UK QUALITY ASH ASSOCIATION

TECHNICAL DATA SHEET

Fly Ash in Pavement Construction

Overview of Fly Ash Bound Granular Mixtures (FABGM) & Soil Treated with Fly Ash (SFA)

Introduction

Fly ash bound mixtures (FABM) contain fly ash and other constituents that have a water content compatible with compaction by rolling. Their performance relies on the properties of the fly ash. The term FABM encompasses both;

- fly ash bound granular mixtures (FABGM)
- soils treated with fly ash (SFA)

The term fly ash refers to coal fly ash, also called pulverized fuel ash (pfa) in the UK. In the case of FABGM and SFA, it is usually conditioned (i.e. moistened) material or less frequently, dry, run-of-station ash. Conditioned fly ash can be fresh or even stockpiled material.

Fly ashes from UK power stations are predominantly siliceous materials and are thus pozzolanic, which means in the presence of lime [CaO or $Ca(OH)_2$], they set and harden when in contact with water.

Characteristics, performance and durability

In FABGM and SFA, fly ash is the main constituent of the binder with quick or hydrated lime the other constituent.

Cement can substitute for lime but is not as effective in achieving the full pozzolanic reaction and thus the cementing potential of the fly ash (Table 1).

Table 1: Typical Compressive strength of a treated fly ash (MPa)

Age of 1:1 sealed cylindrical specimens cured @ 20°C	Fly ash with 2.5% CaO	Fly ash with 5% CaO	Fly ash with 7% CEM I	Fly ash with 9% CEM I
7 days	1.5	2	3	5
28 days	4	4	4	8
91 days	5	7.5	6	9

Compared to mixtures based on cement, FABGM and SFA using lime are slow-setting, slow-hardening, self-healing mixtures. This more protracted rate of hardening has distinct advantages in pavement construction.

- In the short term, they have extended handling times and thus the versatility of unbound granular pavement materials. Their ability to sustain immediate trafficking is discussed in the ‘application’ section.
- In the medium term, they are autogenous. In other words they possess a pozzolanic reserve, which allows them to re-heal (autogenous healing) should say cracking or distress occur under differential settlement.
- In the long term, they develop significant stiffness and strength with the performance and durability of bituminous and cement bound mixtures.

Where quicker hardening is required, say in cold weather, the addition of gypsum or the partial or complete replacement of lime with cement can be employed. However, FABGM and SFA based on cement behave like cement bound mixtures (CBM) and do not have the same degree of laying flexibility and autogenous healing described above.

European Standards and type of FABM

FABM and SFA belong to that family of pavement materials known as hydraulically-bound mixtures (HBM). BS EN 14227 and its various parts, covers the overall HBM family of materials including parts for FABGM and SFA.

FABM are standardized in BS EN 14227-3 as follows:

- FABGM 1: 0/31.5 mm well-graded mixture
- FABGM 2: 0/20 mm well-graded mixture with a compacity (air voids) requirement [0/14 & 0/10 mm mixtures are also available]
- FABGM 3: sand mixture with an immediate bearing index (IBI) requirement, in other words a measure of immediate traffickability
- FABGM 4: mixture with a producer-declared grading and immediate bearing index (IBI) requirement
- FABGM 5: 0/31.5 mm mixture lying within an allowed broad-grading envelope and thus with an immediate bearing index (IBI) requirement
- FABGM 6: fly ash (as aggregate) treated with lime or cement

BS EN 14227-3 specifies the;

- requirements for the constituents of the mixtures e.g. the quality of the fly ash, the lime and the aggregates
- requirements for the various mixtures e.g. grading and, where applicable, compacity and immediate bearing index (more later)
- laboratory mechanical performance classes for the mixtures e.g. the permitted classes of compressive strength (R_c) and tensile strength/modulus of elasticity class (R_tE).

  NOTE: Examples of R_c classes are C3/4, C5/6, C8/10, C9/12 & C12/16 where C denotes compressive strength and the 1st number the compressive strength of cylinders with a slenderness ratio of 2 and the 2nd number, cylinders with a slenderness ratio of 1 or cubes. R_tE classes are T1, T2, T3, T4 & T5, which approximate, very loosely, to the aforementioned R_c classes.

