



Designation: C 33 – 01a

Standard Specification for Concrete Aggregates¹

This standard is issued under the fixed designation C 33; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope *

1.1 This specification defines the requirements for grading and quality of fine and coarse aggregate (other than lightweight or heavyweight aggregate) for use in concrete.²

1.2 This specification is for use by a contractor, concrete supplier, or other purchaser as part of the purchase document describing the material to be furnished.

NOTE 1—This specification is regarded as adequate to ensure satisfactory materials for most concrete. It is recognized that, for certain work or in certain regions, it may be either more or less restrictive than needed. For example, where aesthetics are important, more restrictive limits may be considered regarding impurities that would stain the concrete surface. The specifier should ascertain that aggregates specified are or can be made available in the area of the work, with regard to grading, physical, or chemical properties, or combination thereof.

1.3 This specification is also for use in project specifications to define the quality of aggregate, the nominal maximum size of the aggregate, and other specific grading requirements. Those responsible for selecting the proportions for the concrete mixture shall have the responsibility of determining the proportions of fine and coarse aggregate and the addition of blending aggregate sizes if required or approved.

1.4 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.5 The text of this standard references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of this standard.

2. Referenced Documents

2.1 ASTM Standards:

C 29/C 29M Test Method for Bulk Density (“Unit Weight”) and Voids in Aggregate³

- C 40 Test Method for Organic Impurities in Fine Aggregates for Concrete³
- C 87 Test Method for Effect of Organic Impurities in Fine Aggregate on Strength of Mortar³
- C 88 Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate³
- C 117 Test Method for Material Finer than 75- μ m (No. 200) Sieve in Mineral Aggregates by Washing³
- C 123 Test Method for Lightweight Particles in Aggregate³
- C 125 Terminology Relating to Concrete and Concrete Aggregates³
- C 131 Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine³
- C 136 Test Method for Sieve Analysis of Fine and Coarse Aggregates³
- C 142 Test Method for Clay Lumps and Friable Particles in Aggregates³
- C 150 Specification for Portland Cement⁴
- C 227 Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)³
- C 289 Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method)³
- C 294 Descriptive Nomenclature for Constituents of Concrete Aggregates³
- C 295 Guide for Petrographic Examination of Aggregates for Concrete³
- C 311 Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland-Cement Concrete³
- C 330 Specification for Lightweight Aggregates for Structural Concrete³
- C 331 Specification for Lightweight Aggregates for Concrete Masonry Units³
- C 332 Specification for Lightweight Aggregates for Insulating Concrete³
- C 342 Test Method for Potential Volume Change of Cement-Aggregate Combinations⁵
- C 441 Test Method for Effectiveness of Mineral Admixtures or Ground Blast-Furnace Slag in Preventing Excessive

¹ This specification is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.20 on Normal Weight Aggregates.

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² For lightweight aggregates, see Specifications C 331, C 332, and C 330; for heavyweight aggregates see Specification C 637 and Descriptive Nomenclature C 638.

³ Annual Book of ASTM Standards, Vol 04.02.

⁴ Annual Book of ASTM Standards, Vol 04.01.

⁵ Discontinued; see 2001 Annual Book of ASTM Standards, Vol 04.02.

***A Summary of Changes section appears at the end of this standard.**

- Expansion of Concrete Due to the Alkali-Silica Reaction³
- C 535 Test Method for Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine³
- C 586 Test Method for Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregates (Rock Cylinder Method)³
- C 595 Specification for Blended Hydraulic Cements⁴
- C 618 Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete³
- C 637 Specification for Aggregates for Radiation-Shielding Concrete³
- C 638 Descriptive Nomenclature of Constituents of Aggregates for Radiation-Shielding Concrete³
- C 666 Test Method for Resistance of Concrete to Rapid Freezing and Thawing³
- C 989 Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars³
- C 1105 Test Method for Length Change of Concrete Due to Alkali-Carbonate Rock Reaction³
- C 1157 Performance Specification for Hydraulic Cement⁴
- C 1240 Specification for Use of Silica Fume as a Mineral Admixture in Hydraulic-Cement Concrete, Mortar, and Grout³
- C 1260 Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)³
- C 1293 Test Method for Concrete Aggregates by Determination of Length Change of Concrete Due to Alkali-Silica Reaction³
- D 75 Practice for Sampling Aggregates⁶
- D 3665 Practice for Random Sampling of Construction Materials⁶
- E 11 Specification for Wire-Cloth and Sieves for Testing Purposes⁷

4. Ordering and Specifying Information

4.1 The direct purchaser of aggregates shall include the information in 4.2 in the purchase order as applicable. A project specifier shall include in the project documents information to describe the aggregate to be used in the project from the applicable items in 4.3.

4.2 Include in the purchase order for aggregates the following information, as applicable:

4.2.1 Reference to this specification, as C 33____,

4.2.2 Whether the order is for fine aggregate or for coarse aggregate,

4.2.3 Quantity, in metric tons or tons,

4.2.4 When the order is for fine aggregate:

4.2.4.1 Whether the restriction on reactive materials in 7.3 applies,

4.2.4.2 In the case of the sulfate soundness test (8.1) which salt is to be used. If none is stated, either sodium sulfate or magnesium sulfate shall be used,

4.2.4.3 The appropriate limit for material finer than 75- μ m (No. 200) sieve (Table 1). If not stated, the 3.0 % limit shall apply,

4.2.4.4 The appropriate limit for coal and lignite (Table 1). If not stated, the 1.0 % limit shall apply,

4.2.5 When the order is for coarse aggregate:

4.2.5.1 The grading (size number) (10.1 and Table 2), or alternate grading as agreed between the purchaser and aggregate supplier.

