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StandardSpecification for Silicon Nitride Cylindrical Bearing Rollers[1]

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1. Scope

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

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 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 *ASME Standard:*[3]

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

2.4 *JIS Standards:*[4]

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

R 1607 Testing Method for Fracture Toughness of High Performance Ceramics

2.5 *CEN Standards:*[5]

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

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

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *chips*—break-outs of material greater in extent than 0.25 mm typically at the corner chamfers or the junction of the chamfers with the cylindrical surface or end face.

3.1.2 *cracks*—irregular, narrow breaks in the surface of the roller typically having a visible width of less than 0.002 mm. 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.

3.1.3 *cuts*—short linear or circumferential grooves having a width of more than 0.005 mm and a length of more than 0.20 mm. Cuts are normally assessed under roller surface appearance but large and/or numerous cuts can be considered defects.

3.1.4 *flats*—flat bands running along the length of the cylindrical part of the roller, usually caused by a stop in rotation of the roller during machining. Flats can also be formed at one end only by incorrect approach into a machining operation.

3.1.5 *grooves*—shallow machining marks having a width of more than 0.005 mm extending more than 1⁄4 of the circumference on the cylindrical surface or having a length of more than ¼ of the roller diameter on the end faces.

3.1.6 *inclusions*—isolated areas of ceramic second phases or metallic appearing phases. Inclusions are often the result of contamination by foreign material during the roller blank manufacturing process.

[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] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Three Park Ave., New York, NY 10016-5990, http://www.asme.org.

[4] Available from Japanese Standards Organization (JSA), 4-1-24 Akasaka Minato-Ku, Tokyo, 107-8440, Japan, http://www.jsa.or.jp.

[5] Available from European Committee for Standardization (CEN), 36 rue de Stassart, B-1050, Brussels, Belgium, http://www.cenorm.be.

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

3.1.8 *mean roller diameter*—one half the sum of the largest and smallest of individual diameters measured in a single radial plane.

3.1.9 *mean roller length*—one half the sum of the largest and smallest lengths measured on a roller.

3.1.10 *metallic smears*—metallic material from machining or measuring equipment transferred onto the roller surface.

3.1.11 *pits*—voids or cavities in the roller surface. Pits can be formed by severe material pullout during roller finishing. Pits can also be a result of the breakout of inclusions during machining.

3.1.12 *porosity*—small, closely spaced voids permeating a region of the roller surface or the whole roller.

3.1.13 *pressing defects*—the result of cracks in roller preforms prior to densification. 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 roller. These are known as healed or partially healed pressing defects. Unhealed or open pressing defects can have the appearance of cracks or fissures.

3.1.14 *snowflakes*—regions of localized incomplete densification or regions in which the glassy phase is incompletely bonded to the silicon nitride grains. Snowflakes show up as white dendritic features when viewed with oblique illumination or with ultraviolet light after processing with a fluorescent penetrant.

3.1.15 *steps*—regions at the edge of a roller end face that have been machined to a lower depth than the rest of the end face.

3.1.16 *surface roughness (Ra)*—surface irregularities with relative small spacings, which usually include irregularities resulting from the method of manufacture being used, other influences, or both.

3.1.17 *tears*—circumferential machining marks associated with lateral surface cracks.

3.1.18 *unfinished areas*—regions on the roller surfaces that should be machined but have not been machined at all, or have not been completely machined and finished, due to either faults in blank geometry or errors in the machining process.

4. Classification

4.1 Silicon nitride materials for bearing applications are specified according to the following material classes:

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 applications. This group addresses the concerns of roller 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.).

4.1.4 A material grade approved as a Class I material may be supplied where Class II or III is specified and similarly, a Class II material for a Class III.

5. Roller Dimensions

5.1 Cylindrical rollers are generally identified using a nominal diameter (D) and nominal length (L) where the first value is that of nominal diameter (for example, 9×9 mm, 18×21 mm).

5.2 Rollers are normally manufactured to millimeter dimensions with D equal to L. However, many variations exist where L is larger or smaller than D. There may be a practical limitation to this as L becomes significantly larger than D because of pressing limitations. In these cases, the roller blank supplier should be consulted.

5.3 There should be sufficient stock allowance on the roller blank so that all surface skin effects are removed during machining.

5.4 Silicon nitride rollers should be machined entirely over the diameter and end face surfaces. Corner chamfers need not be machined providing the corners are uniform and have a smooth transition from the diameter to the end face.

6. Material

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

6.2 Silicon nitride rollers 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.

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.

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 ×100 to ×200 shall not exceed the maximum values given in Table 5 for the specified material class.

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/1bm-°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 R 1601.

TABLE 4 Minimum Values for Hardness and Toughness

Property	Unit	Load	Material Class I	II	III
Hardness					
HV5	kg/mm^2	5 kg	1500	1400	1350
HV10		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 (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

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× 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 × sigma) given in Table 7, according to the volume of the component after any finishing operations and the specified material class.

TABLE 6 Maximum Number of Inclusions per cm^2 of Transverse Section

Maximum Extent (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