Designation: G99 – 17

Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus[1]

This standard is issued under the fixed designation G99; 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 test method covers a laboratory procedure for determining the wear of materials during sliding using a pin-on-disk apparatus. Materials are tested in pairs under nominally non-abrasive conditions. The principal areas of experimental attention in using this type of apparatus to measure wear are described. The coefficient of friction may also be determined.

1.2 This test method standard uses a specific set of test parameters (load, sliding speed, materials, etc.) that were then used in an interlaboratory study (ILS), the results of which are given here (Tables 1 and 2). (This satisfies the ASTM form in that "The directions for performing the test should include all of the essential details as to apparatus, test specimen, procedure, and calculations needed to achieve satisfactory precision and bias.") Any user should report that they "followed the requirements of ASTM G99," where that is true.

1.3 Now it is often found in practice that users may follow all instructions given here, but choose other test parameters, such as load, speed, materials, environment, etc., and thereby obtain different test results. Such a use of this standard is encouraged as a means to improve wear testing methodology. However, it must be clearly stated in any report that, while the directions and protocol in Test Method G99 were followed (if true), the choices of test parameters were different from Test Method G99 values, and the test results were therefore also different from the Test Method G99 results. This use should be described as having "followed the procedure of ASTM G99." All test parameters that were used in such case must be stated.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E178 Practice for Dealing With Outlying Observations

G40 Terminology Relating to Wear and Erosion

G117 Guide for Calculating and Reporting Measures of Precision Using Data from Interlaboratory Wear or Erosion Tests (Withdrawn 2016)[3]

2.2 *DIN Standard:*[4]

DIN 50324 Testing of Friction and Wear

3. Summary of Test Method

3.1 For the pin-on-disk wear test, two specimens are required. One, a pin with a radiused tip, is positioned perpendicular to the other, usually a flat circular disk. A ball, rigidly held, is often used as the pin specimen. The test machine causes either the disk specimen or the pin specimen to revolve about the disk center. In either case, the sliding path is a circle on the disk surface. The plane of the disk may be oriented either horizontally or vertically.

NOTE 1—Wear results may differ for different orientations.

3.1.1 The pin specimen is pressed against the disk at a specified load usually by means of an arm or lever and attached weights. Other loading methods have been used, such as hydraulic or pneumatic.

NOTE 2—Wear results may differ for different loading methods.

3.2 Wear results are reported as volume loss in cubic millimetres for the pin and the disk separately. When two different materials are tested, it is recommended that each material be tested in both the pin and disk positions.

3.3 The amount of wear is determined by measuring appropriate linear dimensions of both specimens before and after the

[1] This test method is under the jurisdiction of ASTM Committee G02 on Wear and Erosion and is the direct responsibility of Subcommittee G02.40 on Non-Abrasive Wear.

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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] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from Beuth Verlag GmbH (DIN-- DIN Deutsches Institut fur Normung e.V.), Burggrafenstrasse 6, 10787, Berlin, Germany, http://www.en.din.de.

TABLE 1 Characteristics of the Interlaboratory Wear Test Specimens

NOTE 1—See Note 4 for information.

	Composition (weight%)	Microstructure	Hardness (HV 10)	Roughness[A]	
				R_z (mean) (µm)	R_a (mean) (µm)
Steel ball (100 Cr6) (AISI 52 100)[B] Diameter 10 mm	1.35 to 1.65 Cr ← 0.95 to 1.10 C 0.15 to 0.35 Si 0.25 to 0.45 Mn	martensitic with minor carbides and austenite	838 ± 21	0.100	0.010
Steel disc (100 Cr6) (AISI 52 100)[C] Diameter 40 mm	← <0.030 P <0.030 S	martensitic with minor carbides and austenite	852 ± 14	0.952	0.113
Alumina ball, diameter = 10 mm[D]	← 95 % Al_2O_3 (with additives of TiO_2,	equi-granular alpha alumina with very minor secondary	1610 ± 101 (HV 0.2)	1.369	0.123
Alumina disc, diameter = 40.6 mm[D]	← MgO, and ZnO)	phases	1599 ± 144 (HV 0.2)	0.968	0.041

[A] Measured by stylus profilometry. R_z is maximum peak-to-valley roughness. R_a is arithmetic average roughness.
[B] Standard ball-bearing balls (SKF).
[C] Standard spacers for thrust bearings (INA).
[D] Manufactured by Compagnie Industrielle des Ceramiques Electroniques, France.

