Designation: F648 – 14

Standard Specification for Ultra-High-Molecular-Weight Polyethylene Powder and Fabricated Form for Surgical Implants[1]

This standard is issued under the fixed designation F648; 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 ultra-high molecular weight polyethylene powder (UHMWPE) and fabricated forms intended for use in surgical implants.

1.2 The requirements of this specification apply to UHMWPE in two forms. One is virgin polymer powder (Section 4). The second is any form fabricated from this powder from which a finished product is subsequently produced (Section 5). This specification addresses material characteristics and does not apply to the packaged and sterilized finished implant.

1.3 The requirements of this specification do not apply to UHMWPE virgin powder or fabricated forms intentionally crosslinked or blended with other additives, for example, antioxidants.

1.4 The biological response to polyethylene in soft tissue and bone has been well characterized by a history of clinical use (**1**, **2**, **3**)[2] and by laboratory studies (**4**, **5**, **6**).

1.5 The values stated in SI units are to be regarded as standard.

1.6 The following precautionary caveat pertains only to the test method portion, Section 7, 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:*[3]

D256 Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics
D638 Test Method for Tensile Properties of Plastics
D648 Test Method for Deflection Temperature of Plastics Under Flexural Load in the Edgewise Position
D790 Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
D1505 Test Method for Density of Plastics by the Density-Gradient Technique
D1898 Practice for Sampling of Plastics (Withdrawn 1998)[4]
D4020 Specification for Ultra-High-Molecular-Weight Polyethylene Molding and Extrusion Materials
F619 Practice for Extraction of Medical Plastics
F748 Practice for Selecting Generic Biological Test Methods for Materials and Devices
F749 Practice for Evaluating Material Extracts by Intracutaneous Injection in the Rabbit
F756 Practice for Assessment of Hemolytic Properties of Materials
F763 Practice for Short-Term Screening of Implant Materials
F813 Practice for Direct Contact Cell Culture Evaluation of Materials for Medical Devices
F895 Test Method for Agar Diffusion Cell Culture Screening for Cytotoxicity
F981 Practice for Assessment of Compatibility of Biomaterials for Surgical Implants with Respect to Effect of Materials on Muscle and Bone

2.2 *ISO Standards:*[5]

ISO 3451-1 Plastics—Determination of Ash, Part 1: General Methods
ISO 11542/2 Plastics—Ultra-High Molecular Weight Polyethylene (UHMWPE) Moulding and Extrusion Materials—Part 2: Preparation of Test Specimens and Determination

[1] This specification is under the jurisdiction of ASTM Committee F04 on Medical and Surgical Materials and Devices and is the direct responsibility of Subcommittee F04.11 on Polymeric Materials.

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

[3] 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.

[4] The last approved version of this historical standard is referenced on www.astm.org.

[5] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, http://www.iso.org.

ISO 9001 Quality Management Systems - Requirements
ISO 13485 Medical Devices – Quality Management Systems – Requirements for Regulatory Purposes

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *fabricated form, n*—any bulk shape of UHMWPE, fabricated from the virgin polymer powder and used during the process of fabricating surgical implants prior to packaging and sterilization.

3.1.1.1 *Discussion*—This form results from the application of heat and pressure to the virgin polymer powder, and the material characteristics of this form are subject to the applicable requirements of this specification. In present practice, this includes ram-extruded bars or molded blocks from which the final product form is machined, or a molded shape which is subsequently trimmed.

3.1.2 *generic property, n*—that property which is determined solely by the chemical composition and structure of the virgin polymer.

3.1.3 *morphology index (MI), n*—ratio of the total number of Type A and Type B indications (see Annex A2) to the total surface area examined in cm^2.

3.1.4 *Type A non-fused flake, n*—a Type A non-fused flake (A2.4.1 and Fig. A2.1) is an indication visible under conditions described in A2.5.1 that has an essentially complete circumferential black boundary and a white center.

3.1.5 *Type B non-fused flake, n*—a Type B non-fused flake (A2.4.2 and Fig. A2.2) is an indication visible under conditions described in A2.5.1 that has a partially circumferential black boundary that appears to trace out 50 % to 99 % of a flake's perimeter.

