UNITED KINGDOM QUALITY ASH ASSOCIATION

Technical Datasheet

6.0

Fly Ash in Highways Construction

Fly Ash Bound Mixtures (FABM) for highways and other pavement

Fly ash bound mixtures (FABM) and soil treated with fly ash (SFA) are mixtures of fly ash and other constituents that have a water content compatible with compaction by rolling and a performance that relies on the pozzolanic properties of the fly ash.

The term fly ash refers to coal fly ash, also known as PFA (Pulverized Fuel Ash) in the UK. It is usually conditioned (i.e. moistened) material or less frequently, dry run-of-station ash. Conditioned fly ash can be fresh or even old stockpiled material. Fly ashes from UK power stations are predominantly siliceous materials and pozzolanic, which means in the presence of lime [CaO or $Ca(OH)_2$], they harden when in contact with water.

Characteristics, performance and durability

In FABM 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 mobilising the full pozzolanic and thus 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 @ 20C	*Fly ash with 2.5% CaO*	*Fly ash with 5% CaO*	*Fly ash with 7% CEM 1*	*Fly ash with 9% CEM 1*
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, FABM and SFA based on 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 should say cracking 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, FABM 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). In common with other paving materials, there is European standard BS EN 14227 for the overall family of materials that make up HBM including FABM and SFA.

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

- FABM 1: 0/31.5 mm graded mixture
- FABM 2: 0/20 mm well-graded mixture with a compacity (air voids) requirement. 0/14 & 0/10 mm versions are also available
- FABM 3: sand mixture with an immediate bearing index (IBI), in other words an immediate traffickability requirement
- FABM 4: mixture with a producer-declared grading
- FABM 5: fly ash (as aggregate) treated with lime or cement.

BS EN 14227-3 specifies;

- 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, C6/8, C9/12, C12/16 etc 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. Examples of R_tE classes are T2, T3, T4 and T5 which approximate to the aforementioned R_c classes.

With the exception of FABM 5, which contains no aggregate (the fly ash is both binder and aggregate), the other FABM 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, the fly ash must conform to BS EN 14227-4.

Application of FABM 1 & 2

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

FABM 1 & 2 are very similar mixtures in that they are immediately trafficable and ideal where laying flexibility is paramount such as in small, congested sites, and reconstruction schemes, as well as for large new-build jobs. The aggregate for both 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.

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

FABM 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 departmental standard HD 26. This standard permits FABM 1 as a base material across the full traffic spectrum requiring the tensile strength class T3 as a minimum. Alternatively and conservatively, the compressive strength class C9/12 can be used although testing and experience indicate that C6/8 is usually equivalent to T3 class.

Despite HA acceptance, all UK experience of FABM bases has been for county roads, in Staffordshire particularly, using designs with C6/8 strengths and thinner asphalt surfacing depths compared to HA requirements, and performance has been and continues to be excellent. These design recommendations and specifications are found elsewhere in another UKQAA data sheet. That sheet 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. In these cases, the thickness recommendations use strength class T2. The experience in the Counties suggests that HA recommendations are conservative.

Application of FABM 3, 4 & 5 and SFA

FABM 3, 4 & 5 and SFA are primarily for use in sub-base and capping and thus the foundation layers underneath the base layers. They can also be used for lightly trafficked bases and, particularly in the case of FABM 4, for trench reinstatements.

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

- FABM 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.
- FABM 4 is a mixture where the producer declares the grading and other relevant properties such as IBI. FABM 4 is particularly relevant where the aggregate does not comply with FABM 1, 2 or 3 requirements, but in all other respects produces a material that is eminently suitable for use. FABM 4 could substitute for FABM 1 in base provided it meets the specified strength requirements and the IBI test shows that it is stable.

