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

This standard is issued under the fixed designation G 99; 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 reaffirmation. A superscript epsilon (ε) indicates an editorial change since the last revision or reaffirmation.

1. Scope

1.1 This test method describes 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 The values stated in SI units are to be regarded as standard.

1.3 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:

E 122 Practice for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E 178 Practice for Dealing with Outlying Observations

G 40 Terminology Relating to Wear and Erosion

2.2 Other Standard:

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 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 Table 1 and Table 2 as a guide. Other test conditions may be selected depending on the purpose of the test.

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 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, etc. 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 assurance that the test will predict the wear rate of a given material under conditions differing from those in the test.

5. Apparatus

5.1 General Description—Fig. 1 shows a schematic drawing of a typical pin-on-disk wear test system, and photographs of two differently designed apparatuses. 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, a lever-arm device to hold the pin, and attachments to allow the pin specimen to be forced against 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. Another type of system loads a pin revolving about the disk center against a station.

TABLE 1 Characteristics of the Interlaboratory Wear Test Specimens

<table>
<thead>
<tr>
<th>Specimen Pair</th>
<th>Composition (weight%)</th>
<th>Microstructure</th>
<th>Hardness (HV 10)</th>
<th>Roughness*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel ball (100Cr6) (AISI 52 100)</td>
<td>1.35 to 1.65 Cr → 0.95 to 1.10 C</td>
<td>martensitic with minor carbides and austenite</td>
<td>838 ± 21</td>
<td>0.100 0.010</td>
</tr>
<tr>
<td>Steel disc (100Cr6) (AISI 52 100)</td>
<td>0.25 to 0.45 Mn</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;0.030 P</td>
<td>martensitic with minor carbides and austenite</td>
<td>852 ± 14</td>
<td>0.952 0.113</td>
</tr>
<tr>
<td>Alumina ball, diameter 10 mm²</td>
<td>95% Al₂O₃ with additives of TiO₂</td>
<td>equi-granular alpha alumina with very minor secondary phases</td>
<td>1610 ± 101 (HV 0.2)</td>
<td>1.369 0.123</td>
</tr>
<tr>
<td>Alumina disc, diameter 40.6 mm²</td>
<td>MgO and ZnO</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Measured by stylus profilometry. Rₜ is maximum peak-to-valley roughness. Rₐ is arithmetic average roughness.

TABLE 2 Results of the Interlaboratory Tests

<table>
<thead>
<tr>
<th>Results (ball) (disk)</th>
<th>Specimen Pairs</th>
<th>Steel-steel</th>
<th>Alumina-steel</th>
<th>Steel-alumina</th>
<th>Alumina-alumina</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball wear diameter (mm)</td>
<td>2.11 ± 0.27</td>
<td>NM</td>
<td>2.08 ± 0.35</td>
<td>0.3 ± 0.06</td>
<td></td>
</tr>
<tr>
<td>Ball wear volume (10⁻³ mm³)</td>
<td>198</td>
<td>(198)</td>
<td>186</td>
<td>(169)</td>
<td>(0.08)</td>
</tr>
<tr>
<td>Number of values</td>
<td>102</td>
<td>60</td>
<td>60</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>Disk wear width (mm)</td>
<td>NM</td>
<td>0.64 ± 0.12</td>
<td>NM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disk wear volume (10⁻³ mm³)</td>
<td>...</td>
<td>480</td>
<td>...</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>Number of values</td>
<td>109</td>
<td>75</td>
<td>64</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>Friction coefficient</td>
<td>0.60 ± 0.11</td>
<td>0.76 ± 0.14</td>
<td>0.60 ± 0.12</td>
<td>0.41 ± 0.08</td>
<td></td>
</tr>
</tbody>
</table>

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-Al₂O₃.

5.1 General Description—Fig. 1 shows a schematic drawing of a typical pin-on-disk wear test system, and photographs of two differently designed apparatuses. 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 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 main-
taining 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 inden-
tation hardness (if appropriate).

6.2 Test Specimens—The typical pin specimen is cylindrical
or spherical in shape. Typical cylindrical or spherical pin

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 (a) Schematic of pin-on-disk wear test system. (b) Photographs of two different designs.**
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, etc.) 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 nonchlorinated, 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:

$$\text{pin (spherical end) volume loss, mm}^3 = \frac{\pi (\text{wear scar diameter, mm})^3}{64 (\text{sphere radius, mm})}$$

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.

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

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.

9.1.5 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.

$$\text{volume loss, mm}^3 = \frac{\text{mass loss, g}}{\text{density, g/cm}^3} \times 1000.$$
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 G 40) should be reported when available. Describe the conditions associated with the friction measurements, for example, initial, steady-state, etc.

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

10.1 The precision and bias of the measurements obtained with this test method will depend upon the test parameters chosen.

10.2 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.

10.3 Normal variations in the procedure will tend to reduce the accuracy of the test method as compared to the accuracy of such material property tests as hardness, density, or thermal expansion rate. Properly conducted tests should, however, maintain a within-laboratory coefficient of variation of 20 % or less for wear loss values. Table 2 contains wear data obtained from interlaboratory tests (see Note 4). Standard deviation values are given for the measured quantities. Limits of 95 % repeatability can be obtained by multiplying those standard deviation values by the factor 2.8 ×. Reproducibility limits (between laboratories) are not available but are estimated to be twice as large as the repeatability limits.

10.4 No bias can be assigned to these results since there are no absolute accepted values for wear.

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.

10.5 In any test series, all data must be considered in the calculation, including outliers (data exceeding the obvious range); they are treated according to Practice E 178.

10.6 While two or more laboratories may develop test data that is within the acceptable coefficient of variation for their own individual test apparatus, the actual data of each laboratory may be relatively far apart. The selection of sample size and the test method for establishing the significance of the difference in averages shall be agreed upon between laboratories and shall be based on established statistical methods of Practice E 122, Practice E 177, and STP 15D.

11. Keywords

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

Additional data are available at ASTM Headquarters.

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:

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

(X1.1)

where:

\[ h = r \left[ r^2 - d^2/4 \right]^{1/2} \]

\[ d = \text{wear scar diameter}, \text{ and} \]

\[ r = \text{pin end radius}. \]

Assuming no significant disk wear.

X1.1.2 A disk:

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

(X1.2)

where:

\[ R = \text{wear track radius}, \text{ and} \]

\[ d = \text{wear track width}. \]

Assuming no significant pin wear.

