UNITED KINGDOM QUALITY ASH ASSOCIATION

Technical Datasheet

Fly Ash in Highways Construction Specification for FABM 5

Contents

Foreword

FABM 5 is one of 5 fly ash bound mixtures described in BS EN 14227-3:2004.

Specifically FABM 5 refers to fly ash treated with either lime, quick or hydrated, or cement. No aggregate is included in the mixture. The fly ash is the aggregate but in an active rather than inert manner since it reacts chemically with lime or the lime produced from cement hydration.

The fly ash (also known as PFA in the UK) for FABM 5 is run-of-power-station conditioned (wet) ash in conformity with BS EN 14227-4:2004. In combination with lime, it produces a slow setting slow hardening mixture that behaves in an unbound fashion in the short-term but as a bound material in the long term. Used in combination with cement, it is effectively a cement-bound mixture with, compared to the lime version, a considerably shorter handling time.

Depending on performance requirements, lime contents would typically vary between 3 and 7% and cement contents between 5 and 10% by dry mass.

FABM 5 is specified in the series 800 of the Specification for Highway Works (SHW) along with other FABM and HBM types for use in base and sub-base. This data sheet effectively 'strips-out' these other FABM and HBM to produce a specification for FABM 5 that is appropriate for use with pavement design data sheet 6.3 produced by the United Kingdom Quality Ash Association. The specification is considered equivalent to that in the SHW 800 series but requires no reference to the 800 series nor BS EN 14227-3 or BS EN 14227-4.

1. Scope

1.1. This specification defines the requirements for the composition, the laboratory mechanical performance and the production, placement, and testing of FABM 5.

2. Standards & references

2.1. BS EN 14227-3:2004. Hydraulically bound mixtures – Specifications – Part 3: Fly ash bound mixtures. BSi, London, UK.

2.2. BS EN 14227-4:2004. Hydraulically bound mixtures – Specifications – Part 4: Fly ash for hydraulically bound mixtures. BSi, London, UK.

2.3. HIGHWAYS AGENCY. Manual of Contract Documents for Highway Works. Volume 1. Specification for Highway Works. The Stationery Office, Norwich, UK.

2.4. BS EN 13286-2:2004. Unbound and hydraulically bound mixtures – Part 2: Test methods for laboratory reference density and water content – Proctor compaction

2.5. BS EN 459-1. Building limes. Part 1: Definitions, specifications and conformity criteria.

2.6. BS EN 459-2. Building limes. Part 2: Test methods.

2.7. BS 1377-2. Methods of test for soils for civil engineering purposes. Part 2. Classification tests.

2.8. BS EN 197-1, Cement – Part 1: Composition, specifications and conformity criteria for common cement.

2.9. United Kingdom Quality Ash Association. www.ukqaa.org.uk

2.10. BS EN 13286-46:2003. Unbound and hydraulically bound mixtures – Part 46: Test method for the determination of the moisture condition value.

2.11. BS EN 13286-41:2004. Unbound and hydraulically bound mixtures – Part 41: Test method for determination of the compressive strength of hydraulically bound mixtures.

2.12. BS 1924: Part 2: 1990. Stabilised materials for civil engineering purposes. Part 2. Methods of test for cement-stabilised and lime-stabilised materials.

2.13. BS EN 13286-50:2004. Unbound and hydraulically bound mixtures – Part 50: Method for the manufacture of test specimens of hydraulically bound mixtures using Proctor equipment or vibrating table compaction.

2.14. BS EN 13286-51:2004. Unbound and hydraulically bound mixtures – Part 51: Method for the manufacture of test specimens of hydraulically bound mixtures using vibrating hammer compaction.

2.15. BS EN 13286-53:2004. Unbound and hydraulically bound mixtures – Part 53: Method for the manufacture of test specimens of hydraulically bound mixtures using axial compression.

3. Definitions

3.1. **FABM 5:** Fly ash treated by lime (known as **LFA**) or cement (known as **CFA**), with a water content compatible with compaction by rolling.

