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Standard Specification for Glass and Glass Ceramic Biomaterials for Implantation[1]

This standard is issued under the fixed designation F 1538; 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.

1. Scope

1.1 This specification covers the material requirements and characterization techniques for glass and glass-ceramic biomaterials intended for use as bulk porous or powdered surgical implants, or as coatings on surgical devices, but not including drug delivery systems.

1.2 The biological response to glass and glass-ceramic biomaterials in bone and soft tissue has been demonstrated in clinical use **1-9**[2] and laboratory studies **10-14**.

2. Referenced Documents

2.1 *ASTM Standards:*

C 158 Method for Flexural Testing of Glass (Determination of Modulus of Rupture)[3]

C 169 Method for Chemical Analysis of Soda-Lime and Borosilicate Glass[3]

C 623 Test Method for Young's Modulus, Shear Modulus, and Poisson's Ratio for Glass and Glass-Ceramics by Resonance[3]

C 633 Test Method for Adhesion or Cohesive Strength of Flame-Sprayed Coatings[4]

C 693 Test Method for Density of Glass by Buoyancy[3]

C 729 Test Method for Density of Glass by the Sink-Float Comparator[3]

C 730 Test Method for Knoop Indentation Hardness of Glass[3]

C 958 Method for Determination of Particle Size Distribution of Alumina or Quartz by X-Ray Monitoring of Gravity Sedimentation[3]

C 1069 Method for Specific Surface Area of Alumina or Quartz by Nitrogen Adsorption[3]

C 1070 Test Method for Determining Particle Size Distribution of Alumina or Quartz by Laser Light Scattering[3]

E 228 Test Method for Linear Thermal Expansion of Solid Materials with a Vitreous Silica Dilatometer[5]

F 748 Practice for Selecting Generic Biological Test Methods for Materials and Devices[6]

2.2 *Code of Federal Regulations:*[7]

Title 21, Part 820

2.3 *United States Pharmacopoeia:*[8]

Lead <252>

Mercury <261>

Arsenic <211>

Heavy Metals <231> Method found in Annual Book of ASTM Standards, vol 13.01.

2.4 *U.S. Geological Survey Method:*[7]

(7) Cadmium

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *bioactive glass*—an amorphous solid that is not intrinsically adhesive and that is capable of forming a cohesive bond with both hard and soft tissue when exposed to appropriate in vivo or in vitro environments, such as simulated body fluid or tris-hydroxymethylaminomethane buffer, by developing a surface layer of hydroxycarbonate apatite by release of ionic species from the bulk material.

3.1.2 *bioactive glass-ceramic*—an amorphous-derived crystalline solid that is not intrinsically adhesive and that is capable of forming a cohesive bond with bone and soft tissue when exposed to appropriate in vivo or in vitro environments, such as simulated body fluid or tris-hydroxymethylaminomethane buffer, by developing a surface layer of hydroxycarbonate apatite by release of ionic species from the bulk material.

3.1.3 *bulk material*—intended to describe a unit material used as a load bearing implant.

3.1.4 *coating*—intended to describe a surface layer that is relatively thin compared to the overall dimensions of the prosthetic part that has been coated.

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[1] This specification is under the jurisdiction of ASTM Committee F-4 on Medical and Surgical Materials and Devices and is the direct responsibility of Subcommittee F04.13 on Ceramic Materials.

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[2] The boldface numbers in parentheses refer to the list of references at the end of this specification.

[3] *Annual Book of ASTM Standards*, Vol 15.02.

[4] *Annual Book of ASTM Standards*, Vol 02.05.

[5] *Annual Book of ASTM Standards*, Vols 03.01 and 14.02.

[6] *Annual Book of ASTM Standards*, Vol 13.01.

[7] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

[8] Available from United Stated Pharmacopia, 12601 Twinbrook Parkway, Rockville, MD 20852.

3.1.5 *glass biomaterial*—any one of a number of compositions of amorphous inorganic solids that are used as implant materials for various medical or dental uses, or both.

3.1.6 *glass-ceramic biomaterials*—any one of a number of compositions of an amorphous-derived crystalline solid that is used as an implantable biomaterial for medical or dental use, or both.

3.1.7 *particulate material*—intended to describe several pieces (usually small size) used together within an implant construct.

4. Chemical Requirements

4.1 Bulk compositions shall be tested using Method C 169.

4.2 The concentration of heavy metals in the bioactive glass and glass-ceramics shall be limited as follows:

Element	ppm, max
As	3
Cd	5
Hg	5
Pb	30
total heavy metals (as lead)	50

For referee purposes, the methods listed in 2.2 and 2.3 shall be used.

