Technical Datasheet

Highway Construction - Detailed Descriptions of FABM and ESC

Introduction

Fly ash can be used in variety of ways within highway construction. The following describes the ways it can be used beneficially from the technical, environmental and sustainable aspects of road construction. The aims are;

- To make more extensive use of PFA, a by-product from coal-fired power generation plants.
- To reduce the consumption of primary materials for pavement construction.
- To widen the range of pavement construction materials.
- To produce cost effective pavements as well as being environmentally sustainable.

FABM 1 and 2 (Granular Fly Ash – GFA)

Granular Fly Ash (GFA) is a mixture of coarse and fine aggregates which is used in combination with lime, water and fly ash - or Pulverised Fuel Ash (PFA) as it is known in the United Kingdom. GFA is produced with sufficient moisture to enable compaction with a roller, in a similar way to cement bound materials. The PFA is a pozzolanic material and when in combination with lime acts as a hydraulic binder. GFA relies on the pozzolanic reaction between the lime and the PFA to produce its long term strength characteristics as shown in Figure 1. The objectives of using GFA are:

GFA can be used for sub-bases and road bases of all classes of road & airfield pavements and footways.

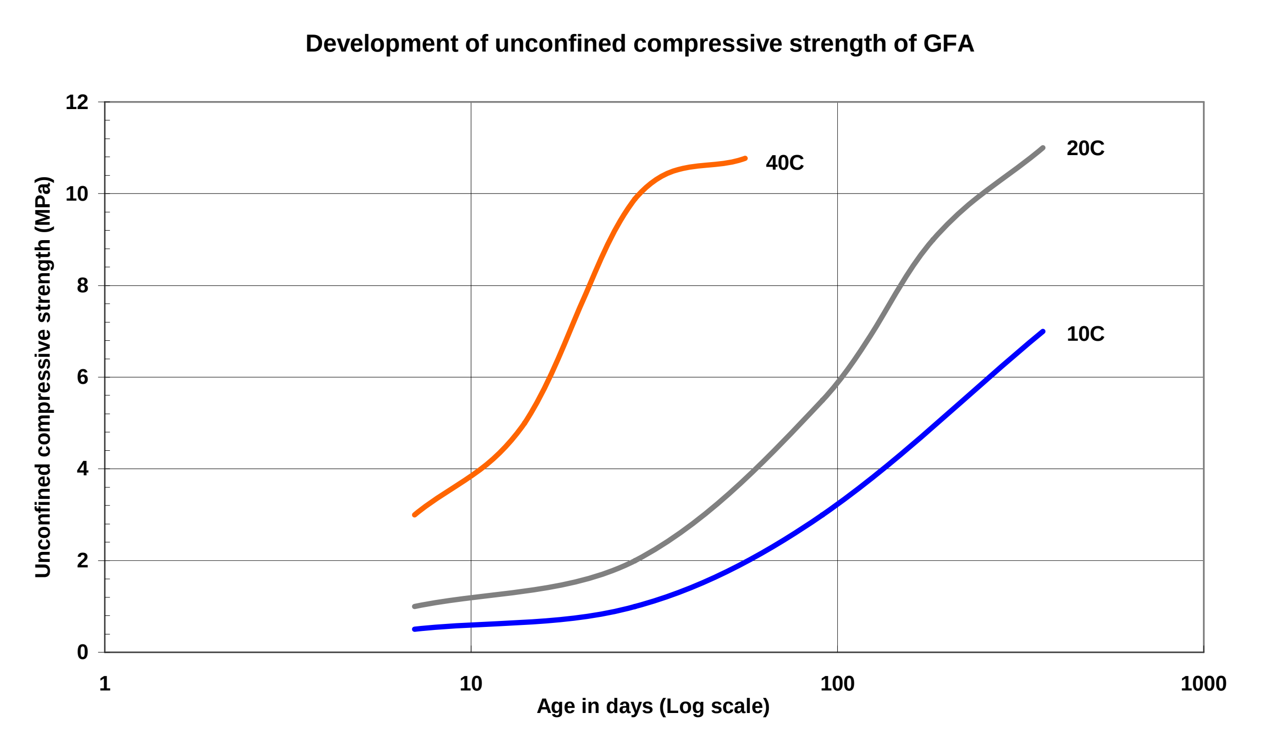

Figure 1 – Compressive Strength of GFA.