4. Symbols & abbreviations

4.1. **OMC:** Optimum moisture content determined using normal Proctor compaction in accordance with BS EN 13286-2.

4.2. **UKQAA:** United Kingdom Quality Ash Association

5. Constituents

5.1. **Fly ash:** Conditioned (wet) fly ash shall comply with the specification given in Annex A.

5.2. **Lime:** Lime shall be CL 90 [NforG] quick lime to BS EN 459-1 or hydrated lime to an equivalent specification from BS EN 459-1. In addition, quick lime;

5.2.1. when tested using the reactivity test in BS EN 459-2, shall attain a temperature of 60 degrees C within 5 minutes,

5.2.2. shall have a particle size with not less than 95% passing 2mm, 70% passing 0.2mm and 50% passing 0.08mm. [NforG]

5.3. **Cement:** CEM 1 cement to BS EN 197-1.

6. Water

6.1. Water shall not contain components that interfere with the setting, hardening and performance of FABM 5.

7. Composition

7.1. Unless agreed otherwise;

7.1.1. FABM 5 shall be designed in accordance with the mixture design procedure in 21

7.1.2. using constituents specified in 5 & 6

7.1.3. using the minimum constituent proportions specified in Table 1

7.1.4. using a water content range selected for compaction on site by rolling

7.1.5. to satisfy the selected class of laboratory mechanical performance from 8, 9 & 10

7.1.6. to satisfy the 'strength after immersion' class $I_{0.8}$ when tested to sub-clause 21.

Constituent	*Minimum addition for batching by mass*	*Minimum addition for batching by volume*
Lime (quick or hydrated)	3%	4%
CEM 1 cement	3%	4%

Table 1: Minimum constituent additions by dry mass of mixture as a function of batching

8. General

8.1. The laboratory mechanical performance class shall be selected using one of the following methods of characterisation:

8.1.1. compressive strength (R_c) or

8.1.2. the combination (R_tE) of tensile strength (R_t) and static modulus of elasticity (E).

NOTE: No correlation or equivalence is intended nor shall be assumed between the 2 methods of characterisation. The choice of method depends on design philosophy, utilisation and experience. NforG

9. Classification by R_c

9.1. Performance shall be classified by the 28 day compressive strength (R_c) determined in accordance with Annex C.

9.2. According to the pavement requirements, the class shall be selected from the following classes:

9.2.1. C3/4, C6/8, or other appropriate class,

9.2.2. where C designates compressive strength and the numbers after C, the minimum standard strength in MPa of the class; the first number referring to the strength of cylinders with a height:diameter ratio of 2 and the second number, to cylinders with a height:diameter ratio of 1 or cubes.

10. Classification by R_tE

10.1. Performance shall be classified by the combination, designated (R_tE), of the tensile strength (R_t) and static modulus of elasticity (E) at 28 days established in accordance with Annex C.

10.2. According to the pavement requirements, the class shall be selected from one of the following classes of R_tE detailed in Figure 1.

10.2.1. T1 or T2.

NOTE: The mixture characteristics and proportions necessary to meet the required R_tE class are determined at the mixture design stage (21). This may also include compressive strength testing which can be used for compliance purposes (sub-clause 20).

11. Production, placing and testing

11.1. General requirements;

11.1.1. Prior to the commencement of the works, the contractor shall provide;

11.1.1.1. The mixture design results, including the 'strength after immersion' results

11.1.1.2. The target proportions of constituents

11.1.1.3. A method statement for production, transport and laying in accordance with 18

11.1.1.4. And a demonstration area in accordance with 19.

11.2. Compaction, including any reworking and reuse, shall be completed within the construction period stated in Table 2. For multi-lift work, the construction period shall be measured from the addition of the lime/cement for the first lift and the completion of compaction of the overlying lift.

