British Standard

BRITISH STANDARD

BS 6699:1992

Specification for

Ground granulated blastfurnace slag for use with Portland cement

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Technical Sector Board for Building and Civil Engineering (B/-) to Technical Committee CAB/1, upon which the following bodies were represented:

Association of Consulting Engineers
Association of Quality Pulverised Fuel Ash Suppliers
Brick Development Association
British Aggregate Construction Materials Industries
British Cement Association
British Precast Concrete Federation
British Ready Mixed Concrete Association
British Steel Industry
Cementitious Slag Makers Association
Concrete Society
County Surveyors' Society
Department of the Environment (Building Research Establishment)
Department of the Environment (Property Services Agency)
Department of Transport
Electricity Industry in United Kingdom
Federation of Civil Engineering Contractors
Institute of Concrete Technology
Institution of Civil Engineers
Institution of Structural Engineers
Mortar Producers Association
Royal Institution of Chartered Surveyors
Society of Chemical Industry
Water Services Association of England and Wales

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Contents

Foreword

This British Standard is published under the authority of the Technical Sector Board for Building and Civil Engineering and supersedes BS 6699:1986 which is withdrawn. This revision takes account of the June 1989 draft European Prestandard specification for cements, ENV 197. Whilst the draft European Prestandard does not include ground granulated blastfurnace slag as a separate material, it does introduce the principle of conformity criteria by continuous inspection during manufacture for cements. This principle has been included in this revision in order that manufacturers may be provided with a similar system for the purpose of demonstrating compliance. Also the test methods in EN 196 have been adopted.

Blastfurnace slag is the by-product produced simultaneously with iron in the blastfurnace and is composed chiefly of calcium and magnesium silicates and aluminosilicates. It is granulated by rapid quenching of the molten material. The resulting granules, which are mainly glassy in composition, are subsequently dried and ground to a fine powder.

Ground granulated blastfurnace slag (ggbs) has been used in composite cements and as a cementitious component of concrete for many years. This standard specifies ggbs for use in combination with Portland cement in concrete, mortar and grout.

Guidance on its use in concretes, either as a component of composite cements such as Portland blastfurnace cements conforming to BS 146 and BS 4246[1)] or as a direct addition to the concrete mix, can be found in BS 5328, BS 6543 and BS 8110-1. Guidance on its use in mortar as a component of composite cements, such as those conforming to BS 146 and BS 4246[1)] or as a direct addition to the mortar mix, can be found in BS 5262 and BS 5628. Information that may be supplied to aid the control of such uses is given in appendix C of this standard.

This revision introduces the following changes.

a) Additives to improve the manufacture or the properties of the ggbs are permitted up to a level of 1 % (m/m).

b) A limit for chloride content has been introduced and the chloride content has now to be declared on the certificate.

c) Additional information on chemical composition is now available if requested at the time of ordering.

d) The methods of sampling and testing are now in accordance with EN 196.

e) The requirements are specified as characteristic values and conformity is assessed by means of a statistical procedure for continuous inspection, operated by the ggbs manufacturer (autocontrol). This includes the concept of major defects which are "likely to reduce materially the usability of the ggbs for its intended purpose". In addition, limits are given for inspection testing to provide a means of assessing compliance at delivery.

f) The 3-day requirement for compressive strength has been replaced by a 7-day requirement since this relates more closely to the early performance of the ggbs.

g) The change in test method for compressive strength, from using concrete cubes in accordance with BS 4550 to using mortar prisms in accordance with EN 196-1[2)], has necessitated a change in the numerical limit for 28-day strength to maintain the same performance. The new limit has been set at a level which corresponds to that in BS 4246 and is effectively a 10 % higher requirement than in BS 6699:1986.

[1)] Also ENV 197 when published.

[2)] The Parts of EN 196 will be published as Parts of BS EN 196.

h) The requirements for compressive strength are based on combination with a Portland cement, class 42.5 conforming to BS 12 and with a restricted alkali content. There is now a requirement for the 7-day and 28-day strengths of this Portland cement to be included in the certificate.

i) The requirement for initial setting time is now related to the setting time of the Portland cement with which the ggbs is tested. A requirement is not given for final setting time.

j) A maximum limit of 2.5 % (m/m) has been specified for sulfur present as sulfate.

k) The definition of the chemical modulus has been changed from $\frac{(CaO) + (MgO) + (Al_2O)}{(SiO_2)}$ to $\frac{(CaO) + (MgO)}{(SiO_2)}$ in order to align with ENV 197.

The minimum permitted value is unchanged so that this is a more stringent requirement than in BS 6699:1986.

l) The microscope counting method for determination of glass content has been deleted.

m) Additional guidance on use, safety requirements and storage has been included in appendices B and C.

Product certification. Users of this British Standard are advised to consider the desirability of third party certification of product conformity with this British Standard based on testing and continuing surveillance, which may be coupled with assessment of a supplier's quality systems against the appropriate Part of BS 5750.

Enquiries as to the availability of third party certification schemes will be forwarded by BSI to the Association of Certification Bodies. If a third party certification scheme does not already exist, users should consider approaching an appropriate body from the list of Association members.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 14, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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1 Scope

This British Standard specifies requirements for the composition and the manufacture, and for the chemical and physical properties as characteristic values, of ground granulated blastfurnace slag (ggbs) for use in combination with Portland cement as a cementitious component of concrete, mortar and grout. Requirements for marking, provision of information, and sampling and testing for acceptance at delivery are also specified. It specifies the procedures for the manufacturer's autocontrol system to ensure conformity with the standard.

NOTE 1 Granulated blastfurnace slag may be taken to include pelletized blastfurnace slag.

NOTE 2 The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this British Standard, the definitions given in BS 6100-6.1 apply, together with the following.

