INTERNATIONAL STANDARD

ISO 14628

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Fine ceramics (advanced ceramics, advanced technical ceramics) — Test method for rolling contact fatigue of silicon nitride ceramics at room temperature by balls-on-flat method

Céramiques techniques — Méthode d'essai de fatigue de contact de roulement des céramiques au nitrure de silicium à température ambiante par la méthode des billes sur surface plane

Reference number
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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 14628 was prepared by Technical Committee ISO/TC 206, *Fine ceramics*.

Introduction

Rolling contact fatigue (RCF) performance is essential for predicting the life of a rolling element. In general, RCF performance is evaluated from the life at a specific failure probability obtained by the Weibull analysis of test data under constant loading conditions. This International Standard specifies a fast and reliable method to compare RCF performance under stepwise loading as an alternative to accurate quantification by RCF tests under constant load. Ranking candidate materials, in other words comparison of performance among them, would be of value for choosing materials of required performance for bearings. In addition, material suppliers would receive feedback from the test results, allowing them to achieve a higher level of RCF performance.

Fine ceramics (advanced ceramics, advanced technical ceramics) — Test method for rolling contact fatigue of silicon nitride ceramics at room temperature by balls-on-flat method

1 Scope

This International Standard specifies a test method for rolling contact fatigue of silicon nitride ceramics under stepwise loading that is carried out at room temperature. This test may be used as follows: relative comparison of the rolling contact fatigue performance, a pass/fail test for material qualification of rolling elements or choosing an appropriate load level for RCF testing under constant load.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3290-1:2008, *Rolling bearings — Balls — Part 1: Steel balls*

ISO 3290-2:2008, *Rolling bearings — Balls — Part 2: Ceramic balls*

ISO 3611:2010, *Geometrical product specifications (GPS) — Dimensional measuring equipment: Micrometers for external measurements — Design and metrological characteristics*

ISO 4287:1997, *Geometrical Product Specification (GPS) —Surface texture: Profile method—Terms, definitions and surface texture parameters*

ISO/IEC 17025:2005, *General requirements for the competence of testing and calibration laboratories.*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
rolling contact
contact between rolling elements

NOTE Under pure rolling contact conditions, the relative velocity at the point of contact is zero. The relative velocity between real rolling elements is not, however, zero in most cases.

3.2
surface failure
flaking of test specimen surface

3.3
rolling contact fatigue
formation of surface failure due to cyclic rolling contact stress well below the stress when surface failure occurs under monotonic loading

3.4
rolling contact fatigue test
test where repeated rolling contact stress is applied to a test specimen, and the number of cycles to surface failure is measured

3.5
stepwise loading
loading method in which load is increased stepwise at regular intervals until the final failure of the test specimen

3.6
contact track
circular trail formed on a test specimen by repeated rolling contact of balls

3.7
mean effective load
constant load equivalent to stepwise loading

3.8
maximum Hertzian stress
maximum contact stress between two bodies using the elastic stress analyzing theory by Hertz

3.9
bearing-grade silicon nitride
silicon nitride ceramics specially designed for rolling elements

4 Principle

The life of flat plate under cyclic rolling contact stress, which is applied by balls rotating unidirectionally thereon, is determined by measuring the number of stress cycles to the final surface failure of the plate.

5 Testing machine

5.1 Structure of testing machine

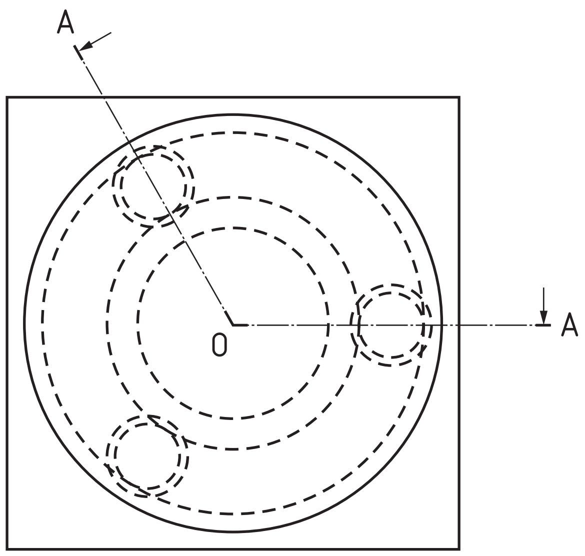
A testing machine shall be so constructed that rolling contact stress can be applied to the surface of a flat plate test specimen by balls thereon equally spaced with a retainer (see Figure 1). The balls shall be rolling in a circle with the rotation of the shaft washer of a 90° contact angle thrust ball bearing of a specified bore diameter. The shaft washer shall be rotated unidirectionally.

