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Standard Specification for Calcium Phosphate Coatings for Implantable Materials[1]

This standard is issued under the fixed designation F1609; 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 for calcium phosphate coatings for surgical implant applications.

1.2 In particulate and monolithic form, the calcium phosphate materials system has been well-characterized regarding biological response (**1,2**)[2] and laboratory characterization (**2-4**). Several publications (**5-10**) have documented the *in vitro* and *in vivo* properties of selected calcium phosphate coating systems.

1.3 This specification includes hydroxylapatite coatings, tricalcium phosphate coatings, or combinations thereof, with or without intentional minor additions of other ceramic or metallic,[3] and applied by methods including, but not limited to, the following: (*1*) mechanical capture, (*2*) plasma spray deposition, (*3*) dipping/sintering, (*4*) electrophoretic deposition, (*5*) porcelainizing, and (*6*) sputtering.

1.4 Substrates may include smooth, porous, textured, and other implantable topographical forms.

1.5 This specification excludes organic coatings that may contain calcium and phosphate ionic species.

1.6 **Warning—**Mercury has been designated by EPA and many state agencies as a hazardous material that can cause central nervous system, kidney, and liver damage. Mercury, or its vapor, may be hazardous to health and corrosive to materials. Caution should be taken when handling mercury and mercury-containing products. See the applicable product Material Safety Data Sheet (MSDS) for details and EPA's website (http://www.epa.gov/mercury/faq.htm) for additional information. Users should be aware that selling mercury or mercury-containing products, or both, in your state may be prohibited by state law.

2. Referenced Documents

2.1 *ASTM Standards:*[4]

E376 Practice for Measuring Coating Thickness by Magnetic-Field or Eddy-Current (Electromagnetic) Testing Methods

F1044 Test Method for Shear Testing of Calcium Phosphate Coatings and Metallic Coatings

F1088 Specification for Beta-Tricalcium Phosphate for Surgical Implantation

F1147 Test Method for Tension Testing of Calcium Phosphate and Metallic Coatings

F1160 Test Method for Shear and Bending Fatigue Testing of Calcium Phosphate and Metallic Medical and Composite Calcium Phosphate/Metallic Coatings

F1185 Specification for Composition of Hydroxylapatite for Surgical Implants

F1854 Test Method for Stereological Evaluation of Porous Coatings on Medical Implants

F1926 Test Method for Evaluation of the Environmental Stability of Calcium Phosphate Coatings

F2024 Practice for X-ray Diffraction Determination of Phase Content of Plasma-Sprayed Hydroxyapatite Coatings

2.2 *Pharmacopeia Convention Documents:*[5]

National Formulary XVI, Tribasic Calcium Phosphate

United States Pharmacopeia:

U.S. Pharmacopeia (most current), Chemical Tests: Calcium (191), Phosphorous (191), Lead <251>, Mercury <261>, Arsenic < 211>, and Heavy Metals <231> Method (1)

2.3 *Other Documents:*

U.S. Geological Survey Method, Cadmium[6]

U.S. Code of Federal Regulations Title 21 (CFR 21), Part 820–Quality System Regulation[7]

[1] This specification is under the jurisdiction of ASTM Committee F04 on Medical and Surgical Materials and Devicesand 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] The Joint Committee on Powdered Diffraction has established a Powder Diffraction File. The committee operates on an international basis and cooperates closely with the Data Commission of the International Union of Crystallinity and ASTM. Hydroxylapatite data can be found on file card No. 9-432; beta tricalcium phosphate data can be found on file card No. 9-169.

[4] 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.

[5] Available from U.S. Pharmacopeia (USP), 12601 Twinbrook Pkwy., Rockville, MD 20852-1790, http://www.usp.org.

[6] Crock, J. G., Felichte, F. E., and Briggs, P. H., "Determination of Elements in National Bureau of Standards Geological Reference Materials SRM 278 Obsidian and SRM 688 Basalt by Inductively Coupled Argon Plasma—Atomic Emission Spectrometry," *Geostandards Newsletter*, Vol 7, 1983, pp. 335–340.

[7] Available from Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098, http://dodssp.daps.dla.mil.

X-Ray Diffraction Analyses[3]

3. Terminology

3.1 *Definitions:*

3.1.1 *amorphous calcium phosphate*—a non-crystalline calcium phosphate.

3.1.2 *beta tricalcium phosphate*—a calcium phosphate substance of empirical chemical formula, $Ca_3(PO_4)_2$ (see Specification F1088).

3.1.3 *calcium phosphate*—any one of a number of inorganic chemical compounds containing calcium and phosphate ions as its principal constituents.

3.1.4 *coating*—a layer of mechanically or chemically attached material covering a substrate material.