TABLE 2 Results of the Interlaboratory Tests[A]

NOTE 1—See Note A for test conditions.

NOTE 2—Numbers in parentheses refer to all data received in the tests. In accordance with Practice E178, outlier data values were identified in some cases and discarded, resulting in the numbers without parentheses. The differences are seen to be small.

NOTE 3—Values preceded by ± are one standard deviation.

NOTE 4—Data were provided by 28 laboratories.

NOTE 5—Calculated quantities (for example, wear volume) are given as mean values only.

NOTE 6—Values labeled "NM" were found to be smaller than the reproducible limit of measurement.

NOTE 7—A similar compilation of test data is given in DIN 50324.

Results (ball) (disk)	Specimen Pairs			
	Steel-steel	Alumina-steel	Steel-alumina	Alumina-alumina
Ball wear scar diameter (mm)	2.11 ± 0.27 (2.11 ± 0.27)	NM	2.08 ± 0.35 (2.03 ± 0.41)	0.3± 0.06 (0.3 ± 0.06)
Ball wear volume (10^{-3} mm^3)	198 (198)	...	186 (169)	0.08 (0.08)
Number of values	102 (102)	...	60 (64)	56 (59)
Disk wear scar width (mm)	NM	0.64 ± 0.12 (0.64 ± 0.12)	NM	NM
Disk wear volume (10^{-3} mm^3)	...	480 (480)	...	...
Number of values	...	60 (60)	...	...
Friction coefficient	0.60 ± 0.11	0.76 ± 0.14	0.60 ± 0.12	0.41 ± 0.08
Number of values	109	75	64	76

[A] Test conditions: $F = 10\ N$; $v = 0.1\ ms^{-1}$, $T = 23°C$; relative humidity range 12 to 78 %; laboratory air; sliding distance 1000 m; wear track (nominal) diameter = 32 mm; materials: steel = AISI 52 100; and alumina = α-Al_2O_3.

test, or by weighing both specimens before and after the test. If linear measures of wear are used, the length change or shape change of the pin, and the depth or shape change of the disk wear track (in millimetres) are determined by any suitable metrological technique, such as electronic distance gaging or stylus profiling. Linear measures of wear are converted to wear volume (in cubic millimetres) by using appropriate geometric relations. Linear measures of wear are used frequently in practice since mass loss is often too small to measure precisely. If loss of mass is measured, the mass loss value is converted to volume loss (in cubic millimetres) using an appropriate value for the specimen density.

3.4 Wear results are usually obtained by conducting a test for a selected sliding distance and for selected values of load and speed. One set of test conditions that was used in an interlaboratory measurement series is given in Tables 1-3. Other test conditions may be selected depending on the purpose of the test. In such cases, the user should report their results as "following the procedure of ASTM G99."

3.5 Wear results may in some cases be reported as plots of wear volume versus sliding distance using different specimens for different distances. Such plots may display non-linear relationships between wear volume and distance over certain

TABLE 3 Test Parameters Used for Interlaboratory Tests

Normal Force (N)	10
Sliding Speed (m/s)	0.1
Sliding Distance (m)	1000
Pin-end Diameter, spherical (mm)	10
Environment	air
Temperature, nominal (°C)	23
Humidity, (%RH)	12–78
Track Diameter (mm)	25–35

portions of the total sliding distance, and linear relationships over other portions. Causes for such differing relationships include initial "break-in" processes, transitions between regions of different dominant wear mechanisms, and so forth. The extent of such non-linear periods depends on the details of the test system, materials, and test conditions.

3.6 It is not recommended that continuous wear depth data obtained from position-sensing gages be used because of the complicated effects of wear debris and transfer films present in the contact gap, and interferences from thermal expansion or contraction.

