contain 11 to 35% fly ash and CEM IIB-V contains between 21 to 35% fly ash. CEM IV-B and VLH IVB[1] can contain up to 55% fly ash. These cements are more suitable for low heat applications. The proportion of fly ash in pre-blended cements is factory controlled by the manufacturer and full quality assurance certification is available. They can be supplied either in bulk tankers or in bags. Special blends of fly ash with other materials are catered for at some works by special arrangement.

[1] BS EN 14216 “Cements - Composition, specifications and conformity criteria for very low heat special cements”

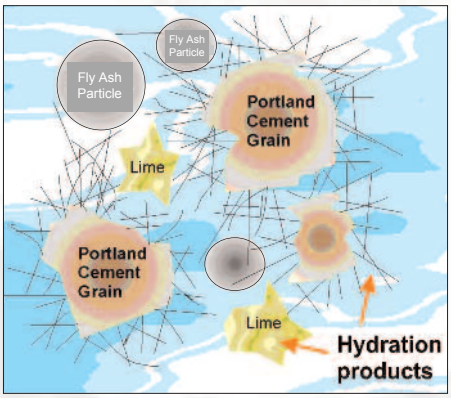
Mixer blended fly ash. A quality assured fly ash can be obtained complying with BS EN450 Category S or N. These are stored in separate silos to the CEM I and blended by the concrete producer in the concrete mixer. The suppliers of fly ash are able to provide certification for all the commonly available Portland cement and fly ash combinations used throughout the UK.



When water is added to Portland Cement crystalline hydration products appear

There are two ways of using mixer blended BS EN450 Category S and N Fly Ash as counting towards all or part of the cementitious content.

- ***BS EN450 Category S fly ash***. This standard restricts the fineness of the fly ash to a maximum of 12.0% retained on the 45μm sieve, which is achieved by classifying the ash. In addition the Loss On Ignition (LOI) is limited to a maximum of 7% (category A or B). These requirements ensure the optimum water reducing, reactivity and consistency properties are achieved within the concrete. Water reductions vary between 6% and 12% when compared to CEM I only concrete of the same cement content. Normally 25% to 55% of the cementitious content would be fly ash.



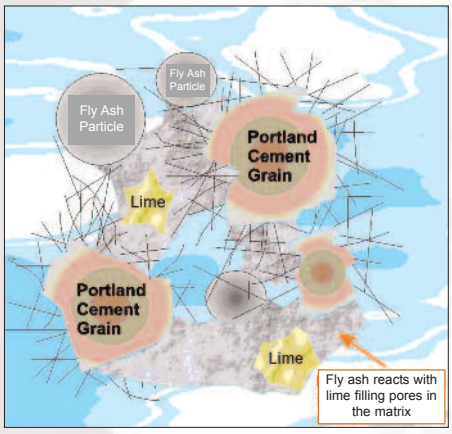
As hydration proceeds lime crystals form

- ***EN 450 Category N fly ash*** is also permitted by BS EN206 and BS 8500. With this ash a greater range of fineness is allowed than with Category S fly ash. The supplier nominates a target fineness value between 0% and 40% retained on the 45μm sieve. The fly ash supplied must not exceed ±10% of this target value. Again the LOI limit is as category A or B in the UK. There is no requirement for water reduction and as this effect is closely related to fineness it will be source specific.

Both category S and N BS EN450 fly ashes are classed as Type II editions, that is they count towards the total cementitious content.

Fly ash can also be used in concrete as inert filler or an aggregate - known as a Type I addition.

- ***Fly ash as a filler aggregate to BS EN 12620 or BS EN 13055-1*** is usually used in precast concrete products and grouting applications. The range of fineness permitted is 70% to 100% passing the 63μm sieve. Though the fly ash is assumed to be inert, in reality it will contribute to strength and durability as the pozzolanic reactions occur.



The pozzolanic reaction adds to the hydration products helping to fill the voids thus reducing permeability

The concrete standards

- ***BS EN206 - Concrete.*** BS EN206 only allows a maximum of 25% of BS EN450 Fly Ash within the total fly ash plus CEM I content to be treated as cementitious through the k-value route. However, more fly ash can be used within the concrete if it is treated as inert filler or 'aggregate'. Alternatively if the BS EN206 'equivalent performance' route is taken, it is the performance of the cementitious combination that is important. In this case all of the fly ash may be counted as being cementitious.
- ***BS8500 the complementary standard to BS EN206.*** This standard complements the European standard and provides the various data relating to mix design, specification and compliance for concrete. BS EN450 may count fully towards the cement content if compliance testing is carried out to the annex in BS8500.

- ***Conditioned, stockpile, and lagoon fly ash*** can also be used in concrete. These ashes have been successfully used for sub base materials[2], roller compacted concrete and as a fine aggregate replacement world-wide. These can be used with CEM I, CEM I and lime, lime only and lime & gypsum combinations as the cementitious binder.

