



Standard Specification for Silicon Nitride Bearing Balls¹

This standard is issued under the fixed designation F2094/F2094M; 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.

^{ε1} NOTE—Table 4 was editorially corrected in November 2016.

1. Scope

1.1 This specification covers the establishment of the basic quality, physical/mechanical property, and test requirements for silicon nitride balls Classes I, II, and III to be used for ball bearings and specialty ball applications.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

2. Referenced Documents

2.1 Order of Precedence:

2.1.1 In the event of a conflict between the text of this document and the references herein, the text of this document takes precedence. Nothing in this document, however, supercedes applicable laws and regulations unless a specific exemption has been obtained.

2.2 ASTM Standards:²

C1161 Test Method for Flexural Strength of Advanced Ceramics at Ambient Temperature

C1421 Test Methods for Determination of Fracture Toughness of Advanced Ceramics at Ambient Temperature

2.3 ANSI Standard:

ANSI/ASQC Z1.4 Sampling Procedures and Tables for Inspection by Attributes³

2.4 ABMA Standards:

STD 10 Metal Balls⁴

2.5 ASME Standard:

B 46.1 Surface Texture (Surface Roughness, Waviness, and Lay)⁵

2.6 ISO Standards:

4505 Hardmetals—Metallographic Determination of Porosity and Uncombined Carbon³

2.7 JIS Standards:

R 1601 Testing Method for Flexural Strength (Modulus of Rupture) of High Performance Ceramics⁶

R 1607 Testing Method for Fracture Toughness of High Performance Ceramics⁶

2.8 CEN Standards:

EN 843-1 Advanced Technical Ceramics—Monolithic Ceramics—Mechanical Properties at Room Temperature, Part 1. Determination of Flexural Strength⁷

ENV 843-5 Advanced Technical Ceramics—Monolithic Ceramics—Mechanical Properties at Room Temperature, Part 5, Statistical Analysis⁷

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 *ball diameter variation, V_{dws}, n* —ball diameter variation is the difference between the largest and smallest diameter measured on the same ball.

3.1.2 *ball gage, S, n* —prescribed small amount by which the lot mean diameter should differ from nominal diameter, this amount being one of an established series of amounts. A ball gage, in combination with the ball grade and nominal ball diameter, should be considered as the most exact ball size specification to be used by a customer for ordering purposes.

¹ This specification is under the jurisdiction of ASTM Committee F34 on Rolling Element Bearings and is the direct responsibility of Subcommittee F34.01 on Rolling Element.

Current edition approved March 15, 2014. Published March 2014. Originally approved in 2001. Last previous edition approved in 2013 as F2094/F2094M–13. DOI: 10.1520/F2094_F2094M-14E01.

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.

³ Application for copies should be addressed to the American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

⁴ Application for copies should be addressed to the American Bearing Manufacturer's Association, 1200 19th Street NW, Suite 300, Washington, DC 20036-2401.

⁵ Application for copies should be addressed to the American Society of Mechanical Engineers (ASME), ASME International Headquarters, Three Park Ave., New York, NY 10016-5990, <http://www.asme.org>.

⁶ Application for copies should be addressed to the Japanese Standards Organization (JSA), 4-1-24 Akasaka Minato-Ku, Tokyo, 107-8440, Japan, <http://www.jsa.or.jp>.

⁷ Application for copies should be addressed to the British Standards Institute (BSI), 389 Chiswick High Rd., London W4 4AL, U.K., <http://www.bsi-global.com>.

3.1.3 *ball gage deviation, ΔS , n* —difference between the lot mean diameter and the sum of the nominal diameter and the ball gage.

3.1.4 *ball grade, G , n* —specific combination of dimensional form and surface roughness tolerances. A ball grade is designated by a grade number followed by the letter “C” indicating Silicon Nitride Ceramic.

3.1.5 *blank lot, n* —single group of same-sized ball blanks processed together from one material lot through densification.

3.1.6 *ceramic second phase, n* —sintering additive based phases, for example, yttria and alumina, which appear darker or lighter than the silicon nitride matrix, but are not highly reflective in nature when viewed under reflected light microscopy and bright field illumination.