Characteristics, performance & durability

GFA is a slow hardening mixture, which progresses from behaving as an unbound crushed stone material into a bound paving material, the rate of reaction being strongly dependent upon temperature (see Figure 1). This has advantages in road construction:

- In the short term, GFA has a handling time of many hours and thus the flexibility of unbound granular paving materials.

- In the long term and depending on the aggregate, GFA develops significant elastic stiffness (10-30 GPa) and tensile strength (1 - 3MPa) and thus results in a pavement material with the performance and durability of bituminous and cement-bound materials.

- The slow reaction rate gives extended workability, permits immediate accessibility to site traffic and the capacity of self-healing.

- In the fresh condition on normal sites, the correct grading framework for the GFA produces a tight closed finish that can withstand rain.

- On hilly sites, the fines in the fresh GFA can be removed by running water and measures should be taken to prevent this occurring.

- The use of crushed material and the correct grading framework is responsible for the immediate trafficability of GFA and thus the stability of GFA over the short and medium-term which permits the stiffness and strength of GFA to develop unimpaired. The lack of reflective cracking found with GFA is largely due to the slower gain in strength.

- The ultimate structural characteristics may not be achieved until 2 to 3 years after laying. The slow reaction rate generally limits construction to the period April to October inclusive to enable frost resistance to be achieved before the first frosts. Outside this period, partial or complete replacement of lime with cement, the addition of gypsum or other suitable material can be employed or the laying of the overlying layers.

Mix composition: Mix composition depends on the materials available and the figures given in Table 1 are illustrative only.

FABM	Conditioned fly ash	CaO or $Ca(OH)_2$*	CEM I	Graded coarse aggregate**	Fine aggregate**	Soil	Typical water content (%)
1, 2	8.5 – 13	1.5 - 3	-	50 – 55	30 - 40	-	6 – 8
1, 2	4 – 6 (dry*)	1*	-	55 - 60	35 – 40	-	5 – 7
1, 2	6 – 8	-	2 – 4	50 - 55	35 - 40	-	6 – 8

Table 1: Typical mix proportions for GFA

* Lime and dry ash may be pre-blended at works. ** Natural, reclaimed or by-product material

Manufacture: GFA is produced by weight in central batching plants equipped with continuous pug-mill mixers.

Laying: Placement and compaction is by conventional plant such as drot, grader, paver and vibrating roller. Pneumatic-tyred rollers are usually specified for finishing purposes. Immediately after compaction, GFA shall be prevented from drying out by the application of an alkaline bitumen emulsion or the repeated light-spray application of water.

Utilisation: GFA can be used as sub-base/road base under bituminous or pavement quality concrete surfacing in either case, the GFA shall be laid on a sub grade, capping or sub-base material with a soaked laboratory CBR of at least 15%. The thickness of GFA and surfacing is a function of the ultimate structural properties of the GFA and traffic and shall be determined by an experienced pavement engineer (Data Sheet 6.3)

FABM 5 (Lime Fly Ash - LFA and Cement Fly Ash - CFA)

FABM 5 is a treated fly ash using either lime (the resulting mixture known as LFA) or cement (the resulting mixture known as CFA). The fly ash is part binder and part aggregate in such formulations. While needing more care than GFA in placing, compaction, etc as they predominantly consists of by-product material they are both very environmentally friendly and highly sustainable.

Characteristics, performance & durability

At optimum moisture content, LFA will support traffic immediately. Surface disturbance will occur but can be rectified with wetting, shaping and rolling before setting commences. This may be between 2 & 4 days after laying depending on temperature. For best results however, the direct trafficking of LFA should be avoided and it should be overlain, before setting and drying out, by the next layer, the latter being delivered over itself to avoid direct trafficking of the LFA. CFA on the other hand behaves more like a conventional CEM I based CBGM. Thus if overlay before setting is not possible, usually within 2 to 4 hours depending on temperature, trafficking should be prohibited for 7 days.

Both LFA and CFA need careful attention at the compaction stage and where direct trafficking occurs, care should be taken to avoid surface shearing and de-lamination, hence the aforementioned advice for trafficking & overlaying. In common with other treated soil mixtures like soil cement, the trafficability of SFA is governed by specified limits on one or more of the following properties; water content, immediate bearing index and moisture condition value; the exact values of the limit and the relevant property being a function of the soil type, cohesive or non-cohesive.

