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Standard Specification for Silicon Nitride Bearing Balls[1]

This standard is issued under the fixed designation F 2094; 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 establishes 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 are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

2. Referenced Documents

2.1 *Order of Precedence*:

2.1.1 In the event of a conflict between the test 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:*

C 373 Test for Water Absorption, Bulk Density[2]
C 1161 Test method for Flexural Strength of Advanced Ceramics at Ambient Temperature[3]
C 1198 Test method for Dynamic Young's Modulus, Shear Modulus, and Poisson's Ratio for Advanced Ceramics by Sonic Resonance[3]
C 1239 Practice for the Reporting Uniaxial Strength Data and Estimating Weibull Distribution Parameters for Advanced Ceramics[3]
C 1327 Test method for Vickers Indentation Hardness of Advanced Ceramics[3]
C 1421 Test Methods for the Determination of Fracture Toughness of Advanced Ceramic Materials at Ambient Temperatures[3]
E 165 Test Method for Liquid Penetrant Examination[4]
E 384 Test Method for Microhardness of Materials[5]
E 831 Test Method for Linear Thermal Expansion of Solid Materials by Thermomechanical Analysis[6]
E 1417 Practice for Liquid Penetrant Examination[4]

2.3 *ANSI Standard:*

ANSI/ASQC Z1.4 Sampling Procedures and Tables for Inspection by Attributes[7]

2.4 *ABMA Standards:*

STD 1 Terminology for Anti-Friction Ball and Roller Bearings and Parts[8]
STD 10 Metal Balls[8]

2.5 *ASME Standard:*

B 46.1 Surface Texture (Surface Roughness, Waviness, and Lay)[9]

2.6 *DIN Standards:*

5401 Rolling bearings; Balls of through-hardening rolling bearing steel, Part 1[10]
5401 Rolling bearings; Balls of through-hardening rolling bearing steel, Part 2[10]

2.7 *ISO Standards:*

3290 Rolling bearings, bearing parts, Balls for rolling bearings[11]
4505 Hardmetals—Metallographic Determination of Porosity and Uncombined Carbon[11]

2.8 *JIS Standards:*

R 1601 Testing Method for Flexural Strength (Modulus of Rupture) of High Performance Ceramics[12]
R 1602 Testing Method for Elastic Modulus of High Performance Ceramics[12]
R 1603 Methods for Chemical Analysis of Fine Silicon Nitride Powders for Fine Ceramics[12]
R 1607 Testing Method for Fracture Toughness of High Performance Ceramics[12]
R 1610 Testing Method for Vicker's Hardness of High Performance Ceramics[12]

[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 Elements.

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

[3] *Annual Book of ASTM Standards*, Vol 15.01.

[4] *Annual Book of ASTM Standards*, Vol 03.03.

[5] *Annual Book of ASTM Standards*, Vol 03.01.

[6] *Annual Book of ASTM Standards*, Vol 14.02.

[7] Application for copies should be addressed to the American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036.

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

[9] Application for copies should be addressed to the American Society of Mechanical Engineers, 345 East Street, New York, NY 10017.

[10] Application for copies should be addressed to the Deutsches Institut Für Normung (German Standards Institute), Burggrafenstrasse 6, D 10787 Berlin, Germany.

[11] Application for copies should be addressed to the American National Standards Institute, 11 West 42nd Street, New York, NY 10036-8002.

[12] Application for copies should be addressed to the Japanese Standards Association, 1-24 Akasaka 4 chome, Minato-ku, Tokyo. 107 Japan.

R 1611 Testing Methods of Thermal Diffusivity, Specific Heat Capacity and Thermal Conductivity for High Performance Ceramics by Laser Flash Method[12]

R 1618 Measuring method of thermal expansion of fine ceramics by thermomechanical analysis[12]

R 1624 Weibull Statistics of Strength Data for Fine Ceramics[12]

2.9 *CEN Standards:*

EN 843-1 Advanced Technical Ceramics—Monolithic Ceramics—Mechanical Properties at Room Temperature, Part 1. Determination of Flexural Strength[13]

EN 843-2 Advanced Technical Ceramics—Monolithic Ceramics—Mechanical Properties at Room Temperature, Part 2 Determination of Elastic Moduli[13]