3.1.6 *virgin polymer powder, n*—form of UHMWPE as obtained from the powder manufacturer and prior to fabrication into a bulk shape.

4. Virgin UHMWPE Powder Requirements

4.1 *Generic Properties:*

4.1.1 The virgin polymer shall be a homopolymer of ethylene in accordance with Specification D4020.

4.1.2 The resin type and solution viscosity number requirements are listed in Table 1.

4.2 *Nongeneric Properties:*

TABLE 1 Requirements for UHMWPE Powders

Property	Test Method	Requirement		
Resin Type		Type 1	Type 2	Type 3
Viscosity Number, mL/g,	ASTM D4020 (0.02 %)	2000-3200	>3200	>3200
Elongation Stress, (Minimum)†	ASTM D4020	0.20	0.42	0.42
Ash, mg/kg, (Maximum)	ISO 3451-1	125	125	300
Extraneous Matter, No. Particles, (Maximum)	4.2.1	3	3	25
Titanium, mg/kg, (Maximum)	7.1.3.1	40	40	150
Aluminum, mg/kg, (Maximum)	7.1.3.1	20	20	100
Calcium, mg/kg, (Maximum)	7.1.3.1	5	5	50
Chlorine, mg/kg, (Maximum)	7.1.3.2	30	30	90

† Editorially corrected.

4.2.1 When a 300 g sample is prepared and viewed in accordance with 7.1.2, there shall be no more particles of extraneous matter than that specified in Table 1.

4.2.2 To promote uniformity between different lots of polymer powder, concentration limits for trace elements have been established and are listed in Table 1.

4.2.3 When determined as described in ISO 3451-1, the mean ash of duplicate samples shall not exceed the limits established in Table 1.

4.3 *Quality System Requirements:*

4.3.1 The UHMWPE powder as described in the scope of this specification shall be produced in accordance with an ISO 9001 or ISO 13485 certified Quality Management System.

5. UHMWPE Fabricated Form Requirements

5.1 *Compositional Requirements:*

5.1.1 No stabilizers, antioxidants, or processing aids are to be added to the virgin polymer powder during manufacture of a fabricated form.

5.1.2 No stabilizers, antioxidants, or processing aids are to be added to the fabricated form during manufacture of the final implant.

5.2 *Physical Requirements:*

5.2.1 *Foreign Matter Requirements:*

5.2.1.1 When 5000 cm^2 is evaluated according to 7.2.2, there shall be no more than ten particles of extraneous matter visible on the surface when visually inspected by a person with normal or fully corrected vision.

5.2.2 *Morphology Requirements:*

5.2.2.1 When evaluated according to Annex A2 the calculated morphology index (MI) and total surface area examined shall be reported.

5.3 *Mechanical Requirements:*

5.3.1 UHMWPE in fabricated form from which implants will be made (after annealing processes, if appropriate) shall meet the requirements listed in Table 2.

5.3.2 The following mechanical tests may be conducted based on agreement between the vendor and purchaser:

5.3.2.1 Deflection temperature; Test Method D648 (1.8 MPa), and Flexural modulus; Test Methods D790 (secant, 2 % offset).

5.4 *Quality System Requirements:*

5.4.1 The UHMWPE fabricated forms as described in the scope of this specification shall be produced in accordance with an ISO 9001 or ISO 13485 certified Quality Management System.

6. Sampling

6.1 Where applicable, the requirements of this specification shall be determined for each lot of powder and fabricated form by sampling sizes and procedures according to Practice D1898, or as agreed upon between the purchaser and seller.

7. Test Methods

7.1 *UHMWPE Powder:*

TABLE 2 Requirements for UHMWPE Fabricated Forms

Property	Test Method	Requirement		
Resin Type		Type 1	Type 2	Type 3
Density, kg/m^3	ASTM D792 or D1505	927-944	927-944	927-944
Tensile Strength, 23°C, MPa, (Minimum)	ASTM D638, Type IV, 1.5 mm ± 0.5 mm, 5.08 cm/min			
Ultimate		40	40	27
Yield		21	19	19
Elongation, %, (Minimum)[A]	ASTM D638, Type IV, 5.08 cm/min	380	340	250
Izod Impact Strength, kJ/m^2, (Minimum)	Annex A1	126	73	25

[A]Use an extensometer for measuring strain and calculating percent elongation.