4.2.5.2 The class designation (11.1 and Table 3),

4.2.5.3 Whether the restriction on reactive materials in 11.2 applies,

4.2.5.4 In the case of the sulfate soundness test (Table 3), which salt is to be used. If none is stated, either sodium sulfate or magnesium sulfate shall be used, and

4.2.6 Any exceptions or additions to this specification (see Note 1).

4.3 Include in project specifications for aggregates the following information, as applicable:

4.3.1 Reference to this specification, as C 33____.

4.3.2 When the aggregate being described is fine aggregate:

4.3.2.1 Whether the restriction on reactive materials in 7.3 applies,

4.3.2.2 In the case of the sulfate soundness test (8.1) which salt is to be used. If none is stated, either sodium sulfate or magnesium sulfate shall be used.

4.3.2.3 The appropriate limit for material finer than the 75- μ m (No. 200) sieve (Table 1). If not stated, the 3.0 % limit shall apply, and

4.3.2.4 The limit that applies with regard to coal and lignite (Table 1). If not stated, the 1.0 % limit shall apply.

4.3.3 When the aggregate being described is coarse aggregate:

4.3.3.1 The nominal maximum size or sizes permitted, based on thickness of section or spacing of reinforcing bars or other criteria. In lieu of stating the nominal maximum size, the specifier shall designate an appropriate size number or numbers (10.1 and Table 2). Designation of a size number to indicate a nominal size shall not restrict the person responsible for selecting proportions from combining two or more gradings of

TABLE 1 Limits for Deleterious Substances in Fine Aggregate for Concrete

Item	Mass Percent of Total Sample, max
Clay lumps and friable particles	3.0
Material finer than 75- μ m (No. 200) sieve:	
Concrete subject to abrasion	3.0 ^A
All other concrete	5.0 ^A
Coal and lignite:	
Where surface appearance of concrete is of importance	0.5
All other concrete	1.0

^A In the case of manufactured sand, if the material finer than the 75- μ m (No. 200) sieve consists of the dust of fracture, essentially free of clay or shale, these limits are permitted to be increased to 5 and 7 %, respectively.

3. Terminology

3.1 For definitions of terms used in this standard, refer to Terminology C 125.

⁶ Annual Book of ASTM Standards, Vol 04.03.

⁷ Annual Book of ASTM Standards, Vol 14.02.

TABLE 2 Grading Requirements for Coarse Aggregates

Size Number	Nominal Size (Sieves with Square Openings)	Amounts Finer than Each Laboratory Sieve (Square-Openings), Mass Percent													
		100 mm (4 in.)	90 mm (3½ in.)	75 mm (3 in.)	63 mm (2½ in.)	50 mm (2 in.)	37.5 mm (1½ in.)	25.0 mm (1 in.)	19.0 mm (¾ in.)	12.5 mm (½ in.)	9.5 mm (¾ in.)	4.75 mm (No. 4)	2.36 mm (No. 8)	1.18 mm (No. 16)	300 µm (No.50)
1	90 to 37.5 mm (3½ to 1½ in.)	100	90 to 100	...	25 to 60	...	0 to 15	...	0 to 5	...	...	...	...	...	...
2	63 to 37.5 mm (2½ to 1½ in.)	...	...	100	90 to 100	...	0 to 15	...	0 to 5	...	...	...	...	...	...
3	50 to 25.0 mm (2 to 1 in.)	...	...	...	100	90 to 100	35 to 70	...	...	...	...	...	...	...	...
357	50 to 4.75 mm (2 in. to No. 4)	...	...	...	100	95 to 100	...	35 to 70	...	...	0 to 5	...	...	...	...
4	37.5 to 19.0 mm (1½ to ¾ in.)	...	...	...	...	100	90 to 100	20 to 55	0 to 15	...	...	...	...	...	...
467	37.5 to 4.75 mm (1½ in. to No. 4)	...	...	...	...	100	95 to 100	...	35 to 70	...	0 to 5	...	...	...	...
5	25.0 to 12.5 mm (1 to ½ in.)	...	...	...	...	...	100	90 to 100	20 to 55	0 to 10	0 to 5	...	...	...	...
56	25.0 to 9.5 mm (1 to ¾ in.)	...	...	...	...	...	100	90 to 100	40 to 85	10 to 40	0 to 5	...	...	...	...
57	25.0 to 4.75 mm (1 in. to No. 4)	...	...	...	...	...	100	95 to 100	...	25 to 60	0 to 10	0 to 5	...	...	...
6	19.0 to 9.5 mm (¾ to ¾ in.)	...	...	...	...	...	...	100	90 to 100	20 to 55	0 to 15	...	...	...	...
67	19.0 to 4.75 mm (¾ in. to No. 4)	...	...	...	...	...	...	100	90 to 100	...	20 to 55	0 to 5	...	...	...
7	12.5 to 4.75 mm (½ in. to No. 4)	...	...	...	...	...	...	...	100	90 to 100	40 to 70	0 to 5	...	...	...
8	9.5 to 2.36 mm (¾ in. to No. 8)	...	...	...	...	...	...	...	...	85 to 100	10 to 30	0 to 5	0 to 5	...	...
89	9.5 to 1.18 mm (¾ in. to No. 16)	...	...	...	...	...	...	...	...	100	20 to 55	5 to 30	0 to 10	0 to 5	0 to 5
9 ^A	4.75 to 1.18 mm (No. 4 to No. 16)	...	...	...	...	...	...	...	...	100	85 to 100	10 to 40	0 to 10	0 to 5	0 to 5

^A Size number 9 aggregate is defined in Terminology C 125 as a fine aggregate. It is included as a coarse aggregate when it is combined with a size number 8 material to create a size number 89, which is a coarse aggregate as defined by Terminology C 125.