2.1
characteristic value

that value of a property corresponding to an acceptable percentage of defects, generally 10 %, but 5 % for the lower strength limits

2.2
lot

quantity of ggbs produced under conditions presumed uniform. After specified tests, this quantity is regarded as a whole "conforming" or "not conforming" to the requirements

2.3
spot sample

sample taken at one time and from one and the same place relating to the intended tests. It can be obtained by combining one or more immediately consecutive increments

3 Composition and manufacture

The ggbs shall be obtained by quenching molten iron blastfurnace slag, e.g. in water or steam, to produce a glassy granular product which is then dried and ground to a fine powder. The ggbs shall contain no added materials except up to 1 % (*m/m*) of additives, e.g. grinding aids to improve the manufacture or the properties of the ggbs. Such additives shall not promote corrosion of reinforcement or impair the properties of the ggbs or of concrete, mortar or grout made using the ggbs. Metallic iron from the grinding process shall not be regarded as an additive.

4 Fineness

The specific surface, determined in accordance with clause **4** of EN 196-6:1989, shall be not less than 275 m^2/kg.

5 Glass content

The glass content, determined in accordance with appendix D, shall be not less than 67 % (*m/m*).

6 Compressive strength

A combination of 30 % (*m/m*) of Portland cement, class 42.5 conforming to BS 12 and having an alkali content, when determined in accordance with EN 196-21, of not less than 0.5 % (*m/m*) and not greater than 0.9 % (*m/m*) and 70 % (*m/m*) of the ggbs when intimately mixed together and determined in accordance with EN 196-1[3)], shall have compressive strengths, expressed as the mean of three results, as follows:

a) at 7 days: not less than 12 N/mm^2;

b) at 28 days: not less than 32.5 N/mm^2.

7 Initial setting time

The initial setting time of the combination of ggbs and Portland cement specified in clause **6**, determined in accordance with EN 196-3, shall be not less than the setting time of the Portland cement when tested on its own.

8 Soundness

The expansion of the combination of ggbs and Portland cement specified in clause **6**, determined in accordance with EN 196-3, shall be not more than 10 mm.

[3)] EN 196-1 describes strength tests on mortar prisms but for 2 years from the date of publication of BS 6699, the strength values may be derived from tests on concrete cubes in accordance with BS 4550-3.4. BS 4550-3.4 will be superseded by BS EN 196-1.

9 Chemical composition

9.1 Insoluble residue

The insoluble residue, when determined in accordance with clause **9** of EN 196-2:1987, shall be not more than 1.5 % (*m*/*m*).

9.2 Magnesia

The magnesia content, when determined in accordance with **13.13** of EN 196-2:1987, shall be not more than 14 % (*m*/*m*).

9.3 Sulfur

The content of sulfur present as sulfide, when determined in accordance with clause **11** of EN 196-2:1987, shall be not more than 2.0 % (*m*/*m*).

The content of sulfate present as SO_3, when determined in accordance with clause **8** of EN 196-2:1987, shall be not more than 2.5 % (*m*/*m*).

9.4 Loss on ignition

The loss on ignition, when determined in accordance with clause **7** of EN 196-2:1987, shall be not more than 3.0 % (*m*/*m*).

9.5 Manganese

The content of manganese, expressed as Mn_2O_3, when determined in accordance with clause **12** of EN 196-2:1987, shall be not more than 2.0 % (*m*/*m*).

9.6 Chloride

The chloride ion content, when determined in accordance with clause **4** of EN 196-21:1989, shall be not more than 0.10 % (*m*/*m*).

9.7 Chemical moduli

The ggbs shall consist of at least two-thirds by mass of the sum of CaO, MgO and SiO_2 when the contents of these oxides are determined in accordance with EN 196-2. The chemical modulus $(CaO + MgO)/(SiO_2)$ shall be not less than 1.0. The chemical modulus $(CaO)/(SiO_2)$ shall be not greater than 1.4.

10 Moisture content

The moisture content, when determined in accordance with appendix E, shall be not more than 1.0 % (*m*/*m*) of dry ggbs.

11 Marking

Ground granulated blastfurnace slag shall be marked on the bag, the certificate or the delivery note with the following particulars:

a) the name, trade mark or other means of identification of the manufacturer to facilitate traceability to the works in which the ggbs was manufactured;

b) the name of the material, i.e. ground granulated blastfurnace slag;

c) the number and date of this British Standard, i.e. BS 6699:1992[4)].

12 Information to be provided

12.1 Certificate

If a certificate is requested it shall affirm that the ggbs conforms to this standard and that it contains no additional materials other than those permitted. It shall include results of the following tests relating to the material delivered:

a) fineness (see clause **4**);

b) initial setting time (see clause **7**);

c) soundness (see clause **8**);

d) compressive strength (see clause **6**);

e) the source of the Portland cement used in the tests and its setting time and compressive strength at 7 days and 28 days when tested in the laboratory which is testing its combination with the ggbs;

f) chloride content (see **9.6**).

NOTE The certificate should be available from the manufacturer.

12.2 Additional information

The following information shall also be made available, if requested at the time of ordering, relating to the material delivered:

a) the content of oxides of silicon, aluminium, iron, calcium, magnesium and manganese;

b) an indication of the variability of the chloride content when its mean level exceeds 0.05 % (*m*/*m*);

c) the alkali content, expressed as the water-soluble sodium oxide equivalent averaged over the manufacturer's latest 25 consecutive composite samples, together with an indication of its variability when the average exceeds 0.1 % (*m*/*m*);

[4)] Marking BS 6699:1992 on or in relation to a product represents a manufacturer's declaration of conformity, i.e. a claim by or on behalf of the manufacturer that the product meets the requirements of the standard. The accuracy of the claim is therefore solely the responsibility of the person making the claim. Such a declaration is not to be confused with third party certification of conformity, which may also be desirable.

d) the alkali content expressed as the acid-soluble sodium oxide equivalent averaged over the manufacturer's latest 25 consecutive composite samples, together with an indication of its variability.

13 Sampling and testing for acceptance inspection at delivery

13.1 When required by the purchaser for assessing conformity at delivery, a spot sample of the ggbs shall be taken in accordance with **3.6** and **6.2**, **6.3**, **6.4** or **6.5** of EN 196-7:1989 either before, or at the time of, delivery. A laboratory sample shall be prepared and packed in accordance with clauses **8** and **9** of EN 196-7:1989. A sampling report shall be completed at the time of sampling and shall be attached to the laboratory sample in accordance with clause **10** of EN 196-7:1989.