Binder	***Construction period in °C hours***
Cement with fly ash	35* from addition of cement (~ 2 hours at 20°C)
Lime with fly ash	800* from addition of lime (~ 48 hours at 20°C)

Table 2: Construction period for FABM 1

* Actual time in hours is the 'construction period °C hours' divided by 'the numerical difference between the actual temperature and 3°C'.

11.3. During cold weather:

11.3.1. the temperature of the mixture shall not be less than 5°C at the time of laying

11.3.2. mixture shall not be laid on a surface with a temperature below 3°C

11.3.3. laying shall cease when the air-temperature falls below 3°C and shall resume only until the rising air temperature reaches 3°C.

11.4. LFA shall be restricted in use to the period 1st May to 30th September unless otherwise agreed.

11.5. In the case of heavy or persistent rain, production shall cease and laid mixture compacted immediately.

12. Storage of constituents

12.1. Conditioned (wet) fly ash shall be stored on a firm and clean substrate avoiding contamination with other constituents. Before mixing with the other constituents, it shall be stored for at least 3 days, at a minimum moisture content of 10%, and screened to remove agglomerations greater than 10mm.

12.2. Lime and cement shall be stored and added via silo(s).

13. Manufacture

13.1. The mixture shall be produced in a central mixing plant with a forced-action mixer that batches by mass.

13.2. For ease of discharge of conditioned fly ash, the hopper(s) shall have steep sides or be lined with sheet plastic or be fitted with vibrators or a combination of these features.

13.3. Either through direct measurement or process control records, the supplier/producer/contractor shall provide evidence that constituents are batched to within 0.5% of the required quantity.

14. Transport

14.1. Transport of mixture shall be by rear-tipping lorries or dump trucks, fitted with covers to protect the mixture from drying or wetting during haulage or delays.

15. Laying

15.1. The total thickness of mixture up to 230mm course thickness shall be placed in one lift, by dozer or blade, avoiding drying out.

15.2. Total course layer thickness greater than 230mm may be undertaken:

15.2.1. in one lift provided the compaction requirements of sub-clause 16 are met or,

15.2.2. in 2 lifts subject to a minimum compacted lift thickness of 150mm.

15.2.3. subject to the other requirements of this clause, the first lift shall always be as thick as possible.

15.3. In no case shall mixture be added to freshly compacted mixture to make up level without vigorous scarifying of the surface of the compacted mixture to a depth of at least 50mm.

15.4. Surface trimmed material and mixture arising from ramps at the end of a day's work or elsewhere can be used in the permanent works day provided the mixture remains within the construction period, has not dried excessively and is uncontaminated.

15.5. The face of previously compacted mixture or other material shall be vertical before placement and compaction of fresh mixture.

15.6. In the case of rain, production shall cease and laid material shall be immediately compacted.

16. Compaction

16.1. Compaction shall be carried out by pneumatic-tyred roller (PTR) [NforG] with a wheel load of not less than 3 tonnes operating at a tyre pressure progressively increasing to circa 300 kPa and shall:

16.1.1. be completed before drying out and/or setting of the mixture

16.1.2. achieve an insitu wet density in the layer not less than 95% of the maximum laboratory wet density as specified in sub-clause 8.10.1

16.1.3. produce a layer with a well-closed surface, free from ridges, cracks, loose material, pot-holes, ruts, shear planes and cracks. [NforG]

16.2. At no time during compaction shall the surface of the mixture be allowed to dry out. To avoid this the contractor shall provide plant capable of applying a light spray of water to the surface.

16.3. Any defective areas shall be rectified during the construction period. If rectification is not completed within this period, the defective area shall be removed to the full thickness of the layer, and new mixture laid and compacted.

17. Curing, protection & trafficking

17.1. The layer shall be protected at all times from the detrimental effects of weather and use during construction and prior to overlaying with the next pavement course.

17.2. At no time after compaction, and prior to the placing of the next lift or layer, shall the surface be allowed to dry out. To avoid this the contractor shall provide plant capable of applying a mist/fog/light spray of water to the surface as necessary.