The testing machine is shown schematically in Figure 2. Load is applied by dead weights at the end of loading arm.

The testing machine shall be equipped with an automatic shutoff with a device detecting the surface failure, an apparatus capable of obtaining the number of rotations until the stop of testing, and a mechanism where its automatic reactivation is prevented when the testing machine is stopped for reasons of power failure or others.

NOTE 1 The shaft washer should be chosen on the basis of diameters of the ball and main shaft of the testing machine.

NOTE 2 The dimensions of the retainer depend on those of the shaft washer, ball diameter and number of balls.



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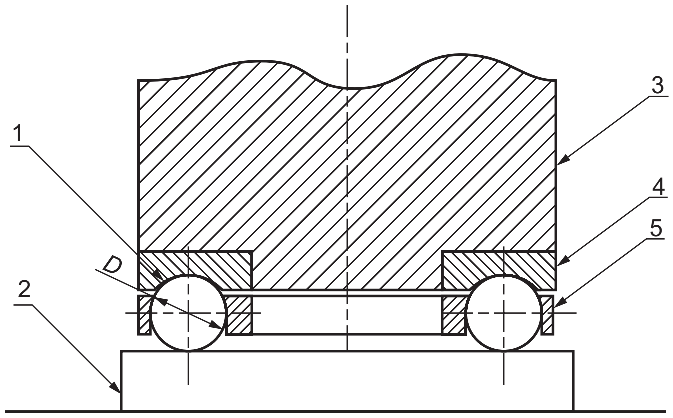


Key

1 ball of diameter *D*

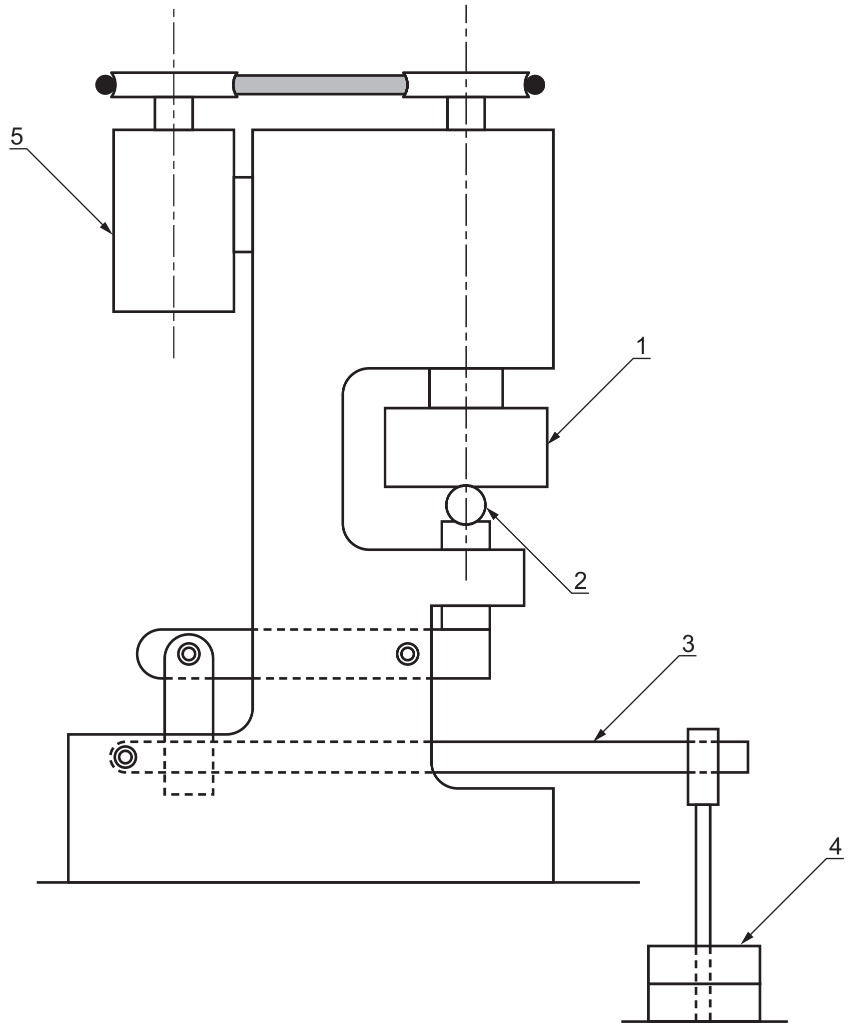
2 test specimen

3 main shaft of a testing machine

4 shaft washer of a 90° contact angle thrust bearing

5 retainer

Figure 1 —Balls-on-flat configurations



Key

1 oil bath (balls-on-flat configurations are inside)

2 ball for pivot point to sustain oil bath

3 loading lever

4 dead weight

5 motor

Figure 2 — Schematic of testing machine

5.2 Loading precision

The fluctuation of the test load shall be within ± 1 % of the chosen value.