With the exception of FABGM 6, where the fly ash is both binder and aggregate, the other FABGM types use aggregate that is specified in accordance with BS EN 13242.

SFA is standardised in BS EN 14227-14.

For all FABM and SFA, fly ash must conform to BS EN 14227-4.

Application of the FABGM 1 & 2

FABGM 1 & 2 are mixtures that are formulated, but not exclusively, for use in the main structural layer, the base, of a pavement.

FABGM 1 & 2 are very similar mixtures in that their well-graded nature means they are immediately trafficable and ideal for large new-build jobs and where laying flexibility is paramount such as in small, congested sites, and reconstruction schemes. Aggregate should be clean, hard and non-plastic and can be made from natural, artificial or recycled material.

Depending on the aggregate, the mixture proportions by dry weight are typically;

- based on the use of conditioned fly ash added via a hopper in a central mixing plant; lime (2-3%), fly ash (8-13%) and aggregate (85-90%) by dry mass of the mixture
- more unusually, based on the use of dry fly ash which would be added via a silo in a central mixing plant (or factory-blended with lime, typically in the ratio of 1 part lime to 6 parts ash), the total addition of the lime & fly ash combination would vary between 7 and 10% by dry mass of the mixture.
- for cement based mixtures, similar overall combined fly ash / cement additions would apply but the cement content would largely be constant at 3% by mass of the overall mixture.

FABGM 1 & 2 do differ however in grading. Compared to FABGM 1, the permitted envelope for FABGM 2 is tighter, the maximum size of aggregate smaller, and FABGM 2 has a compacity requirement to optimise constituent proportioning to achieve minimum voids. FABGM 2 is thus more highly specified than FABGM 1 and is formulated specially for French practice, where surfacings are thinner than in the UK. It has not been called-up for use in the UK.

FABGM 1 however is called up in the UK. The Highways Agency (HA) design recommendations for the bases of trunk roads and motorways are found in HD 26. This standard permits FABGM 1 as a base material across the full traffic spectrum requiring the tensile strength class T3 or compressive strength class C9/12 as a minimum.

Despite HA acceptance however, all UK experience with FABGM bases has been for county roads, in Staffordshire (particularly) and Kent, using designs;

- employing T2 tensile strength class (equivalent to C6/8, possibly C5/6, compressive strength mixture) and thus lower strengths than HA requirements
- employing thinner asphalt surfacing depths compared to HA requirements

Performance has been and continues to be excellent.

These design recommendations and specifications are found in UKQAA data sheets, 6.3 & 6.4 respectively.

Data sheet 6.3 is based on previous UKQAA design advice for a mixture known as GFA (granular material treated with fly ash), which has been responsible for the successful use of FABM bases in Staffordshire and Kent since 1997. The experience in Staffordshire indicates that the HA recommendations are conservative.

Application of FABGM 3, 4, 5 & 6 and SFA

As far as the HA is concerned, FABGM 3, 4, 5 & 6 and SFA are sub-base materials and thus utilised in the foundation layers underneath the base layers. However this approach underrates their capabilities since they are suitable for the bases of more lightly-trafficked pavements and trench reinstatement works up to underside of surfacing.

HA design recommendations for foundations are found in HD 25 (or IAN 73), which permit the use of FABGM 3, 4, 5 & 6 and SFA for sub-base and capping. Unlike FABGM 1 & 2 above however, these FABM cannot be assumed automatically to be capable of immediate trafficking but require verification of this ability as follows;

- FABGM 3 is a sand mixture and verification of its ability to sustain traffic immediately is measured using the immediate bearing index (IBI) test, which is an immediate CBR test without surcharge.
- FABGM 4 is a mixture where the producer declares the grading and other relevant properties, including IBI, and the mixture is particularly relevant for trench reinstatement works.
- FABGM 5 is a mixture to a permitted broad-grading envelope and with an IBI requirement. FABGM 5 is particularly relevant where the grading does not comply with FABGM 1 or 2 requirements, but in all other respects produces a material that could substitute for FABGM 1 in base, particularly light to medium

trafficked bases, provided it meets the specified strength requirements and the IBI test shows that it is mechanically stable for immediate traffickability.