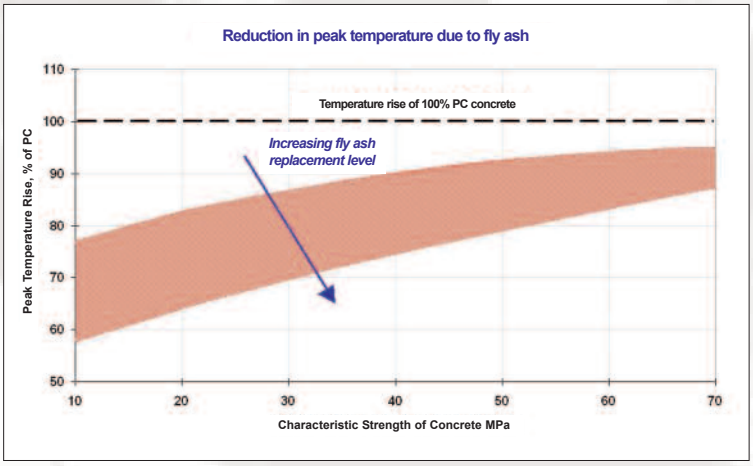


Figure 3 - Effect on peak temperature rise of fly ash

Other properties of fly ash in concrete

By the nature of fly ash many other properties may be exploited beneficially in concrete.

- ***Particle Density*** - fly ash has a lower particle density (2.30 typically) than Portland cements (3.12 typically). Therefore, for a given unit of mass, the volume of fly ash is greater than that for the PC. A 30% replacement by mass of the cement content with fly ash increases the total volume of cementitious material by 15%.

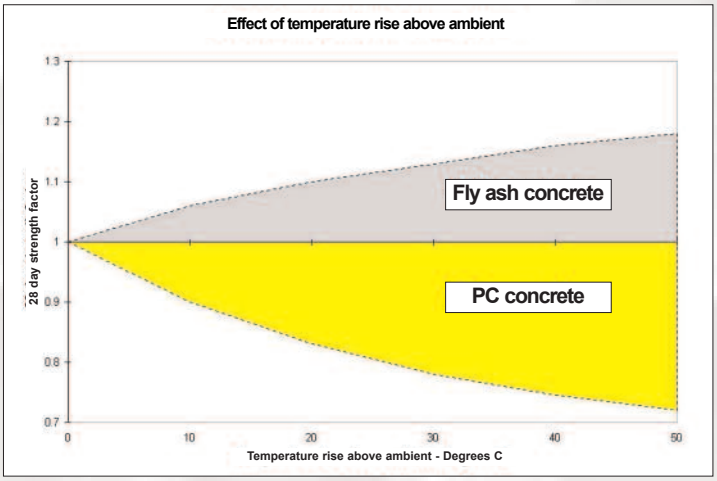


Figure 4 - Fly ash concrete increases in strength with higher curing temperatures

- ***Particle Size Distribution*** - fly ash can be used to correct for deficiencies in marine and single size sands, or for Self Compacting Concrete where a highly cohesive mix is required. The fly ash has a pore blocking effect that reduces bleeding, improves pumpability and surface finishing performance. Marine, crushed rock and heavily washed fine aggregates can benefit significantly from the addition of fly ash.
- ***Peak Temperature Rise*** - The pozzolanic reaction with lime occurs over an extended period of time and is temperature dependent. Figure 3 shows the peak temperature rise in a thick concrete section is reduced in comparison with PC of the same strength[3].
- ***Effect of Curing Temperature*** - Though the strength development of fly ash concrete can be relatively slow at 20C, the rate of reaction does depend on temperature. In adiabatic conditions the strength of PC concretes reduces with increasing temperature, whereas fly ash strength improves as shown in Figures 4 and 5.
- ***Chloride Resistance*** - The chloride resistance of fly ash concrete is improved because of the low permeability that can be achieved. Aluminates within cement can bind and immobilise Cl ions in the concrete. Fly ash contains about 3 to 5 times the aluminate content of PC concrete. Figure 6 shows the reduction in the coefficient of diffusion with varying percentages of fly ash. As the fly ash content and the grade of the concrete used increases the chloride diffusion coefficient reduces significantly.

