PUBLISHED DOCUMENT

PD 6682-7:2003

Aggregates —

Part 7: Armourstone — Guidance on the use of BS EN 13383

ICS 91.100.15

BSI British Standards

Committees responsible for this Published Document

The preparation of this Published Document was entrusted by Technical Committee B/502, Aggregates, to Subcommittee B/502/4, Hydraulically bound and unbound aggregates, upon which the following bodies were represented:

County Surveyor's Society
Department of Trade and Industry — Represented by Building Research Establishment Limited
Institution of Structural Engineers
Quarry Products Association
UK Steel
Co-opted members

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 30 October 2003

The following references relate to work on this Published Document
Committee reference B/502/4

ISBN 0 580 42720 X

Amendments issued since publication

Amd. No.	Date	Comments

Contents

Foreword

This Published Document has been prepared under the direction of Subcommittee B/502/4, Aggregates for unbound and hydraulically bound materials. It is one of nine parts that give guidance on the use and application of a series of European Standards for aggregates. These European Standards were prepared by CEN/TC 154, Aggregates and have been adopted as British Standards. Conflicting British Standards relating to aggregates will be withdrawn in June 2004.

This part of PD 6682 gives guidance on the use of BS EN 13383 which specifies requirements for armourstone. BS EN 13383 supersedes the conflicting recommendations for armourstone in BS 6349-1:2000 which will be amended to remove these conflicting recommendations at the latest by June 2004.

NOTE 1 Users of BS 6349-1:2000 should contact BSI Customer Services for confirmation of amendment.

BS EN 13383 specifies requirements that differ from those found in the CIRIA/CUR manual on the use of rock in coastal and shoreline engineering [1]. The CIRIA/CUR manual will be amended to remove these conflicting recommendations.

NOTE 2 Users of the CIRIA/CUR manual should contact the Construction Industry Research and Information Association for confirmation of amendment.

Attention is drawn to the fact that BS EN 13383 fully takes into account the requirements of the European Commission mandate M125, Aggregates, given under the EU Construction Products Directive (89/106/EEC) [2].

Guidance on the other European Standards in the series is given in the following parts of PD 6682.

— *Part 1: Aggregates for concrete — Guidance on the use of BS EN 12620.*

— *Part 2: Aggregates for bituminous mixtures and surface treatments for roads, airfields and other trafficked areas — Guidance on the use of BS EN 13043.*

— *Part 3: Aggregates for mortar — Guidance on the use of BS EN 13139.*

— *Part 4: Lightweight aggregates for concrete, mortar and grout — Guidance on the use of BS EN 13055-1.*

— *Part 5: Lightweight aggregates for bituminous mixtures and surface treatments and for unbound and bound applications excluding concrete, mortar and grout — Guidance on the use of BS EN 13055-2.*[1)]

— *Part 6: Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction — Guidance on the use of BS EN 13242.*

— *Part 8: Aggregates for railway track ballast — Guidance on the use of BS EN 13450.*

— *Part 9: Guidance on the use of European test method standards.*

This publication does not purport to include all necessary provisions of a contract. Users are responsible for its correct application.

This Published Document is not to be regarded as a British Standard.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 35 and a back cover.

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[1)] Both BS EN 13055-2 and PD 6682-5 are in preparation.

Introduction

This document gives guidance on the use of BS EN 13383 in the UK. BS EN 13383 supersedes the corresponding conflicting recommendations for stone for armouring in BS 6349-1.

NOTE 1 European test method standards for aggregates supersede the BS 812 test methods for aggregates recommended in BS 6349-1 for the quality testing of armourstone. Guidance on which European Standard test methods for aggregates are used for the testing of armourstone is given in Clause **5** and Clause **6**.

BS EN 13883 specifies requirements for armourstone that differ from the recommendations contained in the CIRIA/CUR manual on the use of rock in coastal and shoreline engineering [1].

NOTE 2 The requirements of BS EN 13383 are particularly different from the model specification and test methods specified in Annex 1 and Annex 2 of the CIRIA/CUR manual. The recommendations in the annexes of the CIRIA/CUR manual will be updated to reflect the content of BS EN 13383.

Whilst BS EN 13383 describes armourstone in a different manner to established UK practice and in some cases uses different test methods to evaluate their properties, there is no change to the general quality of the armourstone in use in the UK. BS EN 13383, like the CIRIA/CUR manual, specifies wider gradings than BS 6349-1 for heavier armourstone because there is evidence of the satisfactory use of these grading.

BS EN 13383 is divided into 2 parts:

— *Part 1: Specification;*

— *Part 2: Test methods.*

BS EN 13383-1 specifies a range of categories for properties to enable users to select the appropriate limiting values for the wide range of armourstone produced in Europe. In most instances, provision is also made for producers to identify a declared value for properties when the value of the property is outside indicated categories.

Owing to the special functions and large sizes of armourstone materials, special test methods and sampling methods which differ from those associated with aggregates have been specified in BS EN 13383-2. A tabular summary of all sampling and testing requirements for a particular property is given informatively in BS EN 13383-2:2002, Annex G as an aid for armourstone producers and testing authorities. This summary is considered necessary because of the particularly wide range of test types, test portions and sample reduction procedures needed to accommodate armourstone tests both on individual test pieces of rock as well as on a sample selection of rocks.

An example specification listing recommended BS EN 13383 categories for particular properties is given in Annex A. It can be applied to most general uses of armourstone. For particular armourstone sources and/or end uses, specifiers may need to give requirements for additional properties. Some recommended BS EN 13383 categories for particular armourstone sources and/or end uses in the UK are given in Annex B. Where requirements vary dependent on the particular end use, appropriate values should be inserted for the particular properties.

BS EN 13383 includes manufactured and recycled armourstone within its scope and indicates that their suitability should be assessed in accordance with the regulations valid in the place of use. However, in the UK, there are no relevant regulations for armourstone and there is no current experience of the use of manufactured or recycled materials for this purpose. Precast concrete armour units are not considered to be manufactured armourstone for the purposes of this guide.

1 Scope

This part of PD 6682 gives guidance on the use of BS EN 13383 in the UK. BS EN 13383 specifies the properties of armourstone obtained by processing natural, manufactured or recycled materials and mixtures of these materials.

2 Overview of BS EN 13383

2.1 General

In comparison with BS 6349-1 and the CIRIA/CUR manual, BS EN 13383 gives requirements for different armourstone properties, including different test methods.

The geometrical, physical (mechanical), chemical and durability requirements for armourstone that appear in BS EN 13383-1 are listed in **2.2**, **2.3**, **2.4** and **2.5**. The armourstone test methods that appear in BS EN 13383-2 and other European test method standards for aggregates are listed in **2.6**.

2.2 Geometrical requirements

Requirements for the following geometrical properties are specified for armourstone in BS EN 13383-1:2002, Clause **4**:

a) grading;

b) shape;

c) percentage of crushed and broken surfaces.

2.3 Physical requirements

Requirements for the following physical properties are specified for armourstone in BS EN 13383-1:2002, Clause **5**:

a) particle density, determined in accordance with a BS EN 13383-2 test method derived from a Dutch (NEN[2)]) test method;

b) resistance to breakage determined in accordance with a BS EN 1926 compressive strength test method designed for testing armourstone;

c) resistance to wear measured by determining the (wet) micro-Deval coefficient in accordance with a BS EN 1097-1 test method derived from a French (AFNOR[3)]) test method (and found to have good correlation with another resistance to wear method developed in the UK and published in the CIRIA/CUR manual);

d) grouting;

e) colour.

2.4 Chemical requirements

Requirements for the following chemical properties are specified for armourstone in BS EN 13383-1:2002, Clause **6**:

a) impurities;

b) water-soluble constituents.

[2)] Further information about NEN, the Netherlands national standards body, can be found on www.nen.nl.
[3)] Further information about AFNOR, the French national standards body, can be found on www.afnor.fr.

2.5 Durability requirements

Requirements for the following durability properties are specified for armourstone in BS EN 13383-1:2002, Clause **7**:

a) dicalcium silicate disintegration of air-cooled blast-furnace slag;

b) iron disintegration of air-cooled blast-furnace slag;

c) disintegration of steel slag;

d) water absorption as a screening test for the resistance to freezing and thawing and to salt crystallization;

e) resistance to freezing and thawing using 10 large individual test pieces determined in accordance with BS EN 13383-2 derived from a Dutch (NEN[4]) test method involving 25 freeze-thaw cycles;

f) resistance to salt crystallization determined in accordance with the BS EN 1367-2 magnesium sulfate soundness test for aggregates derived from BS 812-121;

g) "Sonnenbrand" of basalt, a type of rock decay that can be present in some basalts, determined in accordance with a BS EN 13383-2 boiling test derived from a German (DIN[5]) test method.

2.6 Sampling and test methods

Requirements for sampling procedures are specified for armourstone in BS EN 13383-2:2002, Clause **4**.

Test methods to determine the following properties are specified for armourstone in BS EN 13383-2:

a) determination of particle size distribution of coarse gradings;

b) determination of the mass distribution of light and heavy gradings;

c) determination of the percentage of pieces of armourstone with a length-to-thickness ratio greater than 3;

d) determination of particle density and water absorption;

e) determination of resistance to freezing and thawing;

f) determination of signs of "Sonnenbrand" and disintegration of steel slags.

BS EN 13383-1 specifies testing in accordance with European test method standards for aggregates that have not previously been used for armourstone in the UK. European test method standards for aggregates are used to determine the following properties for armourstone:

1) type of armourstone identified using a simplified petrographic description in accordance with BS EN 932-3;

2) a sieving method for the determination of particle size in accordance with BS EN 933-1;

3) resistance to wear by determination of the micro-Deval coefficient in accordance with BS EN 1097-1;

NOTE Attention is drawn to the fact that BS EN 13383-1:2002, **5.4** specifies variations to the requirements for sample preparation given in BS EN 1097-1:1996, Clause **6**.

4) determination of water content in accordance with BS EN 1097-5;

5) resistance to salt crystallization by determination of the magnesium sulfate value in accordance with BS EN 1367-2:1998, Clause **8**;

6) dicalcium silicate or iron disintegration of air-cooled blast-furnace slag determined in accordance with BS EN 1744-1:1998, **19.1** and **19.2**;

7) determination of water-soluble constituents through the preparation of an eluate in accordance with BS EN 1744-3 and subsequent testing using methods developed for water analysis that have been adapted for use in the analysis of eluates;

8) resistance to breakage by testing compressive strength in accordance with BS EN 1926:1999, Annex A.

For the convenience of the user a brief descriptive outline of each test method in BS EN 13383-2 and the other relevant European test method standards for aggregates is given in Clause **5** and Clause **6**.

[4] Further information about NEN, the Netherlands national standards body, can be found on www.nen.nl.
[5] Further information about DIN, the German national standards body, can be found on www.din.de.

2.7 Evaluation of conformity

BS EN 13383-1:2002, Clause **8** requires that producers undertake and on request declare the results from:

a) initial type tests used:

i) to characterize properties for new sources of armourstone; or

ii) where there is a major change in the raw materials or processing which can affect the properties of the armourstone; and

b) factory production control to monitor conformity of the armourstone with the relevant BS EN 13383 requirements and the producer's declared values.

Minimum frequencies of tests are identified in BS EN 13383-1:2002, Annex D.

Guidance on the requirements for attestation of conformity and compliance with the provisions of the EU Construction Products Directive [2] is given in **4.9**.

3 Differences between BS EN 13383 and existing UK guidance documents

3.1 General

BS 6349-1 is the only British Standard covering the subject of armourstone. The subject is dealt with in BS 6349-1:2000, Clause **57** under the title "Stone for armouring or protection works" and comprises about one page of text. BS EN 13383 supersedes the corresponding conflicting recommendations for stone for armouring in BS 6349-1 and introduces a more objective, comprehensive and appropriate system of quality control. BS 6349-1 guidance on armourstone can now be abandoned in favour of BS EN 13383 with confidence.

3.2 Geometrical requirements

3.2.1 *Grading*

The principal means by which any armourstone product is classified is by its grading. BS 6349-1 describes two types of armourstone grading, but no explanation is given as to when either should be used.

BS 6349-1:2000, **57.3.2** discusses *single-sized materials* for which it recommends that all stones should fall within stated upper and lower percentage tolerances of a nominal mass and that a stated percentage of the number of all the stones should exceed the nominal mass. It does not, however, give any guidance as to what these percentage tolerances should be, nor does it state what the percentage of stones required to exceed the nominal weight should be. It does, however, give a rather impractical and unnecessary recommendation that at least 75 % by mass of the stone in each single-sized material should consist of stones within the top half of the stated mass range.