7.1.1 Determine the solution viscosity number in accordance with the method given in Specification D4020 at a concentration of 0.02 %.

7.1.2 Determine the amount of extraneous matter by the following procedure as agreed upon by the purchaser and seller.

7.1.2.1 A 300 g sample is divided into four 75 g samples. Place a 75 g sample in each of four 1000 mL Erlenmeyer flasks, add 400 mL isopropyl alcohol, shake 5 min, and let settle for 5 min. Count the total number of particles of extraneous matter in the four flasks.

7.1.2.2 Visually examine (with 20/20 corrected vision if necessary) the four flasks and count the total number of particles of extraneous matter.

7.1.3 Determine the following trace element concentrations by the following methods, or by methods agreed upon by the purchaser and seller.

7.1.3.1 The elements Ti, Al, and Ca may be determined by atomic absorption (AA) or emission spectroscopy (ES); inductively coupled plasma mass spectroscopy (ICP/MS); or inductively coupled plasma spectroscopy (ICP).

7.1.3.2 The element chlorine (Cl) may be determined potentiometrically, titrametrically, by neutron activation analysis, by inductively coupled plasma mass spectroscopy (ICP/MS), or by the oxygen bomb combustion/UV-Vis spectroscopy method.

7.2 *UHMWPE Fabricated Form:*

7.2.1 The requirement that there will be no addition of any stabilizer, antioxidant, or processing aid during fabrication of the fabricated form shall be met by certification of the fabricator.

7.2.2 Determine the amount of extraneous matter by the following procedure.

7.2.2.1 Prepare a number of test specimens from the fabricated form as agreed upon by the purchaser and seller.

7.2.2.2 Visually examine (with 20/20 corrected vision if necessary) a total area of 5000 cm^2 taken from locations within the fabricated form agreed upon by the purchaser and seller.

7.2.3 Determine the density in accordance with Test Methods D792 or D1505.

7.2.4 Determine specific mechanical properties in accordance with the methods listed in Table 2. Mechanical test specimens shall be produced by methods that represent those used to produce the fabricated form.

7.2.5 Unless otherwise specified, the testing described in Table 2 (except for ash) shall be conducted under standard conditions of 23 ± 2°C after storage of the test specimens for at least 16 h.

8. Biocompatibility

8.1 This material has been shown to produce a well characterized level of biological response following long term clinical use in laboratory animals. The results of these studies and the clinical history indicate an acceptable level of biological response in the applications in which the material has been utilized. When new applications of the material, or modification to the material or physical forms of the materials are being contemplated, the recommendations of Practice F748 should be considered and testing as described in Practices F619, F749, F756, F763, F813, and F981 as well as Test Method F895.

9. Keywords

9.1 fabricated forms; powdered form; ultra-high molecular weight polyethylene

ANNEXES

(Mandatory Information)

A1. IMPACT STRENGTH

A1.1 General Description

A1.1.1 This test method covers the determination of the impact resistance of Ultra-High Molecular Weight Polyethylene (UHMWPE) which is extremely impact resistant. When tested according to Test Method D256, Method A, UHMWPE generally gives a non-break type for failure, rendering the test result invalid. This test method specifies the same type of pendulum impact test machine as given in Test Method D256 but introduces a much higher degree of stress concentration into the specimen by double notching with a razor blade. It is advised that the user be familiar with Test Method D256 before attempting to use this test method.

A1.2. Apparatus

A1.2.1 The Izod type impact machine which conforms to the requirements of Test Method D256, including the calibration and checking methods, shall be used.