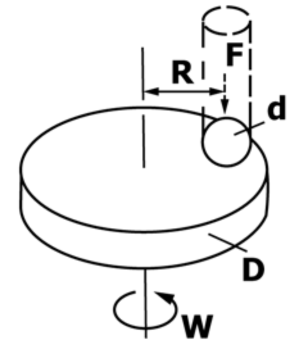
4. Significance and Use

4.1 The amount of wear in any system will, in general, depend upon the number of system factors such as the applied load, machine characteristics, sliding speed, sliding distance, the environment, and the material properties. The value of any wear test method lies in predicting the relative ranking of material combinations. Since the pin-on-disk test method does not attempt to duplicate all the conditions that may be experienced in service (for example; lubrication, load, pressure, contact geometry, removal of wear debris, and presence of corrosive environment), there is no insurance that the test will predict the wear rate of a given material under conditions differing from those in the test.

4.2 The use of this test method will fall in one of two categories: (*1*) the test(s) will follow all particulars of the standard, and the results will have been compared to the ILS data (Table 2), or (*2*) the test(s) will have followed the procedures/methodology of Test Method G99 but applied to other materials or using other parameters such as load, speed, materials, etc., or both. In this latter case, the results cannot be compared to the ILS data (Table 2). Further, it must be clearly stated what choices of test parameters/materials were chosen.

5. Apparatus

5.1 *General Description*—Fig. 1 shows a schematic drawing of a typical pin-on-disk wear test system.[5] One type of typical system consists of a driven spindle and chuck for holding the revolving disk, a lever-arm device to hold the pin, and attachments to allow the pin specimen to be forced against the revolving disk specimen with a controlled load. Another



NOTE 1—*F* is the normal force on the pin, *d* is the pin or ball diameter, *D* is the disk diameter, *R* is the wear track radius, and *w* is the rotation velocity of the disk.

FIG. 1 Schematic of Pin-on-Disk Wear Test System

type of system loads a pin revolving about the disk center against a stationary disk. In any case the wear track on the disk is a circle, involving multiple wear passes on the same track. The system may have a friction force measuring system, for example, a load cell, that allows the coefficient of friction to be determined.

5.2 *Motor Drive*—A variable speed motor, capable of maintaining constant speed (±1 % of rated full load motor speed) under load is required. The motor should be mounted in such a manner that its vibration does not affect the test. Rotating speeds are typically in the range 0.3 to 3 rad/s (60 to 600 r/min).

5.3 *Revolution Counter*—The machine shall be equipped with a revolution counter or its equivalent that will record the number of disk revolutions, and preferably have the ability to shut off the machine after a pre-selected number of revolutions.

5.4 *Pin Specimen Holder and Lever Arm*—In one typical system, the stationary specimen holder is attached to a lever arm that has a pivot. Adding weights, as one option of loading, produces a test force proportional to the mass of the weights applied. Ideally, the pivot of the arm should be located in the plane of the wearing contact to avoid extraneous loading forces due to the sliding friction. The pin holder and arm must be of substantial construction to reduce vibrational motion during the test.

5.5 *Wear Measuring Systems*—Instruments to obtain linear measures of wear should have a sensitivity of 2.5 µm or better. Any balance used to measure the mass loss of the test specimen shall have a sensitivity of 0.1 mg or better; in low wear situations greater sensitivity may be needed.

6. Test Specimens and Sample Preparation

6.1 *Materials*—This test method may be applied to a variety of materials. The only requirement is that specimens having the specified dimensions can be prepared and that they will withstand the stresses imposed during the test without failure or excessive flexure. The materials being tested shall be described by dimensions, surface finish, material type, form, composition, microstructure, processing treatments, and indentation hardness (if appropriate).

[5] A number of other reported designs for pin-on-disk systems are given in "A Catalog of Friction and Wear Devices," American Society of Lubrication Engineers (1973). Three commercially-built pin-on-disk machines were either involved in the interlaboratory testing for this standard or submitted test data that compared adequately to the interlaboratory test data. Further information on these machines can be found in Research Report RR:G02-1008.

6.2 *Test Specimens*—The typical pin specimen is cylindrical or spherical in shape. Typical cylindrical or spherical pin specimen diameters range from 2 to 10 mm. The typical disk specimen diameters range from 30 to 100 mm and have a thickness in the range of 2 to 10 mm. Specimen dimensions used in an interlaboratory test with pin-on-disk systems are given in Table 1.

6.3 *Surface Finish*—A ground surface roughness of 0.8 µm (32 µin.) arithmetic average or less is usually recommended.

NOTE 3—Rough surfaces make wear scar measurement difficult.

6.3.1 Care must be taken in surface preparation to avoid subsurface damage that alters the material significantly. Special surface preparation may be appropriate for some test programs. State the type of surface and surface preparation in the report.