BS 6349-1:2000, **57.3.3** discusses *graded materials*, including riprap. It describes how riprap is frequently specified in terms of its median mass m_{50} with typical maximum and minimum masses of $3.6m_{50}$ to $0.22m_{50}$, respectively.

BS EN 13383 abandons the BS 6349-1 distinction between *single-sized materials* and *graded materials* in favour of standard gradings. BS EN 13383 defines *coarse gradings, light gradings* and *heavy gradings*. The widths of these gradings are much wider for those gradings with smaller average mass than for those gradings with larger average mass.

BS EN 13383 defines *light gradings* as armourstone with a nominal upper limit of 25 kg to 500 kg. Most of these *light gradings*, roughly correspond to the graded materials referred to in BS 6349-1, such as riprap. BS EN 13383 defines *heavy gradings* as armourstone with a nominal upper limit of more than 500 kg. The *heavy gradings* correspond to the single-sized materials described in BS 6349-1 and certainly represent narrower grading widths than for the *light gradings*. The percentage deviation on the nominal weight for both the *light gradings* and *heavy gradings* is wider and thus more realistic than has previously been adopted in BS 6349-1. The width of both *heavy gradings* and *light gradings* is in fact based on accurate calibrations over many tests carried out on rock actually produced for major marine works in the Netherlands, reference to which is made in the CIRIA/CUR manual.

BS EN 13383 also defines *coarse gradings* as armourstone with a nominal upper sieve size limit of 125 mm to 250 mm. *Coarse grading* material is smaller than riprap but larger than the largest coarse aggregates specified in other European aggregate standards, i.e. larger than 40 mm. These *coarse gradings* will be useful as filters and, in the case of the 90/180 mm stone, for gabion filling.

The specification of armourstone sizes in BS EN 13383 is different to BS 6349-1 but has much in common with the system recommended in the CIRIA/CUR manual. *Coarse gradings* for armourstone are classified by sieve size fractions in a manner similar to the general aggregates specified in other European aggregate standards but require sturdier sieves because of the larger size of the material involved. When the grading particle size exceeds that for *coarse gradings*, they are classified by mass. *Light gradings* are generally deemed to be light enough to be bulk-handled. If individual handling of pieces is necessary, they are generally termed *heavy gradings*. Nominal lower and upper limits for sieve sizes (d/D mm) and for masses [(a to b) kg] are used to designate the gradings and indicate the range in which most of the particle distribution occurs.

3.2.2 *Shape*

BS 6349-1 recommends that stone for armouring or protection works should be prismoidal in shape with the maximum dimension of stones never exceeding three times the minimum dimension and generally not exceeding twice the minimum dimension. In preference to these BS 6349-1 recommendations, the majority of UK armourstone producers have adopted the CIRIA/CUR manual's geometrical recommendations. BS EN 13383 specifies geometrical requirements that are based on the recommendations given in the CIRIA/CUR manual. Guidance on BS EN 13383 geometrical requirements is given in **4.2**.

3.3 Physical, chemical and durability requirements

The use of BS 6349-1 and the CIRIA/CUR manual has been widespread in the UK for the specification of the physical (mechanical) and durability properties of armourstone.

BS 6349-1 recommends the use of BS 812 aggregate tests for the determination of the physical and durability properties of armourstone. These tests are performed on samples that are representative of the armourstone. They include test methods for the determination of apparent relative density, water absorption, the aggregate impact value (AIV), the 10 % percent fines value (TFV) and the aggregate abrasion value (AAV). Of these tests, only the density and water absorption tests have been included in BS EN 13383, but in a different form to BS 812. The other BS 812 tests are not included in BS EN 13383 because they are too focussed on aggregate (small-scale stones). Instead, BS EN 13383 has included tests that reflect armourstone (large-scale stones) performance.

Most of the BS EN 13383 tests are the same as those in the CIRIA/CUR manual. The BS EN 13883 tests that are not included in the CIRIA/CUR manual, and are therefore new to the UK, include the uniaxial compressive strength test for determining resistance to breakage, a test for determining percentage of crushed and broken surfaces and the micro-Deval test for resistance to wear.

The magnesium sulphate soundness test specified in BS EN 1367-2 was recommended in BS 6349-1 for the testing of the durability of armourstone. BS EN 13383 also specifies the use of BS EN 1367-2, however BS EN 13383 only requires testing in accordance with the BS EN 1367-2 magnesium sulphate soundness test when the water absorption of the armourstone is greater than 0.5 %. Further guidance on determining the durability of armourstone is given in **4.5**.

BS 6349-1 includes a recommendation for the testing of block integrity in accordance with the drop test outlined in the CIRIA/CUR manual, using full-scale armourstone pieces. BS EN 13383 does not include a requirement to test for block integrity because there is insufficient experience of testing for this property in Europe to be able to set requirement levels. However, BS EN 13383-1:2002, Annex B does give guidance on block integrity, including information about the CIRIA/CUR drop test. Further guidance on block integrity is also given in **4.3.2.2**.

4 Requirements of BS EN 13383-1

4.1 General

Each clause in BS EN 13383 that specifies armourstone properties, i.e. Clause **4**, Clause **5**, Clause **6** and Clause **7**, starts with a general subclause which draws attention to the necessity only to specify those properties relevant to the particular armourstone and end use of the armourstone. Where this is the case the wording "when required" is used.

In BS EN 13383, tables of specified requirements allow the user to choose an appropriate "category" for each property. The style of category designation is intended to be self-explanatory and related to the specified limiting value. For example, category $M_{DE}20$ means that armourstone with a maximum micro-Deval index value of 20 is required. However, there are instances where the category designation represents more than one requirement, for example, the resistance to breakage category CS_{60} specified in BS EN 13383-1:2002, Table 9 represents two different requirements and does not just mean that a compressive strength of greater than 60 MPa is required. Further guidance on resistance to breakage is given in **4.3.2**.

An option to use a "no requirement" category is also provided. For example, a category for the proportion of crushed or broken surfaces of RO_{NR} is included in BS EN 13383:2002, Table 7 and it means that there is no specified requirement for the proportion of crushed or broken surfaces. A category of RO_5, on the other hand, would require a limiting value of 5 % for pieces of armourstone with less than 50 % of crushed or broken surfaces.

When the value obtained for a particular property is outside the indicated limit or categories, the producer can provide a declared value. For example, if the percentage of pieces of armourstone with a length-to-thickness ratio of greater than 3 for a coarse grading exceeds 20 %, the producer can state a maximum value of $LT_{Declared}$ in accordance with BS EN 13383-1:2002, Table 6. Therefore, if the value is 25, the producer would state LT_{25} and the armourstone user should determine whether this is adequate for his purposes.

4.2 Geometrical requirements

4.2.1 *Grading (BS EN 13383-1:2002, 4.2)*

4.2.1.1 *General*

BS EN 13383-1:2002, **4.2** specifies requirements for three different types of armourstone gradings:

a) course gradings, defined as having a nominal upper sieve size limit of 125 mm to 250 mm;

b) light gradings, defined as having a nominal upper limit of 25 kg to 500 kg;

c) heavy gradings, defined as having a nominal upper limit of more than 500 kg.

BS EN 13383-1:2002, Table 1 to Table 5 define coarse, light and heavy gradings in terms of nominal lower and upper limits for sieve sizes (d/D mm) or for masses [(a to b) kg] and indicate the required range in which most of the particle distribution occurs.

The selection of a BS EN 13383-1 grading for armourstone depends on the intended end use of the armourstone. Detailed guidance on the selection of an armourstone grading is given in BS 6349-1 and the CIRIA/CUR manual. This guidance is summarized as follows.

1) For *cover layers*, hydraulic design formulae, such as those given in BS 6349-1 and the CIRIA/CUR manual, are used to determine the armourstone grading needed for a particular end-use. These hydraulic design formulae can produce a value of M_{50}, the mass for which 50 % by mass of the armourstone is lighter. The CIRIA/CUR manual gives guidance that helps to show the correlation between M_{50} and the average mass of an armourstone for some of the light and heavy gradings given in BS EN 13383-1:2002, Table 2 and Table 4. Further guidance on this correlation is given in **4.2.1.2** and **4.2.1.3** for light gradings and heavy gradings, respectively. The general trend is that the M_{50} mass for an armourstone grading is nearly always greater than the average mass.

NOTE 1 The CIRIA/CUR manual actually shows the relationship between W_{50} (the weight for which 50 % by mass of the armourstone is lighter) and W_{em} (the effective mean weight). However, the ratio between W_{50} and W_{em} is the same as that between M_{50} (equivalent to W_{50}/gravitational force) and the average mass (equivalent to W_{em}).

NOTE 2 Armourstone producers should determine values for M_{50} in accordance with the calculations for the distribution of light and heavy gradings given in BS EN 13383-2:2002, Clause **6**.

2) For *underlayers* or *filter layers*, the choice of grading depends on different practical and design criteria to that used for cover layers, e.g. geotechnical filter criteria.

BS EN 13383-1 gives the option to declare coarse, light and heavy gradings that are different from those given in BS EN 13383-1:2002, Table 1 to Table 5. There can be a particular need to declare additional heavy gradings in parts of the UK where the natural discontinuities in a local rock source limit the maximum size of rock available to an armourstone user.

The width of any declared gradings should follow the same general grading widths and ratios between grading limits as exhibited by the gradings specified in BS EN 13383-1:2002, Table 1 to Table 5. In the same way as for the gradings specified in BS EN 13383-1:2002, Table 1 to Table 5, this should include the declaration of four limits. These four limits are defined in BS EN 13383-1:2002, Annex A as the extreme lower limit (ELL), nominal lower limit (NLL), nominal upper limit (NUL) and extreme upper limit (EUL).

4.2.1.2 *Coarse gradings (BS EN 13383-1:2002,* ***4.2.1****)*

Coarse gradings are generally used for filter layers, underlayers, bedding stone and gabions. Coarse gradings are described in BS EN 13383-1 in millimetres with the designation *d*/*D*, where *d* is the lower limiting sieve size and *D* is the upper limiting sieve size. The majority of the particle size distribution of an armourstone lies between these two values and requirements for this are specified in BS EN 13383-1:2002, **4.2.1**.

The coarse gradings in BS EN 13383-1 are expressed in reverse order to the current British Standard system for aggregates, i.e. BS EN 13383-1 gives the lower sieve size before the upper sieve size.

BS EN 13383-1 specifies the use of sieve sizes that are larger than those sieves used in other European Standards for aggregates, extending the range beyond that specified in the ISO 3310-2 series of sieves used in other European Standards for aggregates. However, the sizes of these larger sieves continues along the same geometrical progression of seize sizes described in ISO 3310-2.

NOTE 1 BS EN 13383-2:2002, Clause **5** describes the method of determining the particle size distribution of coarse gradings, including a detailed account of the required sieves sizes.

The armourstone pieces in the finest fraction of the coarse gradings are termed “fragments”. BS EN 13383-1:2002, Table 1 specifies that, for coarse gradings, the fragment fraction shall account for up to 5 % of the armourstone.

BS EN 13383-1:2002, **4.2.1** specifies the following five coarse gradings:

a) three gradings of systematically increasing mean size:

   1) 45/125 mm;

   2) 63/180 mm;

   3) 90/250 mm;

b) one wider grading of 45/180 mm;

c) one narrower grading of 90/180 mm suitable for special applications, e.g. gabions.

NOTE 2 Guidance on the sieves used to determine the particle size distribution of coarse gradings is given in BS EN 13383-2:2002, **5.2.2**.

4.2.1.3 *Light gradings (BS EN 13383-1:2002,* ***4.2.2****)*

Light gradings are generally used for filter layers, underlayers, bedding stone and cover layers in river-banks. Light gradings are described in BS EN 13383-1 in kilograms with the designation *a* to *b*, where *a* is the nominal lower limit (NLL) of stone mass and *b* is the nominal upper limit (NUL) of stone mass. The majority of the particle size distribution of an armourstone lies between these two values and percentage passing requirements for this are specified in BS EN 13383-1:2002, **4.2.2**. Extreme upper limit (EUL) mass values and extreme lower limit (ELL) mass values are also specified in BS EN 13383-1 and are also required to meet percentage passing requirements. BS EN 13383-1:2002, Annex A gives a diagrammatic representation of the relationship between values for ELL, NLL, NUL and EUL.

The armourstone pieces in the finest fraction of the light gradings are termed "fragments". BS EN 13383-1:2002, Table 2 and Table 3 specify that, for light gradings, the fragment fraction shall account for up to 2 % of the armourstone.