TABLE 3 Limits for Deleterious Substances and Physical Property Requirements of Coarse Aggregate for Concrete

NOTE 1—See Fig. 1 for the location of the weathering regions and Note 9 for guidance in using the map. The weathering regions are defined as follows:

- (S) Severe Weathering Region—A cold climate where concrete is exposed to deicing chemicals or other aggressive agents, or where concrete may become saturated by continued contact with moisture or free water prior to repeated freezing and thawing.
- (M) Moderate Weathering Region—A climate where occasional freezing is expected, but where concrete in outdoor service will not be continually exposed to freezing and thawing in the presence of moisture or to deicing chemicals.
- (N) Negligible Weathering Region—A climate where concrete is rarely exposed to freezing in the presence of moisture.

Class Designation	Type or Location of Concrete Construction	Maximum Allowable, %							
		Clay Lumps and Friable Particles	Chert (Less Than 2.40 sp gr SSD)	Sum of Clay Lumps, Friable Particles, and Chert (Less Than 2.40 sp gr SSD)	Material Finer Than 75- μ m (No. 200) Sieve	Coal and Lignite	Abrasion ^A	Magnesium Sulfate Soundness (5 cycles) ^B	
Severe Weathering Regions									
1S	Footings, foundations, columns and beams not exposed to the weather, interior floor slabs to be given coverings	10.0	...	...	1.0 ^C	1.0	50	...
2S	Interior floors without coverings	5.0	...	...	1.0 ^C	0.5	50	...
3S	Foundation walls above grade, retaining walls, abutments, piers, girders, and beams exposed to the weather	5.0	5.0	7.0	1.0 ^C	0.5	50	18	
4S	Pavements, bridge decks, driveways and curbs, walks, patios, garage floors, exposed floors and porches, or water-front structures, subject to frequent wetting	3.0	5.0	5.0	1.0 ^C	0.5	50	18	
5S	Exposed architectural concrete	2.0	3.0	3.0	1.0 ^C	0.5	50	18	
Moderate Weathering Regions									
1M	Footings, foundations, columns, and beams not exposed to the weather, interior floor slabs to be given coverings	10.0	...	...	1.0 ^C	1.0	50	...
2M	Interior floors without coverings	5.0	...	...	1.0 ^C	0.5	50	...
3M	Foundation walls above grade, retaining walls, abutments, piers, girders, and beams exposed to the weather	5.0	8.0	10.0	1.0 ^C	0.5	50	18	
4M	Pavements, bridge decks, driveways and curbs, walks, patios, garage floors, exposed floors and porches, or water-front structures subject to frequent wetting	5.0	5.0	7.0	1.0 ^C	0.5	50	18	
5M	Exposed architectural concrete	3.0	3.0	5.0	1.0 ^C	0.5	50	18	
Negligible Weathering Regions									
1N	Slabs subject to traffic abrasion, bridge decks, floors, sidewalks, pavements	5.0	...	...	1.0 ^C	0.5	50	...
2N	All other classes of concrete	10.0	...	...	1.0 ^C	1.0	50	...

^A Crushed air-cooled blast-furnace slag is excluded from the abrasion requirements. The rodded or jigged unit weight of crushed air-cooled blast-furnace slag shall be not less than 1120 kg/m³ (70 lb/ft³). The grading of slag used in the unit weight test shall conform to the grading to be used in the concrete. Abrasion loss of gravel, crushed gravel, or crushed stone shall be determined on the test size or sizes most nearly corresponding to the grading or gradings to be used in the concrete. When more than one grading is to be used, the limit on abrasion loss shall apply to each.

^B The allowable limits for soundness shall be 12 % if sodium sulfate is used.

^C This percentage under either of the following conditions: (1) is permitted to be increased to 1.5 if the material is essentially free of clay or shale; or (2) if the source of the fine aggregate to be used in the concrete is known to contain less than the specified maximum amount passing the 75- μ m (No. 200) sieve (Table 1) the percentage limit (*L*) on the amount in the coarse aggregate is permitted to be increased to $L = 1 + [(P)/(100 - P)] (T - A)$, where *P* = percentage of sand in the concrete as a percent of total aggregate, *T* = the Table 1 limit for the amount permitted in the fine aggregate, and *A* = the actual amount in the fine aggregate. (This provides a weighted calculation designed to limit the maximum mass of material passing the 75- μ m (No. 200) sieve in the concrete to that which would be obtained if both the fine and coarse aggregate were supplied at the maximum tabulated percentage for each of these ingredients.)

aggregate to obtain a desired grading, provided that the gradings are not otherwise restricted by the project specifier and the nominal maximum size indicated by the size number is not exceeded,

4.3.3.2 The class designation (11.1 and Table 3),

4.3.3.3 Whether the restriction on reactive materials in 11.2 applies,

4.3.3.4 In the case of the sulfate soundness test (Table 3), which salt is to be used. If none is stated, either sodium sulfate or magnesium sulfate shall be used, and

4.3.3.5 The person responsible for selecting the concrete proportions if other than the concrete producer.

4.3.4 Any exceptions or additions to this specification (See Note 1).

FINE AGGREGATE

5. General Characteristics

5.1 Fine aggregate shall consist of natural sand, manufactured sand, or a combination thereof.

6. Grading

6.1 *Sieve Analysis*—Fine aggregate, except as provided in 6.2 and 6.3 shall be graded within the following limits:

Sieve (Specification E 11)	Percent Passing
9.5-mm (¾-in.)	100
4.75-mm (No. 4)	95 to 100
2.36-mm (No. 8)	80 to 100
1.18-mm (No. 16)	50 to 85
600-µm (No. 30)	25 to 60
300-µm (No. 50)	5 to 30
150-µm (No. 100)	0 to 10

NOTE 2—Concrete with fine aggregate gradings near the minimums for percent passing the 300 µm (No.50) and 150 µm (No.100) sometimes have difficulties with workability, pumping or excessive bleeding. The addition of entrained air, additional cement, or the addition of an approved mineral admixture to supply the deficient fines, are methods used to alleviate such difficulties.

6.2 The fine aggregate shall have not more than 45 % passing any sieve and retained on the next consecutive sieve of those shown in 6.1, and its fineness modulus shall be not less than 2.3 nor more than 3.1.