3.1.7 *color variation, n* —an area that appears lighter or darker than the surrounding area under reflected light microscopy but with no discernible physical discontinuity associated with it.

3.1.7.1 *Discussion*—Color variation is often not visible under scanning electron microscopy (SEM) examination.

3.1.8 *c-cracks, n* —curved, constant radius cracks, the result of ball-to-ball impact during finishing or subsequent handling. In extreme cases, the cracks can form a complete circle and multiple concentric cracks can form.

3.1.9 *cracks, n* —irregular, narrow breaks in the surface of the ball typically having a visible width of less than 0.002mm [0.00008 in.]

3.1.9.1 *Discussion*—Most cracks are formed after densification but occasionally may be present as material faults. Some cracks may not be visible with normal white light microscopy and may only show up under ultraviolet light after processing with a suitable fluorescent penetrant.

3.1.10 *cuts, n* —Mechanically induced random, short, linear depressions in the surface.

3.1.11 *deviation from spherical form, ΔR_w , n* —greatest radial distance in any radial plane between a sphere circumscribed around the ball surface and any point on the ball surface.

3.1.12 *finish lot, n* —single group of same-sized balls (which may be derived from multiple blank lots of the same material lot) processed together through finishing.

3.1.13 *inclusion, n* —any discrete inhomogeneity in the microstructure that is not intended to be included in the material.

3.1.13.1 *Discussion*—Inclusions typically consist of foreign material as a result of unintended external powder contamination and resulting reaction product after sintering.

3.1.14 *lot diameter variation, V_{dwl} , n* —difference between the mean diameter of the largest ball and that of the smallest ball in the lot.

3.1.15 *lot mean diameter, D_{wml} , n* —arithmetic mean of the mean diameter of the largest ball and that of the smallest ball in the lot.

3.1.16 *material lot, n* —single process lot of a blended powder (blended with additives), produced from a single lot of silicon nitride or silicon metal raw powder received from a material supplier.

3.1.16.1 *Discussion*—What constitutes a “single process lot” of blended powder can vary depending on the standard practices of the vendor and the requirements of the customer and application. For example, for many customers/applications, combining multiple mill charges from one raw material lot into a single material lot is acceptable while for others, each mill charge would be considered a separate material lot. It is difficult, if not impossible, for a single definition of material lot to apply to all applications. The material lot should be defined such that application-appropriate traceability is maintained and adequate testing appropriate for the intended application is performed to ensure that the chemistry and material properties of densified parts meet specifications. The material lot requirements should be discussed and agreed between the vendor and customer.

3.1.17 *mean diameter of a ball, D_{wm} , n* —arithmetic mean of the largest and the smallest actual single diameters of the ball.

3.1.18 *metallic phase, n* —material phase that is highly reflective when viewed by reflected light microscopy and bright field illumination.

3.1.19 *metallic smears, n* —metallic material from lapping or measuring equipment transferred onto the ball surface.

3.1.20 *nominal diameter, D_w , n* —size ordered that is the basis to which the nominal diameter tolerances apply. The nominal diameter is specified in inches or millimeters (decimal form).

3.1.21 *nominal diameter tolerance, n* —maximum allowable deviation from true specified nominal diameter for the indicated grade.

3.1.22 *pits, n* —voids or cavities in the ball surface.

3.1.22.1 *Discussion*—Pits can be formed by severe material pullout during ball finishing. Pits can also be a result of breakout of inclusions during finishing.

3.1.23 *porosity, n* —small, closely spaced voids permeating a region of the ball surface or the whole ball.

3.1.24 *pressing defects, n* —the result of cracks in the ball blanks prior to densification.

3.1.24.1 *Discussion*—Some pressing defects heal more or less completely on densification resulting in a region of material with slightly different composition and optical characteristics than the rest of the ball. These are known as healed or partially healed pressing defects. Unhealed or open pressing defects can have the appearance of cracks or fissures.

3.1.25 *raw material lot, n* —single process lot of raw silicon nitride or raw silicon metal powder received from a material supplier.

3.1.26 *scratches, n* —narrow, linear, shallow abrasions on the surface.

3.1.27 *scuffs, n* —a dense concentration of small, parallel superficial scratches.

