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Standard Specification for Silicon Nitride Bearing Balls[1]

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.

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.

1.3 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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, supersedes 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 Attributes[3]

2.4 *ABMA Standards:*

STD 10 Metal Balls[4]

2.5 *ASME Standard:*

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

2.6 *ISO Standards:*[6]

4505 Hardmetals—Metallographic Determination of Porosity and Uncombined Carbon

2.7 *JIS Standards:*

R 1601 Testing Method for Flexural Strength (Modulus of Rupture) of High Performance Ceramics[7]

R 1607 Testing Method for Fracture Toughness of High Performance Ceramics[7]

2.8 *CEN Standards:*

EN 843-1 Advanced Technical Ceramics—Monolithic Ceramics—Mechanical Properties at Room Temperature, Part 1. Determination of Flexural Strength[8]

ENV 843-5 Advanced Technical Ceramics—Monolithic Ceramics—Mechanical Properties at Room Temperature, Part 5, Statistical Analysis[8]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *ball diameter variation, Vdws, n*—ball diameter variation is the difference between the largest and smallest diameter measured on the same ball.

[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.

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

[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 Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

[7] 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.

[8] 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.

3.1.2 *ball gauge, 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 gauge, 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.

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

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 0.002 mm [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, ΔRw, 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 imhomogeneity 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, Vdwl, 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, Dwml, 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, Dwm, 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, Dw, 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, Dws, 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 Ra, 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.

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.

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

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.

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
Coefficient of thermal expansion, $\times 10^{-6}$/°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. Physical Properties

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

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 ×100 to ×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× on a polished section is not permissible.

7.1.6 The standard deviation of density measurements 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 the standard deviation 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	1480	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

TABLE 5 Maximum Limits for Microstructural Constituents

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

TABLE 6 Maximum Number of Inclusions per cm^2 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 Standard Deviation Within a Single Lot

Ball Diameter in Inches [mm]	Standard Deviation (g/cm^3) Material Class I	II	III
3/32 to <15/64 [2.38 to <5.95]	0.0033	0.005	0.0067
15/64 to <13/32 [5.95 to 10.32]	0.0027	0.0033	0.005
13/32 to <5/8 [10.32 to <15.88]	0.0017	0.0027	0.004
5/8 to 1 5/16 [15.88 to 33.34]	0.0017	0.0017	0.0033

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