A1.3. Test Specimen

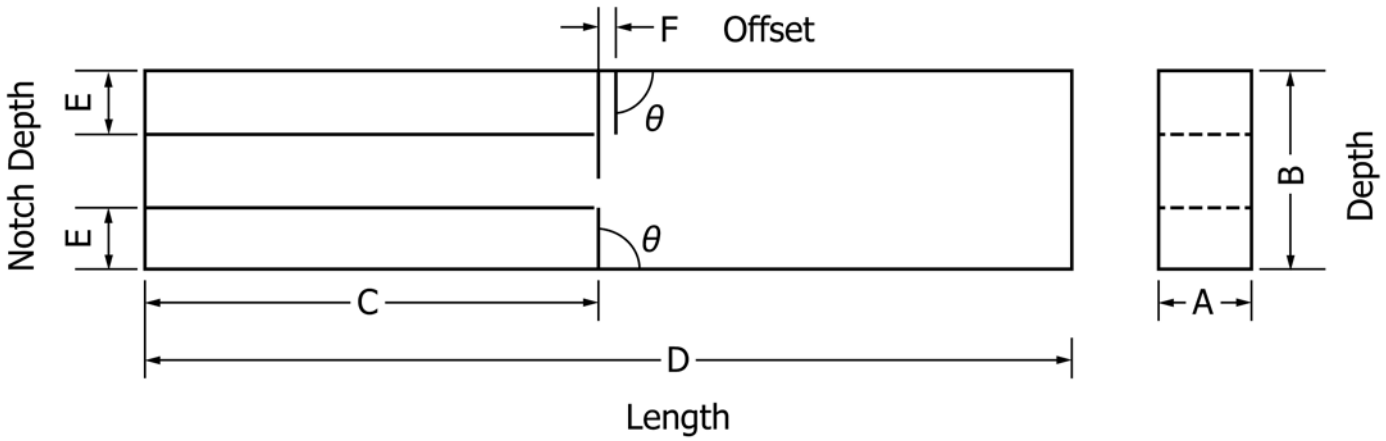
A1.3.1 The geometry and dimensions of the specimen are given in Fig. A1.1.

A1.3.2 The specimens shall be made from the fabricated form.

A1.3.3 Each specimen shall be free of twist and shall be bounded by mutually perpendicular pairs of plane parallel surfaces, free from scratches, pits, and sink marks.

A1.4 Notching of Specimens

A1.4.1 In the case of compression molding, the two notches (or width of two notches) shall be perpendicular to the direction of application of molding pressure; if applicable. The impact resistance of a plastic material may be different if the notch is perpendicular to, rather than parallel to, the direction



	mm		in.
A	6.35 ± 0.38	A	0.250 ± 0.015
B	12.70 ± 0.10	B	0.500 ± 0.004
C	31.75 ± 0.25	C	1.250 ± 0.010
D	63.50 ± 0.38	D	2.500 ± 0.015
E	4.57 ± 0.08	E	0.180 ± 0.003
F	0.00 ± 0.13	F	0.000 ± 0.005
O	90° ± 2°	O	90° ± 2°

FIG. A1.1 Dimensions of Double Notched Izod Test Specimen

of molding. The same is true for specimens cut with or across the grain of an anisotropic sheet or plate.

A1.4.2 A 4.57 ± 0.076 mm (0.180 ± 0.003 in.) deep notch shall be made with a suitable machine by pressing in a 0.25 mm (0.010 in.) thick single edge razor blade with a 15° included angle at the cutting edge. The notching speed shall be less than 508 mm/min. (20 in./min.). A new blade shall be used after notching 40 specimens.

A1.4.3 The calibration of the notching machine shall be checked by direct measurement of the notch depth, perpendicularity, and offset of the two notches. One of the possible measurement methods is given in A1.8.

A1.5. Conditioning

A1.5.1 *Conditioning*—Condition the notched specimens at 23 ± 2°C (73 ± 4°F) for not less than 16 h prior to testing.

A1.5.2 *Test Conditions*—Conduct the test in the standard laboratory atmosphere of 23 ± 2°C (73 ± 4°F).

A1.6. Procedure

A1.6.1 At least five and preferably ten individual determinations of impact value shall be made on each sample to be tested under the conditions prescribed.

A1.6.2 Measure the width of each specimen in the area between notches twice with a micrometer to the nearest 0.025 mm (0.001 in.) and record its average width. Carefully measure the distance between the notch roots on the two sides of the specimen. Use of an optical microscope may improve the accuracy of this measurement. Record the average value and multiply this number by the width of the specimen to get the remaining unnotched cross section area, AR. Also record the identifying markings of the specimen.

A1.6.3 Estimate the breaking energy for the specimen and select a pendulum of suitable energy. Start the test with a pendulum of 11 J (8 ft.-lb), if no prior test data is available. Use the lightest standard pendulum that is expected to break each specimen in the group with a loss of not more than 85 % of its energy.