NOTE Testing may be delayed for up to 5 weeks from the time of sampling provided that there is confirmation that the sample has been stored continuously as described in **9.2** of EN 196-7:1989.

13.2 When the ggbs is tested for strength (see clause **6**), setting time (see clause **7**) or soundness (see clause **8**), unless otherwise agreed between the purchaser and the manufacturer, the source of the Portland cement and, where appropriate, the CEN Standard sand and the type of compaction equipment to be used shall be those in use by the ggbs manufacturer.

13.3 When the ggbs is tested for chemical properties (see clause **9**), the sample shall be prepared by the method described in clause **5** of EN 196-2:1987.

13.4 The limiting values applicable to acceptance inspection shall be those given in Table 1.

Table 1 — Acceptance inspection limits

Property	Deviation from the requirements in clauses 4 to 10 in excess of
Strength lower limit:	
28-day	– 2.5 N/mm^2
7-day	– 2.0 N/mm^2
Fineness	– 25 m^2/kg
Initial setting time	– 15 min
Soundness	+ 1 mm
Insoluble residue	+ 0.5 % (*m*/*m*)
Magnesia content	+ 1.0 % (*m*/*m*)
Sulfide content	+ 0.5 % (*m*/*m*)
Sulfate content	+ 0.1 % (*m*/*m*)
Loss on ignition	+ 0.5 % (*m*/*m*)
Manganese content	+ 0.5 % (*m*/*m*)
Chloride content	+ 0.01 % (*m*/*m*)
Moisture content	+ 0.25 % (*m*/*m*)
Glass content by X-ray diffraction	– 5 %
Chemical moduli	No deviation permitted

14 Conformity criteria (manufacturer's autocontrol)

The conformity criteria for continuous inspection shall be taken from appendix A.

Appendix A Conformity criteria (manufacturer's autocontrol)

A.1 Introduction

A.1.1 A statistically formulated conformity criterion includes three elements as follows:

a) a definition of the requirement in terms of characteristic value, as given in clauses **4** to **10**;

b) the acceptable percentage P_a of defects or, in other words, the fractile of the normal (Gaussian) distribution to which the characteristic value corresponds. In this standard, this is the 10 % fractile or, for the lower strength limits, the 5 % fractile;

c) the probability of acceptance of a lot of ggbs which does not conform to the requirements.

A sampling inspection procedure can produce only an approximate value for the percentage of defects in a lot. The bigger the sample, the better the approximation. The probability of acceptance, also named consumer's risk, controls the degree of approximation by the sampling plan and in this case shall be 5 % for the continuous inspection which is the basis for the assessment of conformity.

A.1.2 The conformity criteria for continuous inspection (see **A.3**, **A.4** and **A.5**) are based upon the principles of **A.1.1**. This standard contains, however, an additional conformity criterion of a different type. In order to provide means for the rejection of ggbs which is likely to reduce materially the usability of the ggbs for the intended purpose, the standard specifies (see **A.6**) that a quantity of ggbs containing one or more so-called major defects does not conform to the requirements.

A.2 Application of conformity procedures

Conformity of ggbs to this standard shall be continuously assessed. In consequence, this appendix specifies that the conformity of such ggbs shall be verified by means of a statistical quality control scheme based upon continuous inspection of the manufactured ggbs. This inspection is operated by the ggbs producer (autocontrol).

NOTE International or national regulations may require the autocontrol of ggbs to be monitored by an officially recognized testing laboratory.

Terms of delivery or other contractual conditions, normally included in documents exchanged between the supplier and the purchaser of ggbs, are outside the scope of this standard.

A.3 General procedure for assessing conformity with the characteristic values

A.3.1 The assessment shall be based upon continuous sampling inspection using spot samples of ggbs taken in accordance with EN 196-7.

A.3.2 The continuous inspection shall take place at the ggbs grinding plant and be operated by the producer (autocontrol).

The series of samples used for assessing the conformity shall be taken over a period of not less than 6 months and not more than 12 months, except in the case of a new factory, when the period for assessing the conformity shall be declared by the manufacturer on the certificate, but shall not be less than 2 weeks.

Minimum testing frequencies are specified in Table 2.

Table 2 — Minimum testing frequencies

Property	Number of samples
Fineness Strength	2 per week
Initial setting time Soundness	1 per week
Glass content Chemical composition Moisture content	1 per month

A.3.3 An observed test value which does not conform to the a ppropriate values in clauses **4** to **10** is characterized as a defect. The European Prestandard specification for cements, ENV 197, distinguishes between minor and major defects. Separate limits are specified for major defects (see **A.6**).

A.4 Conformity criteria and procedures for strength

A.4.1 The strength requirements of clause **6** comprise:

28-day strength, lower limit (L);

7-day strength, lower limit (L).

A.4.2 In the case of the strength requirements, the conformity procedure shall be based upon sampling inspection by variables.

In principle, the overall percentage of defects in the lot from which samples are taken is estimated from the test results. Conformity requires that the estimate does not exceed the acceptable percentage of defects.

NOTE For practical calculations the so-called acceptability constant, k_A, is used for the evaluation of conformity instead of the percentage of defects (see **A.7**).

Table 3 — Parameters determining the conformity procedure

	7-day and 28-day strength (lower limit *L*)	Physical and chemical properties (all limits)
Continuous inspection procedure	By variables	By attributes (by variables is allowed)
Percentage of defects, P_a	5 %	10 %
Consumer's risk	5 %	10 %

A.4.3 The sampling plan (including the number of single spot samples to be taken) is established by means of the following two parameters given in Table 3:

a) acceptable overall percentage of defects;

b) acceptable consumer's risk.

The two parameters together are used for the selection of sampling plans for continuous autocontrol.

Some convenient sampling plans for inspection by variables have been collected in **A.7**. Any other plan satisfying the values in Table 3 is, in principle, acceptable for the conformity procedure.

A.5 Conformity criteria and procedure for physical and chemical properties

A.5.1 Clauses **4**, **5**, **7**, **8**, **9** and **10** specify requirements for the following properties:

a) physical properties:

1) fineness;

2) glass content;

3) initial setting time;

4) soundness.

b) chemical properties:

1) insoluble residue;

2) magnesia content;

3) sulfide content;

4) sulfate content;

5) loss on ignition;

6) manganese content;

7) chloride content;

8) chemical moduli;

9) moisture content.