BS EN 13383-1:2002, **4.2.2** specifies the following five light gradings:

a) four gradings suitable for use in all hydraulic structures, except cover layers that are used in the aggressive conditions defined in the CIRIA/CUR manual:

1) (5 to 40) kg;

2) (40 to 200) kg;

3) (10 to 60) kg;

4) (60 to 300) kg;

NOTE 1 Quarry yields are likely to restrict production to either (5 to 40) kg and (40 to 200) kg or to (10 to 60) kg and (60 to 300) kg.

b) one wider grading of (15 to 300) kg suitable for underlayers, filters and core material and generally more economical to produce, particularly in the smaller UK quarries.

NOTE 2 The (15 to 300) kg grading should not be used in a cover layer because the grading is too wide and is likely to segregate under wave action, resulting in the loss of armourstone material.

BS EN 13383-1:2002, **4.2.2** specifies two categories for each of the five light grading designations. BS EN 13383-1:2002, Table 2 specifies category A light gradings and BS EN 13383-1:2002, Table 3 specifies category B light gradings. BS EN 13383-1:2002, **4.2.2** requires that light graded armourstone conforms to either category A gradings, category B gradings or the gradings declared by the producer.

Category A light gradings confer a tighter control than category B gradings on the mass distribution by limiting the acceptable range of average mass. This will also limit the acceptable range of values for M_{50}, the mass for which 50 % by mass of the armourstone is lighter.

NOTE 3 The CIRIA/CUR manual indicates that the value of M_{50} for the light gradings is greater than their corresponding average mass by a factor of:

a) 1.3 for (5 to 40) kg;

b) 1.15 for (40 to 200) kg;

c) 1.3 for (10 to 60) kg;

d) 1.15 for (60 to 300) kg.

The CIRIA/CUR manual does not give a factor for the (15 to 300) kg grading because M_{50} values are only used in the design of cover layers and the (15 to 300) kg grading is too wide to be used in a cover layer. Guidance on the use of values for M_{50} is given in **4.2.1.1**.

In most cases, armourstone produced to conform to a category B light grading (e.g. $LMB_{60/300}$) will also conform to the equivalent category A light grading (e.g. $LMA_{60/300}$). Therefore, for light grades, category B gradings will be acceptable in the UK. However, where the armourstone is to be used in a cover layer, category A should be used.

BS EN 13383-1 specifies the determination of the mass distribution of light gradings in accordance with either of two methods in BS EN 13383-2:2002, Clause **6**. The reference method specified in BS EN 13383-2:2002, **6.4.1** requires that each individual piece of armourstone is weighed separately whilst the alternative method specified in BS EN 13383-2:2002, **6.4.2** only requires that the total mass and mass of selected pieces of armourstone is determined. Difficulties can occur in the handling and weighing of the larger pieces of stone of the light gradings. Particular attention should be given to ensuring that the weighing equipment, including hand-held gauges if applicable, is adequate to meet the accuracy requirements given in BS EN 13383-2:2002, **6.2.2** and that the equipment can take the weight of the largest stones in a particular light grading.

Generally, the alternative method specified in BS EN 13383-2:2002, **6.4.2** can be used. However, the reference method specified in BS EN 13383-2:2002, **6.4.1** should be used:

1) for the testing of armourstone for cover layers;

2) in cases of dispute;

3) where there is no ongoing production control system;

4) for initial type testing (i.e. for new sources of armourstone and where there is a major change in the raw materials or processing).

4.2.1.4 *Heavy gradings (BS EN 13383-1:2002,* ***4.2.3****)*

Heavy gradings are generally used for cover layers for coastal structures. Heavy gradings are described in BS EN 13383-1 in kilograms with the designation *a* to *b*, where *a* is the nominal lower limit (NLL) of stone mass and *b* is the nominal upper limit (NUL) of stone mass. The majority of the particle size distribution of an armourstone lies between these two values and percentage passing requirements for this are specified in BS EN 13383-1:2002, **4.2.3**. Extreme upper limit (EUL) mass values and extreme lower limit (ELL) mass values are also specified in BS EN 13383-1 and are also required to meet percentage passing requirements. BS EN 13383-1:2002, Annex A gives a diagrammatic representation of the relationship between values for ELL, NLL, NUL and EUL.

The armourstone pieces in the finest fraction of the heavy gradings are termed "fragments". BS EN 13383-1:2002, Table 4 and Table 5 specify that, for heavy gradings, the fragment fraction shall account for up to 5 % of the armourstone.

BS EN 13383-1:2002, **4.2.3** specifies the following five heavy gradings, each successive grading becoming gradually narrower as the average mass increases:

a) (300 to 1 000) kg;

b) (1 000 to 3 000) kg;

c) (3 000 to 6 000) kg;

d) (6 000 to 10 000) kg;

e) (10 000 to 15 000) kg.

NOTE 1 There may be a particular need to declare additional heavy gradings in some parts of the UK, where there is a limitation on the maximum sizes of rock economically available.

BS EN 13383-1:2002, **4.2.3** specifies two categories for each of the five light grading designations. BS EN 13383-1:2002, Table 4 specifies category A heavy gradings and BS EN 13383-1:2002, Table 5 specifies category B heavy gradings. BS EN 13383-1:2002, **4.2.3** requires that heavy graded armourstone conforms to either category A gradings, category B gradings or the gradings declared by the producer.

Category A heavy gradings confer a tighter control than category B gradings on the mass distribution by limiting the acceptable range of average mass. This will also limit the acceptable range of values for M_{50}, the mass for which 50 % by mass of the armourstone is lighter.

NOTE 2 The CIRIA/CUR manual indicates that the value of M_{50} for the heavy gradings is greater than their corresponding average mass by a factor of:

a) 1.10 for (300 to 1 000) kg;

b) 1.05 for (1 000 to 3 000) kg;

c) 1.05 for (3 000 to 6 000) kg;

d) 1.00 for (6 000 to 10 000) kg.

The CIRIA CUR manual does not give a factor for the (10 000 to 15 000) kg grading, however, it would be expected to be 1.00. Guidance on the use of values for M_{50} is given in **4.2.1.1**.

In most cases, armourstone produced to conform to a category B heavy grading (e.g. $HMB_{60/300}$) will also conform to the equivalent category A heavy grading (e.g. $HMA_{60/300}$). Therefore, for heavy grades, category B gradings will be acceptable in the UK. However, where the armourstone is to be used in a cover layer, category A should be used.

BS EN 13383-1 specifies the determination of the mass distribution of heavy gradings in accordance with either of two methods in BS EN 13383-2:2002, Clause **6**. The reference method specified in BS EN 13383-2:2002, **6.4.1** requires that each individual piece of armourstone is weighed separately whilst the alternative method specified in BS EN 13383-2:2002, **6.4.2** requires that the total mass and mass of selected pieces of armourstone is determined. Particular attention should be given to ensuring that the weighing equipment is adequate to meet the accuracy requirements given in BS EN 13383-2:2002, **6.2.2** and that the equipment can take the weight of the largest stones in a particular heavy grading.

Generally, the alternative method specified in BS EN 13383-2:2002, **6.4.2** can be used. However, the reference method specified in BS EN 13383-2:2002, **6.4.1** should be used:

1) for the testing of armourstone for cover layers;

2) in cases of dispute;

3) where there is no ongoing production control system;

4) for initial type testing (i.e. for new sources of armourstone and where there is a major change in the raw materials or processing).

4.2.2 *Shape/length-to-thickness ratio (BS EN 13383-1:2002, 4.3)*

BS EN 13383-1:2002, **4.3** specifies the shape of an armourstone in terms of the percentage of armourstone pieces with a length-to-thickness ratio of greater than 3. The determination of the length to thickness ratio is required by BS EN 13383-1:2002, **4.3** to be carried out in accordance with BS EN 13383-2:2002, Clause **7**.

Unlike the CIRIA/CUR manual, BS EN 13383-1 does not specify limits for the percentage of pieces exceeding a length-to-thickness ratio of 2. Also, unlike BS 6349-1, BS EN 13383-1 does not specify that the maximum dimension of stones should not normally exceed twice the minimum dimensions and should never exceed three times the minimum dimensions.

BS EN 13383-1:2002, Table 6 specifies categories for shape. It is recommended that, in the UK, category LT_A should be used in all cases where shape control is considered important, such as in heavy grading cover layers.

4.2.3 *Proportion of crushed or broken surfaces (BS EN 13383-1:2002, 4.4)*

In some European countries rounded glacial boulders, cobbles and core stones from basalt and dolerite quarries have been used for hydraulic structures. In order to ensure adequate mechanical interlock for these materials, the percentage of crushed or broken surfaces is specified in BS EN 13383-1:2002, **4.4**.

Rounded glacial boulders, cobbles and core stones from basalt and dolerite quarries are not normally available in the UK, therefore it is recommended that category RO_{NR} is adopted. However, if boulders, etc. are being adopted in the design, then the RO_5 category should be specified.

4.3 Physical requirements

4.3.1 *Particle density (BS EN 13383-1:2002, 5.2)*

BS 6349-1 recommends one minimum density for all armourstone as a means of improving overall durability. However, the CIRIA/CUR manual allows for the selection of a different armourstone density for different applications and recommends the testing of other properties in the assessment of durability.

BS EN 13383-1:2002, **5.2** specifies the determination of particle density, x, in accordance with BS EN 13383-2:2002, Clause **8** and reflects the flexible approach to density taken in the CIRIA/CUR manual. BS EN 13383 specifies x as any declared value ≥ 2.30 Mg/m^3. This flexible approach allows armourstone designers to be free to continue using existing sources of armourstone of known density and allows armourstone designers to meet the hydraulic stability requirements for armourstone for a particular end use.

NOTE 1 The wet density ρ_{wet} should be used in the BS 6349-1 and CIRIA/CUR manual design calculations for armourstone stability. A report from the Netherlands Ministry of Transport, Public Works and Water Management [3] indicates that ρ_{wet} can be calculated by multiplying the oven dry density determined in accordance with BS EN 13383-2:2002, Clause **8** by:

a) $[1 + 0.005W_{as}]$ where the armourstone is to be used in a structure of which all, or part, is permanently submerged; or

b) $[1 + 0.0025W_{as}]$ where the armourstone is to be used in a structure of which all, or part, is temporarily submerged;

where W_{as} is the water absorption of the armourstone, determined in accordance with BS EN 13383-2:2002, Clause **8**.

NOTE 2 The particle density determined in accordance with BS EN 13383-2:2002, Clause **8** is the oven dried density of the armourstone. BS 6349-1 specifies the determination of the apparent relative density for armourstone in accordance with BS 812. Values for oven dried density tend to be slightly lower than the values for the apparent relative density.

To reduce costs, armourstone that is both permanently submerged and used as bulk filling does not need to have a high level of durability and can therefore have a low particle density, x.

4.3.2 *Resistance to breakage (BS EN 13383-1:2002, 5.3)*

4.3.2.1 *Mineral fabric breakage*

Experience in the UK of testing for the physical properties of armourstone is largely based on aggregate strength tests specified in BS 812, such as the 10 % fines value (TFV), the aggregate impact value (AIV) and the aggregate abrasion value (AAV). Experience of testing for physical properties is also based on intact strength tests of the rock fabric using the point load strength index [4], the uniaxial compressive strength test [5] or fracture toughness test [6].

BS EN 13383-1:2002, **5.3** specifies resistance to breakage in terms of compressive strength with testing carried out in accordance with BS EN 1926:1999, Annex A. The results from the compressive strength test in BS EN 1926 are recognized as providing an indication of resistance to crushing.

NOTE BS EN 1926:1999, Annex B provides a cheap and simple method for the factory production control of the uniaxial compressive strength of armourstone in terms of the determination of a point load strength index.

BS EN 13383-1:2002, Table 9 specifies categories for resistance to breakage. It is recommended that for most applications and particularly for cover layers, category CS_{80} is selected in order to avoid excessive breakage of the corners of the armourstone during handling and placement. Category CS_{80} is compatible with the CIRIA/CUR manual's requirement level for rock of *good quality* resistance to impact and mineral fabric breakage for coastal and shoreline engineering.

4.3.2.2 *Block integrity*

Attention is drawn to the importance of block integrity in armourstone structures. The Note to BS EN 13383-1:2002, **5.3** recommends that armourstone should be free from discontinuities, which can lead to breakage during loading, unloading or placing. For example, armourstone derived from the metamorphic rock termed gneiss can split into quartzo-feldspathic and mafic rich bands and the anisotropy caused has been reported [7] as leading to planes of weakness in a consignment of stone supplied from Sweden. Blast-induced cracks or the occurrence of styolites acting as zones of weakness within limestone blocks can also lead to armourstone breakage.