17.3. Relating only to CFA, as an alternative to light spraying with water, and before drying out of the surface, the surface shall be sprayed with 40 % bitumen emulsion at the rate of at least 0.5 l/m2 to achieve full and even coverage.

17.4. Reworking and re-compaction of the layer, watering if necessary, shall be permitted within the construction period.

17.5. Unless otherwise agreed, careful and controlled direct trafficking shall only be permitted within the construction periods for LFA and CFA. [NforG]

17.6. Surface contamination of the layer shall be avoided and removed prior to overlaying

18. Method statement

18.1. At least 10 days prior to construction the demonstration area described in 19, the contractor shall provide a full method statement indicating the intended procedures including;

18.1.1. the intended mixture proportions and supporting data to justify the proportions

18.1.2. constituent storage, batching & mixing facilities including production control checks

18.1.3. transport and weather protection to point of use

18.1.4. laying, compaction, curing, protection, trafficking & construction control checks

18.1.5. a sample record sheet for completion each working day, detailing construction times, sample and check locations, and check results (e.g. insitu density) available that day and to be made available by the start of the next working day.

19. Demonstration area

19.1. Prior to the commencement of the main works, the contractor shall construct a demonstration area of at

19.2. least 800 m2 conforming to the submitted method statement. The demonstration shall consist of at least 2 full-width bays so as to include a transverse end-of-bay joint.

19.3. Subject to satisfactory demonstration, the area may be constructed and accepted in the permanent works.

19.4. Once accepted, the constituents, proportions, production and construction procedures shall not be changed without a further demonstration area and or agreement.

20. Tests, controls and checks

20.1. Tests, controls and checks shall be carried out at agreed locations in accordance with Table 3 and sub-clauses below. With agreement, the frequency of the sampling shall be increased or relaxed as necessary.

Test/control/check	*Frequency*	*Reference*
Fly ash properties	Weekly certification	Annex A
Lime, cement	Weekly certification	-
Batching records	Continuously	-
Water content of mixture	3/1000 m2 but not less than 4 per day	BS 1924-2, clause 1.3
Insitu wet density	Sub-clause 20.2	Sub-clause 20.2
Mixture strength	Sub-clause 20.3	Sub-clause 20.3
Volume stability	At mixture design stage	Clause 21

Table 3: Requirements for tests, controls and checks

20.2. The insitu wet density of the layer shall be not less than 95% of the maximum laboratory wet density as determined by the vibrating hammer test of BS EN 13286-4 and shall be the average of 5 results for every 1000m^2 or part thereof laid each day, determined using a nuclear density gauge in direct transmission in accordance with section 3.7 of BS1924-2. The source rod shall be lowered to within 25mm of the bottom surface of the layer and readings taken within 2 hours of completing compaction. The result for each determination shall be the average of the higher 2 of 3 readings taken at 120 degrees to each other. The gauge shall be calibrated on a block of the mixture and recalibrated monthly thereafter or when constituents or proportions are changed.

20.3. For every 1000m^3 of mixture placed or part thereof laid each day, five full-depth samples shall be taken from the layer and from each sample and without further mixing, a cylindrical specimen manufactured for compressive or tensile strength testing at 28 days. The specimens shall be compacted to refusal by vibrating hammer and sealed to prevent loss of moisture and stored for 28 days at 40°C before testing in accordance with Annex B. The average measured strength of each set of 5 specimens shall satisfy the requirements of the selected class as follows.

20.3.1. In the case of pavement design based on R_c, compliance shall be satisfied if the average compressive strength of any group of 5 specimens is equal to or greater than the minimum compressive strength for the specified class with no individual test result less than 67% of the minimum.

20.3.2. In the case of pavement design based on R_tE, compliance shall be satisfied if the average tensile strength of any group of 5 specimens is equal to or greater than the minimum tensile strength, R_t, of the selected T class appropriate to the E value determined from the mixture design process, with no individual result less than 67% of the minimum. Compressive strength R_c may be used for compliance purposes provided the mixture design work established the correlation between R_c and R_t.