3.1.28 *single diameter of a ball, D_{ws} , n* —the distance between two parallel planes tangent to the surface of the ball.

3.1.29 *snowflakes, n* —regions of microporosity in the grain boundary phase that often display a dendritic appearance.

3.1.29.1 *Discussion*—Snowflakes show up as white dendritic features when viewed with oblique illumination or with ultraviolet light after processing with a fluorescent penetrant. The individual micropores are often submicron in size and the snowflakes can range in size from less than 10 μm [.00039 in.] to over 1,000 μm [.039 in.] in extreme cases.

3.1.30 *surface roughness R_a , n* —surface irregularities with relative small spacings, which usually include irregularities resulting from the method of manufacture being used or other influences, or both.

3.1.31 *unit container, n* —container identified as containing balls from the same manufacture lot of the same composition, grade, and nominal diameter, and within the allowable diameter variation per unit container for the specified grade.

4. Classification

4.1 Silicon nitride materials for bearing and specialty ball applications are specified according to the following material classes (see [Appendix X1](#) for typical current applications):

4.1.1 *Class I*—Highest grade of material in terms of properties and microstructure. Suitable for use in the most demanding applications. This group adds high reliability and durability for extreme performance requirements.

4.1.2 *Class II*—General class of material for most bearing and specialty ball applications. This group addresses the concerns of ball defects as is relative to fatigue life, levels of torque, and noise.

4.1.3 *Class III*—Lower grade of material for low duty applications only. This group of applications primarily takes advantage of silicon nitride material properties. For example: Light weight, chemical inertness, lubricant life extension due to dissimilarity with race materials, and so forth.

5. Ordering Information

5.1 Acquisition documents should specify the following:

5.1.1 Title, number, and date of this specification.

5.1.2 Class, grade, and size (see [4.1](#), [8.6](#), and [8.7](#)).

6. Material

6.1 Unless otherwise specified, physical and mechanical property requirements will apply to all material classes.

6.2 To be classified as Class I, silicon nitride balls shall be produced from either silicon nitride powder having the compositional limits listed in [Table 1](#) or from silicon metal powder, which after nitridation complies with the compositional limits listed in [Table 1](#).

6.3 Composition is measured in weight percent. Testing shall be carried out by a facility qualified and approved by the supplier. Specific equipment, tests, and/or methods are subject to agreement between suppliers and their customers.

6.4 Compounds may be added to promote densification and enhance product performance and quality.

TABLE 1 Compositional Limits for Starting Silicon Nitride Powders or Silicon Powder Converted to Silicon Nitride for Class I Materials^A

Constituents	Limits (wt %)
Silicon nitride	97.0 min.
Free silicon	0.3 max.
Carbon	0.3 max.
Iron	0.5 max.

^A Other impurities or elements such as sodium, potassium, chlorine, etc. individually shall not exceed 0.02 wt % max.

6.5 Iron oxides may be added to promote densification with the total iron content for the final product not to exceed 1.0 weight %.

6.6 Precautions should be taken to minimize contamination by foreign materials during all stages of processing up to and including densification.

6.7 A residual content of up to 2 % tungsten carbide from powder processing is allowable.

6.8 Final composition shall meet and be reported according to the specification of the individual supplier.

6.9 Notification will be made upon process changes.

6.10 Specific requirements such as specific material grade designation, physical/mechanical property requirements (for example, density) or quality or testing requirements shall be established by specific application. The special requirements shall be in addition to the general requirements established in this specification.

6.11 Typical mechanical properties will fall within the range listed in [Table 2](#). Individual requirements may have tighter ranges. The vendor shall certify that the silicon nitride material supplied has physical and mechanical properties within the range given in [Table 2](#). In the case of properties indicated by (+), the provision of the data is not mandatory.