In the UK, block integrity is a property for which tests have been specified in the CIRIA/CUR manual. BS EN 13383-1:2002, Annex B contains guidance on block integrity, including the following two types of test method used in the determination of block integrity.

a) Non-destructive methods based on acoustic velocity measurements. These non-destructive methods are being developed or are in use in some parts of Europe as quality control methods for block integrity.

b) A destructive "drop breakage" test in which 50 blocks are subjected to sequential dropping from a height of 3 m. This destructive method is described in BS EN 13383-1:2002, Annex B. Further details about the method for this drop breakage test are given in the CIRIA/CUR manual.

No test methods or requirement levels for block integrity could be agreed upon in the preparation of BS EN 13383 as there was insufficient experience of the proposed test methods, such as the CIRIA/CUR manual drop test or the ultrasonic pulse velocity test [8]. The block integrity of armourstone is now a major area of research and, until conclusions can be drawn from the research, experience of use and a knowledge of the source is the best guide for the assessment of block integrity.

In the UK, it is recommended that the drop breakage test described in the CIRIA/CUR manual is adopted for use in the assessment of block integrity.

4.3.3 *Resistance to wear (BS EN 13383-1:2002, 5.4)*

BS EN 13383-1:2002, **5.4** specifies the determination of resistance to wear in terms of the micro-Deval coefficient test in accordance with BS EN 1097-1. BS EN 13383-1:2002, Table 10 specifies categories for resistance to breakage and gives guidance on when to choose categories $M_{DE}10$, $M_{DE}20$ and $M_{DE}30$. At present, there is little experience in the UK of the micro-Deval coefficient for assessing resistance to wear.

It is recommended that category $M_{DE}NR$ is selected in the UK for armourstone used in:

a) underlayers, because they are not subjected to significant wear;

b) coverlayers where insignificant sediment loads are present in the water.

For all coverlayers other than those covered by b), it is recommended that categories $M_{DE}10$, $M_{DE}20$ and $M_{DE}30$ should be selected with reference to the guidance given in BS EN 13383-1:2002, Table 10.

The micro-Deval test correlates relatively well with the CIRIA/CUR manual mill abrasion test. Guidance on the correlation between mill abrasion values and the micro-Deval coefficient is given in the Geological Society's Engineering Geology Special Publication on advances in aggregates and armourstone evaluation [9]. The following list summarizes how the BS EN 13383-1:2002, Table 10 categories relate to requirement levels given in the CIRIA/CUR manual.

1) Category $M_{DE}10$ is not compatible with the CIRIA/CUR manual requirement level for rock of *excellent quality* abrasion resistance. Category $M_{DE}10$ represents an even higher level of resistance that is required in only the very exceptional circumstances described for this category in BS EN 13383-1:2002, Table 10.

2) Category $M_{DE}20$ is compatible with the CIRIA/CUR manual requirement level for rock of *good quality* abrasion resistance. Category $M_{DE}20$ is appropriate for armourstone used in most exposed UK coastal environments such as those described for this category in BS EN 13383-1:2002, Table 10.

3) Category $M_{DE}30$ is not compatible with the CIRIA/CUR manual requirement level for rock of *marginal quality* abrasion resistance. Category $M_{DE}30$ represents a higher level of resistance that will generally ensure sufficient wear resistance in moderately abrasive environments such as those described for this category in BS EN 13383-1:2002, Table 10. Poorly cemented sedimentary rocks are unlikely to be resistant enough to wear to conform to Category $M_{DE}30$.

4.3.4 *Requirement associated with grouting (BS EN 13383-1:2002, 5.5)*

BS EN 13383-1:2002, **5.5** specifies a requirement that only applies to armourstone intended for use in grouting. BS EN 13383-1:2002, **5.5** requires that in such cases the armourstone being grouted is not covered with observable clayey or other adhesive soil. This requirement is given to ensure that the necessary adhesion between grout and armourstone is achieved.

4.3.5 *Colour (BS EN 13383-1:2002, 5.6)*

BS EN 13383-1:2002, **5.6** specifies that the presence of natural variation in the colour of armourstone supplied from a quarry with an established pattern of supply is not grounds for rejection of the armourstone material. The Note to BS EN 13383-1:2002, **5.6** recommends that if necessary, the purchaser should advise the supplier of any preferences for a particular armourstone colour.

4.4 Chemical requirements

4.4.1 *Impurities (BS EN 13383-1:2002, 6.2)*

BS EN 13383-1:2002, **6.2** requires that armourstone does not contain any foreign matter in a quantity that will cause damage to the structure or the environment in which it is used. BS EN 13383-1:2002, Table D.2 specifies that this is to be determined by visual inspection of the armourstone material.

4.4.2 *Water-soluble constituents (BS EN 13383-1:2002, 6.3)*

BS EN 13383-1:2002, **6.3** specifies the determination of water-soluble constituents through the preparation of an eluate in accordance with BS EN 1744-3 and subsequent testing using methods developed for water analysis that have been adapted for use in the analysis of eluates. The methods used for the analysis of eluates depends on what national regulations exist in the place of use of the armourstone. In the UK there are no regulations for water soluble constituents in armourstone.

It is unlikely that requirements to test for the presence of water-soluble constituents will be specified for natural sources of armourstone in the UK because there has not been a problem with water-soluble constituents in such armourstone. However, it is likely that requirements for this property will be specified in the UK for manufactured and recycled armourstone because there is little experience of their use.

4.5 Durability requirements

4.5.1 *Constituents which affect the durability of blast-furnace and steel slags (BS EN 13383-1:2002, 7.2)*

BS EN 13383-1:2002, **7.2** specifies the determination of the content of constituents which affect the durability of blast-furnace and steel slags. It is likely that requirements for these constituents will be specified in the UK.

4.5.2 *Water absorption as a screening test for resistance to freezing and thawing and to salt crystallization (BS EN 13383-1:2002, 7.3)*

BS EN 13383-1:2002, **7.3** uses the water absorption value determined in accordance with BS EN 13383-2:2002, Clause **8** as a screening test for resistance to freezing and thawing and to salt crystallization.

NOTE The water absorption test in BS EN 13383-2:2002, Clause **8** has been used in the Netherlands as a screening test for resistance to freezing and thawing.

BS EN 13383-1:2002, **7.3** specifies that armourstone is satisfactory without further testing if it conforms to water absorption category $WA_{0.5}$. Armourstone with water absorption greater than 0.5 % requires further testing in accordance with BS EN 13383-1:2002, **7.4** and/or **7.5**.

BS EN 13383-1:2002, Annex C gives further guidance on testing for the resistance of armourstone to freezing and thawing and to salt crystallization.

In the UK, it is recommended that water absorption should be used as a screening test for resistance to freezing and thawing and to salt crystallization.

4.5.3 *Resistance to freezing and thawing (BS EN 13383-1:2002, 7.4)*

BS EN 13383-1:2002, **7.4** provides a means for assessing the durability of an armourstone by determining its resistance to freezing and thawing in accordance with BS EN 13383-2:2002, Clause **9**.

BS EN 13383:2002, **7.3** specifies the determination of resistance to freezing and thawing when the water absorption, determined in accordance with BS EN 13383-2:2002, Clause **8**, is greater than 0.5 %. Situations in the UK where water absorption can be greater than 0.5 % includes freshwater inland lakes, reservoirs and salt-water saturated rocks above the water-line subject to freezing. However, note that the determination of resistance to freezing and thawing when water absorption is greater than 0.5 % does not apply to situations where the armourstone is permanently submerged because freezing and thawing is unlikely to occur underwater.

BS EN 13383-1:2002, Annex C gives further guidance on testing for the resistance of armourstone to freezing and thawing.

In the UK it is recommended that resistance to freezing and thawing should be tested where freeze-thaw attack is significant and water absorption is found to be greater than 0.5 %.

When freeze-thaw resistance is tested in accordance with BS EN 13383-2:2002, Clause **9** it is recommended that freeze-thaw category FT_A from BS EN 13383-1:2002, Table 13 should be adopted.

4.5.4 *Resistance to salt crystallization (BS EN 13383-1:2002, 7.5)*

BS EN 13383-1:2002, **7.4** provides a means for assessing the durability of an armourstone by determining its resistance to salt crystallization in accordance with BS EN 1367-2.

BS EN 13383-1:2002, **7.3** specifies the determination of resistance to salt crystallization when the water absorption, determined in accordance with BS EN 13383-2:2002, Clause **8** is greater than 0.5 %.

BS EN 13383-1:2002, Annex C gives further guidance on testing for the resistance of amourstone to salt crystallization.

In the UK it is recommended that resistance to salt crystallization should be tested in all cases where water absorption is found to be greater than 0.5 %. However, note that the determination of resistance to salt crystallization when water absorption is greater than 0.5 % does not apply to situations where the armourstone is permanently submerged because salt crystalization is unlikely to occur underwater.

When salt crystallization resistance is tested in accordance with BS EN 1367-2 it is recommended that salt crystallization category MS_{25} from BS EN 13383-1:2002, Table 14 should be adopted.

NOTE 1 When the BS EN 1367-2 test is used for armourstone, the results should be treated with caution. The size of the particles tested by BS EN 1367-2 is very small (i.e. 10 mm to 14 mm), thereby providing a larger surface area of material for testing than would occur if a sample of the armourstone itself was tested. This larger surface area can produce significantly different results. In order to overcome concerns about the accuracy of results BS EN 13383-1:2002, Annex C recommends petrographic examination of the rock material, prior to testing in accordance with BS EN 1367-2, and visual identification of the mode of disintegration after testing. In the case of test results that marginally fail to meet the requirements of category MS_{25}, the results from the BS EN 1367-2 test method may be compared to the results of the following two test methods:

a) testing in accordance with BS EN 1367-2 using larger, wider and different ranges of particle sizes (e.g. 63 mm to 125 mm); and/or

b) repeating the BS EN 1367-2 test using sodium sulfate, e.g. in accordance with the procedure in BS EN 12370:1999, Clause **7**.

However, there is little experience of either testing armourstone in accordance with items a) and b) or establishing salt crystallization requirement levels for armourstone tested in accordance with items a) and b).

NOTE 2 The scope of BS EN 1367-2 states that the majority of aggregates can be tested for resistance to salt crystallization using the BS EN 1367-2 method. Precision has been established for the rock types listed in BS EN 1367-2:1998, Annex A. However, the scope of BS EN 1367-2 also states it is possible that the test is not suitable for all rock types and reservations have been expressed in respect of some carbonate aggregates and some aggregates with a high proportion of magnesium bearing minerals or cryptocrystalline quartz. The same reservations apply to armourstone. It is possible to avoid problems raised by the BS EN 1367-2 magnesium sulfate test through the use of the BS EN 12370 sodium sulfate test for resistance to salt crystallization. However, further research is necessary in order to establish suitable salt crystallization requirement levels for armourstone that is tested in accordance with BS EN 12370.

4.5.5 *"Sonnenbrand" of basalt (BS EN 13383-1:2002, 7.6)*

BS EN 13383-1:2002, **7.6** specifies the determination of the presence of Sonnenbrand in accordance with BS EN 13383-2:2002, Clause **10**.

Sonnenbrand is a type of rock decay that is tested in order to determine the susceptibility of certain types of young basalt armourstone, found in some European countries, to degradation through mineralogical instability. This phenomenon is not experienced in the UK and it is not anticipated that this test will be applied in the UK. It is recommended that category SB_{NR} is adopted, although further information should be obtained on the susceptibility of imported basalt armourstone.

4.6 Evaluation of conformity

4.6.1 *General*

BS EN 13383-1:2002, Clause **8** contains requirements for the evaluation of conformity necessary for producers to demonstrate that their products conform to BS EN 13383-1. The procedures described here are called up by BS EN 13383-1:2002, Annex ZA as part of the procedure for attestation of conformity to be used for demonstrating compliance with the requirement of the EU Construction Products Directive [2].

4.6.2 *Initial type tests (BS EN 13383-1:2002, 8.2)*

Initial type testing is a series of tests carried out on the armourstone, relevant to its intended end use, before it is first placed on the market. This testing is used to identify the categories specified within BS EN 13383-1 to which the armourstone conforms.

Initial type testing is required for new sources, if there is a major change in raw materials or when the armourstone is to conform to a new requirement for which it has not previously been tested.

Where armourstone users require additional data or properties for particular uses of the armourstone, these should be requested prior to ordering, allowing sufficient time for testing.

4.6.3 *Factory production control (BS EN 13242:2002, 8.3)*

Factory production control is the means by which to define the quality system which producers are required to operate to demonstrate ongoing conformity of their product to the relevant European Standard, in this case BS EN 13383-1.