5. Physical Characterization

5.1 The following physical and mechanical characterizations may be applicable to various bioactive glass and glass-ceramics products and should be used whenever possible to verify the material.

5.1.1 *Density*—The densities of glass and glass ceramic materials are related directly to the processing history and composition of the material. The density of the bulk material shall be measured using Test Method C 729 and shall be consistent for the specific materials.

NOTE 1—This test should use a non-aqueous liquid for bioactive glass and glass ceramic materials, which are known to react in an aqueous environment and could thereby affect the measurement.

5.1.2 *Flexural Strength*—When used as bulk materials in load bearing applications, the flexural strength of the bulk material shall be measured using Method C 158.

5.1.3 *Young's Modulus*—When used as a bulk material, Young's Modulus of glass and glass ceramic biomaterials shall be determined following Test Method C 623.

5.1.4 *Hardness*—Where applicable, for characterization of the material, the hardness of bulk samples shall be determined using Test Method C 730. The knoop indentation hardness is one of many properties that is used to characterize glasses. Attempts have been made to relate knoop hardness to tensile strength, but no generally accepted methods are available. Such conversion is limited in scope and should be used with caution, except for special cases in which a reliable basis for conversion has been obtained by conversion tests.

5.1.5 *Surface Area*—The surface area of a particulate may be important in determining the reliability of the bioactivity of the material. Whenever the specific surface area of the material relates to function, the surface area of particulate glass and glass ceramic biomaterials shall be measured using Method C 1069.

5.1.6 *Bond Strength of Glass or Glass Ceramic Coating*—When used as a coating on a metallic or ceramic substrate, the bond strength of the coating shall be measured following Test Method C 633.

5.1.7 *Crystallinity*—For glass-ceramic biomaterials, the percent crystallinity and crystal phases present in glass ceramic biomaterials shall be determined by means of X-ray diffraction analysis. While there is no single standard method for determining the crystallinity and crystal phases of glass ceramic materials, techniques such as those detailed in reference 10.16 and 10.17 should be followed to standardize methods as much as possible.

5.1.8 *Thermal Expansion*—Thermal expansion shall be measured using Test Method E 228, when materials are to be used for coatings (raw materials are to be measured), or on finished product as a quality control test.

6. Biocompatibility

6.1 Glass and glass-ceramic biomaterials should be evaluated thoroughly for biocompatibility before human use. Bioactive glass and glass-ceramic materials are unique in their mode of action when implanted in the body due to the released ionic species and the mechanisms by which these materials bond with bony tissue. These materials have been found to exhibit an excellent tissue response in laboratory studies **10-14** and clinical usage **1-7**. Before any new formulations are used clinically, the tissue response should be characterized by the methods recommended in Practice F 748.

7. Test Specimen Fabrication

7.1 Test specimens should be prepared concurrent with implant devices, as well as from the same batch of material and by the same processes as those used in fabricating the glass and glass-ceramic implant device.

8. Quality Program Requirement

8.1 The manufacturer shall conform to good manufacturing practices (2.1) or its equivalent.

9. Keywords

9.1 bioactive glass; bioactive glass-ceramics; glass biomaterials; glass-ceramic biomaterial; —surgical implants

APPENDIX

(Nonmandatory Information)

X1. RATIONALE

X1.1 A number of glass-ceramic materials are available commercially. Bioactive glass and glass-ceramic materials are available commercially as synthetic graft materials for maintenance of the alveolar ridge; as devices for spinal fushion; as implants for replacement of the vertebral body, iliac crest, and ossicular chain of the middle ear; as bone filler to substitute for bone defects remaining after the excision of bone tumors and extraction of loosened joint prostheses; and as coatings on dental and orthopedic implants. As with any implant material, the bioresponse is critically dependent on the material properties. To achieve reliable biocompatibility, these properties must be known and consistent. This specification provides specifications for biocompatible grades of bioactive glass and glass-ceramics.

X1.2 In order to be called bioactive, the materials must demonstrate that living tissue is bonding to a significantly higher level than non-bonding implant control, as well as demonstrate that ionic species are released from the material into solution in a controlled and reproducible manner.

X1.3 Bioactive glass and glass-ceramic materials are generally silicate-based materials, with additions of oxides of calcium, phosphorous, and various alkalis. They may be phosphate-based materials as well. These materials may also include fluoride and other alkali earth metals. Table X1.1 gives a few specific examples of the bioactive glass and glass-ceramic materials produced. Since the compositions of these materials may vary greatly from product to product, it is not possible to specify their exact compositions.