6.3 Fine aggregate failing to meet these grading requirements shall meet the requirements of this section provided that the supplier can demonstrate to the purchaser or specifier that concrete of the class specified, made with fine aggregate under consideration, will have relevant properties at least equal to those of concrete made with the same ingredients, with the exception that the reference fine aggregate shall be selected from a source having an acceptable performance record in similar concrete construction.

NOTE 3—Fine aggregate that conforms to the grading requirements of a specification, prepared by another organization such as a state transportation agency, which is in general use in the area, should be considered as having a satisfactory service record with regard to those concrete properties affected by grading.

NOTE 4—Relevant properties are those properties of the concrete which

are important to the particular application being considered. STP 169C⁸ provides a discussion of important concrete properties.

6.4 For continuing shipments of fine aggregate from a given source, the fineness modulus shall not vary more than 0.20 from the base fineness modulus. The base fineness modulus shall be that value that is typical of the source. The purchaser or specifier has the authority to approve a change in the base fineness modulus.

NOTE 5—The base fineness modulus should be determined from previous tests, or if no previous tests exist, from the average of the fineness modulus values for the first ten samples (or all preceding samples if less than ten) on the order. The proportioning of a concrete mixture may be dependent on the base fineness modulus of the fine aggregate to be used. Therefore, when it appears that the base fineness modulus is considerably different from the value used in the concrete mixture, a suitable adjustment in the mixture may be necessary.

7. Deleterious Substances

7.1 The amount of deleterious substances in fine aggregate shall not exceed the limits prescribed in Table 1.

7.2 Organic Impurities:

7.2.1 Fine aggregate shall be free of injurious amounts of organic impurities. Except as herein provided, aggregates subjected to the test for organic impurities and producing a color darker than the standard shall be rejected.

7.2.2 Use of a fine aggregate failing in the test is not prohibited, provided that the discoloration is due principally to the presence of small quantities of coal, lignite, or similar discrete particles.

7.2.3 Use of a fine aggregate failing in the test is not prohibited, provided that, when tested for the effect of organic impurities on strength of mortar, the relative strength at 7 days, calculated in accordance with Test Method C 87, is not less than 95 %.

7.3 Fine aggregate for use in concrete that will be subject to wetting, extended exposure to humid atmosphere, or contact with moist ground shall not contain any materials that are deleteriously reactive with the alkalis in the cement in an amount sufficient to cause excessive expansion of mortar or concrete, except that if such materials are present in injurious amounts, use of the fine aggregate is not prohibited when used with a cement containing less than 0.60 % alkalis calculated as sodium oxide equivalent ($\text{Na}_2\text{O} + 0.658\text{K}_2\text{O}$) or with the addition of a material that has been shown to prevent harmful expansion due to the alkali-aggregate reaction. (See Appendix X1.)

8. Soundness

8.1 Except as provided in 8.2 and 8.3, fine aggregate subjected to five cycles of the soundness test shall have a weighted average loss not greater than 10 % when sodium sulfate is used or 15 % when magnesium sulfate is used.

8.2 Fine aggregate failing to meet the requirements of 8.1 shall be regarded as meeting the requirements of this section provided that the supplier demonstrates to the purchaser or specifier that concrete of comparable properties, made from

⁸ *Significance of Tests and Properties of Concrete and Concrete Making Materials, STP 169C, ASTM, 1994.*

similar aggregate from the same source, has given satisfactory service when exposed to weathering similar to that to be encountered.

8.3 Fine aggregate not having a demonstrable service record and failing to meet the requirements of 8.1 shall be regarded as meeting the requirements of this section provided that the supplier demonstrates to the purchaser or specifier it gives satisfactory results in concrete subjected to freezing and thawing tests (see Test Method C 666).

COARSE AGGREGATE

9. General Characteristics

9.1 Coarse aggregate shall consist of gravel, crushed gravel, crushed stone, air-cooled blast furnace slag, or crushed hydraulic-cement concrete, or a combination thereof, conforming to the requirements of this specification.

NOTE 6—Although crushed hydraulic-cement concrete has been used as an aggregate with reported satisfactory results, its use may require some additional precautions. Mixing water requirements may be increased because of the harshness of the aggregate. Partially deteriorated concrete, used as aggregate, may reduce freeze-thaw resistance, affect air void properties or degrade during handling, mixing, or placing. Crushed concrete may have constituents that would be susceptible to alkali-aggregate reactivity or sulfate attack in the new concrete or may bring sulfates, chlorides, or organic material to the new concrete in its pore structure.

10. Grading

10.1 Coarse aggregates shall conform to the requirements prescribed in Table 2 for the size number specified.

NOTE 7—The ranges shown in Table 2 are by necessity very wide in order to accommodate nationwide conditions. For quality control of any specific operation, a producer should develop an average grading for the particular source and production facilities, and should control the production gradings within reasonable tolerances from this average. Where coarse aggregate size numbers 357 or 467 are used, the aggregate should be furnished in at least two separate sizes.

11. Deleterious Substances

11.1 Except for the provisions of 11.3, the limits given in Table 3 shall apply for the class of coarse aggregate designated in the purchase order or other document (see Note 8 and Note 9). If the class is not specified, the requirements for Class 3S, 3M, or 1N shall apply in the severe, moderate, and negligible weathering regions, respectively (see Table 3 and Fig. 1).