- FABGM 6 is a treated fly ash using either lime (the resulting mixture is also known as LFA) or cement (the resulting mixture is also known as CFA)

  Note: Combinations of lime + cement or lime + FGD (flue-gas desulfurisation) gypsum can be employed. More advice can be obtained from the UKQAA.

- 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 placement 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 CBM. Thus if overlay before setting is not possible, usually within 4 hours depending on temperature, trafficking should be prohibited for 7 days.
- Both LFA and CFA need careful attention at the compaction stage and under early trafficking to avoid surface shearing or de-lamination close to the surface, hence the aforementioned advice for trafficking & overlaying.
- In common with other treated soil mixtures like soil cement, the traffickability of SFA is governed by specified limits in BS EN 14226-14 for 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.

Overall application of the FABGM types & SFA

Such is the range of FABM types, FABGM & SFA can thus be specified and formulated to meet trench, capping, sub-base and base requirements of all classes of road, and airfield, port, residential and commercial pavements. Suggestions with aggregate recommendations are in table 2.

Table 2: Suggested aggregate categories from BS EN 13242 and application guidance for FABGM, and SFA

(subject to site trial to illustrate procedures and performance for FABGM 3, 4 and 5 and SFA[1])

FABM type	*Bases*		*Sub-base: surface subject to direct site traffic*		*Other sub-bases, capping & trench reinstatement*	
	Crushed or broken particles category[3]	Los Angeles coefficient category[4]	Crushed or broken particles category (and or with IBI category for mixture where indicated[2])	Los Angeles coefficient category	Crushed or broken particles category (and or with IBI category for mixture where indicated[2])	Los Angeles coefficient category
1 & 2	C90/3	LA50	C90/3	LA50	C50/30	LA60
3	Low-traffic bases but seek advice from UKQAA		IBI 40	N/A for sand mixtures	IBI 25	N/A for sand mixtures
4 & 5	Low to medium traffic bases but seek advice from UKQAA		C50/30 & IBI 50	LA50	IBI 50	No requirement
6	Low-traffic bases but seek advice from UKQAA		Generally not applicable for use		Applicable but no aggregate requirements since properties irrelevant	
SFA	Low-traffic bases but seek advice from UKQAA		May be applicable if strength and IBI adequate – seek UKQAA advice		Applicable but no aggregate requirements since properties irrelevant	

1. SFA designates 'soil treated by fly ash' as described in BS EN 14227-14.
2. The IBI test is specified in BS EN 13286-47, Unbound and hydraulically bound mixtures – Part 47: Test method for the determination of the California bearing ratio, immediate bearing index and linear swelling.
3. With the crushed or broken particles category, i.e. C90/3, the first number is the minimum percentage of crushed material and the second the maximum percentage of rounded particles.
4. With the Los Angeles category, LA50 is equivalent to a 10% fines value of 50 kN, and LA60 approximately equivalent to a 10% fines value of 30 kN.
5. Note that where any requirement is not met, then a curing and non-trafficking period is required until set commences.

Table 3: Examples of FABM with constituent proportions as a % by dry mass

FABM type	*Conditioned fly ash*	*CaO or $Ca(OH)_2$*	*CEM I*	*Typical water content (%)*
1 & 2	8 - 13	1.5 - 3	-	6 - 8
1 & 2	5 - 7 (dry*)	1 - 1.5*	-	5 - 7
1 & 2	4 - 8	-	3 - 4	6 - 8
3	9 - 12	2 - 4	-	~ 10
3	6 - 8	-	3 - 4	~ 10
4 & 5	12 - 21	3 - 4	-	Depends on aggregate
4 & 5	6 - 20	-	3 - 5	Depends on aggregate
6	93 - 97	3 - 7	-	~ 20
6	90 - 95	-	5 - 10	~ 20
SFA	6 - 8 (dry*)	1 - 2*	-	Depends on soil
SFA	3 - 6	-	2 - 4	Depends on soil

Mixture design and FABM examples

Mixture design, particularly for lime based FABM using conditioned fly ash, is covered in detail in data sheet 6.2.