Mix composition: Various compositions can be used depending on the source and reactivity of the constituents. The examples given in Table 2 are illustrative only and FABM 5 mixtures should be subject to laboratory trial mixes.

Sealed specimens	LFA with 2.5% CaO	LFA with 5% CaO	CFA with 7% PC	CFA with 9% PC
7 days	1.5	1.8	3.0	5.0
28 days	---	---	4.0	8.0
35 days	4.0	4.0	---	---
28 days + 7 days in water	3.3	3.3	---	---
91 days	5.0	7.3	6.0	9.0

Table 2: Compressive strength for FABM 5 (LFA & CFA): (MPa):

Notes:

1. Standard Proctor Optimum Moisture Content (OMC) for mixtures ~ 21%. Typical specimen wet density ~ 1600 Kg/m^3.
2. Mixture percentages are based on dry weight. Thus 2.5% CaO ~ 33 kg/m^3.
3. Strength results are for 1:1 cylinders and can be considered equivalent to cubes.
4. Specimens were cured at 20C and sealed to prevent evaporation.
5. The results at 28 + 7 days designate 28 days curing by sealing followed by 7 days in water.

The results show the advantage of CEM I over CaO at 7 days but illustrate the superiority of CaO at 91 days. The above results suggest that 5% CaO ~ 8% CEM I are equivalent at later ages. Soaked strengths for LFA are about 80% of un-soaked strengths. The typical UK requirement for capping is a soaked CBR of 15%. The above results indicate that since the LFA mixture with 2.5% CaO that soaked strengths are good, it should satisfy capping strength requirements.

Manufacture: It should be noted that below 5 degrees C, the reaction between lime and PFA virtually ceases. This is generally not a problem with capping but when LFA is used for sub-base applications its use should be limited to April to September unless the road base is laid & surfaced before the first frosts. Soft burnt fine grade quick lime or hydrated lime should be used for LFA. LFA is best produced in pug-mill mixers.

Laying: Placement and compaction is by conventional plant such as drot, grader, paver and vibrating roller. Pneumatic-tyred rollers are usually specified for finishing purposes. FABM 5 should be laid ‘high’ & trimmed by ‘tracked’ blades, and compacted by pneumatic-tyred roller. At Optimum Moisture Content, LFA will support traffic immediately, though surface disturbance may/will occur. This can be rectified with wetting, shaping & rolling 3 days & probably longer after laying.

For best results, LFA should be overlain within 4 hours by the next layer. If this is not possible, LFA should be sealed or kept moist to prevent drying out.

Utilisation: FABM 5 can be used as sub-base/road base under bituminous or pavement quality concrete surfacing in either case, the materials shall be laid on a sub grade, capping or sub-base material with a soaked laboratory CBR of at least 15%.

Figure 2 - Gotham by-pass, Notts. Compacting CFA.

Enhanced Stabilised Capping (ESC)

Enhanced stabilised capping (ESC) is an enhancement of normal stabilized capping and is constructed by mixing powder additives to site arisings, generally using the mix-in-place method of stabilization. Following the availability of TRL Report 248, which illustrated the benefit of ESC over standard Type 1 granular sub-base, ESC is increasingly being considered and used in roads as a replacement for the standard foundation of sub-base and capping. In some instances, ESC is realising significant financial benefits. To date, combinations of lime, cement and ground granulated blast furnace slag have been used for ESC. Fly Ash can also be used and would realise significant economic benefits because of its price compared to the aforementioned powders.

Specification of ESC

The specification for ESC is still evolving and to date mechanical performance has been specified by a variety of methods. What has been used and to what level has depended on the degree of enhancement desired and durability considerations. As a guide, either soaked CBRs > 50%, compressive strengths > 1 MPa, or NAT stiffness > 500 MPa, have been specified. Whichever is used, the specification must also cover the issues of durability and volume stability, particularly with the treatment of clays which to date have figured prominently as the 'aggregate' for ESC. In addition the specification needs to recognise that ESC will normally be carried out by mix-in-place methods that by definition are a more variable process than central-plant mix. In order to take account of this and also the durability and volume stability issues, minimum total binder additions of 8% have been used, and specifications, although based on standard stabilized capping specifications, have been modified, in effect tightened, to reflect the fact that ESC is being used as sub-base. A specification for ESC is described in UKQAA Technical Data Sheet 6.4.3.