4.7 Designation and description (BS EN 13383-1:2002, Clause 9)

BS EN 13383-1:2002, Clause **9** requires armourstone to be identified using the following characteristics.

a) Source and producer, i.e. the quarry name and company. Where armourstone is re-handled in a depot both the original source and the depot should be given.

b) Type of armourstone. Reference is made to BS EN 932-3 which should be consulted for specific guidance. All rock types should be declared where a producer is working a source of rock which generates armourstone that contains more than one distinct rock type when assessed in accordance with the petrographic description given in BS EN 932-2.

c) Designation of the grading.

4.8 Marking and labelling (BS EN 13383-1:2002, Clause 10)

Delivery tickets are required to contain both the designation and the European Standard number, BS EN 13383-1, in addition to other information listed in BS EN 13833:2002, Clause **10**.

4.9 Provisions of the EU Construction Products Directive

BS EN 13383-1:2002, Annex ZA addresses the provisions of the EU Construction Products Directive [2]. Both BS EN 13383-1:2002 and its Annex ZA have been produced under a Mandate given by the European Commission and the European Free Trade Association to CEN.

Annex ZA is described as "informative" but its requirements become mandatory to ensure compliance with the Mandate and/or where CE marking is applicable to armourstone.

NOTE CE marking is a "passport" enabling a product to be legally placed on the market in any European Member State. However, this does not necessarily mean that the product will be suitable for all end uses in all Member States. It simply shows that the product addresses the regulatory requirements set out in a particular European Directive, in this case the EU Construction Products Directive [2].

Clauses in BS EN 13383-1 identified in BS EN 13383-1:2002, Table ZA.1a indicate the characteristics that are subject to regulatory requirements for the specified application in one or more European Member States. There is no obligation to determine or declare a value for a characteristic in a Member State where there is no regulatory requirement for that characteristic unless it is subject to a "threshold" value.

Conformity to these identified requirements confers a prescription of fitness of the armourstone for the intended uses indicated in the scope of BS EN 13383-1. However, to meet the provisions of the EU Construction Products Directive [2], armourstone is also required to conform to any transposed European legislation and national laws relating to dangerous substances referred to in BS EN 13383-1.

Within the notes in BS EN 13383-1:2002, Table ZA.1a, reference is made to the type of compliance requirement, for example:

— fail threshold value;

— categories;

— declared value.

BS EN 13383-1:2002, Annex ZA also details the allowed levels for attestation of conformity as "2+" or "4". The requirements of the two levels are summarized in Table 1.

Table 1 — Levels of attestation of conformity in accordance with the EU Construction Products Directive and referred to in BS EN 13383-1

Tasks	Conformity attestation EU numbering system	
	2+	4
Tasks for the producer		
Factory production control	Yes	Yes
Further testing of samples taken at a factory according to a prescribed test plan	Yes	No
Initial type testing	Yes	Yes
Tasks for third party notified accreditation body		
Certification of factory production control	Yes	No
Surveillance of factory production control	Yes	No

In the UK, the level of attestation for armourstones in the UK will be "4".

For other applications where the specifier or purchaser has particular concerns that the integrity of the armourstone will have a major impact on:

a) safety when in use;

b) other performance properties of an installation (for example armourstone applications involving the storage or containment of dangerous substances);

the specifier or purchaser should adopt appropriate contract specific quality assurance procedures or acceptance testing regimes to give the required degree of confidence. It is not appropriate to expect higher attestation of conformity requirements, as these are general national requirements related to the demonstration of fitness to be placed on the market for general use and are not readily flexible to meet specific contract needs. However, wherever possible such additional requirements should follow the same basic format as those in BS EN 13383-1.

BS EN 13383-1:2002, Annex ZA identifies the requirements for CE marking and labelling.

The UK and two other EU Member States do not currently consider that there is a mandatory requirement to CE mark products. Consequently there is no current legal requirement to CE mark armourstone supplied within the UK or to or from Ireland and Sweden. CE marking will be required for armourstone supplied to or within other Member States translated into the language of the Member State supplied.

If producers voluntarily or otherwise decide to CE mark their armourstone, the producers need to strictly comply with the indicated requirements. Where the CE mark identifies particular characteristics, the supplier is required to indicate the category or declared value appropriate to the armourstone. The user is responsible for confirming that the declaration of properties on the CE mark complies with their particular requirements.

It should also be noted that where armourstone is placed on the market in a European Member State where there is no regulatory requirement for a particular characteristic, the supplier is not required to determine the performance for this characteristic. In this case "No performance determined" should be stated in the CE marking information.

5 Test methods of BS EN 13383-2

5.1 General

BS EN 13383-1 specifies the use of BS EN 13383-2 test methods. **5.2** to **5.9** give a description of each of the BS EN 13383-2 test methods along with guidance on their relevance and familiarity to UK users. Table 2 lists these BS EN 13383-2 test methods and directs the user to the advice given in the relevant subclause in this guide.

Table 2 — Test methods in BS EN 13383-2

BS EN 13383-2 clause	Test method	UK guidance subclause
Clause **4**	Methods for sampling	**5.2**
Clause **5**	Determination of the particle size distribution of coarse gradings	**5.3**
Clause **6**	Determination of the mass distribution of light and heavy gradings	**5.4**
Clause **7**	Determination of the percentage of pieces of armourstone with a length-to-thickness ratio greater than 3	**5.5**
Clause **8**	Determination of particle density and water absorption	**5.6**
Clause **9**	Determination of resistance to freezing and thawing	**5.7**
Clause **10**	Determination of signs of "Sonnenbrand"	**5.8**
Clause **10**	Determination of disintegration of steel slags	**5.9**

5.2 Methods for sampling (BS EN 13383-2:2002, Clause 4)

5.2.1 *General*

BS EN 13383-2:2002, Clause **4** specifies methods for obtaining samples of armourstone from preparation and processing plants including silos, stockpiles and deliveries. The aim is to obtain samples that are representative of the average properties of the batch.

BS EN 13383-2:2002, Clause **4** also specifies methods for sample reduction.

5.2.2 *Sampling methods*

5.2.2.1 *Particle size distribution, mass distribution and shape characteristics*

BS EN 13383-2:2002, **4.5.2** specifies procedures for obtaining samples to be used for the determination of particle size distribution, mass distribution and shape characteristics, from:

a) belt and chute discharge points;

b) stationary conveyor belts;

c) silos;

d) stockpiles;

e) floating equipment (e.g. barges);

f) wheeled transport.

BS EN 13383-2:2002, Annex G gives a summary of BS EN 13383-2 sampling requirements for a particular property test, including the number and sizes of samples and test portions together with any methods for preparing the test portions.

5.2.2.2 *Physical, chemical, durability and other properties*

BS EN 13383-2:2002, **4.5.3** specifies a procedure for obtaining a random selection of individual pieces of armourstone to be used for the determination of physical, chemical, durability and other properties. Sampling increments (quantities of material taken from a batch by one operation of the same sampling apparatus) are preferably taken from samples obtained in accordance with BS EN 13383-2:2002, **4.5.2** for the determination of the particle size or mass distribution. When samples obtained in accordance with BS EN 13383-2:2002, **4.5.2** are not available, sampling increments are taken from the batch to be tested.

BS EN 13383-2:2002, **4.5.3** specifies the following procedures for selecting sampling increments from either the sample obtained in accordance with BS EN 13383-2:2002, **4.5.2** or from the batch to be tested.

a) Use random numbers.

b) Select from pre-determined positions using a random chosen starting point.

c) Use an assisted blindfolded sampler selecting from random sieve fractions during or after the BS EN 13383-2:2002, **4.5.2** method of determining particle size distribution.

d) Select at a time or number interval from a random sequence of stones.

BS EN 13383-2:2002, **4.5.3** specifies that when the testing of an aggregate is permitted for use in the determination of properties for an armourstone, the aggregate is required to be sampled in accordance with BS EN 932-1.

BS EN 13383 references the following test method standards that specify the use of BS EN 932-1.

1) BS EN 932-3, specified in BS EN 13383-1:2002, **9.1** for the identification of armourstone type.

2) BS EN 1367-2 magnesium sulfate test, specified in BS EN 13383-1:2002, **7.5** for the determination of resistance to salt crystalization.

3) BS EN 1744-1, specified in BS EN 13383-1:2002, **7.2** for the determination of constituents which affect the durability of blast-furnace and steel slags.

4) BS EN 1744-3, specified in BS EN 13383-1:2002, **6.3** for the determination of water-soluble constituents.

NOTE When an aggregate, that is representative of the armourstone, is not available for the test referred to in 2), BS EN 13383-1:2002, **7.5** specifies an alternative method of preparing a sample from the armourstone itself.

BS EN 13383-2:2002, Annex G gives a summary of BS EN 13383-2 sampling requirements for a particular property test, including the number and sizes of samples and test portions together with any methods for preparing the test portions.

Attention is drawn to the fact that when a sample of armourstone is taken from a quarry with more than one rock type, it is possible that the sample is not representative of the armourstone supply as a whole.

5.2.3 *Sample reduction methods*

BS EN 13383-2:2002, **4.6** specifies the following procedures for reducing a sample at the sampling location to an appropriate size for testing two:

a) reduction using buckets (applicable to coarse grade armourstone only);

b) reduction using plates and wires (applicable to both coarse grade and light grade armourstone).

5.3 Determination of the particle size distribution of coarse gradings (BS EN 13383-2:2002, Clause 5)

5.3.1 *General*

BS EN 13383-2:2002, Clause **5** specifies two test methods that use steel rod sieves for the determination of the particle size distribution of coarse grade armourstone. The two methods are dry sieving and wet sieving. Wet sieving is used if fine particles are attached to the surface of armourstone pieces or are present in larger lumps such that breaking of adhesion by brushing is not possible.

5.3.2 *Dry sieving method*

BS EN 13383-2:2002, **5.4.1** specifies a method for dry sieving. The sample is passed over steel rod sieves in order of increasing aperture size starting with a 63 mm sieve. Subsequent sieves can have an aperture size of 90 mm, 125 mm, 180 mm, 250 mm and/or 360 mm. Each sieve is mounted over a receiver in order to collect the sieved material. Any fine material adhering to pieces of armourstone is brushed off and caught in the receiver mounted under the 63 mm sieve.

The percentage passing the 63 mm sieve is further sieved using perforated plate sieves in accordance with BS EN 933-1. Where the quantity of material passing the 63 mm sieve is greater than 80 kg, only a fraction of at least 40 kg of the material is weighed out for further sieving.

NOTE Guidance on the use of BS EN 933-1 is given in **6.5**.

5.3.3 *Wet sieving method*

BS EN 13383-2:2002, **5.4.2** specifies a method for wet sieving that makes the following modifications to the dry sieving procedure specified in BS EN 13383-2:2002, **5.4.1**.

a) During sieving the sample is hosed with water and brushed to remove any fine particles adhering to the armourstone.

b) The whole of the fraction passing the 63 mm sieve is sieved in accordance with BS EN 933-1 and not split into a smaller fraction if the quantity of material is greater than 80 kg.

c) Material retained on each sieve is allowed to drain before the retained material is weighed.

d) The fraction passing the smallest aperture sieve used in the BS EN 933-1 sieving column is discarded.

5.3.4 *Calculation of results*

BS EN 13383-2:2002, **5.5** specifies that the particle size distribution of coarse gradings is calculated from the percentages by mass retained on each sieve.

NOTE If the fraction which passes the 63 mm sieve has been split before being sieved further in accordance with BS EN 933-1, a scalar factor is applied.

An example of calculating the particle size distribution of coarse gradings is given in BS EN 13383-2:2002, Annex B.

5.4 Determination of the mass distribution of light and heavy grading (BS EN 13383-2:2002, Clause 6)

5.4.1 *General*

BS EN 13383-2:2002, Clause **6** specifies the following two methods for determining the mass distribution of light and heavy gradings.

a) The "reference method", which should be used in cases of dispute.

b) The "alternative method", which is quicker and more suitable for production control than the reference method but is less precise.

BS EN 13383-2:2002, **6.3** specifies the minimum number of pieces of armourstone, excluding fragments, required to be used in a test portion. The minimum number is dependent upon which BS EN 13383-1 grading category the armourstone material appears to fall into on initial visual inspection.

5.4.2 *Reference method*

The reference method specified in BS EN 13383-2:2002, **6.4.1** requires that each piece of armourstone, excluding fragments, is weighed separately and that the fragments are weighed together. In practice, pieces of armourstone that are classified as fragments will be separated from other pieces of armourstone by a mixture of visual inspection and weighing. The total number of pieces of armourstone heavier than a fragment is recorded.

BS EN 13383-2:2002, **6.5.1** specifies how to assess mass distribution by calculating M_n, the cumulative mass of pieces of armourstone, including fragments, with a mass smaller than each of the masses specified for a particular BS EN 13383-1 grading category. M_n is expressed as a percentage of the cumulative mass of all pieces of armourstone, including fragments, P_n.