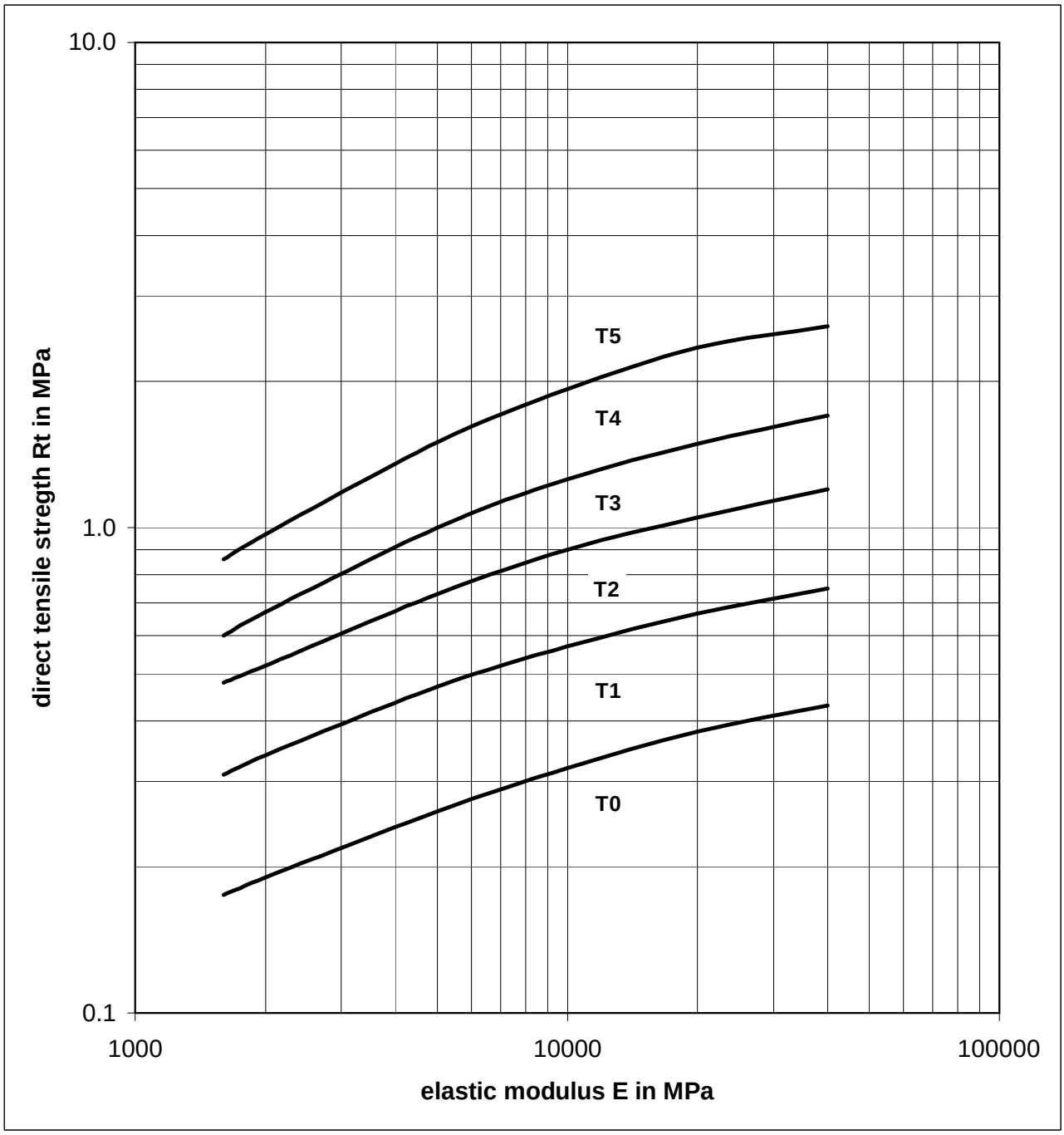
21. Mixture design procedure

21.1. The composition of the mixture shall be based on a mixture design test schedule using a minimum of 3 binder contents and a minimum of 2 water contents for each binder content, that satisfies the selected laboratory mechanical performance and the volume stability requirement.