Typical examples however of the various FABM types and constituent proportions are given in Table 3.

*Examples are illustrative proportions for factory-blended lime & dry fly ash

Specification and construction advice for FABGM & SFA

Specification

FABM are specified in the series 800 of the HA's Specification for Highway Works (SHW) along with other HBM types.

In addition, stand-alone specifications for some FABM are found in UKQAA 6.4 series data sheets.

General

FABGM and SFA to C2.3/3 strength category can be considered resistant to frost heave.

For FABGM and SFA for use in trench reinstatement and other low strength applications, where the specified compressive strength class may be C1.5/2 or even C0.8/1, resistance to frost heave can also be assumed if the indirect tensile strength is greater than 0.25 MPa.

Ideally, FABGM should be laid in the period April to October inclusive, particularly if to be left exposed without an overlying layer protection, but, in any event, whatever the time of year, it is advisable that FABM be overlain as soon as possible to limit exposure to weather and traffic or protected with a surface dressing.

Where drainage and edge details are to be constructed on SFA, the use of binder combinations employing cement is recommended.

The construction of drainage and edge details using the surface of an FABGM 6 layer as the platform should be avoided.

Manufacture

With respect to the quality of the finished product, mixture production has been very successful using central batching plants with pug-mill continuous mixers, although other types of stationary mixer and the mix-in-place method of construction can be employed.

Laying & compaction

Layer lifts should not be less than 150mm or greater than 230mm subject to satisfactory density compliance except for trench reinstatement or say footpaths where no vehicular traffic and 100mm is the minimum. On weak formations, the first lift of multi-lift FABGM or SFA should be as thick as possible compatible with above.

Not more than 3 days should elapse between successive lifts of FABGM for thick layers say or trench reinstatement, but, ideally inter-lift bond is required, lifts should be laid the same day or the second lift not more than 1 day later and before drying out and setting of the underlying lift or layer.

Placement of FABM and SFA uses conventional plant such as drot, grader and paver.

Compaction for new pavements is by vibrating roller followed by a pneumatic-tyred roller (PTR) for finishing purposes.

Vibrating rollers can result in surface overstressing of some FABM, producing shear cracks and de-lamination. This is often the case with FABGM 6 where compaction should be by PTR alone. The same may apply to FABGM 3.

After compaction, the final surface of FABGM & SFA shall be prevented from drying out by the application of an alkaline bitumen emulsion, gritted to prevent removal by the tyres of traffic, or the repeated and frequent application of water by light spray.

Bibliography

- BS EN 14227-3. Hydraulically bound mixtures - Specifications - Part 3: Fly ash bound mixtures. BSI, London, UK.
- BS EN 14227-4. Hydraulically bound mixtures - Specifications - Part 4: Fly ash for hydraulically bound mixtures. BSI, London, UK.
- BS EN 14227-14. Hydraulically bound mixtures - Specifications - Part 14: Soil treated by fly ash. BSI, London, UK.
- BS EN 13242. Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction. BSI, London, UK.
- HD 26 Pavement Design. DMRB Volume 7 Section 2 Part 3
- HD 25 Foundations. DMRB Volume 7 Section 2 Part 2 (currently issued as IAN 73)
- Specification for Highway Works. 800 Series. MCHW Volume 1
- UKQAA dada sheets;
    - 6.0 Fly ash in pavement construction – Overview of FABGM & SFA
    - 6.1.1 Fly ash in pavement construction – FABGM 1
    - 6.1.2 Fly ash in pavement construction – FABGM 6 (treated fly ash)
    - 6.1.3 Fly ash in pavement construction – SFA (soil treated with fly ash)
    - 6.2 Fly ash in pavement construction – Laboratory mixture design for FABGM & SFA
    - 6.3 Fly ash in pavement construction – Thickness design using FABGM 1 & FABGM 6
    - 6.4.1 Fly ash in pavement construction – Specification for FABGM 1
    - 6.4.2 Fly ash in pavement construction – Specification for FABGM 6
    - 6.4.3 Fly ash in pavement construction – Specification for SFA
    - 6.5 Fly ash in pavement construction – Fly ash & lime stabilised clays – preventing sulfate heave

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.