



Designation: **F2094/F2094M—11 F2094/F2094M – 13**

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.

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, 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 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](#)

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 May 1, 2011/Oct. 1, 2013. Published May 2011/October 2013. Originally approved in 2001. Last previous edition approved in 2008/2011 as F2094/F2094M—08/F2094/F2094M—11. DOI: 10.1520/F2094_F2094M-11.

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. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 ball diameter variation (V_{dws})—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)—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.

3.1.3 ball gage deviation (ΔS)—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)—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—lot, n —single group of same-sized ball blanks processed together from one material lot through densification.

3.1.6 ceramic second phase, n —additive phases, for example, yttria and alumina, which appear darker or lighter than the silicon nitride matrix, but are not highly reflective in nature.

3.1.7 deviation from spherical form (ΔR_w)—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.

3.1.8 finish lot—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.

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

3.1.9.1 Discussion—

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

3.1.10 lot diameter variation (V_{dwl})—variation, V_{dwl} , 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 (D_{wml})—diameter, D_{wml} , n —arithmetic mean of the mean diameter of the largest ball and that of the smallest ball in the lot.

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

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

3.1.14 metallic phase, n —material phase that is highly reflective when viewed by light microscopy

3.1.15 nominal diameter (D_w)—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).

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

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

3.1.18 surface roughness (R_a)— 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.

3.1.19 unit container—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, etc. 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 Silicon nitride balls should 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.
- 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.
 - 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 ~~ceramic-metallic or mixed~~ 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

TABLE 1 Compositional Limits for Starting Silicon Nitride Powders or Silicon Powder Converted to Silicon Nitride^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.

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-°K [Btu/h-ft-°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.

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.

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.

8. Inspection and Verification

8.1 The intent of this section is to list potential defects 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 defects, methods of inspection, and limits should be agreed upon by the customer and vendor to meet the specific requirements for a given application.

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.

**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	7	1480	1380	1325
	HV20	20 kg	1460	1360	1300	
Indentation Fracture Resistance, IFR (or "TP") (Annex A1)	MPa√m		6.0	5.0	5.0	
Fracture Toughness, K _{Ic} (Test Methods C1421 or JIS R 1607)	MPa√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 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 × Sigma) Within a Single Lot

Ball Diameter in Inches [mm]	Density Variation (g/cm ³)		
	Material Class		
	I	II	III
³ / ₃₂ to < ¹ / ₆₄ [2.38 to <5.95]	0.010	0.015	0.020
¹ / ₆₄ to < ¹ / ₃₂ [5.95 to 10.32]	0.008	0.010	0.015
¹ / ₃₂ to < ⁵ / ₁₆ [10.32 to <15.88]	0.005	0.008	0.012
⁵ / ₁₆ to ¹ / ₈ [15.88 to 33.34]	0.005	0.005	0.010

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 defects listed in Section 8.5.1, which may be inspected for using the methods in 8.5.2 as required.

8.5.1 Types of Defects:

8.5.1.1 Inclusions;

8.5.1.2 Porosity;

8.5.1.3 Pits, scratches, nicks, scuffs;

8.5.1.4 Cracks or linear indications; and

8.5.1.5 Color variation.



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 (Rw)
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]

8.5.2 Methods of Inspection:

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

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

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

8.5.2.4 *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,