BS EN 13383-2:2002, **6.5.1** also specifies how to calculate the average mass of the pieces of armourstone.

An example of calculating the mass distribution and average mass of light and heavy gradings is given in BS EN 13383-2:2002, Annex C.

5.4.3 *Alternative method*

The alternative method specified in BS EN 13383-2:2002, **6.4.2** requires that both the total mass and the mass of selected pieces of armourstone are weighed.

The alternative method is more convenient than the reference method because it avoids the need to weigh all individual armourstone pieces when determining the average mass. This is a convenient method to use for category B light and heavy gradings specified in BS EN 13383-1:2002, Table 3 and Table 5 because average masses are not required to be determined for these gradings. The alternative method is also more convenient because, rather than measuring the test portion as a whole, the test portion can be weighed in parts on a weighbridge using a loader bucket or lorry.

BS EN 13383-2:2002, **6.4.2** specifies that, after the total test portion has been weighed, each piece of armourstone is weighed with the exception of the pieces in the fraction with a mass between the mass values used to define a grading category, e.g. for heavy grading category $HMA_{3000/6000}$, stones judged on initial visual inspection to be between 3 000 kg and 6 000 kg are not weighed. The weight of all the fragments is also measured. The total number of pieces of armourstone heavier than a fragment is assessed through visual inspection and recorded.

BS EN 13383-2:2002, **6.5.2** specifies how to assess mass distribution in a similar way to the method specified for the reference method in BS EN 13383-2:2002, **6.5.1**. A value is calculated for M_n, the cumulative mass of pieces of armourstone, including fragments, with a mass smaller than each of the masses specified for a particular BS EN 13383-1 grading category. M_n is expressed as a percentage of the cumulative mass of all pieces of armourstone, including fragments, P_n.

The calculation of M_n for the alternative method differs from that described for the reference method because, unlike the reference method, the mass of every single piece of armourstone is unknown. For the alternative method M_n is determined from:

a) the masses of individually weighed pieces of armourstone (M_i);

b) the total mass of all the fragments (M_s); and

c) the mass of all the pieces of armourstone which were not weighed individually (M_c).

BS EN 13383-2:2002, **6.5.2** also specifies how to calculate the average mass of the pieces of armourstone.

An example of calculating the mass distribution and average mass of light and heavy gradings is given BS EN 13383-2:2002, Annex D.

5.5 Determination of the percentage of pieces of armourstone with a length-to-thickness ratio greater than 3 (BS EN 13383-2:2002, Clause 7)

5.5.1 *General*

BS EN 13383-2:2002, Clause **7** specifies the classification of the shape of armourstone pieces in terms of their length-to-thickness by specifying a method for determining the percentage of pieces of armourstone with a length-to-thickness ratio greater than 3.

5.5.2 *Summary of method*

BS EN 13383-2:2002, **7.3** specifies the minimum number of pieces of armourstone required to be used in a test portion. The minimum number is dependent upon which BS EN 13383-1 grading category the armourstone material falls into, after testing for the particle size distribution of coarse grading in accordance with BS EN 13383-2:2002, Clause **5** and the mass distribution of light and heavy grading in accordance with BS EN 13383-2:2002, Clause **6**.

BS EN 13383-2:2002, **7.4.1** implies that the assessment of whether the length (L) to thickness (E) ratio of individual pieces of armourstone is greater than 3 can be made visually. Where visual assessment is ambiguous, BS EN 13383-2:2002, **7.4.1** describes a method for determining L and E using two straight laths positioned parallel to each other at right-angles to the longest dimension (L) and then to the smallest dimension (E). L and E are measured using a carpenter's rule, a tape measure or, to achieve greater accuracy, callipers.

5.5.3 *Calculation of results*

The percentage of pieces of armourstone with $L/E > 3$ is calculated:

a) for heavy gradings, as the number of pieces with $L/E > 3$ expressed as a percentage of the total number of pieces tested;

b) for light gradings, as the mass of pieces of armourstone with $L/E > 3$ expressed as a percentage of the total mass of pieces tested;

c) for coarse gradings, by:

1) determining the masses of pieces of armourstone with $L/E > 3$ in each size fraction;

2) dividing each value by the total mass in each size fraction;

3) multiplying each value by the percentage by mass of the size fraction in the test portion;

4) summing these individual values for the total percentage.

NOTE The results from the BS EN 13383-2:2002, Clause **7** method are calculated for coarse gradings to be a weighted average of the percentage of pieces of armourstone with a length-to-thickness ratio greater than 3. The weighted average is intended to more accurately reflect the overall shape of stones in a coarse graded armourstone by eliminating the skewing effect that a large number of small pieces with a length-to-thickness ratio greater than 3 would have on the results if they were not weighted.

5.6 Determination of particle density and water absorption (BS EN 13383-2:2002, Clause 8)

BS EN 13383-2:2002, Clause **8** specifies a method for determining particle density and water absorption.

The water absorption is determined by weighing the test portion in both the saturated surface-dried condition and oven-dried condition. The volume of water absorbed is determined from the mass of water displaced, by weight reduction in a wire basket. The method for calculating water absorption is specified in BS EN 13383-2:2002, **8.6** and should be familiar to UK users.

The method for calculating particle density is also specified in BS EN 13383-2:2002, **8.6** and is calculated as the oven dried particle density, in a way familiar to UK users, from the mass to volume ratio of a piece of armourstone. BS EN 13383-2:2002, Annex E provides a correction for the density of the water arising from its temperature at the time of the determination.

5.7 Determination of resistance to freezing and thawing (BS EN 13383-2:2002, Clause 9)

BS EN 13383-2:2002, Clause **9** specifies a method for determining how armourstone behaves when it is subjected to the cyclic action of freezing and thawing.

NOTE 1 If the water absorption determined in accordance with BS EN 13383-2:2002, Clause **8** is not greater than 0.5 % the armourstone can be considered resistant to freezing and thawing and no further testing is necessary.

The BS EN 13383-2 freeze-thaw test involves freezing a water-saturated piece of armourstone at −17.5 °C and then thawing it at 20 °C. After 25 cycles the degree of degradation is assessed by measuring the percentage loss in mass of the armourstone and by recording any instances of crack formation and other signs of disintegration. The presence of cracks can be determined by visual examination.

NOTE 2 The use of a change in the velocity of acoustic waves before and after freezing-thaw cycling has been identified as a more objective method of assessing crack development. However, further research is needed to determine the percentage change, in the velocity of acoustic waves, that would constitute a threshold for unacceptable freeze-thaw resistance.

5.8 Determination of signs of "Sonnenbrand" (BS EN 13383-2:2002, Clause 10)

BS EN 13383-2:2002, Clause **10** specifies a method for determining the presence of signs of "Sonnenbrand" in basalt.

"Sonnenbrand" is defined in BS EN 13383-2:2002, **10.1** as a type of rock decay that can be present in some basalts and which manifests itself under the influence of atmospheric conditions. Sonnenbrand starts with the appearance of grey/white star-shaped spots. Usually hairline cracks are generated radiating out from the spots and interconnecting them. This reduces the strength of the mineral fabric, and as a result the rock decays to small particles.

The laboratory sample for testing for Sonnenbrand consists of a single piece of basalt armourstone, which is cut to give two test portions each with a sawn surface equal to or greater than 0.005 m^2.

One test portion is examined for signs of "Sonnenbrand" after boiling for 36 h. A record is made of any formation of grey/white star shaped spots and cracks (both hairline and larger) and any breakage of the test portion. As an aid to examining the boiled test portion, a comparison can be made with the unboiled test portion.

There is no experience of Sonnenbrand rock decay in UK basalts. It is likely that requirements to test for Sonnenbrand will only be specified for basalt that is imported into the UK.

5.9 Determination of disintegration of steel slags (BS EN 13383-2:2002, Clause 10)

BS EN 13383-2:2002, Clause **10** specifies a method for determining the disintegration of steel slags.

Steel slags can contain oxides of calcium and magnesium which in contact with water will react to form hydroxides and cause an increase in volume which may cause cracks and/or disintegration.

When testing for the disintegration of steel slags in accordance with BS EN 13383-2:2002, Clause **10** a test portion of steel slag is weighed before boiling for 8 h and the test portion or largest remaining fragment is weighed after boiling.

The degree of disintegration is assessed by measuring the percentage loss in mass of the test portion and recording any crack formation observed after boiling.

6 Test method standards referenced in BS EN 13383

6.1 General

BS EN 13383 specifies the use of a number of European and international test method standards. **6.2** to **6.14** give guidance on each of the European and international test methods standards, with the scope of each standard reproduced in full. Table 3 lists these test method standards and directs the user to the relevant subclause for guidance.

NOTE Most of the guidance given in **6.2** to **6.14** for each of the European and international test method standards specified in BS EN 13383 is taken from PD 6682-9, the guide to European test method standards for aggregates. The guidance in PD 6682-9 has been repeated here partly for convenience and partly to highlight any differences that arise when the European test method standards for aggregates are applied to the testing of armourstone.

Table 3 — Test method standards referenced in BS EN 13383

Standard	Test method	UK guidance subclause
BS EN 932-1	Methods of sampling	**6.2**
BS EN 932-3	Procedure and terminology for simplified petrographic description	**6.3**
BS EN 932-5	Common equipment and calibration	**6.4**
BS EN 933-1	Determination of particle size distribution — Sieving method	**6.5**
BS EN 933-2	Determination of particle size distribution — Test sieves, nominal size of apertures	**6.6**
BS EN 933-3	Determination of particle size distribution — Flakiness index	**6.7**
BS EN 1097-1	Determination of the resistance to wear (micro-Deval)	**6.8**
BS EN 1097-5	Determination of water content by drying in a ventilated oven	**6.9**
BS EN 1367-2	Magnesium sulfate test	**6.10**
BS EN 1744-1	Chemical analysis	**6.11**
BS EN 1744-3	Preparation of eluates by leaching of aggregates	**6.12**
BS EN 1926	Determination of the compressive strength	**6.13**
ISO 3310 (published in the UK as BS 410)	Test sieves of perforated metal plate	**6.14**

6.2 Guidance on the use of BS EN 932-1 — Tests for general properties of aggregates — Part 1: Methods for sampling

6.2.1 *Scope of BS EN 932-1*

BS EN 932-1 specifies methods for obtaining samples of aggregates from deliveries, preparation and processing plants including stocks.

The aim of sampling is to obtain a bulk sample that is representative of the average properties of the batch. The methods specified in BS EN 932-1 are also suitable for obtaining sampling increments that may be tested separately.

Methods to be used for sample reduction are also given. The methods specified in BS EN 932-1 are based on manual procedures. Mechanical or automatic sampling and sample reduction may also be used. Criteria for the design and the assessment of such equipment are given in BS EN 932-1:1997, Annex A.

The methods specified in BS EN 932-1 are limited to civil engineering purposes.

6.2.2 *Relationship to BS EN 13383*

BS EN 13383-2:2002, **4.5.3** specifies that when the testing of an aggregate is permitted for use in the determination of properties for an armourstone, the aggregate is required to be sampled in accordance with BS EN 932-1.

BS EN 13383 references the following test method standards that specify the use of BS EN 932-1.

a) BS EN 932-3, specified in BS EN 13383-1:2002, **9.1** for the identification of armourstone type.

b) BS EN 1367-2 magnesium sulfate test, specified in BS EN 13383-1:2002, **7.5** for the determination of resistance to salt crystalization.

c) BS EN 1744-1, specified in BS EN 13383-1:2002, **7.2** for the determination of constituents which affect the durability of blast-furnace and steel slags.

d) BS EN 1744-3, specified in BS EN 13383-1:2002, **6.3** for the determination of water-soluble constituents.

NOTE When an aggregate, that is representative of the armourstone, is not available for the test referred to in b), BS EN 13383-1:2002, **7.5** specifies an alternative method of preparing a sample from the armourstone itself.

6.2.3 *Summary of method*

BS EN 932-1 specifies procedures for sampling from specific types of location, e.g. conveyors, silos, belt and sampling stockpiles, etc., with informative examples of equipment such as sampling scoops, frames, tubes, spears, etc.

BS EN 932-1 also covers the reduction of bulk samples for the production of laboratory samples, nominating rotary sample dividers as the preferred means of sample reduction and giving examples of such dividers for both coarse and fine aggregate sizes. However, operational procedures for the use of rotary sample dividers are only included in BS EN 932-2, which specifies methods for reducing laboratory samples for the production of test portions.

Sample reduction by fractional shovelling and the use of random numbering techniques are also specified in BS EN 932-1. These methods are not specified in the current British Standard for aggregate sampling, BS 812-102.

NOTE BS EN 932-1:1997 partially supersedes BS 812-102:1989, which will be withdrawn on 1 June 2004.