A1.6.4 Before testing the specimens, perform the operations on the machine.

A1.6.4.1 With the excess energy indicating pointer in its normal starting position but without a specimen in the vise, release the pendulum from its normal starting position and note the position the pointer attains after the swing as one reading of Factor A.

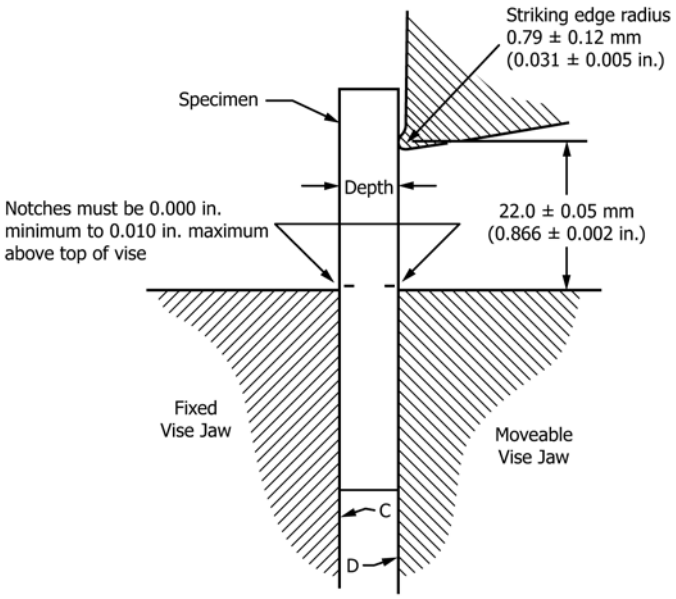
A1.6.4.2 Without resetting the pointer, raise the pendulum and release again. The pointer should move up the scale an additional amount. Repeat this procedure until a swing causes no additional movement of the pointer and note the final reading as one reading of Factor B.

A1.6.4.3 Repeat the above two operations several times and calculate and record the average A and B readings.

A1.6.5 Position the specimen precisely and rigidly but not too tightly clamped in the vise. The relationship of the vise, specimen, and striking edge of the pendulum to each other is given in Fig. A1.2. Note that the top plane of the vise shall be 0.13 ± 0.13 mm (0.005 ± 0.005 in.) below the notches.

A1.6.6 Release the pendulum and note and record the excess energy remaining in the pendulum after breaking the specimen.

A1.6.7 From the breaking strength of the specimen and Factors A and B, determine the energy loss of the pendulum due to windage and friction using the correction charts from the commercial testing machine supplier. If these charts are not



Planes C and D must be parallel to within 0.025 mm (0.001 in.)

FIG. A1.2 Relationship of Vise, Specimen, and Striking Edge to Each Other

available, use the method given in Appendix X2 or X3 of Test Method D256. Subtract the correction so calculated from the indicated breaking strength of the specimen. If a pendulum of improper energy was used, discard the result and make additional tests on new specimens with the proper pendulum. If the proper pendulum was used, divide the net value so found by the unnotched area AR of the specimen as measured in A1.6.2 to obtain its double notched Izod impact resistance in kJ/m^2 ($ft\text{-}lb/in.^2$).

A1.6.8 Record the type of failure for each specimen as one of the three coded categories defined as follows:

A1.6.8.1 *C (Complete Break)*—A break in which the specimen separates into two pieces and the fracture plane contains both lines of the notch roots.

A1.6.8.2 *IB (Irregular Break)*—The specimen separates into two pieces but the fracture plane contains only one of the notch roots.

A1.6.8.3 *NB (Nonbreak)*—A break in which the specimen does not separate into two pieces.

A1.6.9 Calculate the average impact resistance and standard deviation of the group of specimens.

A1.7. Report

A1.7.1 Report the following information:

A1.7.1.1 Complete identification of notch orientation, the material tested, including type, source, and manufacturer's lot number,

A1.7.1.2 Capacity of the pendulum in joules (foot-pounds-force);

A1.7.1.3 Total number of specimens tested;

A1.7.1.4 Average double notched Izod impact resistance in kJ/m^2 ($ft\text{-}lb/in^2$);

A1.7.1.5 Standard deviation; and

A1.7.1.6 Percent of specimens failing in each category suffixed by the corresponding letter code from A1.6.8.