X1.4 It is recognized that separate performance standards may be necessary for each end-use product. Physical and mechanical properties were not specified for this reason. A source of general test methods for glass and ceramic materials may be found in Ref **(15)**.

REFERENCES

(**1**) Reck, R., "Tissue Reactions to Glass Ceramics in the Middle Ear," *Clin. Otolaryngol*, Vol 6, 1981, pp. 59–63.
(**2**) Merwin, G. E., "Review of Bioactive Materials for Otological and Maxillofacial Applications," *Handbook of Bioactive Ceramics*, Vol 1, Ed. T. Yamamuro, L. L. Hench, and J. Wilson, CRC Press, Boca Raton, Florida, 1990, pp. 323–328.
(**3**) Douek, E., "Otological Applications of Bioglass® Implants," *Proceedings Fourth International Symposium on Bioceramics in Medicine*, Ed. W. Bonfield, London, United Kingdom, September 10 and 11, 1990.
(**4**) Stanley, H. R., et al., "Residual Alveolar Ridge Maintenance with a New Endosseous Implant Material," *J. Pros. Dent.*, Vol 58, No. 5, November 1987.
(**5**) Nakamura, T., et al., "A New Glass-Ceramic for Bone Replacement: Evaluation of its Bonding to Bond Tissue," *Journal of Biomedical Material Research*, Vol 19, 1985.
(**6**) Yamamuro, T., et al., "Novel Methods for Clinical Application of Bioactive Ceramics," *Bioceramics: Material Characteristics Versus in Vivo Behavior*, Ann. New York Acad. Sci., Vol 523, 1988, pp. 107–114.
(**7**) Yamamuro, T., "Reconstruction of the Iliac Crest with Bioactive Glass-Ceramic Prosthesis," *Handbook of Bioactive Ceramics Prosthesis*, Eds. T. Yamamuro, L. L. Hench, and J. Wilson, Vol 1, CRC Press, Boca Raton, FL, 1990, pp. 335–342.
(**8**) Yamamuro, T., "Replacement of the Spine with Bioactive Glass-Ceramic Prosthesis," pp. 343–352, idem.
(**9**) Taguchi, T., "A Bioactive Glass Powder-Ammonium Hydrogen Phosphate Composite for Repairing Bone Defects," *Journal of Appl. Biomater.*, Vol 1, pp. 217–223.
(**10**) Hench, L. L., and Paschall, H. A., "Histo-Chemical Responses at a Biomaterials Interface," *Journal of Biomedical Material Research*, Vol 5, 1974, p. 1.
(**11**) Kitsugi, T., et al., "Bonding Behavior of a Glass-Ceramic Containing Apatite and Wollastonite in Segmental Replacement of the Rat Tibia Under Load-Bearing Conditions," *Journal of Bone St. Surg.*, Vol 71A, 1989.
(**12**) Gross, U., et al., "The Response of Bone to Surface Active Glasses/Glass-Ceramics," *CRC Critical Reviews in Biocompatibility*, Vol 4, No. 2, 1988, pp. 155–179.
(**13**) Piotrowski, G., et al., "Mechanical Studies of the Bone Bioglass® Interfacial Bond," *Journal of Biomedical Material Research*, Vol 6, 1975, p. 47.
(**14**) Strunz, V., et al., "The Mechanical Strength of the Bond Between Bone and Implants of Glass-Ceramics with Apatite," *Dental Implants*, Ed. G. Heimke, Henser, Munich, 1980, pp. 27–34.
(**15**) Cullity, B. D., *Elements of X-ray Diffraction*, 2nd ed., Addison-Wesley Publishing Company, Reading, MA, 1978.

TABLE X1.1 Typical Bioactive Glass and Glass-Ceramic Compositions (Compositions in Weight %)

	45S5 Bioglass®	45S5.4F Bioglass®	52S4.6 Bioglass®	KGC Ceravital	A-W-GC
SiO_2	45	45	52	46.2	34.2
P_2O_5	6	6	6		16.3
CaO	24.5	14.7	21	20.2	44.9
CaF_2		9.8			0.5
$Ca(PO_3)_2$				25.5	
MgO				2.9	4.6
Na_2O	24.5	24.5	21	4.8	
K_2O				0.4	

(**16**) Li, P., et al., "The Effect of Residual Glassy Phase in a Bioactive Glass-Ceramic on the Formation of its Surface Apatite Layer In-Vitro," *Journal Mater. Sci. in Med.*, Vol 3, 1992, pp. 452–456.