NOTE 8—The specifier of the aggregate should designate the class of coarse aggregate to be used in the work, based on weathering severity, abrasion, and other factors of exposure. (See Table 3 and Fig. 1.) The limits for coarse aggregate corresponding to each class designation are expected to ensure satisfactory performance in concrete for the respective type and location of construction. Selecting a class with unduly restrictive limits may result in unnecessary cost if materials meeting those requirements are not locally available. Selecting a class with lenient limits may result in unsatisfactory performance and premature deterioration of the

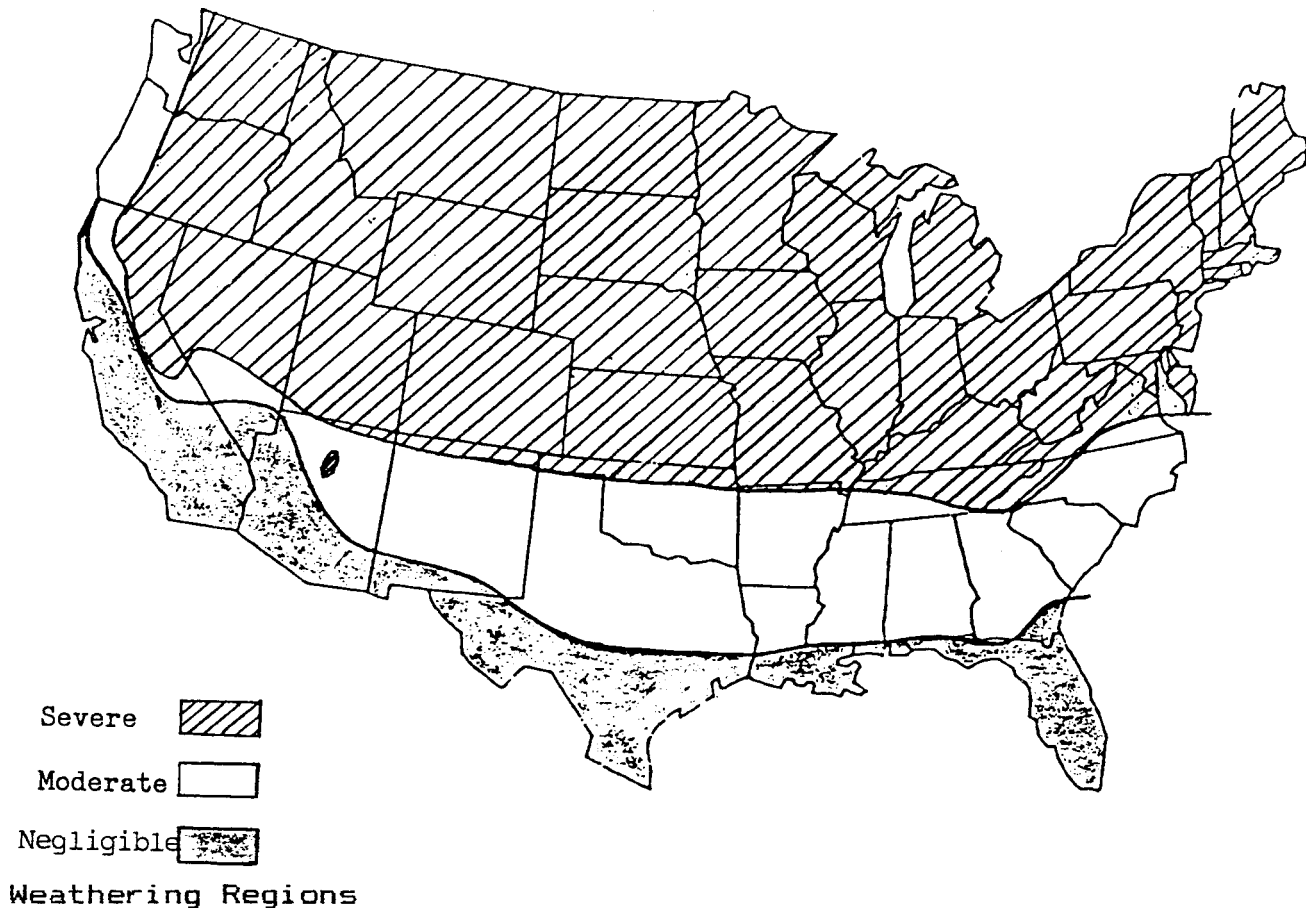


FIG. 1 Location of Weathering Regions

concrete. While concrete in different parts of a single structure may be adequately made with different classes of coarse aggregate, the specifier may wish to require the coarse aggregate for all concrete to conform to the same more restrictive class to reduce the chance of furnishing concrete with the wrong class of aggregate, especially on smaller projects.

NOTE 9—For coarse aggregate in concrete exposed to weathering, the map with the weathering regions shown in Fig. 1 is intended to serve only as a guide to probable weathering severity. Those undertaking construction, especially near the boundaries of weathering regions, should consult local weather bureau records for amount of winter precipitation and number of freeze-thaw cycles to be expected, for determining the weathering severity for establishing test requirements of the coarse aggregate. For construction at altitudes exceeding 1520 m (5000 ft) above sea level, the likelihood of more severe weathering than indicated by the map should be considered. In arid areas, severity of weathering may be less than that indicated. In either case, the definitions of weathering severity in Table 3 would govern. If there is doubt in choosing between two regions, select the more severe weathering region.

11.2 Coarse aggregate for use in concrete that will be subject to wetting, extended exposure to humid atmosphere, or contact with moist ground shall not contain any materials that are deleteriously reactive with the alkalis in the cement in an amount sufficient to cause excessive expansion of mortar or concrete except that if such materials are present in injurious amounts, the coarse aggregate is not prohibited when used with a cement containing less than 0.60 % alkalis calculated as sodium oxide equivalent ($\text{Na}_2\text{O} + 0.658\text{K}_2\text{O}$) or with the addition of a material that has been shown to prevent harmful expansion due to the alkali-aggregate reaction. (See Appendix X1.)

11.3 Coarse aggregate having test results exceeding the limits specified in Table 3 shall be regarded as meeting the requirements of this section provided the supplier demonstrates to the purchaser or specifier that concrete made with similar aggregate from the same source has given satisfactory service when exposed in a similar manner to that to be encountered; or, in the absence of a demonstrable service record, provided that the aggregate produces concrete having satisfactory relevant properties (see Note 4).