A1.8 Measurement Method of Imperfections in Specimen Notching

A1.8.1 The following is one of the possible test methods to directly measure the imperfections in specimen notching, which can be classified into three kinds: deviation from perpendicularity, incorrect notch depth, and, offset of notches (Fig. A1.3).

A1.8.2 *Apparatus:*

A1.8.2.1 An *Ocular*, 40 to 60×, reflective optical microscope with an X-Y stage accurate to 0.0025 mm (0.0001 in.);

A1.8.2.2 An *Eyepiece*, with a crosshair;

A1.8.2.3 *Fiber Optic Illumination.*

A1.8.3 *Procedure:*

A1.8.3.1 Lay the specimen on one of its sides and mount it securely on the X-Y stage.

A1.8.3.2 The beginning and ending points of the notches are labeled from A to D in Fig. A1.3. Select one of the edges of the specimen as the datum line from which the perpendicularity of the notches to the edges is measured (in this case line *AE*). Note that point *E* is approximately 6.35 mm (0.25 in.) from point *A*.

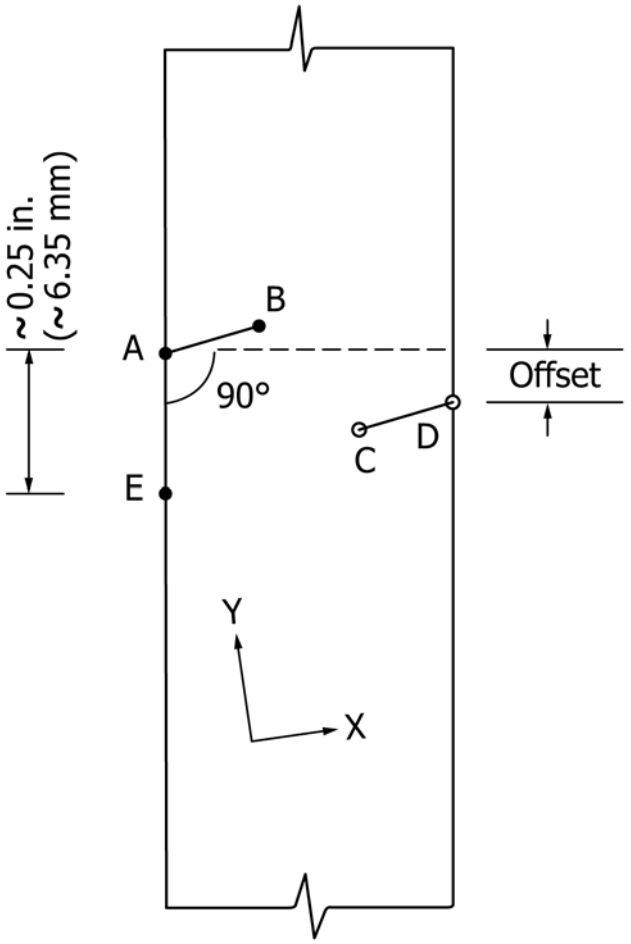


FIG. A1.3 Notch Geometry of Double Notched Izod Specimen

A1.8.3.3 Both the microscope and the base of the X-Y stage should be stationary. Measure the coordinates of points *A* to *E* with respect to an arbitrarily selected coordinate system by moving the X-Y stage and by targeting the points by the crosshair of the eyepiece.

A1.8.4 *Calculation:*

A1.8.4.1 The following equation is used to calculate perpendicularity of the notches:

$$/EAB = \tan^{-1}[(m_2 - m_1)/(1 + m_1\ m_2)] \qquad (A1.1)$$

where:

m_1 and m_2 are the slopes of line *AE* and *AB* with respect to the coordinate system. m_1 and m_2 are calculated from:

$$m = (y_2 - y_1)/(x_2 - x_1) \qquad (A1.2)$$

where:

m is the slope, and (x_1y_1) and (x_2y_2) are the coordinates of the end points of the line. The distance between two points, I, is obtained from:

$$I = [(x_2 - x_1)^2 + (y_2 - y_1)^2]^{0.5} \qquad (A1.3)$$

A2. MORPHOLOGY EVALUATION

A2.1 General Description

A2.1.1 This test method covers the determination of the morphology quality of fabricated forms of Ultra-High Molecular Weight Polyethylene (UHMWPE). Well consolidated UHMWPE will have none or few regions of incompletely fused UHMWPE flake particles. This procedure is designed to evaluate the relative consolidation quality (morphology) of fabricated forms of UHMWPE by measuring the number of incompletely fused UHMWPE particles.