3.1.5 *hydroxylapatite*—a calcium phosphate crystalline compound of empirical chemical formula, $Ca_5(PO_4)_3OH$ (see Specification F1185).

4. Chemical or Crystallographic Requirements, or Both

4.1 *Chemical:*

4.1.1 Elemental analysis for calcium and phosphorous and intentional additions (other than trace elements) shall be consistent with the expected stoichiometry of the specific calcium phosphate compound(s).

4.1.2 *Trace Element Analysis for Hydroxylapatite and Beta Tricalcium Phosphate*—The concentration of trace elements in the coating shall be limited as follows:

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

For reference purposes, the *U.S. Pharmacopeia (most current)* and *U.S. Geological Survey Method, Cadmium*, shall be used.

4.1.3 The analysis of other trace elements may be required, based on the conditions, apparatus, or environments specific to the coating application technique used.

4.1.4 The analysis of intentional additional elements or compounds such as fluorine, manganese, magnesium, carbonate, and so forth shall be specified for calcium phosphate coatings.

4.1.5 Calcium to Phosphorus ratio (Ca/P) shall be performed on both the powder and coating forms using a suitable method.

4.2 *Crystallographic Characterization:*

4.2.1 Crystallographic characterization shall be in accordance with Practice F2024.

4.2.2 Testing shall include quantitative phase analysis and amorphous calcium phosphate content.

4.2.3 FTIR (Fourier Transform Infrared Spectroscopy) shall be performed to identify functional groups.

4.3 *Environmental Stability*—Environmental stability testing shall be performed in accordance with Test Method F1926 to access the relative dissolution behavior of the material.

5. Physical Characterization

5.1 *Coverage of Substrate:*

5.1.1 Microscopic examination of the surface will be made at 10× magnification; “bare” areas, “pinholes,” cracking, foreign debris, unmelts, chips, delamination and the appearance at the coating/substrate interface, and so forth shall be reported.

5.2 *Thickness*—The thickness shall be measured from cross sections in accordance with Test Method F1854. If distinct layers exist, they should be reported.

5.2.1 Alternatively, a magnetic field or eddy current technique may be used if it has been shown to be equivalent to Test Method F1854.

5.3 *Porosity*—The microporosity and macroporosity characterization shall be determined in accordance with Test Method F1854.

5.4 *Color*—A macroscopic examination of color should be performed to guarantee a uniform and consistent appearance, in consideration of the specific process, substrate material and geometry, and coating thickness.

5.5 *Surface Topography*—The surface topography shall be measured using equipment designed to determine surface roughness. Characterization of the surface topography of the underlying substrate may be required, if applicable, for the specific coating method. Scanning electron microscopy shall be used to provide a visual representation of the coating surface characteristics.

5.6 *Density*—Density of both the powder and coated forms shall be performed using a suitable method.

6. Mechanical Characterization

6.1 The following mechanical characterizations may be applicable to a coating, depending on the substrate material or geometry, coating thickness or location, or coating method(s). Characterization reports shall contain sufficient information regarding the test techniques, procedures, and standards used and details such as specimen orientation and proportional depth of thickness in order to represent the analysis accurately.

6.1.1 The tensile bond strength of the coating to the substrate shall be determined using Test Method F1147.

6.1.2 The shear strength shall be determined using Test Method F1044.

6.1.3 The fatigue strength shall be determined using Test Method F1160. Both the coating/substrate interface, and the effect on the substrate should be evaluated. The effect of the coating on the resulting fatigue strength of an actual device should also be considered.

7. Test Specimen Fabrication

7.1 All test specimens for coating characterizations shall be prepared from coating lots and samples from the same production feedstock lots and prepared on the same equipment used to apply the coating to actual devices.

7.2 For device characterization, all test specimens should be subjected to the same processing and sterilization as the finished device, if applicable.

8. Contact with Calcium Phosphate Coatings

8.1 In general, extra precautions should be taken when handling calcium phosphate coatings.

8.1.1 Contact with the coatings should be limited to soft, biocompatible polymers.

8.1.2 The only liquids to come in contact with the coating shall be distilled water, acetone, and isopropyl alcohol.

8.1.2.1 pH is critical, and should measure 7.0 or higher in any liquid that comes in contact with the coating.

8.1.3 Powder-free latex or nitrile gloves shall be the only gloves used for handling coatings.

9. Quality Program Requirements

9.1 The manufacture of calcium phosphate coatings shall conform to the applicable FDA and ISO quality standards.

10. Keywords

10.1 bone implant; calcium phosphate; coating; dental implant materials; hydroxylapatite; mechanical tests; orthopedic medical devices; physical characterizations; tricalcium phosphate

APPENDIX

(Nonmandatory Information)

X1. RATIONALE

X1.1 Ceramic hydroxylapatite and beta-tricalcium phosphate are commercially available in many forms as synthetic bone grafting materials. Specifications F1088 and F1185 have been established for these substances as particulates. For most implant materials, the biological performance is critically dependent on the material's properties, including chemical and mechanical properties and physical form. These properties must be well-characterized and consistent in order to achieve reproducible clinical results and reliable biocompatibility. This specification shall cover biocompatible grades of calcium phosphate coatings only.