METHODS OF SAMPLING AND TESTING

12. Methods of Sampling and Testing

12.1 Sample and test the aggregates in accordance with the following methods, except as otherwise provided in this specification. Make the required tests on test specimens that

comply with requirements of the designated test methods. It is not prohibited to use the same test specimen for sieve analysis and for determination of material finer than the 75- μm (No. 200) sieve. The use of separated sizes from the sieve analysis is acceptable for soundness or abrasion tests, however, additional test specimen preparation is required (see Note 10). For other test procedures and the evaluation of potential alkali reactivity, when required, use independent test specimens.

NOTE 10—The material used for the soundness test requires resieving to allow proper test specimen preparation as specified in Test Method C 88.

12.1.1 *Sampling*—Practice D 75 and Practice D 3665.

12.1.2 *Grading and Fineness Modulus*—Test Method C 136.

12.1.3 *Amount of Material Finer than 75- μm (No. 200) Sieve*—Test Method C 117.

12.1.4 *Organic Impurities*—Test Method C 40.

12.1.5 *Effect of Organic Impurities on Strength*—Test Method C 87.

12.1.6 *Soundness*—Test Method C 88.

12.1.7 *Clay Lumps and Friable Particles*—Test Method C 142.

12.1.8 *Coal and Lignite*—Test Method C 123, using a liquid of 2.0 specific gravity to remove the particles of coal and lignite. Only material that is brownish-black, or black, shall be considered coal or lignite. Coke shall not be classed as coal or lignite.

12.1.9 *Weight of Slag*—Test Method C 29/C 29M.

12.1.10 *Abrasion of Coarse Aggregate*—Test Method C 131 or Test Method C 535.

12.1.11 *Reactive Aggregates*—See Appendix X1.

12.1.12 *Freezing and Thawing*—Procedures for making freezing and thawing tests of concrete are described in Test Method C 666.

12.1.13 *Chert*—Test Method C 123 is used to identify particles in a sample of coarse aggregate lighter than 2.40 specific gravity, and Guide C 295 to identify which of the particles in the light fraction are chert.

13. Keywords

13.1 aggregates; coarse aggregate; concrete aggregates; fine aggregate

X1. METHODS FOR EVALUATING POTENTIAL FOR DELETERIOUS EXPANSION DUE TO ALKALI REACTIVITY OF AN AGGREGATE
X1.1 Introduction

X1.1.1 *Laboratory Methods*—Many test methods for evaluating the potential for deleterious expansion due to alkali reactivity of an aggregate have been proposed and some have been adopted as ASTM standards. However, there is no general agreement on the relation between the results of these tests and the amount of expansion to be expected or tolerated in service. Therefore, evaluation of the suitability of an aggregate should be based upon judgment, interpretation of test data, and results of examinations of concrete structures containing the same aggregates and similar cementitious materials having similar levels of alkalis. Results of the tests referred to in this appendix may assist in making the evaluation. When interpreting expansion of laboratory specimens, consideration should be given not only to expansion values at specific ages, but also to the shape of the expansion curve, which may indicate whether the expansion is leveling off or continuing at a constant or accelerating rate.

X1.1.2 *Service Record Evaluation*—Valid, comparable concrete service record data, if available, should take precedence over laboratory test results in most cases. To be considered valid, a record of satisfactory service should be available for at least 10 years for aggregates, cementitious materials, and exposures sufficiently similar to those in which an aggregate is being considered for future use. Longer periods of documented service may be required for proposed work designed for a particularly long service life in moist conditions, or if laboratory test results show that the aggregate may be deleteriously reactive.

X1.1.3 *Mitigation of Alkali-Aggregate Reaction*—If an aggregate has been judged to be potentially deleteriously reactive in concrete either through laboratory or service record evaluation, use of the aggregate should be considered with measures known to prevent excessive expansion due to alkali-aggregate reaction. See the mitigation sections in this appendix under X1.3 Alkali-Silica Reaction and X1.4 Alkali-Carbonate Rock Reaction and References cited for discussion of prevention strategies for new concrete.

X1.2 Background

X1.2.1 Background information on alkali-aggregate reaction can be found in Ref (1)⁹, Descriptive Nomenclature C 294, and Guide C 295 as discussed as follows. Additional discussion is included in Refs (2) (3). These references address both alkali-silica reaction and alkali-carbonate rock reaction.

X1.2.1.1 *Descriptive Nomenclature C 294 for Constituents of Concrete Aggregates*—This nomenclature provides descriptions of constituents of mineral aggregates and includes dis-

ussion of which have been associated with deleterious expansion due to alkali reaction.

X1.2.1.2 *Guide C 295 (Petrographic Examination of Aggregates)*—This guide outlines the procedures for examining an aggregate sample or a sample from a potential aggregate source to determine whether substances that are potentially deleteriously reactive are present; and, if so, in what amounts.

X1.2.1.3 *Alkali-Silica Reaction*—Certain materials are known to be potentially deleteriously alkali-silica reactive. These include forms of silica such as opal, chalcedony, tridymite, and cristobalite; cryptocrystalline and microcrystalline, strained, or highly fractured quartz; and intermediate to acid (silica-rich) volcanic glass such as is likely to occur in rhyolite, andesite, or dacite. Determination of the presence and quantities of these materials by petrographic examination is helpful in evaluating potential alkali reactivity. An aggregate can be potentially deleteriously reactive when some of these materials, such as opal, are present in very small quantities (for example, 1 %).

X1.2.1.4 *Alkali-Carbonate Rock Reaction*—The reaction of dolomite in certain carbonate rocks with alkalis has been associated with deleterious expansion of concrete containing such rocks as coarse aggregate. The most rapidly reactive carbonate rocks possess a characteristic texture in which relatively large crystals of dolomite are scattered in a finer-grained matrix of calcite and clay. These rocks also have a composition in which the carbonate portion consists of substantial amounts of both dolomite and calcite, and the acid-insoluble residue contains a significant amount of clay. Certain purely dolomitic rocks also may produce slow expansion in concrete.