21.2. The selected age of testing shall be 28 days and other ages reflecting the time available for testing, the desired age of compliance testing and the strength age relationships in Annex C.

21.3. Volume stability shall be assessed by comparing the average 28-day strength of 3 specimens immersed in aerated water with that of 3 sealed specimens. The immersed specimens shall be unconfined and have water contact to all surfaces. For mixtures containing less than 3% CEM 1 cement by dry mass of the mixture, the immersion period shall be 14 days following 14 days sealed curing, both using 40C. In the case of mixtures containing 3% or more cement, the procedure is identical but employs 20C rather than 40C.

Figure 1



NOTE The table beside gives the values of Rt and E used to draw the curves limiting the categories T5, T4, T3, T2 and T1.

E (MPa)	2000	5000	10000	20000	40000
Low limit of category	Rt (MPa)				
T5	0,97	1,50	1,93	2,35	2,60
T4	0,67	1,00	1,26	1,49	1.70
T3	0,52	0,73	0,90	1,05	1,20
T2	0,34	0,47	0,57	0,67	0,75
T1	0.19	0,26	0,32	0,38	0,43

ANNEX A: Specification for fly ash

A1 Scope

This specification applies to fly ash for use in FABM and other HBM.

A2 References

BSEN451-1 Method of testing fly ash - Part 1: Determination of free calcium oxide content.

BSEN451-2 Method of testing fly ash - Part 2: Determination of fineness by wet sieving.

BSEN196-2 Method of testing cement. Part 2. Chemical analysis of cement.

BSEN196-3 Methods of testing cement. Part 3. Determination of setting time and soundness.

A3 Definitions

Fly ash Fine powder produced by the combustion of pulverized coal in energy generating plants and captured by mechanical or electrostatic precipitators. The essential chemical components are silicates, aluminates and iron oxides. Fly ash is a pozzolanic material. It can be stored, supplied and used either in a conditioned (typically 10 – 20% added water) or dry (less than 1% water) condition.

A4 Particle size

Particle size, carried out in accordance with BSEN451-2, shall conform with the following.

Sieve	% by mass passing
90 micron	$\geq$ 70
45 micron	$\geq$40

A5 Chemical composition

Chemical composition shall comply with the following expressed as a percentage by mass of the dry product. The composition shall be determined on a laboratory sample, obtained by drying to constant weight in a well-ventilated oven at 105$\pm$5 degrees C, and then cooled in a dry atmosphere.

A5.1. Loss on ignition (LOI)

The LOI, measured in accordance with BSEN196-2, but using an ignition time of 1 hour, or other equivalent method, shall not exceed 15% (Note: Previously 10%).

NOTE: The purpose of this requirement is to limit the residue of unburnt carbon in fly ash. It is sufficient therefore, to show through direct measurement of unburnt carbon residue, that it is less than the value specified above.

A5.2. Sulfate content

The sulphate content, expressed as total SO_3, shall not exceed 4% by mass when measured in accordance with BSEN196-2.

A5.3. Free calcium oxide content

The free calcium oxide content, measured in accordance with BSEN451-1, shall not exceed 1% by mass. If this requirement is not met, soundness shall be measured in accordance with BSEN196-3, and the expansion shall not exceed 10mm with a 50:50 blend of fly ash and cement.

ANNEX B: Determination of compressive strength, tensile strength and elastic stiffness

B1. For characterisation or mixture design testing in the laboratory, the representative values of R or E shall be taken as the average result from at least 3 specimens. If one results varies by more than 20% of the average, it shall be discarded and R or E taken as the average of the other values.

B2. For compliance testing, acceptance shall be in accordance with 8.10.2.