Conformity shall be assessed for one property at a time.

A.5.2 In the case of physical and chemical requirements, the conformity procedure is based upon sampling inspection by attributes.

The number of defective items is counted and compared with an estimated number of defects, calculated from the number of tests and the specified acceptable overall percentage of defects.

In order to improve inspection efficiency, the ggbs producer is allowed to employ inspection by variables (see **A.4**). This is preferable for setting time, and for chloride content in the case where this is close to the specified limit.

A.5.3 The sampling plan (including the number of spot samples to be taken) is established on the same basis as in **A.4** (see also Table 3).

Some convenient sampling plans for inspection by attributes have been collected in **A.7**. Any other plan satisfying the values specified in Table 3 is, in principle, acceptable for the conformity procedure.

A.6 Limits for major defects

A quantity of ggbs yielding one or more major defective samples does not conform to the requirements of this standard.

In general terms, a major defect is defined as a deviation from the requirements in clauses **4** to **10** so large that the usability of the ggbs for its intended purpose is likely to be reduced and that in extreme cases even failure may be produced.

Table 4 presents a more specific definition for the different properties. If a test result deviates by more than the value in this table it is denoted major defective.

A.7 Sampling plans

A.7.1 *General*

This clause contains a number of sampling plans for the following two alternatives which satisfy the conditions of Table 3. The alternatives are as follows:

a) continuous inspection by variables;

b) continuous inspection by attributes.

The number of samples and the test frequency are specified in **A.3.2**.

Table 4 — Major defects

Property	Deviation from the requirements in clauses 4 to 10 in excess of
Strength lower limit	
28-day	– 2.5 N/mm^2
7-day	– 2.0 N/mm^2
Soundness	+ 1 mm
Loss on ignition	Value of deviation not specified
Chloride content	+ 0.01 % (m/m)
Insoluble residue	Value of deviation not specified
Initial setting time	– 15 min
Magnesia content	+ 1.0 % (m/m)
Sulfate content	+ 0.5 % (m/m)
Fineness Glass content Sulfide content Manganese content Chemical moduli Moisture content	Values of deviation not specified

A.7.2 *Inspection by variables*

In this case the mean value, $\bar{x}$, and the standard deviation, s, of the complete series of test results (one result per sample) are calculated. The conformity criteria are:

$$\bar{x} - k_A s \geq L$$

and

$$\bar{x} + k_A s \leq U$$

where

k_A is the acceptability constant;

L is the specified lower limit;

U is the specified upper limit.

The acceptability constant k_A depends on the parameters specified in Table 3 and on the number of test results (n). Values of k_A are listed in Table 5.

Table 5 — Acceptability constant k_A

n	P_a = 5 %	P_a = 10 %
40 to 49	2.13	1.70
50 to 59	2.07	1.65
60 to 79	2.02	1.61
80 to 99	1.97	1.56
100 to 149	1.93	1.53
150 to 199	1.87	1.48
≥ 200	1.84	1.45

A.7.3 *Inspection by attributes*

In this case the number c_D of defective test results (one result per sample) in the complete series of samples is counted.

The conformity is checked by the equation:

$$c_D \leq c_A$$

where the acceptable number of defects c_A depends on the parameters specified in Table 3 and on the number n of test results. Values of c_A are listed in Table 6.

Table 6 — Acceptable number of defects c_A

n	c_A
0 to 39	0
40 to 54	1
55 to 69	2
70 to 84	3
85 to 99	4
100 to 109	5
NOTE If $n \geq 100$, $c_A = 0.075\ (n - 30)$.	

Appendix B Product guidance

B.1 Safety warning

Dry ggbs or cement in normal use has no harmful effect on dry skin. Precautions should however be taken to avoid them entering the eyes, mouth and nose and to prevent skin contact with wet ggbs or cement.

Repeated skin contact with wet cement over a period may cause irritant contact dermatitis. Although no connection has been established between ggbs and dermatitis, this possibility cannot be ruled out. The abrasiveness of the particles of cement, ggbs and aggregate in mortar or concrete can contribute to this effect. Continued contact during a working day can lead to alkali burns with ulceration, but this is not common.

When working in places where dry ggbs becomes airborne, protection for the eyes, mouth and nose should be worn.

When working with wet mortar or concrete, waterproof or other suitable protective clothing should be worn such as long sleeved shirts, full length trousers, waterproof gloves and wellington boots. Clothing contaminated with wet ggbs, cement, mortar or concrete should be removed and washed before further use.

If ggbs enters the eye it should immediately be washed out thoroughly with clean water and medical treatment should be sought without delay. Wet mortar or concrete on the skin should be washed off immediately.

B.2 Storage

To protect ggbs from premature hydration after delivery, bulk silos should be waterproof and internal condensation should be minimized.

Paper bags should be stored clear of the ground, not more than eight bags high and protected by a waterproof structure. Deliveries should be controlled and used in order of receipt.

B.3 Grouting

Where ggbs is to be used for grouting and other applications, requiring it to be pumped through small apertures, such as spray nozzles, it is recommended that the user passes these materials through a screen of suitable mesh aperture to retain any occasional coarse particles.

B.4 Heat generation

The hydration of Portland cement causes significant generation of heat. This may be an advantage when small concrete sections are being cast or when concreting is undertaken in colder weather. This may be a disadvantage when larger concrete sections are cast because of the temperature gradients which can be set up.

The ggbs hydration process generates heat at a slower rate than that for Portland cement.

Consequently an increase in the proportion of ggbs to Portland cement can be beneficial in limiting both the rate of heat generation and the peak temperature attained by the concrete.

B.5 Sulfate resistance

There is at present no universally agreed direct test for sulfate resistance other than prolonged storage of concrete or mortar specimens in sulfate solutions; this type of test is not suitable as the basis for a standard specification. However, experimental work and practical experience have shown that a considerable degree of sulfate resistance is conferred on concrete containing combinations of Portland cements conforming to BS 12 and ggbs if the slag proportion is not less than 70 % (m/m) provided that the alumina (Al_2O_3) content by mass of the ggbs is limited (see BS 5328-1, BS 8110-1 and BRE Digest 363).