X1.2 Powder X-ray diffraction analysis provides differentiation between crystalline forms of these various calcium phosphate crystalline species, one or more of which will be a major phase in coatings covered by this specification, while others may occur as second or minor phases. It is anticipated that a separate performance standard may be necessary for each separate coating as designated by the major crystalline phase. The physical and mechanical property assessments are not specific to any one type of coating for this reason, but rather they are listed generically as guidelines for analysis. Minor or significant modifications to these procedures may have to be made to result in useful characterization data for the maintenance of individual coating consistency. The sources of general test methods for these coatings are listed in Section 2.

REFERENCES

(1) Jarcho, M., Kay, J. F., Gumaer, K. I., Doremus, R. H., and Drobeck, H. P., "Tissue, Cellular and Subcellular Events at a Bone-Ceramic Hydroxylapatite Interface," *Journal of Bioengineering* , Vol 1, 1977, pp. 79–92.

(2) Jarcho, M., "Calcium Phosphate Ceramics as Hard Tissue Prosthetics," *Clin Orthop*, Vol 157, 1981, pp. 259.

(3) de Groot, K., "Ceramics of Calcium Phosphates: Preparation and Properties," *Bioceramics of Calcium Phosphate*, K. de Groot, ed., CRC Press, Inc., Boca Raton, FL, 1982.

(4) Jarcho, M., Bolen, C. H., Thomas, M. B., Bobick, J., Kay, J. F., and Doremus, R. H., "Hydroxylapatite Synthesis and Characterization in Dense Polycrystalline Form," *Journal of Materials Science*, Vol 11, 1976, pp. 2027–2035.

(5) "Bioceramics: Material Characteristics Versus In-Vivo Behavior," P. Ducheyne and J. Lemons, eds., *N.Y. Academy of Science*, Vol 523, 1988.

(6) Cook, S. D., Kay, J. F., Thomas, K. A., and Jarcho, M., "Interface Mechanics and Histology of Titanium and Hydroxylapatite-Coated Titanium for Dental Implant Applications," *International Journal of Oral Maxillofac Implants*, Vol 2, 1987, pp. 15–22.

(7) Cook, S. D., Kay, J. F., Thomas, K. A., and Jarcho, M., "Hydroxylapatite-Coated Porous Titanium for Use as an Orthopaedic Biological Attachment System," *Clin Orthop*, Vol 230, 1988, pp. 303–312.

(8) Kay, J. F., Golec, T. S., and Riley, R. L., "Hydroxylapatite-Coated Subperiosteal Dental Implants: Design Rationale and Clinical Experience," *Journal of Prosthet Dent*, Vol 58, 1987, pp. 339–343.

(9) Block, M. S., Kent, J. N., and Kay, J. F., "The Evaluation of Hydroxylapatite-Coated Dental Implants in Dogs," *Journal of Oral Maxillofac Surg*, Vol 45, 1987, pp. 601–607.

(10) Thomas, K. A., Kay, J. F., and Cook, S. D., "The Effect of Surface Macrostructure and Hydroxylapatite Coating on the Mechanical Strengths and Histologic Profiles of Titanium Implant Materials," *Journal of Biomed Mater Res*, Vol 21, 1987, pp. 1395–1414.

(11) Cullity, B. D., *Elements of X-Ray Diffraction*, Addison Wesley, Reading, MA, 1967.

(12) *Handbook of Bioactive Ceramics, II: Calcium Phosphate and Hydroxylapatite Ceramics*, Yamamuro, Hench, Wilson, eds., CRC Press, Boca Raton, FL, 1990.

(13) Balmain, N., Legros, R., and Bonel, G., "X-Ray Diffraction of Calcified Bone Tissue: A Reliable Method for the Determination of Bone Ca/P Molar Ratio," *Calc Tiss Res*, Vol 34, 1982, pp. 93–98.

(14) Toth, J., Hirthe, W., Hubbard, W., Brantley, W., and Lynch, K., "Determination of the Ratio of HA/TCP Mixtures by X-Ray Diffraction," *Journal of Applied Biomaterials*, Vol 2, 1991, pp. 37–40.

(15) Sendax, V., "Hydroxylapatite Coated Implants," *Dent Clin N Am*, Vol 36, 1992.