7. Test Parameters

7.1 *Load*—Values of the force in Newtons at the wearing contact.

7.2 *Speed*—The relative sliding speed between the contacting surfaces in metres per second.

7.3 *Distance*—The accumulated sliding distance in meters.

7.4 *Temperature*—The temperature of one or both specimens at locations close to the wearing contact.

7.5 *Atmosphere*—The atmosphere (laboratory air, relative humidity, argon, lubricant, and so forth.) surrounding the wearing contact.

8. Procedure

8.1 Immediately prior to testing, and prior to measuring or weighing, clean and dry the specimens. Take care to remove all dirt and foreign matter from the specimens. Use non-chlorinated, non-film-forming cleaning agents and solvents. Dry materials with open grains to remove all traces of the cleaning fluids that may be entrapped in the material. Steel (ferromagnetic) specimens having residual magnetism should be demagnetized. Report the methods used for cleaning.

8.2 Measure appropriate specimen dimensions to the nearest 2.5 µm or weigh the specimens to the nearest 0.0001 g.

8.3 Insert the disk securely in the holding device so that the disk is fixed perpendicular (±1°) to the axis of the resolution.

8.4 Insert the pin specimen securely in its holder and, if necessary, adjust so that the specimen is perpendicular (±1°) to the disk surface when in contact, in order to maintain the necessary contact conditions.

8.5 Add the proper mass to the system lever or bale to develop the selected force pressing the pin against the disk.

8.6 Start the motor and adjust the speed to the desired value while holding the pin specimen out of contact with the disk. Stop the motor.

8.7 Set the revolution counter (or equivalent) to the desired number of revolutions.

8.8 Begin the test with the specimens in contact under load. The test is stopped when the desired number of revolutions is achieved. Tests should not be interrupted or restarted.

8.9 Remove the specimens and clean off any loose wear debris. Note the existence of features on or near the wear scar such as: protrusions, displaced metal, discoloration, microcracking, or spotting.

8.10 Remeasure the specimen dimensions to the nearest 2.5 µm or reweigh the specimens to the nearest 0.0001 g, as appropriate.

8.11 Repeat the test with additional specimens to obtain sufficient data for statistically significant results.

9. Calculation and Reporting

9.1 The wear measurements should be reported as the volume loss in cubic millimetres for the pin and disk, separately.

9.1.1 Use the following equations for calculating volume losses when the pin has initially a spherical end shape of radius *R* and the disk is initially flat, under the conditions that only one of the two members wears significantly:

$$\text{pin (spherical end) volume loss, mm}^3 \quad (1)$$

$$= \frac{\pi\,(\text{wear scar diameter, mm})^4}{64\,(\text{sphere radius, mm})}$$

assuming that there is *no significant disk wear*. This is an approximate geometric relation that is correct to 1 % for (wear scar diameter/sphere radius) <0.3, and is correct to 5 % for (wear scar diameter/sphere radius) <0.7. The exact equation is given in Appendix X1.

$$\text{disk volume loss, mm}^3 \quad (2)$$

$$= \frac{\pi\,(\text{wear track radius, mm})(\text{track width, mm})^3}{6\,(\text{sphere radius, mm})}$$

assuming that there is *no significant pin wear*. This is an approximate geometric relation that is correct to 1 % for (wear track width/sphere radius) <0.3, and is correct to 5 % for (wear track width/sphere radius) <0.8. The exact equation is given in Appendix X1.

9.1.2 Calculation of wear volumes for pin shapes of other geometries use the appropriate geometric relations, recognizing that assumptions regarding wear of each member may be required to justify the assumed final geometry.

9.1.3 Wear scar measurements should be done at least at two representative locations on the pin surfaces and disk surfaces, and the final results averaged.

9.1.4 In situations where both the pin and the disk wear significantly, it will be necessary to measure the wear depth profile on both members. A suitable method uses stylus profiling. Profiling is the only approach to determine the exact final shape of the wear surfaces and thereby to calculate the volume of material lost due to wear. In the case of disk wear, the average wear track profile can be integrated to obtain the track cross-section area, and multiplied by the average track length to obtain disk wear volume. In the case of pin wear, the wear scar profile can be measured in two orthogonal directions, the profile results averaged, and used in a figure-of-revolution calculated for pin wear volume.