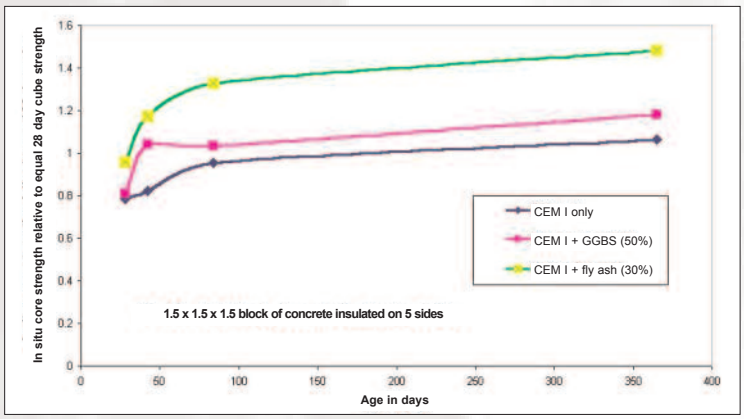


Figure 5 - The insitu strength of thick section concrete is higher due to the pozzolanic reaction

[2] UKQAA Technical Datasheets 6 series discuss Fly Ash Bound Mixtures (FABM) for a variety of roads and airfield applications.

[3] To take full advantage of the pozzolanic reaction the concrete must be properly cured, that is kept moist and warm, for as long as is practicable.

- ***Economy*** - In addition to all the technical benefits that fly ash can give to concrete there are economic advantages. The later strength development properties can give enhanced benefits if the age at which the specified strength required is extended beyond the usual 28 days. When compared to PC at 56 days and 112 days fly ash concrete strengths are still increasing at a significant rate. Specifying later ages makes feasible economic concretes with high strengths. Fly Ash may be specified to enhance durability. BS 8500 provides lists of exposure classes for both designed, standardised prescribed and designated mixes and limits of the types and quantities of additions that may be used.

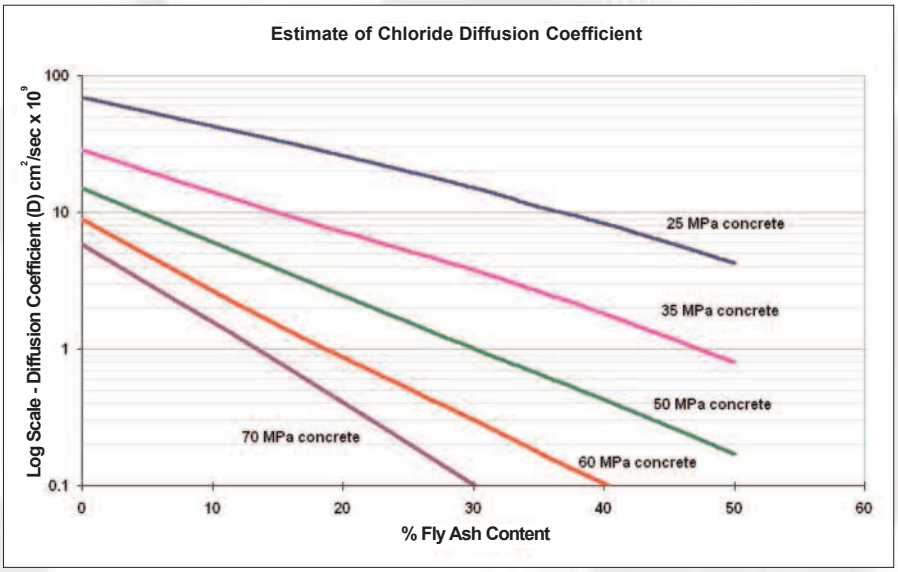


Figure 6 - Typical effect of fly ash on chloride diffusion coefficient

Environmental Considerations

As fly ash is a by product of the burning of coal in power stations to produce electricity, it is a valuable resource. It can be used as a source of silica in the cement making process as well as its use in blended cements. Using fly ash reduces the total energy demand of producing the concrete - simply because less CEM I is used. It reduces the need for extraction of raw materials used in the cement making process. Coupled with the enhanced durability of the resulting concrete structures and the subsequent extended working life, fly ash can make a valuable contribution to reducing environmental impacts.

General Information

Storage - Bagged fly ash and pre-blended fly ash cement should be stored as one would Portland cement (CEM I). The lower particle density of fly ash means that less can be stored in a silo in comparison with CEM I. Fly ash in a silo should be kept well fluidised with dry aeration to prevent self compaction and in addition silos must be water tight.

Admixtures - Admixtures can be used with fly ash concrete in exactly the same way as CEM I concrete. For air entrainment higher than usual admixture dosages are likely to be required, to counteract the effects of carbon on the air bubble generation. Special air entraining admixtures are available that are designed to minimise these effects.

Mix Design - As the volume of cementitious material increases when substituting fly ash for CEM I, some adjustment in the mix design may give significant benefits. Normally a 5% reduction in fine aggregate content can be used without affecting the handling properties. The best results are achieved by carrying out laboratory trial mixes.

Fly ash concrete being used on East Midlands Airport taxiways
(courtesy of Fitzpatrick Contracting Ltd)

In general usage the term 'fly ash' is used for pulverized coal ash but it can also cover ash from burning other materials. Such 'fly ash' may have significantly differing properties and may not offer the same advantages as ash from burning pulverized coal. UKQAA datasheets only refer to fly ash produced from the burning of predominantly coal in power stations.