BS EN 932-1 notes that sampling from stockpiles should, wherever possible, be avoided but includes a method for sampling from flat-topped sampling stockpiles. Guidance on sampling from conical and prismatically shaped stockpiles is given informatively in BS EN 932-1:1997, Annex C.

Guidance on the measurement of sampling variation is given informatively in BS EN 932-1:1997, Annex B. This information provides the user with a procedure that checks whether the number of sampling increments taken is adequate for subsequent test methods.

6.3 Guidance on the use of BS EN 932-3 — Tests for general properties of aggregates — Part 3: Procedure and terminology for simplified petrographic description

6.3.1 *Scope of BS EN 932-3*

BS EN 932-3 specifies a basic procedure for the petrographic examination of aggregates for the purposes of classification. The procedure is not suitable for the detailed petrographical study of aggregates for specific end uses.

NOTE The examination should be carried out by a qualified geologist (petrographer), with experience of materials used in civil engineering.

This European Standard covers only natural aggregates, sand and gravel or crushed rock aggregate as well as their source materials.

6.3.2 *Relationship to BS EN 13383*

The BS EN 932-3 procedure for the petrographic examination of aggregates is applicable to armourstone. BS EN 13383-1:2002, **9.1** requires that the type of armourstone is identified using the BS EN 932-3 procedure.

The BS EN 932-3 procedure in turn specifies sampling in accordance with BS EN 932-1. And therefore requires the tests to be performed using a sample of aggregate that is representative of the armourstone.

NOTE The Note to BS EN 13383-2:2002, **4.5.3** states that if individual pieces of armourstone are significantly larger than the minimum size or mass required for a test to be preformed, a portion of appropriate size or mass can be obtained by breaking a representative piece. The objective is to obtain laboratory samples representative of the batch to be tested but to have carried out sample reduction in accordance with BS EN 13383-2:2002, **4.6** at source so as to minimize transport costs and reduce unnecessary sample reduction at the testing laboratory.

6.3.3 *Summary of method*

BS EN 932-3 is intended for the general classification of rocks and aggregates rather than detailed petrographic study for specific end uses.

BS EN 932-3 specifies the minimum mass to be "delivered for examination". BS EN 932-3 also specifies examination methods for both rock and aggregate samples.

For the examination of aggregate samples, BS EN 932-3 specifies that, in addition to petrographic identification, a description of particle shape, roundness and surface texture is required. BS EN 932-3 also specifies that, for aggregate samples, the degree of weathering and the presence of any exterior coating on the surface of the grains shall be noted.

The series of European Standards for aggregates does not include a method for qualitative and quantitative petrographic examination. BS 812-104 describes such a method and as such will remain in use in the UK.

6.4 Guidance on the use of BS EN 932-5 — Tests for general properties of aggregates — Part 5: Common equipment and calibration

6.4.1 *Scope of BS EN 932-5*

BS EN 932-5 specifies general requirements for common equipment, calibration procedures and reagents for the testing of the properties of aggregates.

6.4.2 *Relationship to BS EN 13383*

BS EN 13383-2 requires that, unless otherwise stated, all apparatus conforms to BS EN 932-5.

6.4.3 *Summary of method*

BS EN 932-5 is based on, and closely follows, the requirements specified in BS 812-100.

NOTE BS EN 932-5:2000 supersedes BS 812-100:1990, which will be withdrawn on 1 June 2004.

BS EN 932-5, **5.5.2** informatively references the International Organization for Legal Metrology (OILM) classification of weights. BS EN 932-5 adopts the OILM classification of weights for the purposes of calibrating and checking measuring instruments.

BS EN 932-5 simplifies some of the requirements of BS 812-100 and redefines the method for calibration and the methods for checking ovens and test sieves.

6.5 Guidance on the use of BS EN 933-1 — Tests for geometrical properties of aggregates — Part 1: Determination of particle size distribution — Sieving method

6.5.1 *Scope of BS EN 933-1*

BS EN 933-1 specifies a method, using test sieves, for the determination of the particle size distribution of aggregates. It applies to aggregates of natural or artificial origin, including lightweight aggregates, up to 63 mm nominal size, but excluding filler.

NOTE The determination of the grading of fillers is specified in BS EN 933-10.

6.5.2 *Relationship to BS EN 13383*

BS EN 13383-2:2002, Clause **5** requires that the sieving methods used in the determination of particle size distribution are performed in accordance with BS EN 933-1.

In addition, BS EN 13383-1:2002, **5.4** references the BS EN 1097-1:1996, Clause **7** micro-Deval test that specifies the use of BS EN 933-1.

6.5.3 *Summary of method*

BS EN 933-1 specifies that the test portion is washed to remove fine particles passing a 0.063 mm sieve. After drying, the remaining material is separated on a series of sieves of decreasing aperture sizes and the particle size distribution is calculated from the percentages by mass retained on each sieve.

The test procedure specified in BS EN 933-1 is based on the traditional UK method of washing and dry sieving specified in BS 812-103.1, the existing British Standard for sieving methods for the determination of particle size distribution, albeit using sieves of a different size series.

NOTE BS EN 933-1:1997 supersedes BS 812-103.1:1985, which will be withdrawn on 1 June 2004.

The requirements of BS EN 933-1 for the minimum test portion masses and the maximum loading limits of sieves are not identical to BS 812-103.1.

In the UK, aggregates are washed by agitating the test portion with water in a container. However, it should be noted that elsewhere in Europe, whilst aggregates are washed in the same way, the washing process is often completed directly on the guarded 0.063 mm sieve rather than decanting only the wash water and suspended fines. Either process is permitted in BS EN 933-1 with a note that overloading and overflowing should be avoided.

6.6 Guidance on the use of BS EN 933-2 — Tests for geometrical properties of aggregates — Part 2: Determination of particle size distribution — Test sieves, nominal size of apertures

6.6.1 *Scope of BS EN 933-2*

BS EN 933-2 specifies nominal aperture sizes and shape for woven wire cloth and perforated plate in test sieves used for test methods for aggregates.

It applies to aggregates of natural or artificial origin including lightweight aggregates.

6.6.2 *Relationship to BS EN 13383*

BS EN 13383-2:2002, Clause **10** requires that the test sieves used in the determination of signs of Sonnenbrand conform to BS EN 933-2.

In addition, BS EN 13383 references the following test method standards that specify the use of BS EN 933-2.

a) BS EN 933-1 sieving methods, specified in BS EN 13383-2:2002, Clause **5** for the determination of particle size distribution of coarse graded armourstone.

b) BS EN 933-3, specified in BS EN 13383-1:2002, **5.4** for sampling for the determination of resistance to wear.

c) BS EN 1367-2 magnesium sulfate test, specified in BS EN 13383-1:2002, **7.5** for the determination of resistance to salt crystalization.

d) BS EN 1744-3, specified in BS EN 13383-1:2002, **6.3** for the determination of water-soluble constituents.

6.6.3 *Summary of method*

BS EN 933-2 does not contain a test method, but sets out requirements for test sieves used in the testing of aggregates, including coarse graded armourstone. The key BS EN 933-2 requirements are listed below.

a) Test sieves shall have square apertures.

b) Sieves with an aperture size of <4 mm shall be woven wire test sieves conforming to ISO 3310-1.

c) Sieves with an aperture size of ≥ 4 mm shall be perforated plate square hole test sieves and shall conform to ISO 3310-2.

NOTE 1 ISO 3310-1 and ISO 3310-2 are reproduced verbatim and published in the UK as BS 410-1:2000 and BS 410-2:2000 respectively.

A standard set of sieves from the R 20 series specified in ISO 565 is listed. These sieves are required to be included when carrying out a particle size distribution, in addition to any other required sieves.

NOTE 2 Further guidance on sieve sizes used for coarse graded armourstone is given in **4.2.1.2**.

The UK practice of using perforated plate square hole sieves rather than woven wire sieves for larger aperture sieves is retained by BS EN 933-2.

6.7 Guidance on the use of BS EN 933-3 — Tests for geometrical properties of aggregates — Part 3: Determination of particle shape — Flakiness index

6.7.1 *Scope of BS EN 933-3*

BS EN 933-3 specifies the procedure for the determination of the flakiness index of aggregate and applies to aggregates of natural or artificial origin, including lightweight aggregates.

The test procedure specified in BS EN 933-3 is not applicable to particle sizes of <4 mm or >80 mm.

6.7.2 *Relationship to BS EN 13383*

BS EN 13383-1:2002, **5.4** requires that, for sampling for the determination of resistance to wear where there is no aggregate that is representative of the armourstone, flaky particles and cubical particles shall be removed using bar sieves that conform to BS EN 933-3.

6.7.3 *Summary of test method*

BS EN 933-3 requires that test portions are first sorted by sieving into a specific series of particle size fractions.

Each particle size fraction is then sorted by sieving on a bar sieve with parallel slot openings of a width specified for that particle size fraction.

Flaky particles are those which can pass through the slots in the bar sieve.

The flakiness index is calculated as the sum of the masses of the flaky particles in each size fraction as a percentage of the total mass tested. However, flakiness is not determined for armourstone.

6.8 Guidance on the use of BS EN 1097-1 — Tests for mechanical and physical properties of aggregates — Part 1: Determination of resistance to wear (micro-Deval)

6.8.1 *Scope of BS EN 1097-1*

BS EN 1097-1 specifies a procedure for measuring the resistance to wear of a sample of aggregate. The sample is normally tested in a wet condition but the test may also be carried out in a dry condition. BS EN 1097-1 applies to natural or artificial aggregates used in building or civil engineering.

6.8.2 *Relationship to BS EN 13383*

BS EN 13383-1:2002, **5.4** requires the determination of resistance to wear in accordance with the BS EN 1097-1 micro-Deval test, using a sample of aggregate that is representative of the armourstone.

NOTE Where aggregate that is representative of the armourstone is not available, a procedure for preparing a test portion using the armourstone itself is provided in BS EN 13383-1:2002, **5.4**.

6.8.3 *Summary of method*

BS EN 1097-1 requires that the test portion consists of two 500 g test specimens of dry aggregate from the 10/14 mm size fraction with a specified proportion of particles passing the 11.2 mm or 12.5 mm sieve.

Each test specimen is abraded by being rotated at a speed of 100 revolutions per minute for 12 000 revolutions in separate stainless steel drums, each containing 5 kg of steel balls and 2.5 l of water.

After abrading, each test specimen is passed through a 1.6 mm sieve protected by an 8 mm guard sieve and dried. The mass of the test portion retained on the 1.6 mm sieve is used to calculate the micro-Deval coefficient (M_{DE}).

A method to determine the micro-Deval coefficient in a dry condition (M_{DS}), without the addition of water to the drums, is included in BS EN 1097-1:1996, Annex A. However, the determination of the micro-Deval coefficient in a dry condition should not be used for armourstone.

6.9 Guidance on the use of BS EN 1097-5 — Tests for mechanical and physical properties of aggregates — Part 5: Determination of water content by drying in a ventilated oven

6.9.1 *Scope of BS EN 1097-5*

BS EN 1097-5 specifies a procedure for determining the water content of aggregates by drying in a ventilated oven.

6.9.2 *Relationship to BS EN 13383*

BS EN 13383-2:2002, Clause **9** requires that, for the determination of resistance to freezing and thawing, test portions of armourstone shall be dried in accordance with BS EN 1097-5 until a constant mass is achieved.

6.9.3 *Summary of method*

The test method specified in BS EN 1097-5 is based on the "definitive oven-drying method" of determining the moisture content of aggregate specified in BS 812-109:1990, Clause **6**.

NOTE BS EN 1097-5:1998 supersedes BS 812-109:1990, which will be withdrawn on 1 June 2004.

BS EN 1097-5 differs from BS 812-109 in that the minimum test portion masses are directly proportioned to the upper aggregate size (D), the temperature of drying is defined as (110 ± 5) °C and a method for drying the test portion to a constant mass is specified.

In common with other European test method standards for aggregates, BS EN 1097-5 specifies that the temperature for oven drying to constant mass is (110 ± 5) °C rather than the (105 ± 5) °C specified in current British test method standards for aggregates.

Test procedures in some UK laboratories will need amending in order to conform to these BS EN 1097-5 requirements for the minimum test portion mass and the establishment of constant mass conditions.

6.10 Guidance on the use of BS EN 1367-2 — Tests for thermal and weathering properties of aggregates — Part 2: Magnesium sulfate test

6.10.1 *Scope of BS EN 1367-2*

BS EN 1367-2 specifies a method for assessing how an aggregate behaves when subjected to the cyclic action of immersion in magnesium sulfate, followed by oven drying.