A2.2 Test Specimens

A2.2.1 Test specimens are approximately 100 µm thick slices of the material.

A2.2.2 Test specimens shall be collected from locations known to be most prone to consolidation difficulties; otherwise, at the approximate center of the sample or as agreed upon between the purchaser and seller.

A2.2.3 The number of test specimens collected shall be as agreed upon between the purchaser and seller.

A2.2.4 If multiple film specimens are taken from the same piece, they shall be spaced at least 0.5 mm apart.

A2.2.5 Approximately 2 cm^2 from the center region of each test specimen shall be examined according to A2.5.

A2.3 Preparing Thin Film Specimens

A2.3.1 Thin translucent film specimens approximately 100 µm thick shall be prepared. Films should be relatively uniform in thickness and essentially free of skives, tears, etc. commonly resulting from the use of dull cutting equipment.

A2.3.2 The thin films may be placed flat between two clean glass microscope slides for convenient microscopic examination.

A2.4 Definitions

A2.4.1 *Type A Non-Fused Flake, n*—A Type A non-fused flake is an indication visible under the conditions described in A2.5.1 that has an essentially complete circumferential black boundary and a white center. See Fig. A2.1.

A2.4.2 *Type B Non-Fused Flake, n*—A Type B non-fused flake is an indication visible under the conditions described in A2.5.1 that has a partially circumferential black boundary that appears to trace out 50 to 99 % of a flake's perimeter. See Fig. A2.2.

A2.4.3 *Morphology Index (MI), n*—Material morphology quality shall be described by a morphology index (MI) defined as the ratio of the total number of Type A and Type B indications to the total surface area examined in cm^2.

A2.5 Procedure

A2.5.1 Test specimens are evaluated by optical microscopy at no lower than 40x using thin films of the material illuminated by transmitted light. Dark field, reflection, or other such means may be used to visualize regions of incompletely fused flakes if they are demonstrated to give essentially equivalent results.