X1.3 Alkali-Silica Reaction

X1.3.1 *Test Method C 289 (Chemical Method)*—The results of the test are values for the quantities of dissolved silica (S_c) and reduction in alkalinity (R_c) for each of the three test portions from the prepared aggregate test sample. Aggregates represented by plotted points (S_c , R_c), which lie on the deleterious side of the solid curve of Fig. X1.1 of Test Method C 289 usually should be considered potentially reactive. Three regions are delineated in the figure: (1) aggregates considered innocuous; (2) aggregates considered potentially deleterious; and (3) aggregates considered deleterious. Aggregates represented by points lying in the potentially deleterious region above the dashed line in Fig. X1.1 of Test Method C 289 may give relatively low expansions in mortar or concrete even though they are extremely reactive with alkalis. The test can be made quickly and can provide helpful information, except for slowly reactive rocks such as some granitic gneiss and quartzite. Also, as pointed out in the appendix to Test Method C 289, the results may not be correct for aggregates containing

⁹ The boldface numbers in parentheses refer to the list of references at the end of this standard.

carbonates or magnesium silicates, such as antigorite (serpentine), or constituents producing late-slow reactivity. See the appendix to Test Method C 289 for a discussion of the interpretation of results and applicable references. If test results indicate deleterious or potentially deleterious character, the aggregates should be tested in accordance with Test Methods C 227 or C 1293 to verify the potential for expansion in concrete.

X1.3.2 Test Method C 227 (Mortar-Bar Method for Cement-Aggregate Combinations)—The results of this test method, when a high-alkali cement is used, furnish information on the likelihood of potentially deleterious expansion occurring. The alkali content of the portland cement should be at least 0.8 %, expressed as percent sodium oxide equivalent ($\%Na_2O + 0.658 \times \%K_2O$). Combinations of aggregate and cementitious materials that have produced excessive expansions in this test method should be considered potentially reactive. While the line of demarcation between innocuous and potentially deleterious combinations is not clearly defined, expansion is generally considered to be excessive if it exceeds 0.05 % at 3 months or 0.10 % at 6 months. Expansions greater than 0.05 % at 3 months should not be considered excessive when the 6-month expansion remains below 0.10 %. Data for the 3-month tests should be considered only when 6-month results are not available. The limits may not be conservative for slowly reactive aggregates. Test Method C 227 is not suitable for slowly reactive aggregates, and its use for this purpose is not advised (**1, 2**). Aggregates suspected of being slowly reactive should be evaluated using Test Method C 1260 or Test Method C 1293. Test Method C 227 is also used with a specific reactive glass aggregate to verify the mitigation effectiveness of blended cements meeting Specification C 595, with the Table 2 optional mortar expansion requirement, and meeting Performance Specification C 1157 with Option R. These procedures are similar to the provisions of Test Method C 441 discussed as follows for mineral admixtures and ground slag.

X1.3.3 Test Method C 342 (Mortar Bars Subjected to Changes in Moisture and Temperature)—This withdrawn test method was intended for research concerning the potential expansion of cement-aggregate combinations involving selected aggregates found in parts of Oklahoma, Kansas, Nebraska, and Iowa. Due to the specimen conditioning procedures, the expansion of mortar bars in this test method may not be related to alkali-silica reaction under normal-temperature conditioning. Data on the use of this test method are given in the references cited in a footnote in the test method. It is indicated that cement-aggregate combinations tested by this procedure in which expansion equals or exceeds 0.20 % at an age of 1 year may be considered unsatisfactory for use in concrete exposed to wide variations of temperature and degree of saturation with water. This test method is not recommended for use in regions other than previously cited.

X1.3.4 Test Method C 1260 (Mortar-Bar Method for Potential Alkali Reactivity of Aggregate)—This test method is an accelerated screening technique developed for the detection of materials that develop deleterious expansions slowly over a long period of time. Some aggregates that perform well in the field have been shown to fail this test (**4, 5**). Results of this test

method should not be used for rejection of aggregates unless it has been established using the sources of supplementary information cited in the test method that the detected expansion is actually due to alkali-silica reaction. There is good agreement in the published literature cited in the test method for the expansion limits: (1) expansions of less than 0.10 % at 16 days after casting are indicative of innocuous behavior in most cases; (2) expansions of more than 0.20 % at 16 days are indicative of potentially deleterious expansion; and (3) expansions between 0.10 and 0.20 % at 16 days include both aggregates that are known to be innocuous and deleterious in field performance. If test results indicate expansion greater than 0.10 % at 16 days, the aggregate should be tested in accordance with Test Method C 1293 unless appropriate field experience demonstrates that it does not cause deleterious expansion in concrete. (See X1.3.7.)

X1.3.5 Test Method C 1293 (Concrete Prism Method for Alkali-Silica Reactivity)—The test method evaluates the aggregates for potential alkali-silica reaction expansion using concrete prisms. The test method is accelerated by using an elevated alkali content and Test Method C 227 exposure conditions. The appendix to Test Method C 1293 provides guidance on interpretation of the results. Aggregates with expansions equal to or greater than 0.04 % at one year are considered potentially deleteriously reactive. This test method is considered to be the most reliable procedure among ASTM Test Methods for the evaluation of aggregates for alkali-silica reaction.