- FABM 5 is a treated fly ash using either lime (the resulting mixture is sometimes referred to as LFA) or cement (the resulting mixture is sometimes referred to as CFA).
- 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 CBM. 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 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 14226-4 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 FABM types & SFA

Such is the range of FABM types, FABM & SFA can thus be specified and formulated to meet trench, capping, sub-base and base requirements of all classes of road, and for 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 FABM and SFA (subject to site trial to illustrate procedures and performance for FABM 3, 4 and 5 and SFA)

FABM type	*Bases*		*Sub-base subject to significant site traffic*		*Other sub-bases, capping & trench reinstatement*	
	Crushed or broken particles category for aggregate	**Los Angeles coefficient category for aggregate**	**Crushed or broken particles category for aggregate (and or with IBI category for mixture where indicated)**	**Los Angeles coefficient category for aggregate**	**Crushed or broken particles category for aggregate (and or with IBI category for mixture where indicated)**	**Los Angeles coefficient category for aggregate**
1 (&2)	C90/3	LA50	C90/3	LA50	C50/30	LA60
3	Mixture may be applicable – seek advice from UKQAA		IBI 40	Property not applicable	IBI 25	Property not applicable
4	Mixture may be applicable – seek advice from UKQAA		C50/30 & IBI 50	LA50	IBI 50	No requirement
5	Mixture may be applicable for low-traffic bases – seek advice from UKQAA		Mixture generally not applicable		Applicable but no requirement for aggregate since properties are not relevant	
SFA	Mixture may be applicable for low-traffic bases – seek advice from UKQAA		Mixture may be applicable provided IBI and strength are adequate – seek UKQAA advice		Applicable but no requirement for aggregate since properties are not relevant	

Notes

1. 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.
2. 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.
3. 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.
4. Note that where any of the requirements are not met, then a curing and non-trafficking period is required until set commences.

Mixture design and FABM examples

Mixture design, particularly for lime based FABM using conditioned fly ash, is described elsewhere in UKQAA datasheets. Typical examples however of the various FABM types and constituent proportions are given in Table 3.

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

FABM	*Conditioned fly ash*	*CaO or $Ca(OH)_2$*	*CEM I*	*Typical water content (%)*
1, 2	8.5 – 13	1.5 - 3	-	6 – 8
1, 2	5 – 7 (dry*)	1 - 1.5*	-	5 – 7
1, 2	6 – 8	-	2 – 4	6 – 8
3	9 – 12	2 - 4	-	~ 10
3	6 – 8	-	2 – 4	~ 10
4	12 – 21	3 - 4	-	Depends on aggregate
4	10 – 20	-	4 – 5	Depends on aggregate
5	93 – 97	3 - 7	-	~20
5	90 – 95	-	5 - 10	~20
SFA	6 – 8 (dry*)	1 – 2*	-	Depends on soil
SFA	3 – 6	-	2 – 4	Depends on soil

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

Specification and construction advice for FABM & SFA

Specification

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

General

FABM and SFA to C3/4 strength category can be considered resistant to frost heave. For FABM and SFA for use in trench reinstatement and other low strength applications, where the specified compressive strength class may be C1.5/2 or C0.8/1, resistance to frost heave can be assumed if the indirect tensile strength is greater than 0.25 MPa.

Ideally, FABM should be laid in the period May to September 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 formations prior to sub-base placement, the use of binder combinations employing cement is recommended. The construction of drainage and edge details on FABM 5 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. It is strongly recommended that FABM bases are plant-mixed.

Laying & compaction

Base layers should be laid in one lift for new pavements. Sub-base lifts for new pavements should not be thinner than 150mm or greater than 230mm subject to satisfactory density compliance. Lift thicknesses for trench reinstatement should not be thinner than 100mm. On weak formations, the first lift of multi-lift FABM or SFA should be as thick as possible compatible with above.

Not more than 3 days should elapse between FABM sub-base and FABM base or successive lifts of FABM for thick sub-base layers say or trench reinstatement, but, ideally and preferably, both should be laid the same day or the second lift not more than 1 day later and before drying out of the underlying lift or layer.

Placement of FABM and SFA uses conventional plant such as drot, grader and paver. Compaction for new pavement is by vibrating roller followed by a pneumatic-tyred roller (PTR) for finishing purposes. Vibrating rollers however can result in surface overstressing, producing shear cracks and delamination, with some FABM. This is often the case with FABM 5 and compaction should be by PTR alone. . The same may apply to FABM 3. After compaction, the layer 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 data sheets.

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 might not offer the same advantages as ash from burning pulverized coal. UKQAA datasheets only refer to PFA / fly ash produced from the burning of predominantly coal in power stations.