7. Physical Properties

7.1 The following physical properties shall be measured, at a minimum, on each material lot.

TABLE 2 Typical Mechanical Properties^A

Properties	Minimum	Maximum
Density, g/cc [lb/ft ³]	3.0 [187]	3.4 [212]
Elastic modulus, GPa [ksi]	270 [39 150]	330 [47 850]
Poisson's ratio	0.23	0.29
Thermal conductivity, W/m ² ·K [Btu/h-ft ² ·°F]— @ 20°C (room temp.)	20 [11.5]	38 [21.9]
Specific heat, J/kg·°K [Btu/lbm·°F]	650 [0.167]	800 [0.191]
Coefficient of thermal expansion, ×10 ⁻⁶ /°C [†] (room temp. to 500°C)	2.3	3.4
+ Resistivity, Ohm-m	10 ¹⁰	10 ¹⁶
+ Compressive strength, MPa [ksi]	3000 [435]	

^A Special material data should be obtained from individual suppliers.

7.1.1 Average values for room temperature rupture strength (bend strength/modulus of rupture) for a minimum of 20 individual determinations shall exceed the minimum values given in **Table 3**. Either 3-point or 4-point test methods may be used for flexural strength, which should be measured in accordance with Test Method **C1161** (size B), CEN 843-5, or JIS R 1601. Weibull modulus for each test series shall also exceed the minimum permitted values given in **Table 3**. If a sample set of specimens for a material lot does not meet the Weibull modulus requirement in **Table 3**, then a second sample set may be tested to establish conformance.

7.1.2 The hardness (HV) shall be determined by the Vickers method (see **Annex A1**) using a load of at least 5 kg but not exceeding 20 kg. Fracture resistance shall be measured by either an indentation technique (see **Annex A1**) or by a standard fracture toughness test method. Average values for hardness and fracture resistance shall exceed the minimum of values for the specified material class given in **Table 4**.

7.1.3 Microstructure constituents visible at magnification in the range $\times 100$ to $\times 200$ shall not exceed the maximum values given in **Table 5** for the specified material class.

7.1.4 The number of inclusions observed in transverse sections shall not exceed the limits given in **Table 6**.

7.1.5 Macrostructure variation visible at $1\times$ on a polished section is not permissible.

7.1.6 Density variation from the mean value of a sample of at least 10 pieces taken from a batch of components manufactured under the same conditions shall not exceed the values for 3 times the standard deviation ($3 \times \text{sigma}$) given in **Table 7**, according to the volume of the component after any finishing operations and the specified material class. Density variation testing will apply to all lots of material for the initial 50 lots. If consistent results are achieved, the testing will be optional.

TABLE 3 Minimum Values for Mean Flexural Strength and Weibull Modulus

	Unit	Material Class		
		I	II	III
Transverse-rupture strength ^A 3 point $\sigma_{3,40}$ ($\sigma_{3,30}$)	MPa	900 [920]	800 [825]	600 [625]
Weibull modulus		12	9	7
Transverse-rupture strength ^A 4-point $\sigma_{4,40}$ ($\sigma_{4,30}$)	MPa	765 [805]	660 [705]	485 [530]
Weibull modulus		12	9	7

^A The Flexural strength equivalents are based on Weibull volume or surface scaling using the value of m for each cell and are rounded to the nearest 5 MPa.

$\sigma_{n,L}$ = denotes the flexure strength, $n = 3$ or 4 point, on spans of size L .
 $\sigma_{4,40} = 660$ MPa means the four point flexure strength, on 40 mm spans is 660 MPa as per Test Method **C1161** (size B) and CEN EN 843-1.

$\sigma_{4,30} = 705$ MPa means the four point flexure strength, on 30 mm spans is 705 MPa as per JIS R1601.

TABLE 4 Minimum Values for Hardness and Toughness

Property	Unit	Load	Material Class		
			I	II	III
Hardness	HV5	5 kg	1500	1400	1350
	HV10	kg/ mm ²	10 kg [†]	1380	1325
	HV20	20 kg	1460	1360	1300
Indentation Fracture Resistance, IFR (or "TP") (Annex A1)	MPa \sqrt{m}		6.0	5.0	5.0
Fracture Toughness, K_{Ic} (Test Methods C1421 or JIS R 1607)	MPa \sqrt{m}		6.0	5.0	5.0

[†] Editorially corrected in November 2016.