The role of Fly Ash

Because of its rapid set, cement has limitations for ESC work. Typically 8% cement would require the spreading and mixing-in of 40kg/m^2 of cement. To achieve this in one spread and mix operation is accepted as being unwieldy, and as a consequence, such quantities of binder are traditionally handled in two spread-and-mix operations. Since the first requires compaction to be carried out in order that the second can be accurately undertaken, the cement from the first stage has often commenced setting before the second stage has been completed.

It is acknowledged that the effect of this apparent shortcoming with cement is unknown. However it cannot be considered sound technical practice, particularly bearing in mind that ESC is required to be more structurally significant than standard stabilized capping. Fly Ash is particularly appropriate for ESC constructed from slightly plastic or silty site arisings which is currently considered the domain of cement. A technically more robust solution than cement alone is to employ a slower setting binder for the first stage followed by cement in the second stage. Fly Ash would be ideal for this first stage or alternatively, Fly Ash could be used with lime instead of cement.

Mixture proportioning

As intimated previously, exact binder additions would be subject to advance laboratory testing depending on exact mechanical performance requirements. However since 8% minimum total binder contents are currently recommended where cement, lime or ground granulated blast furnace slag are used, typical proportioning employing Fly Ash can be considered against this yardstick. Since it is also possible to use run-of-station Fly Ash for this work and that this is probably available at about 10% of the price of cement, lime and ground granulated blast furnace slag, it is possible to use quite high Fly Ash additions and still show significant overall cost savings.

Thus considering silty materials, Fly Ash could be added in advance of a reduced cement addition. For illustrative purposes, 8% or more Fly Ash could be spread and mixed as a first stage followed by 4% cement in the second stage. As well as the cement reaction, the lime released by the cement during hydration would act hydraulically with the Fly Ash to provide further strengthening to give, subject to laboratory testing, a total enhancement equivalent to 8% cement alone.

In the case of slightly cohesive soils, where typically lime might be used in advance of cement, Fly Ash could follow the lime instead. For illustrative purposes, 3/4% lime followed by 8 to 12% Fly Ash might be appropriate.

Fly Ash

Run-of-station Fly Ash, typically conditioned at the power station with water, can be used for ESC. A specification for run-of-station Fly Ash can be found in UKQAA Technical Data Sheet 6.4.3.

Construction of ESC using Fly Ash

Construction of ESC using siliceous Fly Ash in combination with lime or cement, would follow similar procedures used for either lime or cement stabilized capping in accordance with the 600 series in the Highways Agency's SHW, except that Fly Ash would be added as a first stage when used with cement and as either a first or second stage with lime depending on the plasticity of the material to be treated. Note that the Fly Ash could be either spread dry using purpose-made spreaders (as normal for lime and cement) or spread in a conditioned (wet) form by blade.

Example of design and benefits of using Fly Ash

Consider a road designed to carry in excess of 80msa on a sub grade CBR of 3%. Using HMB35 as the base layer material, conventional and ESC foundation options might be as follows:

<table>
<tr><td colspan="3">30mm thin wearing course system</td></tr>
<tr><td colspan="3">280mm HBM35 base layer</td></tr>
<tr><td>150mm Type 1</td><td rowspan="2">or 300mm Type 1 granular sub-base</td><td>or 300mm ESC using mix-in-plant method</td></tr>
<tr><td>350mm capping</td><td>or 350mm ESC using mix-in-place method</td></tr>
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Table 3: Typical design for ESC

Subject to site demonstration, 350mm of ESC should be constructible in one lift. Benefits of using the ESC foundation will be a function of the price of Type 1 granular sub-base material and the earthworks balance on the job bearing in mind the ESC will be constructed from site arisings, including material that without treatment might otherwise have been considered unsuitable for earthworks use. In addition, there will be programme benefits since experience indicates that, even allowing for curing, ESC operations will proceed quicker than Type 1 operations. Experience also indicates that properly sealed, cured & dressed, ESC will be robust with respect to trafficking and other site operations such as drainage and edge details although programme and design modifications to some of these site operations may enhance even more the advantages of ESC.

References

TRL Report 248. Stabilized sub-bases in road foundations: structural assessment and benefits. Transport Research Laboratory, Crowthorne, Berkshire, 1997.

UKQAA Technical Data Sheet 6.4.3: Fly Ash in Highways Construction - Specification for ESC

UKQAA Technical Data Sheet 6.0: Fly ash for Highway Construction.