B.6 Alkali-silica reaction

Advice on the use of combinations of Portland cement and ggbs to reduce to an acceptable level the expansion caused by the alkali-silica reaction may be obtained from BRE Digest 330, BS 5328-1, BS 8110-1, Concrete Society Technical Report No. 30 “Alkali-silica reaction — minimizing the risk of damage to concrete — guidance notes and model specification clauses”, and the Department of Transport’s “Specification for highway works”.

B.7 Further information

Further guidance on the use of ggbs in mortar and concrete can be found in BS 5262, BS 5328, BS 5628, BS 6543 and BS 8110-1.

Appendix C Equivalence of within-mixer combinations to Portland blastfurnace cements

C.1 General

The following procedure has been designed for a combination consisting of two materials which are manufactured, delivered and batched separately. There are necessarily distinct differences from the procedure used for the testing of a factory-blended Portland blastfurnace cement, e.g. the chemical composition of the combination is obtained by calculation using the chemical composition of the two components and their ratio. In the case of a factory-blended cement, the procedures for conformity criteria and autocontrol demonstrate that the cement as a single material conforms to the relevant standard. The procedure for combinations determines the range of proportions over which their properties equate to the requirements of the relevant Portland blastfurnace cement specification and has been designed to provide the user with a similar degree of protection against nonconformity as in BS 146 or BS 4246. Users may adopt any proportions within the declared range and these need not be identical to the proportions used for testing.

The requirements for properties specified in this standard are such that a combination of ggbs conforming to it and of Portland cement conforming to BS 12 will have chemical and physical properties that conform to the requirements of BS 146 or BS 4246 (provided that the proportions of the combinations are within the limits specified in these standards).

Where Portland cement of standard strength class 52.5, having an initial setting time less than 60 min (in conformity to BS 12), is to be combined with ggbs, it is necessary to demonstrate that, for the declared range of proportions, the initial setting time will conform to the requirement of BS 146 or BS 4246, as appropriate.

This appendix sets out a procedure for strength testing that enables the strength characteristics of combinations to be related to the strength classes in BS 146 and BS 4246. It applies to combinations of ggbs conforming to this standard and Portland cement conforming to BS 12 and establishes the range of combination proportions within which the strength characteristics equate to the requirements of specific strength classes in BS 146 or BS 4246.

C.2 Principles of the procedure

The conformity criteria are the same as those in BS 146 and BS 4246 which are that:

> In principle, the overall percentage of defects in the lot from which the samples are taken is estimated from the test results. Conformity requires that the estimate does not exceed the acceptable percentage of defects.

The limitations on the acceptable percentage of defects can be found in Table **8** of BS 146:1991 and in Table 6 of BS 4246:1991. Any plan satisfying the conformity criteria for strength in BS 146 or BS 4246 is, in principle, acceptable for the conformity procedure.

As an example, a convenient procedure for the certification of equivalence to BS 146 strength class 42.5L follows. It is suitable for the certification of one source of ggbs with several sources of Portland cement. It establishes limits on the proportions of the ggbs with each specific Portland cement to ensure that the conformity criteria for strength are met.

a) The relationship between strength and proportion of the ggbs is established for each Portland cement (see **C.3**).

b) Monthly composite samples of the ggbs and each Portland cement are tested in combination and mean compressive strength values are determined over not less than 6 months nor more than 12 months (see **C.4**).

c) Spot samples of the ggbs and a nominated Portland cement are tested in combination and the standard deviation of the compressive strengths calculated over the same period of between 6 months and 12 months as used in item b) (see **C.5**).

d) The relationships between strength and proportions, mean strength, and standard deviation are used, with the limits for strength in Table 2 of BS 146:1991, to determine the range of proportions within which the strength characteristics of the combination are equivalent to the requirements of strength class 42.5L (see **C.6**).

NOTE In the case of a combination with a new Portland cement, the period for assessing equivalence should be declared on the certificate. In the case of a new ggbs source, the standard deviation should be determined from a minimum of 40 spot samples of the ggbs taken over a period of not less than 2 weeks.

C.3 Establishment of the relationship between compressive strength and blend proportions

A composite sample of the ggbs is obtained by blending a minimum of eight spot samples obtained at regular intervals over at least one calendar month. A composite sample of each Portland cement is similarly obtained.

Strength tests are carried out at 7 days and 28 days, in accordance with EN 196-1, on the following blends of the composite samples:

mass of ggbs (in %)	0 30 50 70 90
mass of Portland cement (in %)	100 70 50 30 10

The relationship between compressive strength and blend proportions should be re-established at least once every 2 years.

C.4 Monthly tests on individual Portland cements with ggbs

Monthly bulk average samples of the ggbs and each Portland cement source are obtained either from the manufacturers or by combining at least eight spot samples taken regularly throughout the month. These monthly bulk average samples of the ggbs and each Portland cement are blended in the proportion 50 : 50 and tests are carried out in accordance with EN 196-1 for strength at 7 days and 28 days. The mean strength $\bar{x}$ of each combination of the ggbs and a specific Portland cement is the average of the most recent monthly strength tests taken over a period of not less than 6 months and not more than 12 months.

C.5 Estimation of the standard deviation

If tests on every source are to be avoided, the highest probable standard deviation should be determined from data based on the anticipated most variable combination of Portland cement and ggbs. The choice of the nominated Portland cement for the most variable combination should be reviewed at least every 2 years. The basis of the review should be the variability of the monthly tests of the various combinations given in **C.4** or, where no historical data exists for combinations, the variability of the autocontrol data for the various Portland cements where such information is available.

At least once a week, a spot sample of the nominated Portland cement and a spot sample of the ggbs are taken in accordance with EN 196-7 and blended in the proportion 50 : 50. The blend is tested in accordance with EN 196-1 for strength at 7 days and 28 days. The standard deviation is determined from the results of tests carried out in the period corresponding to that used in **C.4**.