TABLE 5 Maximum Limits for Microstructural Constituents

	Material Class		
	I	II	III
Porosity: Size(μm) Volume Rating / ISO 4505	10 0.02	10 0.06	25 0.06
Metallic Phases: Size (μm)	10	10	25
Ceramic 2nd Phases: Size (μm)	25	25	25

TABLE 6 Maximum Number of Inclusions per cm² of Transverse Section

Maximum Extent in μm	Material Class		
	I	II	III
200	0	0	1
100 to <200	0	1	2
50 to <100	1	2	4
25 to <50	4	8	16

TABLE 7 Maximum Allowable Density Variation ($3 \times \text{Sigma}$) Within a Single Lot

Ball Diameter in Inches [mm]	Density Variation (g/cm ³)		
	Material Class		
	I	II	III
$\frac{3}{32}$ to $<\frac{15}{64}$ [2.38 to <5.95]	0.010	0.015	0.020
$\frac{15}{64}$ to $<\frac{13}{32}$ [5.95 to 10.32]	0.008	0.010	0.015
$\frac{13}{32}$ to $<\frac{5}{8}$ [10.32 to <15.88]	0.005	0.008	0.012
$\frac{5}{8}$ to $\frac{15}{16}$ [15.88 to 33.34]	0.005	0.005	0.010

8. Inspection and Verification

8.1 The intent of this section is to list possible observable indications and methods of inspection of finished balls. As the spectrum of applications for silicon nitride balls is very broad, this is not intended to define requirements, but to highlight these points. The type of observable indications, methods of inspection, and limits should be agreed upon by the customer and vendor to meet the specific requirements for a given application.

**TABLE 8 Quality Conformance Inspections**

Requirement	Inspection Level	AQL
Quality of geometry (see 8.6 for limits)	S4 ^A	0.4 %
Quality of surface (see 8.8 for tolerances)	S4	0.4 %
Surface roughness	Use sample size shown below and accept lot if all test results are within specifications	
	Number of Balls per Lot	Sample Size
	0–35 000	5
	35 001 and over	8

^A Minimum sample size of 32 balls shall apply only to lots of 1200 or more pieces. For lots of less than 1200, sample size shall be set by agreement between manufacturer and customer.

TABLE 9 Tolerances by Grade for Individual Balls Micrometers [Micro-inches]

Grade (G)	Allowable Ball Diameter Variation (V_{dws})	Allowable Deviation from Spherical Form (R_w)
2C	0.05 [2]	0.05 [2]
3C	0.08 [3]	0.08 [3]
5C	0.13 [5]	0.13 [5]
10C	0.25 [10]	0.25 [10]
16C	0.40 [16]	0.40 [16]
24C	0.61 [24]	0.61 [24]
48C	1.22 [48]	1.22 [48]

8.2 Unless otherwise specified, all dimensional and form inspections shall be performed under the following conditions:

8.2.1 *Temperature*—Room ambient 20° to 25°C [68° to 77°F].

8.2.2 *Humidity*—50 % relative, maximum.

8.3 Unless otherwise required, product shall be capable of passing acceptance inspection in accordance with ANSI/ASQC Z1.4 as specified in **Table 8**.

8.4 Certain manufacturer to manufacturer or lot to lot variation in color is acceptable. Color variation within a single ball should be investigated per **8.5**.

8.5 There may exist in silicon nitride bearing balls the observable indications listed in **8.5.1**, which may be inspected for using the methods in **8.5.4** as required.

8.5.1 *Types of Observable Indications:*

- (1) Color variation,
- (2) Inclusions,
- (3) Porosity,
- (4) Pressing defects, and
- (5) Snowflakes.

8.5.2 *Processing Origin:*

- (1) C-cracks,
- (2) Cuts,
- (3) Metallic smears,
- (4) Scratches, and
- (5) Scuffs.

8.5.3 *Material or Processing Origin:*

- (1) Cracks, and
- (2) Pits.

8.5.4 *Methods of Inspection:*

8.5.4.1 Visual white light (unaided eye and magnification-aided eye);

8.5.4.2 Black light (unaided eye and magnification-aided eye);

8.5.4.3 Fluorescent penetrant inspection (FPI) (unaided eye and magnification-aided eye); and

8.5.4.4 *Ultrasonic Inspection* (The following methods are currently in development and may require extensive evaluation to be applicable):

(1) Resonant inspection (resonant ultrasound spectroscopy),

(2) Rayleigh wave, and

(3) Acoustic microscopy.