NOTE The test load can be applied with a dead weight with accuracy thereof. Usually the load by dead weight(s) is increased with a lever by a specific factor.

6 Test specimens

6.1 Test specimen geometry

The test specimen shall be a flat plate. The parallelism tolerance on opposite surfaces of the plate is 0,015 mm. The use of test specimens having twisting or warpage, which may lead to oscillation of the testing apparatus, is not permitted. The test specimen shall have enough margin outside a contact track to be fixed, as well as to prevent the effect of the edge of the test specimen on the stress distribution around the point of contact, which may cause chipping of material.

6.2 Fixation of test specimen

The test specimen shall be fixed on the bottom of an oil bath to be immobilized and to prevent oscillation.

Special care should be paid to the surface finish and flatness of the bottom of the oil bath to fix the test specimen firmly thereon.

6.3 Specimen thickness

The specimen shall have enough thickness to prevent flexural oscillation of a plate. The thickness should be measured with a micrometer such as that described in ISO 3611 or alternative-dimension measuring instruments with a resolution of 0,002 mm or finer. If the specimen is measured before the test, measure the thickness at around the central part to avoid unnecessary contact to a prospective contact track.

6.4 Surface finish

The test specimen shall have a ground and polished surface. The roughness shall be 0,1 μm Ra or smaller, as defined in ISO 4287. Subsurface damage during grinding shall be removed by subsequent polishing to eliminate the effect thereof on the test result.

The skewness Rsk, as defined in ISO 4287, of the test specimen should also be measured.

NOTE When the Rsk exhibits a large positive value, it implies that the measured surface has more convex area than concave. The Rsk of a large positive value is not recommended for RCF testing because the test result may be affected by the surface integrity of a test specimen

6.5 Number of test specimens

The number of test specimens shall be based on the agreement between the tester and the requester. If a threshold value for a pass/fail test is set, at least five test specimens should be prepared.

7 Test method

7.1 Balls

Balls made of bearing-grade silicon nitride should be used for testing materials for bearing applications. The ball grade of balls should be G5 or G3, as defined in ISO 3290-2. If the purpose of the test is a pass/fail test for material qualification of rolling elements, bearing balls made of steel as defined in ISO 3290-1 may also be used.

Balls shall be in a retainer to keep a fixed spacing.

The ball diameter and number of balls should be agreed between a tester and a requester.

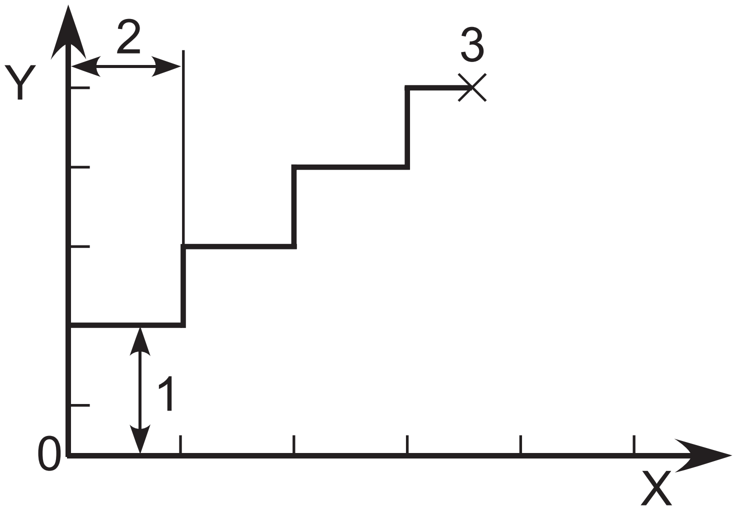
NOTE Three or six balls are commonly used in the balls-on-flat configuration.