9.1.4.1 If little wear has occurred as evidenced by very small wear scars, or if the wear scars are covered by any solid film formed during wear, it is best practice to use surface profilometry to determine wear volume. Further, if the amount of pin wear is small and the pin wear scar is not flat, profilometry must be used.

9.1.5 While mass loss results may be used internally in laboratories to compare materials of equivalent densities, this test method reports wear as volume loss so that there is no confusion caused by variations in density. Take care to use and report the best available density value for the materials tested when calculating volume loss from measured mass loss.

9.1.6 Use the following equation for conversion of mass loss to volume loss.

$$\text{volume loss, mm}^3 = \frac{\text{mass loss, g}}{\text{density, g/cm}^3} \times 1000. \quad (3)$$

9.2 If the materials being tested exhibit considerable transfer between specimens without loss from the system, volume loss may not adequately reflect the actual amount or severity of wear. In these cases, this test method for reporting wear should not be used.

9.3 Friction coefficient (defined in Terminology G40) should be reported when available. Describe the conditions associated with the friction measurements, for example, initial, steady-state, and so forth.

9.4 Adequate specification of the materials tested is important. As a minimum, the report should specify material type, form, processing treatments, surface finish, and specimen preparation procedures. If appropriate, indentation hardness should be reported.

10. Precision and Bias[6]

10.1 *Statement of Precision:*

10.1.1 The precision of the measurements obtained with this test method will depend upon the test parameters chosen. The reproducibility of repeated tests on the same material will depend upon material homogeneity, machine and material interaction, and careful adherence to the specified procedure by the machine operator. Normal variations in the wear test procedure will tend to reduce the precision of the test method as compared to the precision of such material property tests as hardness or density.

10.1.2 Table 2 contains wear data obtained from interlaboratory tests. Mean and standard deviation values are given for all measured quantities.

10.1.3 Statistical analysis (using Guide G117) of the steel vs. steel ball wear scar diameter results for 24 laboratories leads to a mean and standard deviation of 2.14 and 0.29 mm, respectively. The 95 % repeatability limit (within-lab) was 0.37 mm, and the 95 % reproducibility limit (between-labs) was 0.81 mm. Statistical analysis of the steel vs. steel ball friction results for 25 laboratories leads to a mean and standard deviation of 0.60 and 0.11, respectively. The 95 % repeatability limit (within-lab) was 0.19, and the 95 % reproducibility limit (between-labs) was 0.32.

10.2 *Statement of Bias*—No bias can be assigned to these results since there are no absolute accepted values for wear.

10.3 *General Considerations*—Participants in the interlaboratory testing that led to the statements of precision and bias given above involved 28 laboratories, 2 different materials (4 material pairs), 1 test condition, and 3 to 5 replicate measurements each (see Note 4). Subsequent to this testing, data were received from another laboratory that utilized a commercial test machine. These data were found consistent with the results in the interlaboratory study.

NOTE 4—The interlaboratory data given in Table 1 and Table 2 resulted through the cooperation of thirty one institutions in seven countries with the help of national representatives within the Versailles Advanced Materials and Standards (VAMAS) working party on wear test methods.[7]

11. Keywords

11.1 ceramic wear; friction; metal wear; non-abrasive; pin-on-disk; wear

[6] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:G02-1008.

[7] Czichos, H., Becker, S., and Lexow, J., *Wear*, Vol 114, 1987, pp. 109–130 and *Wear*, Vol 118, 1987, pp. 379–380.

APPENDIX

(Nonmandatory Information)

X1. EQUATIONS

X1.1 Exact equations for determining wear volume loss are as follows for:

X1.1.1 A spherical ended pin:

$$\text{pin volume loss} = (\pi h/6)[3d^2/4 + h^2] \quad (X1.1)$$

where:

h = $r - [r^2 - d^2/4]^{1/2}$
d = wear scar diameter, and
r = pin end radius.

Assuming no significant disk wear.

X1.1.2 A disk:

$$\text{disk volume loss} = 2\pi R\left[r^2 \sin^{-1}(d/2r) - (d/4)(4r^2 - d^2)^{1/2}\right] \quad (X1.2)$$

where:

R = wear track radius, and
d = wear track width.

Assuming no significant pin wear.