8.6 Dimensional and Form.

8.6.1 *Tolerances by Grade for Individual Balls and Tolerances by Grade for Lots of Balls*—Tests shall be in accordance with **Tables 8-10**. A minimum of three measurements shall be taken in random orientations on each sample ball examined.

8.6.2 Acceptable methods of determining errors in spherical forms include the following: roundness measuring equipment procedures and Vee Block examination procedure. Explanation and details of these methods shall be as indicated in ABMA STD-10. Tests shall be in accordance with **Tables 8 and 9**.

8.7 The nominal diameter of the balls shall be as specified in the contract or purchase order. Tolerance limits for size variations and form deviations shall be in accordance with **Tables 9 and 10**.

8.8 The surface roughness of the balls shall not exceed the value specified in **Table 11** for the specified grade. Surface roughness shall be in accordance with ASME B 46.1.

9. Certificates of Quality and Material Certification

(This section contains information of a general or explanatory nature which may be helpful but is not mandatory.)

9.1 When specified in the contract or purchase order, certificates of quality (conformance) supplied by the manufacturer of the balls may be furnished in lieu of actual performance of such testing by the manufacturer, provided the lot identity has been maintained and can be demonstrated to the customer. The certificate may include:

- 9.1.1 Name of the customer,
- 9.1.2 Contract or purchase order number,
- 9.1.3 Name of the manufacturer or supplier,
- 9.1.4 NSN (National Stock Number) item identification number,
- 9.1.5 Name of the material,
- 9.1.6 Lot number,
- 9.1.7 Lot size.
- 9.1.8 Sample size,
- 9.1.9 Date of testing,
- 9.1.10 Test method,
- 9.1.11 Individual test results, and
- 9.1.12 Specification requirements.

9.2 When specified in the contract or purchase order, a certified report shall be available for review or when requested submitted by the manufacturer or supplier on each lot of balls. The report may contain the following:

TABLE 10 Tolerances by Grade for Lots of Balls Micrometers [Micro-inches]

Grade (G)	Allowable Lot Diameter Variation (V_{dwl})	Nominal Diameter Tolerance	Allowable Ball Gage Deviation (s)	
			High	Low
2C	0.08 [3]	±.51 [±20]	+ .51 [+20]	- .51 [-20]
3C	0.13 [5]	±.51 [±20]	+ .51 [+20]	- .51 [-20]
5C	0.25 [10]	±.76 [±30]	+ .76 [+30]	- .76 [-30]
10C	0.51 [20]	±2.54 [±100]	+1.27 [+50]	-1.02 [-40]
16C	0.80 [32]	±2.54 [±100]	+1.27 [+50]	-1.02 [-40]
24C	1.22 [48]	±2.54 [±100]	+2.54 [+100]	-2.54 [-100]
48C	2.44 [96]	N/A	N/A	N/A

TABLE 11 Surface Roughness by Grade for Individual Balls

Grade (G)	Maximum Surface Roughness Arithmetical Average (Ra) Micrometers [Micro-inches]
2C	0.004 [0.15]
3C	0.004 [0.15]
5C	0.005 [0.20]
10C	0.006 [0.25]
16C	0.009 [0.35]
24C	0.013 [0.50]
48C	0.013 [0.50]

TABLE 12 Preferred Ball Gages Micrometers

Grade (G)	Ball Gages	
	Minus Gages	Plus Gages
3C to 5C	-8 -7 -6 -5 -4 -3 -2 -1	0 +1 +2 +3 +4 +5 +6 +7 +8
10C to 16C	-10 -8 -6 -4 -2	0 +2 +4 +6 +8 +10
24C	-12 -10 -8 -6 -4 -2	0 +2 +4 +6 +8 +10 +12
48C	-16 -12 -8 -4	0 +4 +8 +12 +16

- 9.2.1 Contract or purchase order number,
- 9.2.2 Material specification number and revision,
- 9.2.3 Size,
- 9.2.4 Quantity,
- 9.2.5 Batch identification code,
- 9.2.6 Chemical analysis of silicon nitride that meets the blank manufacturer's specification (optional),

- 9.2.7 Flexural Strength (optional),
- 9.2.8 Materials properties as listed in **Table 2** of this specification (optional),
- 9.2.9 Hardness,
- 9.2.10 Fracture toughness, and
- 9.2.11 Microstructure ratings.
- 9.2.12 A statement that this material has been processed and tested in accordance with this specification (latest revision) and/or approved material specifications.
- 9.2.13 Contract or purchase order requirements other than those specified within this specification will have authority over this document.