NOTE The majority of aggregates can be tested for performance using this method. Precision has been established for the rock types listed in BS EN 1367-2:1998, Annex A. The test may not be suitable for all rock types and reservations have been expressed elsewhere in respect of some carbonate aggregates and some aggregates having a high proportion of magnesium bearing minerals or of cryptocrystalline quartz.

6.10.2 *Relationship to BS EN 13383*

BS EN 13383-1:2002, **7.5** requires the determination of resistance to salt crystalization in accordance with the BS EN 1367-2 magnesium sulfate test, using a sample of aggregate that is representative of the armourstone.

NOTE 1 Where aggregate that is representative of the armourstone is not available, a procedure for preparing a test portion using the armourstone itself is provided in BS EN 13383-1:2002, **7.5**.

NOTE 2 Further UK guidance on when and how to test armourstone for resistance to salt crystallization is given in **4.5.4**.

6.10.3 *Summary of method*

The BS EN 1367-2 test procedure is based on the method given in BS 812-121. At least two test specimens of aggregate in the size range 10 mm to 14 mm are subjected to five cycles of immersion in a saturated solution of magnesium sulfate, followed by oven drying. Each cycle takes (48 ± 2) h.

NOTE BS EN 1397-2:1998 supersedes BS 812-121:1989, which will be withdrawn on 1 June 2004.

Any aggregate degradation is measured by the extent to which material finer than 10 mm in particle size is produced.

The magnesium sulfate (*MS*) value is calculated as the mass of aggregate retained on the 10 mm sieve as a percentage of the initial mass of the test specimen.

The BS EN 1367-2 test method is identical to the soundness test in BS 812-121, but it should be noted that the results are calculated in a different manner.

The *MS* value calculated in accordance with BS EN 1367-2 is equivalent to (100 – MSSV) where MSSV is the magnesium sulfate soundness value determined in accordance with BS 812-121.

6.11 Guidance on the use of BS EN 1744-1 — Tests for chemical properties of aggregates — Part 1: Chemical analysis

6.11.1 *Scope of BS EN 1744-1*

BS EN 1744-1 specifies procedures for the chemical analysis of aggregates. It specifies the reference procedures and, in certain cases, an alternative method which can be considered as giving equivalent results.

If other methods are used it is necessary to show that they give results equivalent to those given by the reference methods.

NOTE In cases of dispute, only the reference procedures should be used.

Unless otherwise stated, the test methods specified in BS EN 1744-1 may be used for factory production control, for audit tests or for type tests.

6.11.2 *Relationship to BS EN 13383*

BS EN 13383-1:2002, **7.2** specifies the use of the following two BS EN 1744-1 test methods for the determination of the content of constituents which affect the durability of air-cooled blast-furnace slag.

a) The determination of dicalcium silicate disintegration (unsoundness) of air-cooled blast-furnace slag armourstone in accordance with BS EN 1744-1:1998, **19.1**.

b) The determination of iron disintegration (unsoundness) of air-cooled blast-furnace slag armourstone in accordance with BS EN 1744-1:1998, **19.2**.

The BS EN 1744-1:1998, **19.1** and **19.2** test methods specified in BS EN 13383-1:2002, **7.2** in turn specify sampling in accordance with BS EN 932-1. And therefore requires the tests to be performed using a sample of aggregate that is representative of the armourstone.

NOTE The Note to BS EN 13383-2:2002, **4.5.3** states that if individual pieces of armourstone are significantly larger than the minimum size or mass required for a test to be preformed, a portion of appropriate size or mass can be obtained by breaking a representative piece. The objective is to obtain laboratory samples representative of the batch to be tested but to have carried out sample reduction in accordance with BS EN 13383-2:2002, **4.6** at source so as to minimize transport costs and reduce unnecessary sample reduction at the testing laboratory.

6.11.3 *Summary of methods*

6.11.3.1 *Summary of the method to determine dicalcium silicate disintegration (unsoundness)*

BS EN 13383-1:2002, **7.2.1** specifies that, when required by the armourstone user, air-cooled blast-furnace slag armourstone is free from dicalcium silicate disintegration (i.e. is sound) when tested in accordance with BS EN 1744-1:1998, **19.1**.

The BS EN 1744-1:1998, **19.1** test method involves viewing broken slag surfaces from at least 30 test portions under ultra-violet light. Broken slag surfaces flouresce under ultra-violet light in the visible range. The aspect and colour of flourescence enables detection of slags potentially subject to disintegration. An experienced technician should be used to determine whether the armourstone slag is sound or unsound.

6.11.3.2 *Summary of the method to determine iron disintegration (unsoundness)*

BS EN 13383-1:2002, **7.2.2** specifies that, when required by the armourstone user, air-cooled blast-furnace slag armourstone is free from iron disintegration (i.e. is sound) when tested in accordance with BS EN 1744-1:1998, **19.2**.

The BS EN 1744-1:1998, **19.2** test method involves examining the behaviour of a sample of 30 pieces of slag of size 40 mm to 150 mm which has been immersed in water for 2 days. The slag samples are then examined for cracking and disintegration resulting from hydrolysis of iron and manganese sulfides. An experienced technician should be used to determine whether the armourstone slag is sound or unsound.

6.12 Guidance on the use of BS EN 1744-3 — Tests for chemical properties of aggregates — Part 3: Preparation of eluates by leaching of aggregates

6.12.1 *Scope of BS EN 1744-3*

BS EN 1744-3 specifies a method for the preparation of eluates, by leaching of aggregates, for subsequent investigation of physical and chemical properties by existing standard methods for the purposes of compliance testing. It applies to unbound aggregates that have a particle size below 32 mm with or without size reduction.

6.12.2 *Relationship to BS EN 13383*

BS EN 13383-1:2002, **6.3** specifies the determination of water-soluble constituents through the preparation of an eluate in accordance with BS EN 1744-3 and subsequent testing using methods developed for water analysis that have been adapted for use in the analysis of eluates.

BS EN 1744-3 in turn specifies sampling in accordance with BS EN 932-1. And therefore requires the tests to be performed using a sample of aggregate that is representative of the armourstone.

NOTE The Note to BS EN 13383-2:2002, **4.5.3** states that if individual pieces of armourstone are significantly larger than the minimum size or mass required for a test to be preformed, a portion of appropriate size or mass can be obtained by breaking a representative piece. The objective is to obtain laboratory samples representative of the batch to be tested but to have carried out sample reduction in accordance with BS EN 13383-2:2002, **4.6** at source so as to minimize transport costs and reduce unnecessary sample reduction at the testing laboratory.

6.12.3 *Summary of method*

BS EN 1744-3 specifies that the aggregate test portion is leached by stirring in water on a screen in a tank for 24 h and a sufficient quantity of eluate drawn off for analysis.

Dependent upon whether the inorganic or organic parameters of the eluate are determined, the eluate is either filtered or centrifuged.

The properties of the eluate can subsequently be measured using methods developed for water analysis that have been adapted for use in the analysis of eluates. The methods used for the analysis of eluates depends on what national regulations exist in the place of use of the armourstone. The filtrate or centrifugate should be analysed immediately after completion of the BS EN 1744-3 test procedure. If this is not possible, it should be preserved.

The BS EN 1744-3 leaching procedure relies on an initial wash-off effect and the solubility of components from the outer surfaces of the aggregate particles. BS EN 1744-3 comprises a reproducible leaching test suitable for the production control of arourstone.

6.13 Guidance on the use of BS EN 1926:1999, Annex A — Determination of the compressive strength of armourstone

BS EN 13383-1:2002, **5.3** specifies the determination of resistance to breakage of armourstone, when required by the armourstone user, in terms of the compressive strength value measured in accordance with BS EN 1926:1999, Annex A.

BS EN 1926:1999, Annex A requires that cubic or cylindrical armourstone test specimens are immersed in water for 2 days and subjected to strength tests 1 h after removal from the water.

Careful preparation of the test specimens is necessary, taking into account the planes of anisotropy of the specimen in relation to the direction of loading of the specimen and taking into account the fact that the compressive strength of the armourstone is related to the size of the specimen.

It is possible that the hand-sized samples used in the BS EN 1926:1999, Annex A test contain only intact mineral fabric and do not reflect the presence of flaws typical of those found in pieces of armourstone. This means that the results of the test method specified in BS EN 1926:1999, Annex A can sometimes only describe the resistance to breakage of the intact mineral fabric of the armourstone. Therefore, it is recommended that resistance to breakage is also assessed along pre-existing flaws (a property described as block integrity).

NOTE Guidance on methods used to assess block integrity in the UK is given in **4.3.2.2**.

6.14 Guidance on the use of ISO 3310 — Test sieves —Technical requirements and testing

The series of European test method standards for aggregates, including BS EN 13383-2 test methods for armourstone, specifies the use of:

a) sieves with an aperture size of <4 mm that are woven wire test sieves conforming to ISO 3310-1;

b) sieves with an aperture size of ≥ 4 mm that are perforated plate square hole test sieves conforming to ISO 3310-2.

NOTE 1 ISO 3310-1:2000 and ISO 3310-2:1999 are reproduced verbatim and published in the UK as BS 410-1:2000 and BS 410-2:2000.

NOTE 2 BS EN 933-2 specifies European requirements for test sieves and the size of their apertures, including requirements specifying the use of ISO 3310. Guidance on BS EN 933-2 is given in **6.6**.

Annex A (informative)
Example specification for armourstone for general uses

An example of a specification listing recommended BS EN 13383-1 requirements for general uses of armourstone is given in Table A.1.

NOTE Additional recommended BS EN 13383-1 requirements for particular armourstone sources and/or end uses are given in Annex B.

Table A.1 — Recommended BS EN 13383-1 categories for armourstone for general uses

Property	Recommended BS EN 13383-1 category
Grading	
— Coarse grading	Insert appropriate categories from BS EN 13383-1:2002, Table 1
— Light grading	Insert appropriate categories from BS EN 13383-1:2002, Table 2 category A for cover layer applications or BS EN 13383-1:2002, Table 3 category B for other applications
— Heavy grading	Insert appropriate categories from BS EN 13383-1:2002, Table 4 category A or, where the material is not being used in a cover layer, BS EN 13383-1:2002, Table 5 category B
Shape	LT_A LT_{NR} where the armourstone is being used beneath more than two stone thicknesses of other armourstone
Proportion of crushed or broken surfaces	RO_{NR}
Particle density	In accordance with BS EN 13383-1:2002, Table 8. (The selection of the value of x is a matter for the designer/specifier)
Resistance to breakage	CS_{80}
Resistance to wear	$M_{DE}20$
Water absorption	$WA_{0.5}$
Resistance to salt crystallization, where WA exceeds 0.5 %	MS_{25} MS_{NR} for armourstone that is permanently submerged
Block integrity	Checks for block integrity are strongly advised: for guidance see **4.3.2.2** and BS EN 13383-1:2002, Annex B

Annex B (informative)
Additional specification details for particular armourstone sources and/or end uses

For particular armourstone sources and/or end uses, additional BS EN 13383-1 requirements can be added to the example specification given in Annex A. Some additional recommended BS EN 13383-1 requirements are given in Table B.1. Where the additional requirements vary depending on the particular end use, appropriate values should be inserted for the particular properties.

NOTE The additional recommended BS EN 13383-1 requirements given in Table B.1 should not be included in a specification for an armourstone where they are not applicable to that particular armourstone source and/or end use.

Table B.1 — Additional recommended BS EN 13383-1 categories for particular armourstone sources and/or end uses

Source/end use	Property	Recommended BS EN 13383-1 category
Source: air-cooled blast-furnace slag	Dicalcium silicate disintegration	Free, when tested in accordance with BS EN 1744-1:1998, **19.1**
	Iron disintegration	Free, when tested in accordance with BS EN 1744-1:1998, **19.2**
Source: steel slag	Disintegration	DS_A
Source: basalts	Signs of "Sonnenbrand"	SB_A
Situations in the UK where there is a significant risk of freezing[a] and where water absorption, *WA*, is greater than 0.5 %, for example: — freshwater inland lakes and reservoirs — salt-water saturated rocks above the water-line subject to freezing	Resistance to freezing and thawing	FT_A
Natural boulders for use in structures in which rounded stones could lead to instability	Proportion of crushed or broken surfaces	RO_5
Very highly abrasive environment (e.g. frequently stormy seas with shingle-structure interaction, fluvial torrents, dynamic armour layers including berm breakwaters)	Resistance to wear	$M_{DE}10$
Highly abrasive environment (e.g. occasionally stormy seas with shingle or sandy foreshore)		$M_{DE}20$
Moderately abrasive environment (e.g. occasional wave or current action with suspended sediment load)		$M_{DE}30$

[a] Further guidance on the applicability of the freeze-thaw test is given in BS EN 13383-1:2002, Annex C.

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