Designation: C 637 – 98a (Reapproved 2003)

Standard Specification for Aggregates for Radiation-Shielding Concrete[1]

This standard is issued under the fixed designation C 637; 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 covers special aggregates for use in radiation-shielding concretes in which composition or high specific gravity, or both, are of prime consideration.

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

1.3 The following precautionary caveat pertains only to the test method portion, Section 8, of this specification:*This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

C 33 Specification for Concrete Aggregates

C 127 Test Method for Density, Relative Density (Specific Gravity) and Absorption of Coarse Aggregate

C 128 Test Method for Density, Relative Density, (Specific Gravity) and Absorption of Fine Aggregate

C 131 Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

C 136 Test Method for Sieve Analysis of Fine and Coarse Aggregates

C 535 Test Method for Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

C 638 Descriptive Nomenclature of Constituents of Aggregates for Radiation-Shielding Concrete

3. Classification

3.1 Aggregates covered by this specification include:

3.1.1 Natural mineral aggregates of either high density or high fixed water content, or both. These include aggregates that contain or consist predominately of materials such as barite, magnetite, hematite, ilmenite, and serpentine.

3.1.2 Synthetic aggregates such as iron, steel, ferrophosphorus and boron frit or other boron compounds (see Descriptive Nomenclature C 638).

3.1.3 Fine aggregate consisting of natural or manufactured sand including high-density minerals. Coarse aggregate may consist of crushed ore, crushed stone, or synthetic products, or combinations or mixtures thereof.

4. Composition and Specific Gravity

4.1 Table 1 gives data on chemical composition and specific gravity of aggregate materials covered by this specification.

4.2 The purchaser shall specify the minimum specific gravity for each size and type of aggregate.

4.2.1 *Uniformity of Specific Gravity*—The bulk specific gravity (saturated surface-dry) of successive shipments of aggregate shall not differ by more than 3 % from that of the sample submitted for source approval tests. The average specific gravity of the total shipment shall be equal to or greater than the specified minimum.

4.3 The purchaser shall specify the minimum fixed water content of hydrous ores. If the design temperature, *T,* is different from that given in 8.1.3.5, the purchaser shall specify the value of *T.*

4.3.1 *Uniformity of Fixed Water Content*—For hydrous aggregates the fixed water content of successive shipments of aggregate shall not be less than 95 % of the specified minimum value. The average fixed water content of the total shipment shall be equal to or exceed the specified minimum value.

5. Aggregate Grading

5.1 *Sieve Analysis*—Fine and coarse aggregates for conventionally placed concrete shall be graded within the limits given in Specification C 33, except that with the approval of the purchaser, as much as 20 % of the material passing the 9.5-mm (⅜ -in.) sieve may also pass the 150-µm (No. 100) sieve, with

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

TABLE 1 Composition and Specilc Gravity of Aggregates Covered by This Specifl cation

Predominant Constituent	Class of Material	Chemical Composition of Principal Constituent[A]	Specific Gravity of Available Aggregates
Serpentine[B]	crushed stone, hydrous siliente	$Mg_3Si_2O_5(OH)_4$	2.4 to 2.65
Limonite[C]	crushed stone, hydrous iron ore	$(HFeO_2)_x(H_2O)_y$	3.4 to 3.8
Goethite[C]	crushed stone, hydrous iron ore	$HFeO_2$	3.5 to 4.5
Barite	gravel or crushed stone	$BaSO_4$	4.0 to 4.4
Ilmenite	crushed stone, iron ore	$FeTiO_3$	4.2 to 4.8
Hematite	crushed stone, iron ore	Fe_2O_3	4.6 to 5.2
Magnetite	crushed stone, iron ore	$FeFe_2O_4$	4.6 to 5.2
Iron	manufactured from iron/steel	Fe	6.5 to 7.5
Ferrophosphorous[D]	synthetic	Fe_nP	5.8 to 6.3
Boron Frit[E]	synthetic	B_2O_3, Al_2O_3, SiO_2, CaO	2.6 to 2.8
Boron Carbide	synthetic	B_4C, B_2O_3, C	2.5
Calcium Boride	synthetic	C_aB_6, C	2.5

[A] When it is necessary to minimize the production of long-lived secondary radiation in the shield, or to avoid using materials having inherent radioactivity, the purchaser should specify limits on the contents of objectionable elements.

[B] The fixed water content of serpentine ranges from 10 to 13 percent by weight.

[C] The fixed water content of limonite and goethite ranges from 8 to 12 percent by weight.