10. Packaging

- 10.1 For acquisition purposes, the packaging requirements shall be as specified in the contract or order.
- 10.2 Preservatives are not required.

10.3 *Special Handling*. It is recommended that for Class I applications, balls $\frac{3}{8}$ inch in diameter and greater should be packaged to prevent ball-to-ball contact.

11. Keywords

- 11.1 ball bearings; bearing balls; ceramic; silicon nitride; Si_3N_4 ; precision balls

ANNEX

(Mandatory Information)

A1. VICKER'S HARDNESS AND NIIHARA'S TOUGHNESS MEASUREMENTS

A1.1 Measurements for hardness and toughness are made on a polished cross-section.

A1.2 Indentations for toughness measurement are made using a Vicker's indenter under the following conditions:

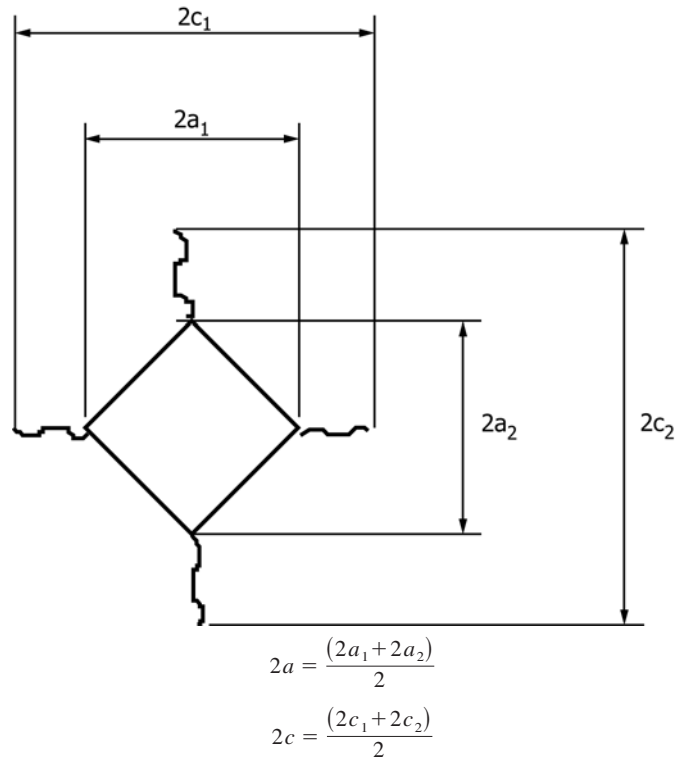


FIG. A1.1 Hardness and Toughness Calculation

Load 20 kgf
Dwell Time 30 s

A1.3 Hardness and toughness are calculated as follows (see Fig. A1.1):

A1.3.1 Measure both diagonals of each hardness impression as “*a*” values according to orientation except when impressions are placed on separate pieces.

A1.3.2 Measure visible tip-to-tip crack lengths associated with the hardness impressions as “*c*” values according to orientation except when impressions are placed on separate pieces.

A1.3.3 Calculate the mean values of $2a = (2a_1 + 2a_2)/2$ and $2c = (2c_1 + 2c_2)/2$ in micron (μm).

A1.3.4 Calculate the Vickers hardness value as follows:

$$HV = 1,854,400 P/(2a)^2$$

where:

HV = Vicker’s hardness number. The symbol should be written with the indentation load in kilograms denoted in parentheses (for example, HV(20) for a 20kgf load.)

P = the applied load in kilogram force (kgf).
a(2*a*/2) = the mean half length diagonal value in microns (μm).