X1.3.6 Test Method C 441 (Mortar-Bar Method for Effectiveness of Mineral Admixtures or Ground Blast-Furnace Slag in Preventing Excessive Expansion of Concrete Due to the Alkali-Silica Reaction)—In general, the potential for expansion due to alkali-silica reactivity can be controlled by using a sufficient amount of an effective pozzolan or ground granulated blast-furnace slag as a portion of the cementitious material component in concrete, or by using a cement of a low alkali content. In the case of pozzolan, it is necessary to establish its effectiveness using a standard test; and the only ASTM test method that evaluates the effectiveness of pozzolan or slag is Test Method C 441. This test method uses mortar bars as in Test Method C 227. Specification C 618 provides a criterion for its use as applied to pozzolans when sampled and tested in accordance with Test Methods C 311. Appendix X3 to Specification C 989 describes its use for ground granulated blast-furnace slag.

X1.3.7 Mitigation of Alkali-Silica Reaction—Normally if an aggregate is shown to be nonreactive or innocuous by producing little or no expansion in Test Method C 1260 or Test Method C 1293, no mitigation is necessary. Similarly, if the aggregate has a long satisfactory service record with similar cementitious materials having similar or higher alkali levels, no mitigation is necessary. On the other hand, use of aggregates judged to be potentially deleteriously alkali-silica reactive should be considered with the use of measures known to prevent excessive expansion. These include measures such as: low-alkali cement (Specification C 150 with the low-alkali option); blended cements (Specification C 595 with the Table 2

optional mortar expansion requirement or Performance Specification C 1157 with Option R); pozzolanic materials (meeting the optional physical requirement on effectiveness in controlling alkali-silica reaction in Specification C 618 or reactivity with cement alkalis in Specification C 1240 for silica fume); or ground slag (shown to be effective in preventing excessive expansion of concrete due to alkali-aggregate reaction as discussed in Appendix X3 of Specification C 989). The effectiveness of the cementitious materials or admixtures, or both, chosen to mitigate a potentially reactive aggregate should be demonstrated through tests of the individual materials, or tests of the proposed combination in concrete.

X1.4 Alkali-Carbonate Rock Reaction

X1.4.1 Test Method C 586 (Rock Cylinders Method for Alkali-Carbonate Rock Reaction)—Rocks that are capable of potentially deleterious carbonate rock reaction are relatively infrequent and seldom constitute a significant proportion of a deposit of rock being considered for use in making aggregate for concrete. Test Method C 586 has been successfully used in research and in preliminary screening of aggregate sources to indicate the presence of material with a potential for deleterious expansions when used in concrete.

X1.4.2 Test Method C 1105 (Concrete-Prism Method for Alkali-Carbonate Rock Reaction)—This test method is intended to evaluate specific combinations of materials in concrete when the aggregate is regarded as susceptible to deleterious expansion in service due to the alkali-carbonate rock reaction.

rious expansion in service due to the alkali-carbonate rock reaction. The appendix to Test Method C 1105 provides general information and references concerning the interpretation of results. A cement-aggregate combination might reasonably be classified as potentially deleteriously reactive if the average expansion of six concrete specimens is equal to or greater than: 0.015 % at 3 months; 0.025 % at 6 months; or 0.030 % at 1 year. Data for later ages are preferred.

X1.4.3 Mitigation of Alkali-Carbonate Rock Reaction—Normally, if a carbonate rock does not show the characteristic texture and composition associated with this type of reaction, or if it does not produce expansion in rock cylinders (Test Method C 586) or concrete prisms (Test Method C 1105), no mitigation is necessary for alkali-carbonate rock reaction. Similarly, if the aggregate has a long satisfactory service record with similar materials and conditions, no mitigation is necessary. On the other hand, use of aggregates judged to be potentially deleteriously alkali-carbonate reactive in concrete is not recommended unless it can be shown that mitigation methods will be effective. Pozzolans generally have not been found to control alkali-carbonate rock reaction. Measures suggested for mitigation includes: avoiding reactive carbonate rocks; selective quarrying; diluting reactive rock to less than 20 % of the aggregate in the concrete; use of smaller maximum size; and the use of very low alkali cement.

REFERENCES

- (1) *Significance of Tests and Properties of Concrete and Concrete-Making Materials*, Klieger, Paul and Lamond, Joseph F., Eds, *ASTM STP 169C*, 1994, 623 pages. See Chapter 31 on “Petrographic Evaluation of Concrete Aggregates,” by Richard C. Mielenz, Chapter 32 on “Alkali-Silica Reactions in Concrete” by David Stark, and Chapter 33 on “Alkali-Carbonate Rock Reaction” by Michael A. Ozol.
- (2) “State-of-the-Art Report on Alkali-Aggregate Reactivity” by ACI Committee 221 on Aggregates, ACI 221.1R-98, American Concrete Institute, Farmington Hills, MI, 1998, 31 pages.
- (3) *Alkali-Aggregate Reaction in Concrete*, Berube, M. A., Fournier, B., and Durand, Eds, *Proceedings of the 11th International Conference*, Quebec City, Canada, June 2000, 1402 pages. (Note—This conference and proceedings includes information on ASR and ACR in concrete by researchers and experts from all over the world. Copies of the volume can be obtained from the International Centre for Sustainable Development of Cement and Concrete, 405 Rochester Street, Ottawa, Ontario, Canada, K1A 0G1.)
- (4) Hooton, R.D., and Rogers, C.A., “Evaluation of Rapid Test Methods for Detecting Alkali-Reactive Aggregates,” *Proceedings of Eighth International Conference on Alkali-Aggregate Reaction*, Kyoto, 1989, pp. 439–444.
- (5) Fournier, B., and Berube, M.A., “Application of the NBRI Accelerated Mortar Bar Test to Siliceous Carbonate Aggregates Produced in the St. Lawrence Lowlands, Part 2: Proposed Limits, Rates of Expansion, and Microstructure of Reaction Products,” *Cement and Concrete Research*, Vol 21, 1991, pp. 1069–1082.

SUMMARY OF CHANGES

This section identifies the location of changes to this specification that have been incorporated since the last issue.

- (1) Entire appendix was revised.
- (2) Section 2 was updated.
- (3) A section on References was added.

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