C.6 Establishment of limits on proportions for conformity to strength class 42.5L

The conformity criteria are:

$$\bar{x} \geq (L + k_A s)$$

and

$$\bar{x} \leq (U - k_A s)$$

where

k_A is the acceptability constant;

L is the specified lower limit;

U is the specified upper limit;

$\bar{x}$ is the mean strength determined in accordance with **C.4**;

s is the standard deviation determined in accordance with **C.5**.

The acceptability constant, k_A, depends on the number of samples, n, and differs between the upper (P_a = 10 %) and the lower (P_a = 5 %) limits (see Table 5, which is identical to Table 8 of BS 146:1991). For the certification of equivalence, n should be the number of spot samples taken in accordance with **C.5**.

To determine the limits on proportions for conformity to strength class 42.5L, construct a diagram showing the relationship obtained in accordance with **C.3** between 28-day strength and proportion for the ggbs and each specific Portland cement. On this diagram mark ($L + k_A s$) and ($U - k_A s$) where $k_A s$ is the margin determined from the standard deviation of the tests on spot samples in **C.5** (see Figure 1).

Then mark the mean strength $\bar{x}$ for the ggbs in combination with the specific Portland cement, in proportion 50 : 50, on the diagram. Draw a line through this point parallel to the relationship between 28-day strength and proportion.

Conformity with strength class 42.5L is achieved at proportions where this line exceeds ($L + k_A s$) but is less than ($U - k_A s$).

Carry out a similar exercise for the 7-day strength results (in this case no upper limit is applicable).

The range of proportions for conformity to strength class 42.5L is that for which *both* 7-day and 28-day strength conformity are met.

C.7 Issue of certificates

Certificates should be issued monthly. A certificate should relate to ggbs from a specific source used with Portland cement from a specific source. It should contain the following information:

a) identification of the materials sampled;

b) the period represented by the sample;

c) the means by which samples were obtained;

d) the blend composition tested;

e) the results of the tests carried out on the blend, which should include tests for initial setting time and strength;

f) details of the blend compositions derived to give equivalent properties and proportions to the requirements of the relevant Portland blastfurnace cement standard, stating the equivalent strength class in the case of equivalence to BS 146;

g) the signature of the person responsible for the testing.

NOTE The certificate may also contain a statement classifying combinations in accordance with Table 7, in terms of standard strength classes intermediate between those for Portland blastfurnace cements in BS 146. The standard strength classes in Table 7 have no equivalents in BS 146.

It should be noted that the use of combinations corresponding to standard strength classes 37.5 and 47.5 could give concrete strengths which are up to 10 % greater respectively than a 32.5 or 42.5 standard strength class blastfurnace cement. For the purposes of demonstrating equivalence, conformity to strength class 37.5 or 47.5 in accordance with this standard is deemed to satisfy strength classes 32.5 or 42.5 of BS 146 respectively.

Table 7 — Compressive strength classes for combinations

Intermediate standard strength classes for combinations	Early strength 7-day	Standard strength 28-day
N/mm^2	N/mm^2	N/mm^2
37.5	> 16.0	≥ 37.5 and ≤ 57.5
47.5	> 20.0	≥ 47.5 and ≤ 67.5

The issue of a certificate is a declaration of the equivalence of the within-mixer blend to the requirements for properties and proportions of the relevant Portland blastfurnace cement standard.

The accuracy of the claim is solely the responsibility of the issuer of the certificate. Such a claim should not be confused with third party certification of conformity which may also be desirable.

C.8 Inspection testing

When inspection testing is required, a spot sample of the ggbs and a spot sample of the Portland cement shall be taken in accordance with **3.6** and **6.2**, **6.3**, **6.4** or **6.5** of EN 196-7:1989. Laboratory samples shall be prepared and packed in accordance with clauses **8** and **9** of EN 196-7:1989. A sampling report shall be completed at the time of sampling and shall be attached to the laboratory samples in accordance with clause **10** of EN 196-7:1989. The sample of ggbs and of Portland cement shall be combined in the laboratory in the blend ratio being used. The laboratory combination shall then be tested in accordance with clause **11** of BS 146:1991 or clause **11** of BS 4246:1991 as appropriate.