A1.3.5 Calculate the indentation fracture resistance by Niihara’s method as follows:

$$IFR = 10.4 (E^{0.4}) (P^{0.6}) (a^{0.8}/c^{1.5})$$

where:

IFR = the indentation fracture resistance in megapascals–square root meter (Mpa·m^{1/2})
E = the elastic modulus in gigapascals (Gpa).
P = the applied load in kilogram force (kgf).
a = the mean half diagonal value in microns (μm).
c = the mean half tip-to-tip crack length in microns (μm).

A1.4 Alternative formulas or calibration constants for indentation fracture resistance may be used by mutual agreement of customer and vendor.

NOTE A1.1—The within-lab (repeatability) consistency of results by this method may be acceptable, but the between-laboratory (reproducibility) consistency is often poor due to variations in the interpretation of the crack length arising from microscopy limitations as well as operator experience or subjectivity.

APPENDIX

(Nonmandatory Information)

X1. Examples of Typical Current Markets (Arrows Indicate Potential Overlap)

RELATED MATERIAL

	Grade 2, 3	Grade 5	Grade 10, 16	Grade 24, 48
Class I				
Class II				
Class III				

FIG. X1.1 Examples of Typical Current Markets (Arrows Indicate Potential Overlap)

ASTM Standards:

- C373 Test Method for Water Absorption, Bulk Density, Apparent Porosity, and Apparent Specific Gravity of Fired Whiteware Products
- C1198 Test Method for Dynamic Youngs Modulus, Shear Modulus, and Poissons Ratio for Advanced Ceramics by Sonic Resonance
- C1239 Practice for Reporting Uniaxial Strength Data and Estimating Weibull Distribution Parameters for Advanced Ceramics
- C1327 Test Method for Vickers Indentation Hardness of Advanced Ceramics
- E165 Test Method for Liquid Penetrant Examination
- E384 Test Method for Microindentation Hardness of Materials
- E831 Test Method for Linear Thermal Expansion of Solid Materials by Thermomechanical Analysis
- E1417 Practice for Liquid Penetrant Testing

ABMA Standards:⁴ STD 1 Terminology for Anti-Friction Ball and Roller Bearings and Parts

DIN Standards:⁸

- 5401 Rolling Bearings; Balls of Through-Hardening Rolling Bearing

Steel, Part 1

- 5401 Rolling Bearings; Balls of Through-Hardening Rolling Bearing
- Steel, Part 2

ISO Standards:³

- 3290 Rolling Bearings, Bearing Parts, Balls for Rolling Bearings

JIS Standards:⁶

- R 1602 Testing Method for Elastic Modulus of High Performance Ceramics
- R 1603 Methods for Chemical Analysis of Fine Silicon Nitride Powders for Fine Ceramics
- R 1610 Testing Method for Vicker's Hardness of High Performance Ceramics
- R 1611 Testing Methods of Thermal Diffusivity, Specific Heat Capacity and Thermal Conductivity for High Performance Ceramics by Laser Flash Method
- R 1618 Measuring Method of Thermal Expansion of Fine Ceramics by Thermomechanical Analysis
- R 1624 Weibull Statistics of Strength Data for Fine Ceramics

CEN Standards:⁷

- EN 843-2 Advanced Technical Ceramics--Monolithic Ceramics--Mechanical Properties at Room Temperature, Part 2 Determination of Elastic Moduli

⁸ Application for copies should be addressed to the Deutsches Institut Für Normung (German Standards Institute), Burggrafenstrasse 6, D10787 Berlin, Germany.



ENV 843-4 Advanced Technical Ceramics—Monolithic Ceramics--
Mechanical Properties at Room Temperature, Part 4. Vickers, Knoop
and Rockwell Superficial Hardness Tests

EN 623-2 Advanced Technical Ceramics--Monolithic Ceramics--
General and Textural Properties--Determination of Density and Porosity

EN 821-2 Advanced Technical Ceramics--;Monolithic Ceramics--
Thermo-physical Properties—Part 2: Determination of Thermal Diffusivity by the Laser Flash (or Heat Pulse) method

EN 821-1 Advanced Technical Ceramics--Monolithic Ceramics--
Thermo-physical Properties--;Part 1: Determination of Thermal Expansion

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org). Permission rights to photocopy the standard may also be secured from the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, Tel: (978) 646-2600; <http://www.copyright.com/>