[D] Ferrophosphorus when used in Portland cement concrete will generate flammable and possibly toxic gases which can develop high pressures if confined. See Clendenning, T. G., Kellam, B., and MacInnis, C., "Hydrogen Evolution from Ferrophosphorous Aggregate in Portland Cement Concrete," *Journal of the American Concrete Institute, No. 12,* December 1968. (*Proceedings*, Vol 65, pp. 1021–1028), and Mather, Bryant, discussion of Davis, Harold S., "Concrete for Radiation Shielding—In Perspective," and closure by author in "Concrete for Nuclear Reactors," *Journal of the American Concrete Institute* SP-34, Vol 1, 1972, pp. 11–13.

[E] The fixed water content of boron frit is less than 0.5 %.

up to 10 % passing the 75-µm (No. 200) sieve if the material passing the 75-µm (No. 200) sieve is essentially free of clay or shale.

5.1.1 Fine and coarse aggregates for preplaced aggregate concrete shall be graded according to the requirements of Table 2 and as follows:

	Grading of Aggregate	
Specific Gravity of Fine Aggregate	Coarse Aggregate	Fine Aggregate
Up to 3.0	Grading 1	Grading 1
Greater than 3.0	Grading 1	Grading 2
Full range	Grading 2	Grading 2

5.1.2 When boron frit is used as part of the fine aggregate, the grading shall be such that 100 % passes the 4.75-mm (No. 4) sieve and not more than 5 % passes the 600-µm (No. 30) sieve.

TABLE 2 Grading Requirements for Coarse and Fine Aggregates for Preplaced Aggregate Concrete

Sieve Size	Percentage Passing	
	Grading 1 For 37.5-mm (1½ -in.) Nominal Maximum Size Aggregate	Grading 2 For 25-mm (1-in.) Nominal Maximum Size Aggregate
Coarse Aggregate		
50-mm (2-in.)	100	. . .
37.5-mm (1½ in.)	95 to 100	100
25.0-mm (1-in.)	40 to 80	95 to 100
19.0-mm (¾ in.)	20 to 45	40 to 80
12.5-mm (½-in.)	0 to 10	0 to 15
9.5-mm (⅜-in.)	0 to 2	0 to 2
Fine Aggregate		
2.36-mm (No. 8)	100	. . .
1.18-mm (No. 16)	95 to 100	100
600-µm (No. 30)	55 to 80	75 to 95
300-µm (No. 50)	30 to 55	45 to 65
150-µm (No. 100)	10 to 30	20 to 40
75-µm (No. 200)	0 to 10	0 to 10
Fineness modulus	1.30 to 2.10	1.00 to 1.60

5.2 *Fineness Modulus*—If the fineness modulus of the fine aggregate varies more than 0.2 from the value corresponding to that of the sample submitted for acceptance, the fine aggregate shall be rejected unless suitable adjustments are made in concrete proportions to compensate for the difference in grading.

6. Deleterious Substances

6.1 Fine and coarse aggregates shall meet the requirements of Specification C 33.

6.2 Boron frit shall not contain more than 2.0 % of water soluble material.

NOTE 1—This limit is based on concrete mixtures containing no more than 300 kg/m^3(500 lb/yd^3) of boron frit.

7. Abrasion Resistance of Coarse Aggregate

7.1 Coarse aggregate shall have an abrasion loss not greater than 50 % when tested in accordance with Test Method C 131, or Test Method C 535, as applicable. Coarse aggregate failing to meet this requirement may be used, provided it can be shown that it produces satisfactory strengths in concrete of the proportions selected for the work.

8. Methods of Sampling and Testing

8.1 Sample and test the aggregates in accordance with the methods cited in Specification C 33 as applicable, except as follows:

8.1.1 *Specific Gravity*—Determine the bulk specific gravity (saturated surface-dry basis) of fine aggregate in accordance with Test Method C 128, and of coarse aggregate in accordance with Test Method C 127, except that the weight of the test sample for fine and coarse aggregate shall be approximately the specified weight multiplied by the ratio:

specific gravity of aggregate/2.65

using for specific gravity the higher value given in Table 1.

8.1.2 *Grading* — Method C 136, except that the weight of the test sample for fine and coarse aggregate shall be approximately the specified weight multiplied by the ratio:

specific gravity of aggregate/2.65

using for specific gravity the higher value given in Table 1.

8.1.3 *Fixed Water Content*—When 90 % or more of the weight loss on ignition of the aggregate is due to fixed water content, determine the fixed water content, *F,* by the loss-on-ignition test according to 8.1.3.1. When less than 90 % of the loss on ignition is due to fixed water content, determine the fixed water content by the train method (8.1.3.2). In case of dispute, use results obtained by the train method as the basis for acceptance or rejection of the aggregate. Use the train method to demonstrate that 90 % or more of the weight lost during ignition is fixed water. When loss-on-ignition tests are being made on aggregate samples from the same source, also determine the fixed water content of the first sample and each tenth sample thereafter by the train method.