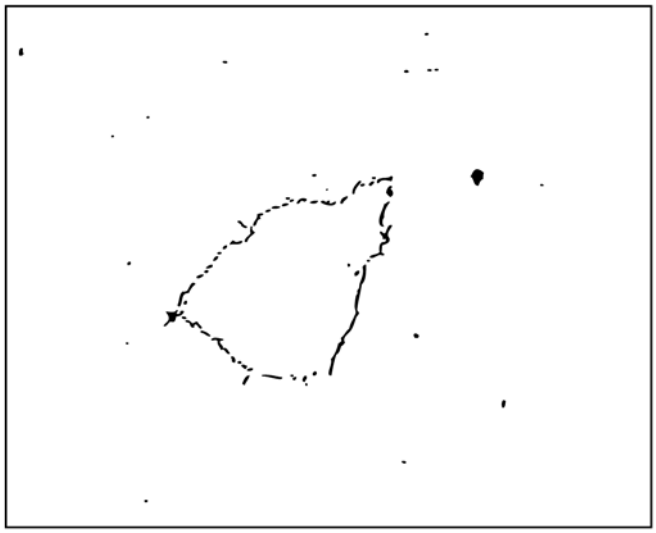


FIG. A2.1 Representative Type A Indication

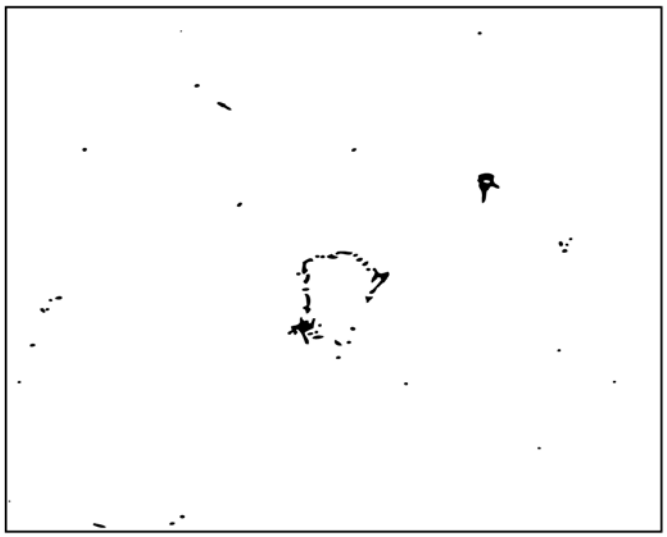


FIG. A2.2 Representative Type B Indication

A2.6 Report

A2.6.1 Report the following for each material tested:

A2.6.1.1 Complete identification of the material tested, including virgin resin type consolidation method, and converter.

A2.6.1.2 Total number of Type A indications observed,

A2.6.1.3 Total number of Type B indications observed,

A2.6.1.4 Total surface area examined in cm^2, and

A2.6.1.5 Calculated Morphology Index (MI) in accordance with A2.4.3.

APPENDIX

(Nonmandatory Information)

X1. RATIONALE

X1.1 This specification is intended to describe the properties required and procedures to be followed in testing and using this specification.

X1.2 While the biocompatibility of this material in bulk form is well characterized as it has been used historically, the data cannot necessarily be assumed to be applicable to modified forms or applications of the material. The material user should carefully analyze the published biocompatibility data and then decide whether additional testing may be necessary as a result of the changes which may have been made.

X1.3 While the precise relationship between the bulk properties and wear resistance of implants and the molecular weight of the polyethylene used to fabricate them has not been established quantitatively, it has been demonstrated that UHMWPE is more suitable for such applications than are polyethylenes of lower molecular weight.

X1.4 The viscosity number of dilute solutions of UHMWPE powder may be used as an adequate indicator that some minimum value of molecular weight is attained. At present, there is some uncertainty regarding the extension of the solution viscosity/molecular weight relationship to the UHMWPE range.

X1.5 Information on the molecular weight distribution may permit control of the weight fraction of low-molecular weight material. Presently, there is no adequate method for determining this distribution.

X1.6 There is no evidence at this time that the concentration of trace elements has any effect on the physical properties or the biological response of UHMWPE fabricated forms.

X1.7 The relationship between these mechanical properties and the in-vivo performance of a fabricated form has not been determined. While trends are apparent, specific property-polymer structure relationships are not well understood. These mechanical tests are frequently used to evaluate the reproducibility of a fabrication procedure and are applicable as quality control tests to determine lot-to-lot repeatability for a process of converting virgin polymer powder into a fabricated form. The mechanical properties are subject to variation as the fabrication process variables (such as temperature, pressure, and time) are changed.

X1.8 At the present time there are no clear correlations between a sample's morphology index and its functional characteristics. For this reason this document does not specify a maximum allowed index.

REFERENCE

(1) Charnley, J., Cupiz, A., "The Nine and Ten Year Results of the Low Friction Arthroplasty of the Hip," *Clinical Orthopaedics*, Vol 95, No. 9, 1973.

(2) Cimbrelo, E.G., Munera, L., "Early and Late Loosening of the Acetabular Cup After Low-Friction Arthroplasty", *The Journal of Bone and Joint Surgery*, Vol 74-A, No. 8, 1992.

(3) Mirra, J., Amstutz, H., Matos, M., Gold, R., "The Pathology of the Joint Tissues and Its Clinical Relevance in Prosthesis Failure," *Clinical Orthopaedics*, No. 117, 1976.

(4) Turner, J., Lawrence, W., Autian, J., "Subacute Toxicity Testing of Biomaterials Using Histopathologic Evaluation of Rabbit Muscle Tissue," *Journal of Biomedical Materials Research*, Vol 7, 1973.

(5) Laing, P., "Compatibility of Biomaterials," *Orthopedic Clinics of North America*, Vol 4, No. 2, 1973.

(6) Escalas, F., Galante, J., Rostoker, W., "Biocompatibility of Materials for Total Joint Replacement," *Journal of Biomedical Materials Research*, Vol 10 , No. 2, 1976.