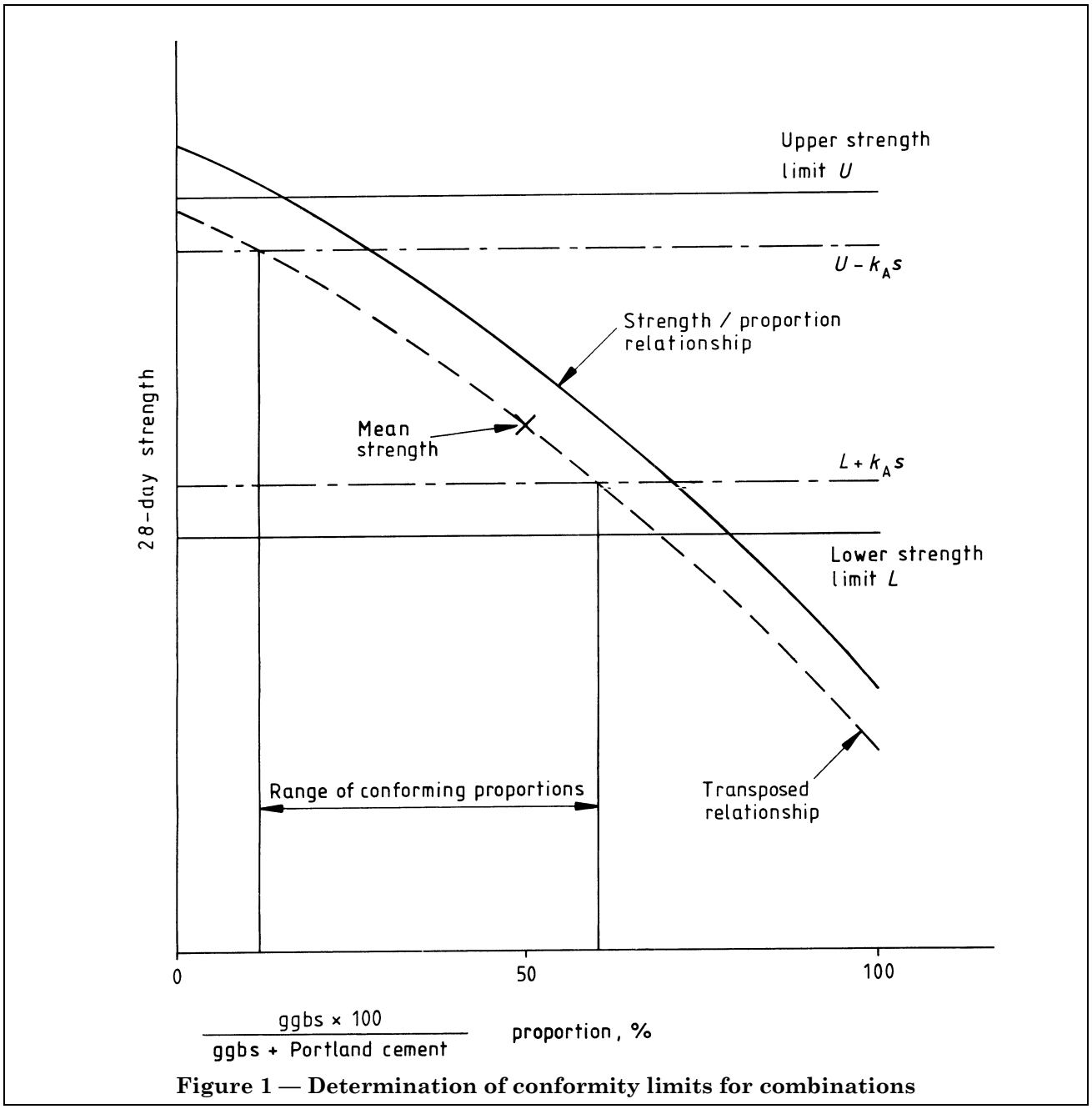

Figure 1 — Determination of conformity limits for combinations

Appendix D Method of determining the glass content of ggbs by X-ray diffraction

D.1 Principle

A typical X-ray diffraction pattern of a ggbs consists of diffractions (peaks) produced by the crystalline components, the broad diffraction effect (hump) produced by the glassy (amorphous) material and a background component which is essentially linear. This is shown schematically in Figure 2.

The ratio of the integrated intensity arising from the glassy material (i.e. the area of the hump) to the total integrated intensity (i.e. the area above the linear background) is a measure of the glass content of the slag.

D.2 Reagent

D.2.1 *Cyclohexane,* laboratory reagent grade.

D.3 Apparatus

D.3.1 *X-ray diffractometer system,* capable of recording the diffracted X-ray pattern onto a paper chart.

NOTE Attention is drawn to the appropriate statutory safety regulations for ionizing radiations with which this X-ray equipment has to conform.

The output produced on a chart recorder shall be such that:

a) the linear distance equivalent to an angle of deviation of 1° (2θ) is not less than 10 mm on the chart paper;

b) the height of the strongest diffraction whose interplanar spacing (d-spacing) between 0.404 nm and 0.237 nm, after a correction has been made to account for the linear background (see **D.6**), is greater than 100 mm;

c) the diffraction pattern is recorded with a scanning speed equal to or less than 1° (2θ) per minute;

d) the time constant is capable of being adjusted to give a scatter of background less than 5 mm.

D.3.2 *Grinding mill*[5)], capable of reducing all particles in the sample to less than 20 µm in diameter when used as described in **D.4** and without detectable contamination from the grinding media.

NOTE It is recommended that agate media be used.

D.3.3 *Balance*, capable of weighing to an accuracy of 0.0001 g.

D.3.4 *Specimen holder.*

D.4 Sample preparation

Dry the ggbs sample at (105 ± 5) °C in accordance with **E.3**. Weigh (**D.3.3**) into the mill container (**D.3.2**) a representative subsample, as recommended by the mill manufacturer. Add an appropriate amount of cyclohexane (**D.2.1**) and grind for such time as is necessary to reduce the maximum diameter of all particles to less than 20 µm. Dry again at room temperature in a fume cupboard to remove the cyclohexane.

D.5 Procedure

Pack a subsample of the fine dry powder into a specimen holder (**D.3.4**) using hand pressure for compaction. Mount the specimen in the X-ray diffractometer (**D.3.1**) in the normal way.

Determine the maximum intensity and adjust the full-scale deflection to make maximum use of the width of the recorder chart. Using a suitable scanning speed and an appropriate time constant (see **D.3.1**), scan the specimen from d-spacings of 2.209 nm to 0.134 nm, recording the output onto the chart recorder.

NOTE This extended scan range allows a search to be made for large peaks due to crystalline components not originating from the ggbs. Should any such contaminants be found with major peaks outside the region of interest (see **D.6**), they should be identified and reported as well as the glass content.

D.6 Calculation

Draw a straight line across the diffraction pattern such that it passes through those places on the pattern having d-spacings of 0.404 nm and 0.237 nm, i.e. at 22.0° and 38.0° (2θ) respectively when copper Kα radiation is used. This line represents the linear background associated with the diffraction pattern. Consider only those areas in the calculation which are contained within the regions defined by these d-spacings and which are above the linear background.

Define the amorphous region between 0.404 nm and 0.237 nm by drawing a line through the mid-point of the variation of the diffracted intensity representing the hump, interpolating its path below those diffractions which are due to crystalline material (see Figure 2). Cut out those parts of the paper delineated as representing the peaks and the amorphous region and weigh each to the nearest 0.0001 g (see **D.3.3**).

NOTE 1 A photocopy or tracing of the original scan may be used.

Determine the mass of glass present (G) as a percentage from the following equation.

$$G = \frac{W_1}{W_1 + W_2} \times 100$$

where

W_1 is the mass of paper representing the mass of glass in the sample (in g);

W_2 is the mass of paper representing the mass of crystalline components in the sample (in g).

NOTE 2 Methods of measuring the relevant areas directly are permissible, provided that they can be shown to give equivalent results.

D.7 Report

Report the glass content to the nearest 1 %.

[5)] For information on the availability of grinding mills, write to Customer Information, BSI, Linford Wood, Milton Keynes MK14 6LE.