8.1.3.1 For the loss-on-ignition test crush a representative sample of aggregate weighing 20 to 50 g *(W)* to pass the 4.75-mm (No. 4) sieve. Heat the sample to constant weight at a temperature, *T,* in a furnace, open to the atmosphere. Cool the heated sample in a desiccator and then weigh it, (W_t). Place the sample in the oven again, heat at the ignition temperature, *t,* cool in a desiccator, and determine the final weight (W_t). Constant weight may be considered to have been attained when further heating at the design temperature *T* causes or would cause less than 0.1 % additional weight loss.

8.1.3.2 In the train test, heat approximately 1 g *(W′)* of the finely ground sample to constant weight (W'_T) at a temperature of *T.* Then heat the sample W'_T in a stream of argon gas at the ignition temperature *t.* Pass water vapor and gaseous material driven from the heated sample through magnesium perchlorate. The gain in weight (W'_g) of the magnesium perchlorate is an indication of the fixed water content of the sample at temperature *T.* Also determine the dehydrated weight (W'_t) of the sample at the ignition temperature *t.*

8.1.3.3 Compute the fixed water content at temperature *T* by one of the following equations:

Ignition Test:

$$F, \text{ percent} = [(W_T - W_t)/W_T] \times 100 \quad (1)$$

where:

W_T = sample heated to constant weight, g, and
W_t = heated and cooled sample, g.

Train Test:

$$F, \text{ percent} = [(W'_g - W'_T) \times 100 \quad (2)$$

where:

W'_g = gain in weight of sample, g, and
W'_T = dehydrated weight, g.

8.1.3.4 Determine the percent of nonhydrous volatile material, *V,* as follows:

Train Test:

$$V, \text{ percent} = \{[W' - (W'_t + W'_g)]/W'_T\} \times 100 \quad (3)$$

where:

W' = sample weight, g,
W'_t = dehydrated weight of sample, g,
W'_g = gain in weight of sample, g, and
W'_T = sample heated to constant weight, g.

8.1.3.5 Water vapor driven from the sample by heating at temperature *T* is considered as part of the nonhydrous volatile material. Absorbed water at 110°C is not considered as part of the nonhydrous volatile material. Determine percent absorption by Test Methods C 127 and C 128.

8.1.3.6 Temperature values shall be as follows:

	Design Temperature, *T*		Ignition Temperature, *t*	
Hydrous Aggregate	°F	°C	°F	°C
Iron ore	230	110	932	500
Serpentine	572	300	1652	900

Heat the sample until it reaches constant weight at the specified temperature, unless otherwise approved. Determine weights after sample has been cooled in a desiccator to room temperature. Duplicate determinations of fixed water content should check to within 0.3 %.

8.1.4 *Water-Soluble Material in Boron Frit*—Place a 5.00-g sample passing a 600-µm (No. 30) sieve and retained on a 300-µm (No. 50) sieve in contact with 100 mL of distilled water at 20 ± 5°C for 16 h. Filter, wash with about 200-mL of hot (70 ± 5°C) water, and dry at 125 ± 10°C for 1 h. Weigh the residue, *s,* to the nearest 0.01 g. Calculate the percentage of water soluble material (W_s) to the nearest 0.1 % as follows:

$$W_3 = [(5.00 - s)/s] \times 100$$

where:

s = residue, g

9. Precision and Bias

9.1 *Precision* — The following precision statement addresses the test of the water-soluble material in Boron Frit. The precision for fixed water content by either the loss on ignition test or by the train test method has not been evaluated.

9.1.1 Data from one laboratory was available for estimating the precision of water-soluble material in boron frit, therefore, only a within-laboratory estimate of precision is made. The estimate is based on 15 replicate analyses of 5 lots of frit produced by one company. The 15 replicates were determined on 5 separate days, 3 replicates per day. The mean water soluble material ranged from 1.23 to 1.75 % among the 5 lots.

9.1.2 *Within-laboratory Precision*—The within-laboratory standard deviation among individual determinations of water-soluble material in boron frit is 0.224 %.[3] Therefore, two analyses of the same material should differ by no more than 0.627 %[3] in 95 % of cases.

9.2 *Bias*—Since there is no accepted reference material suitable for determining the bias of this test method, no statement on bias is made.

[3] These numbers represent, respectively, the 1s and d2s limits as described in Practice C 670.

10. Keywords

10.1 aggregates; boron frit; calcium boride; high-density aggregates; high water-content aggregates; hydrous aggregates; radiation shielding concrete