7.2 Loading method

The test load shall be applied under the stepwise loading condition where the load is increased stepwise at regular intervals until a final failure as shown schematically in Figure 3. The starting load of the loading step and the loading interval should be agreed between a tester and a requester.

NOTE 1 Some sorts of silicon nitride ceramics may exhibit a sensitivity to loading history. An excessively low starting load may lead to overestimating of rolling contact fatigue performance.

NOTE 2 If the objective of the test is the relative comparison with existing data of tests under constant loading, the test may be conducted under constant load as an alternative.



Key

X number of revolutions

Y load (kN)

1 starting load

2 regular interval of loading

3 final failure of a test specimen

Figure 3 — Stepwise loading

7.3 Lubrication

The test specimen and balls shall be immersed in lubricating oil during a test.

The kinematic viscosity of oil should be chosen to maintain the contact under partial or complete elastohydrodynamic lubrication.

NOTE To maintain the contact under partial or complete elastohydrodynamic lubrication, a paraffinic oil of higher kinematic viscosity, such as 68 mm^2/s, should be chosen.

7.4 Detection of surface failure

The surface failure of a test specimen may be detected by the increase in vibrational acceleration of balls. An accelerometer should be mounted on a component where the vibration is mechanically amplified, such as the loading end of a loading lever. (See Figure 2.) If the acceleration exceeds a set threshold, the testing machine shall be automatically stopped.

NOTE To avoid automatic shutoff by noise, the set threshold may range from 2 to 3 times of the signal level for vibrational acceleration immediately after the start of testing at each loading step.

8 Treatment of test result

8.1 Mean effective load

Calculate the mean effective load P_m according to the following equation from loading conditions and number of rotations at each loading step until the stop of testing.

$$P_m = \left(\frac{\sum_{k=1}^{k} P_k^p N_k}{\sum_{k=1}^{k} N_k} \right)^{\frac{1}{p}} \tag{1}$$

where

P_k is the load per ball at k th loading step (N);

N_k is the number of revolution at k th loading step;

p is the exponential in the Lundberg and Palmgren theory equation shown below:

$$L = \left(\frac{C}{P} \right)^p \tag{2}$$

where

L is the basic rating life;

C is the basic dynamic load rating (N);

P is the dynamic equivalent load (N).

NOTE 1 Strictly, the exponential p should be determined experimentally for bearings made of each test material. Considering the scope of this International Standard, i.e. relative comparison of rolling contact fatigue performance, choosing a specified value for p is a practical solution.

NOTE 2 The p value may be taken as 3, which is widely accepted as the value for steel bearing balls used in commercially available hybrid ball bearings.

8.2 Mean effective mechanical input

Calculate the maximum Hertzian stress between a ball and test specimen at the load of $Q = P_m$ according to the following equation.

$$\left(p_{max} \right)_m = \frac{3Q}{2\pi a^2} = \frac{3P_m}{2\pi a^2} \tag{3}$$

where

Q is the load per ball (N);

a is the radius of the contact circle (m).

For contact between the ball and plate, a is expressed in terms of the following equation.

$$a = \left(\frac{3}{8} QD \left(\frac{1-\varepsilon_1^2}{E_1} + \frac{1-\varepsilon_2^2}{E_2} \right) \right)^{\frac{1}{3}} \quad (4)$$

where

D is the diameter of the ball (m);

E_1 is the elastic modulus of the ball (Pa);

E_2 is the elastic modulus of the plate (Pa);

ε_1 is the Poisson's ratio of the ball;

ε_2 is the Poisson's ratio of the plate.

Multiplying the maximum Hertzian stress by the number of stress cycles N_c provides the mean effective mechanical input.

$$\left(M_{in}\right)_m = N_c \cdot \left(p_{max}\right)_m \quad (5)$$

where N_c is half the product of total number of revolutions until the failure and the number of balls.

NOTE The equation for the mean effective mechanical input implies that material of a higher $(M_{in})_m$ value withstands higher loads for longer cycles with the assumption that the entire $(M_{in})_m$ is consumed in the rolling contact fatigue.

8.3 Flaking of ball surface

Flaking on the ball surface may cause the automatic stop of the testing machine. If surface damage such as scratch thereby is observed on the contact track, the test shall be terminated. If not, change the ball(s) with flaking and lubricating oil, and resume the test.