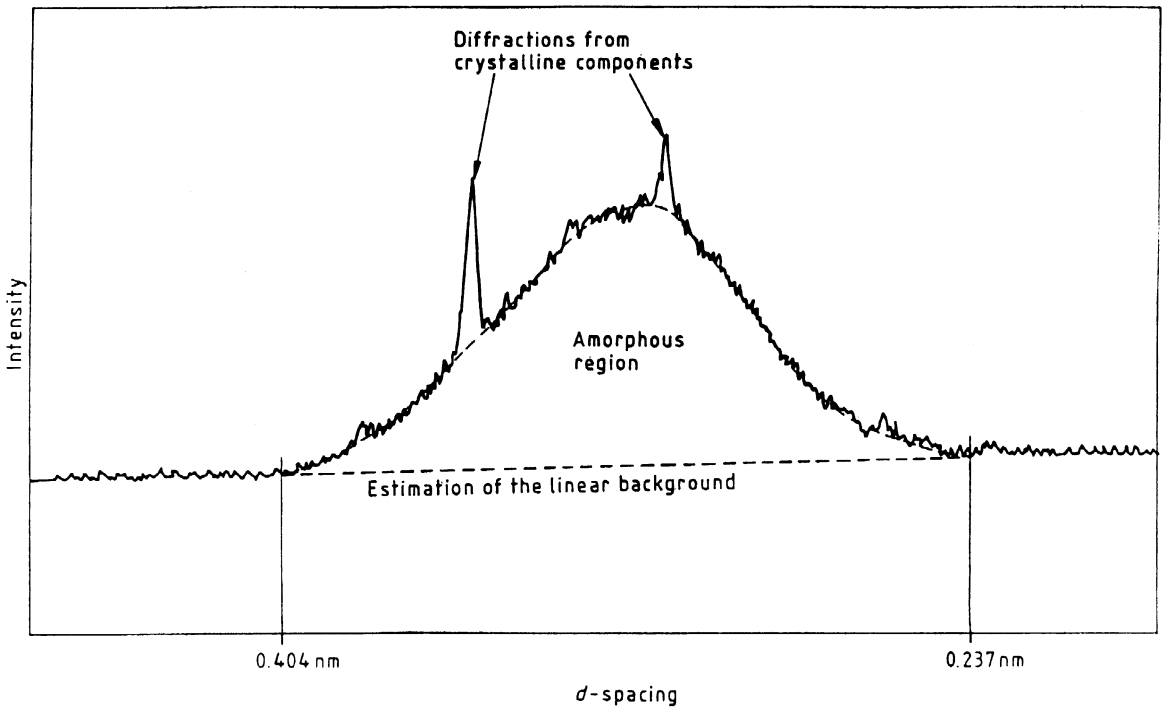

Figure 2 — Schematic representation of a portion of an X-ray diffraction pattern of a ggbs

Appendix E Method of determining the moisture content of ggbs

E.1 Principle

The moisture content of the ggbs is determined by drying a sample in an oven until constant mass is achieved.

E.2 Apparatus

E.2.1 *Balance,* capable of weighing to an accuracy of 0.001 g.

E.2.2 *Shallow container,* of about 20 g capacity.

E.2.3 *Electric oven,* with natural ventilation controlled at (105 ± 5) °C.

E.2.4 *Desiccator,* containing dried magnesium perchlorate.

E.3 Procedure

Weigh, to the nearest 0.001 g (**E.2.1**), (10 ± 0.05) g of ggbs into the shallow container (**E.2.2**), which has previously been dried and weighed. Place the container in the electric oven (**E.2.3**). Heat it for 1 h. Remove the shallow container and allow it to cool in the desiccator (**E.2.4**) to room temperature and weigh it. Repeat the heating and cooling cycle until constant mass is achieved, i.e. when the difference between two successive weighings is less than 0.005 g.

E.4 Calculation

Calculate the moisture content, C, of the sample as a percentage, to the nearest 0.1 %, from the following equation:

$$C = \frac{(M_1 - M_2)}{M_2} \times 100$$

where

M_1 is the mass of initial sample (in g);

M_2 is the mass of dried sample (in g).

E.5 Report

Report the moisture content as a percentage of the dry mass to the nearest 0.1 %.

blank

Publication(s) referred to

BS 12, *Specification for Portland cement.*
BS 146, *Specification for Portland blastfurnace cements.*
BS 4246, *Specification for high slag blastfurnace cement.*
BS 4550, *Methods of testing cement.*
BS 4550-3.4, *Strength tests.*
BS 5262, *Code of practice. External rendered finishes.*
BS 5328, *Concrete.*
BS 5328-1, *Guide to specifying concrete.*
BS 5628, *Code of practice for use of masonry.*
BS 5750, *Quality systems*[6)].
BS 6100, *Glossary of building and civil engineering terms.*
BS 6100-6.1, *Binders.*
BS 6543, *Guide to use of industrial by-products and waste materials in building and civil engineering.*
BS 8110, *Structural use of concrete.*
BS 8110-1, *Code of practice for design and construction.*
BS 196, *Methods of testing cement.*
BS 196-1, *Determination of strength.*
BS 196-2, *Chemical analysis of cement.*
BS 196-3, *Determination of setting time and soundness.*
BS 196-6, *Determination of fineness.*
BS 196-7, *Methods of taking and preparing samples of cement.*
BS 196-21, *Determination of the chloride, carbon dioxide and alkali content of cement.*
ENV 197, *Cement — Composition, specifications and conformity criteria*[7)].
BRE Digest 330, *Alkali aggregate reactions in concrete*[8)].
BRE Digest 363, *Sulphate and acid resistance of concrete in the ground*[8)].
Concrete Society Technical Report No. 30 "Alkali-silica reaction — minimizing the risk of damage to concrete — guidance notes and model specification clauses". 1987[9)]
Department of Transport. "Specification for highway works". HMSO

[6)] Referred to in the foreword only.
[7)] In preparation. Referred to in the foreword only.
[8)] Available from Building Research Establishment, Garston, Watford WD2 7JR.
[9)] Available from Concrete Society, Framewood Road, Wexham, Slough SL3 6PJ.

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