B3. Specimens for R and/or E shall be cylindrical specimens with a height diameter ratio of 1 (2 for E) made to refusal using vibrating hammer compaction in accordance with BS EN 13286-51 or refusal MCV specimens using the MCV apparatus.

NOTE: Either metal, split or otherwise, or rigid plastic moulds can be employed. 100mm diameter HDPE (10mm wall thickness) pipe precision cut to 100mm (200mm for E) lengths has been found particularly convenient for FABM 5 since the specimen can be left in the mould until time of test and the mould is sufficiently robust to allow reuse. Proctor specimens have also been employed.

B4. Specimens shall be stored:

- Vertically
- In a manner that prevents loss of moisture
- At a temperature within $\pm$ 2 C of the specified or selected curing temperature
- Such that weight loss during storage is not in excess of 2%.

Non-compliance with the above shall lead to rejection of the specimen.

B5. Specimens shall be tested for compressive and/or tensile strength in accordance with BS EN 13286-41 and BS EN 13286–42 respectively. The latter describes the test to determine the indirect tensile strength also known as the tensile splitting or Brazilian test. Indirect tensile strength, R_{it} , is related to direct tensile strength, R_t , as follows:

- $R_t = 0.8\ R_{it}$

B6. Direct measurement of E shall be determined in accordance with BS EN 13286-43. However E is determined, it can be assumed that:

- $E = E_t = E_c = E_{it}$

Notes for Guidance

NG 5.2: Lime

The BS EN for FABM, BS EN 14227-3, and the SHW, allow the use of either CL90 or CL 80 quick lime for FABM 5. Since the performance of FABM depends on the efficient and full mobilisation of the pozzolanic potential of fly ash and since this is a function of the purity or available CaO in quick lime, the use of CL90 quick lime or equivalent hydrated lime is preferred and recommended here.

Similarly, the finer the particle size of the quick lime, the more effective is the reaction between fly ash and lime. Thus the finer of the two quick lime categories allowed in BS EN 14227-3 is also recommended here.

NG 8.1: Laboratory mechanical performance

It is now common in Highway Engineering to use ultimate strength and stiffness properties for pavement design purposes. The ultimate strength (R) or static elastic stiffness (E) of FABM 1 & 2 is taken as the value measured at 360 days on specimens sealed to prevent water ingress or egress and stored at 20 degrees C. Compliance results on the other hand are required considerably earlier, usually at 28 days or even earlier provided correlations exist.

The 360-day or ultimate values are normally established from 28-day results as follows:

Ultimate R or E ~ 28 day R or E after sealed storage at 40^{o}C

NOTE: This relationship is considered conservative since extensive testing indicates that the ultimate R or E is typically 1.15 x the 28-day value after 40^{o}C sealed curing.

For illustration, Table NG1 gives a tentative relationship between the R_c and R_tE classifications. For comparison, the old UK cement-bound material (CBM) classes are also included. The illustration is conservative with regard to the R_tE classes showing them in a poor light compared to compressive strength classification. Pavement design based on R_tE is more appropriate and robust than based on R_c and is used in data sheet 6.3.

R_tE classes	*Equivalent R_c classes*	*Nearest equivalent 'old' UK CBM classes*
T1	C 3 / 4	CBM 1
T2	C 6/8	CBM 2

Table NG1: Tentative relationship between the R_c and R_tE classifications

NG 16: Production, placing and testing

Vibrating rollers are not recommended for the compaction of FABM 5 since they can overstress the surface, which may result in shear planes in the top 50mm or so of the layer. Pneumatic-tyred rollers can do the same but usually less so.

Direct trafficking can also cause the same problem, hence the requirement for overlaying with the next layer within the construction period. In this case, the compaction of the next layer has the effect of re-compacting and re-moulding the top of the underlying FABM 5 layer should it be distressed and helps to eliminate the shear cracking.

NG 21 Mixture design procedure

For the situations where pavement design is based on R_tE, compliance may be more conveniently carried out monitoring R_c. In this case, the mixture design procedure should include R_c testing.

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.