9 Test report

The test report shall be in accordance with ISO/IEC 17025, unless there are valid reasons for not doing so. The report of the results of a rolling contact fatigue test shall include the following items:

a) the name and address of the testing establishment;

b) the date of the test, a unique identification of the report and of each page, customer name and address, signatory of the report;

c) a reference to this International Standard, i.e. determined in accordance with ISO 14628.

d) a description of the test material, elastic modulus, batch codes, date of manufacture, as appropriate;

e) geometry and dimensions of test specimen;

f) surface roughness of test specimen;

g) a description of balls, diameter, ball grade, name of material, elastic modulus, etc.;

h) loading conditions (load and interval of each loading step);

i) a description of lubricating oil (name of manufacturer, product code, kinematic viscosity, etc.);

j) a list of test results (the number of stress cycles, mean effective mechanical input, etc.).

The report of the results of a rolling contact fatigue test should preferably also include the following items:

k) name of testing machine and its type;

l) kinds of additives and sintering method of test material;

m) sampling conditions of test specimen from material and its machining conditions (when a specimen is heat treated, its conditions are included);

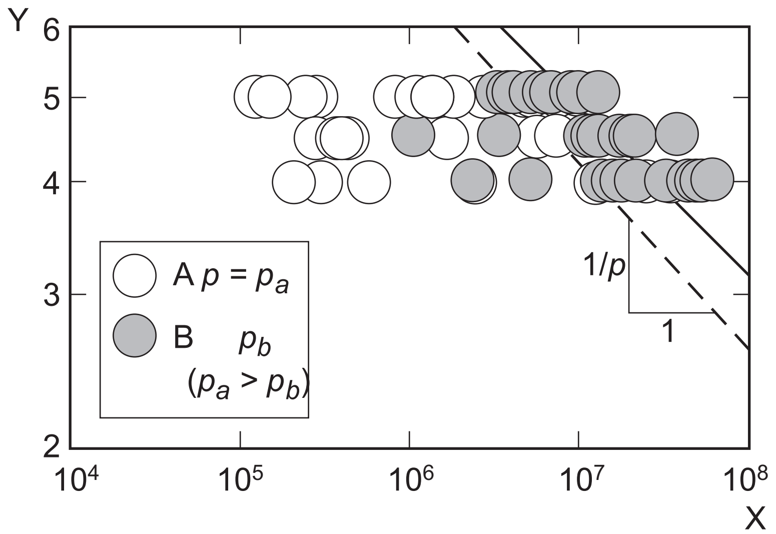
n) mechanical properties of test material, such as bending strength, fracture toughness value, etc..

Annex A
(informative)

General information

A.1 The p value of silicon nitride for the calculation of mean effective load

The exponent $\boldsymbol{p}$ defined in the well-known Lundberg and Palmgren theory is experimentally determined. The $\boldsymbol{p}$ value is the reciprocal of the slope in empirical fit in the load versus stress cycles relation (see Figure A.1). For silicon nitrides, there is no generally accepted value for $\boldsymbol{p}$, whereas the value of 3 is recognized as the $\boldsymbol{p}$ value for steel bearing balls. Some experimental attempts have been, however, made to determine this parameter and the mean value of $\boldsymbol{p}$ for silicon nitride has been reported in the range from 5,0 to 5,5; References [1,2].



Key

X life (stress cycles)

Y load (kN)

A material A

B material B

Figure A.1 — Example of load versus stress cycles plot for the determination of p

A.2 Lubrication

In the balls-on-flat testing configuration, the motion of balls involves sliding. Wear behavior between balls and a test specimen is strongly influenced by lubricating conditions. In this International Standard, oil bath lubrication is adopted. Specimen and balls are immersed in the same lubricating oil for the duration of the test. To prevent wear by third body particles, balls and the shaft washer should be replaced with new ones and test fixtures should be ultrasonically cleaned in acetone before every test.

A.3 Handling of test specimen and balls

A test specimen and balls must be handled with special care until they are introduced to the testing setup to reduce the likelihood of surface damage caused by solid-solid contact between them. The use of balls, which are the same as those used in hybrid bearings available commercially, is recommended because they should have been meticulously fabricated to minimize machining flaws which could cause ball failure during the rolling contact fatigue testing.

Bibliography

[1] E. V. Zaretsky, “Ceramic Bearings for Use in Gas Turbine Engines,” *Journal of Engineering for Gas Turbines and Power*, Vol. 111(January), 1989, pp. 146-157.

[2] W. Kanematsu, “Relative comparison method of rolling contact fatigue performance of silicon nitrides by stepwise loading balls-on-flat test - Experimental verification of validity of some assumptions for the method,” *J.ASTM International*, Vol.7, No.10, 2010, PaperID JAI103090.

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