ENV 843-4 Advanced Technical Ceramics—Monolithic Ceramics—Mechanical Properties at Room Temperature, Part 4. Vickers, Knoop and Rockwell Superficial Hardness Tests[13]

ENV 843-5 Advanced Technical Ceramics—Monolithic Ceramics—Mechanical Properties at Room Temperature, Part 5, Statistical Analysis[13]

EN 623-2 Advanced Technical Ceramics—Monolithic Ceramics—General and Textural Properties—Determination of Density and Porosity[13]

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[13]

EN 821-1 Advanced Technical Ceramics—Monolithic Ceramics—Thermo-physical Properties—Part 1: Determination of Thermal Expansion[13]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

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

3.1.2 *ball gage*, *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.

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

3.1.4 *ball grade*, *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 *basic diameter*, *n*—size ordered which is the basis to which the basic diameter tolerances apply. The basic diameter is specified in inches or millimeters (decimal form).

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

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

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

3.1.9 *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.

3.1.10 *lot diameter variation*, *n*—difference between the mean diameter of the largest ball and that of the smallest ball in the lot.

3.1.11 *lot mean diameter*, *n*—arithmetic mean of the mean diameter of the largest ball and that of the smallest ball in the lot.

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

3.1.13 *mean diameter of a ball*, *n*—arithmetic mean of the largest and the smallest actual single diameters of the ball.

3.1.14 *nominal size*, *n*—size which is used for the purpose of general identification, e.g. $1/16$, $1/8$, etc.

3.1.15 *specific diameter*, *n*—diameter marked on the unit container and expressed in the grade standard marking increment nearest to the average diameter of the balls in the container.

3.1.16 *unit container*, *n*—container identified as containing balls from the same manufacture lot of the same composition, grade and basic 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:[14]

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, etc.

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 and 8.6)

6. Material

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

6.2 Silicon nitride balls should be produced from either silicon nitride powder having the compositional limits listed in

[13] Application for copies should be addressed to the British Standards Institute, 389 Chiswick High Road, London, W4 4AL, UK.

[14] See Appendix X1 for typical current applications.

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 The following compounds may be added to promote densification and/or enhance product performance and quality. The following may be added as oxides, nitrides, oxynitrides, or mixtures:

6.4.1 Aluminum.

6.4.2 Magnesium.

6.4.3 Barium.

6.4.4 Lanthanum.

6.4.5 Yttrium.

6.4.6 Calcium

6.4.7 Other Rare Earths.

6.5 The following may be added as nitrides, oxynitrides, or carbonites:

6.5.1 Titanium.

6.5.2 Tantalum.

6.5.3 Zirconium.

6.6 Aluminum silicon oxynitrides (aluminum nitride polytypes) may be added to promote densification.

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

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

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

6.10 Notification will be made upon process changes.

6.11 Specific requirements such as specific material grade designation, physical/mechanical property requirements i.e. density, 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.

6.12 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.

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 ASTM C 1161 (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.

TABLE 1 Compositional Limits[A]

Constituents	Limits (wt %)
Silicon Nitride	97.0 Min.
Free silicon	0.3 Max.
Carbon	0.3 Max
Iron	0.1 Max.

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

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 (39150)	330 (47850)
Poisson's ratio	0.23	0.29
Thermal Conductivity, W/m-°K (Btu/h-ft-°F) – @ 20°C (Room Temp.)	20 (11.5)	38 (21.9)
Specific Heat, J/kg-°K (Btu/1bm-°F)	650 (0.167)	800 (0.191)
Coefficient of thermal expansion, $\times 10^6$/°C (Room Temp. to 500°C)	2.8	4.0
+ Resistivity, Ohm-m	10^{10}	10^{16}
+ Compressive Strength, MPa (ksi)	3000 (435)	

[A] Special material data should be obtained from individual suppliers.

TABLE 3 Minimum Values for Mean Flexural Strength & Weibull Modulus

		Material Class		
	Unit	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	700 (745)	600 (645)	450 (495)
Weibull modulus		10	8	6

[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 ASTM C 1161 (size B) and CEN EN 843-1.

$\sigma_{4,30}$ = 700 MPa means the four point flexure strength, on 30 mm spans is 700 MPa as per JIS R1601.