Designation: G 83 – 96

Standard Test Method for
Wear Testing with a Crossed-Cylinder Apparatus[1]

This standard is issued under the fixed designation G 83; 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 test for ranking metallic couples in their resistance to sliding wear using the crossed-cylinder apparatus. During the test, wear occurs at a contact between a rotating cyclinder and a stationary cylinder which have their long axes oriented normal to each other.

1.2 When the rotating and stationary cylinders are of the same material, wear test results are reported as the total volume loss in cubic millimetres for the rotating and stationary cylinders. The manner of recording the results also specifies the particular test procedure used. The value is obtained by adding the volume loss of the rotating member to the volume loss of the nonrotating member. Materials of higher wear resistance will have lower volume loss.

NOTE 1—To attain uniformity among laboratories, it is the intent of this test method to require that volume loss due to wear be reported only in the metric system as cubic millimetres (1 $mm^3 = 6.102 \times 10^{-5}$ $in.^3$).

1.3 When dissimilar materials are being tested, wear test results are reported as the total volume loss in cubic millimetres for the rotating and stationary test cylinders as well as the volume loss of each cylinder separately. When two different metals or alloys are tested, it is also recommended that each metal or alloy be tested in both the stationary and moving positions. Then, for each metal or alloy, the combined volume of wear in both positions should be used in comparisons with self-mated wear volume.

1.4 The test method describes three recommended procedures that are appropriate for different degrees of wear resistance.

NOTE 2—The crossed-cylinder wear test inherently exhibits a time varying contact area. A plot of wear volume versus sliding distance is typically nonlinear. Therefore, results obtained using parameters other than those specified in the test method cannot be used to calculate an expected value.

1.4.1 *Procedure A*—This is a relatively severe test that will rank metallic materials which have high-wear resistance. Materials with wear resistance in the high-speed tool steel category are particularly suited to this test.

1.4.2 *Procedure B*—This is a short-term variation of Procedure A.

1.4.3 *Procedure C*—This is a lower speed and shorter term variation of Procedure A that is particularly useful in ranking materials of low-wear resistance.

1.5 In reporting, the values stated in SI units are preferred.

1.6 *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[2]

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[2]

G 40 Terminology Relating to Wear and Erosion[3]

3. Terminology

3.1 Definitions used in this test method are defined in accordance with Terminology G 40 as follows:

3.1.1 *coefficient of friction or f in tribology*—the dimensionless ratio of the friction force (F) between two bodies to the normal force (N) pressing these bodies together

$$\mu = (F/N)$$

3.1.2 *debris*—in tribology, particles that have become detached in a wear or erosion process.

3.1.3 *lubricant*—any substance interposed between two surfaces for the purpose of reducing the friction or wear between them.

3.1.4 *wear*—damage to a solid surface generally involving progressive loss of material, due to relative motion between that surface and a contracting substance or substances.

3.1.5 *wear rate*—the rate of material removal or dimensional change due to wear per unit of exposure parameter for example, quantity of material removed (mass, volume, thickness) in unit distance of sliding or unit time.

3.1.5.1 *Discussion*—Because of the possibility of confusion, the manner of computing wear rate should always be carefully specified.

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[1] This test method is under the jurisdiction of ASTM Committee G-2 on Wear and Erosion and is the direct responsibility of Subcommittee G02.40 on Non-Abrasive Wear.

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[2] *Annual Book of ASTM Standards*, Vol 14.02.

[3] *Annual Book of ASTM Standards*, Vol 03.02.

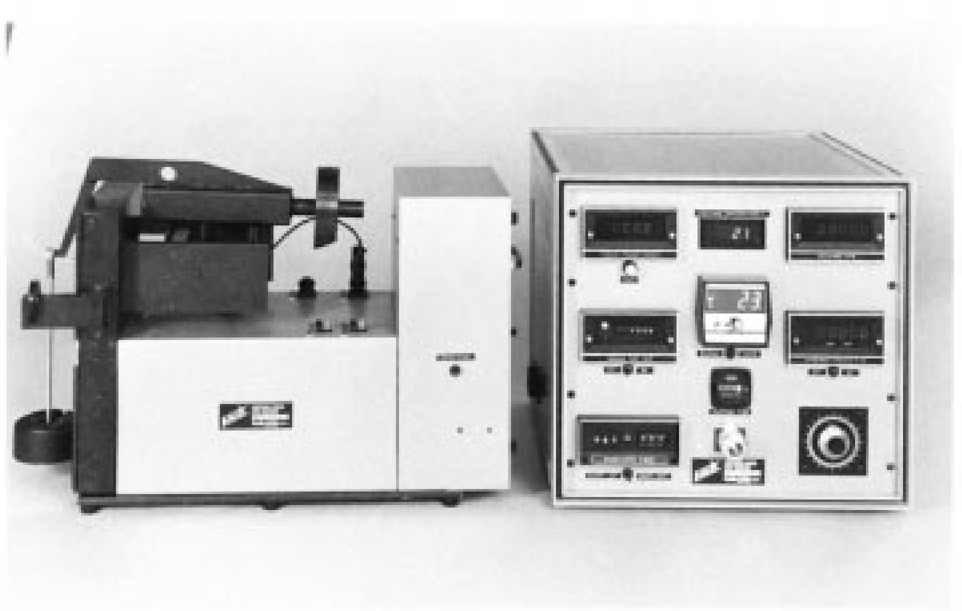

FIG. 1 Falex Crossed Cylinders Test Machine

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *applied load*—the dead-weight load placed on the crossed-cylinders.

3.2.1.1 *Discussion*—The weight of the stationary specimen holder is included.

3.2.2 *crossed-cylinder apparatus*—machine capable of testing two cylindrical specimens, positioned perpendicular to each other under load, one rotating at a specified speed while the other is stationary.

3.2.3 *sliding distance*—the distance computed, as the product of the circumference of the unworn cylinder and the number of revolutions.

3.2.4 *sliding speed*—the test speed of the rotating specimen.

3.2.5 *wear track*—the visual surface damage due to relative motion between the crossed cylinder specimens.

4. Summary of Test Method

4.1 For the crossed-cylinder wear test, two cylindrical specimens are positioned perpendicular to each other. The test machine should allow one specimen to rotate at speeds up to 400 r/min. The second, nonrotating specimen is pressed against the rotating specimens at a specified load by means of an arm and attached weights. It is the intent of the apparatus design that dead-weight loading be used. The test duration and rotational speed are varied as noted in Procedures A through C (see Section 8).

4.2 The amount of wear is determined by weighing the specimens before and after the test. Because of the wide differences in the density of materials, it is necessary to convert the weight loss to volume loss in cubic millimetres. Wear measurements are reported as volume loss per specified procedure.

5. Significance and Use

5.1 The amount of wear in any system will, in general, depend upon a number of factors such as the applied load, sliding speed, the sliding distance, environment as well as the material properties. In this test method, these conditions are standardized to provide a means of determining the relative wear rates of different metal couples. The value of the test method lies in predicting the relative ranking of various materials where metal-to-metal contact takes place. Since the test method does not attempt to duplicate all the conditions that may be experienced in service (for example, lubricant, load, removal of wear debris, and presence of corrosive environment), there is no assurance that the test will predict the relative wear rate of a given material under conditions differing from those in the test.

6. Apparatus

6.1 *General Description*—Fig. 1 shows a commercially available design of this test equipment. This type of machine will typically consist of a belt-driven spindle, a chuck or collet device for holding the rotating specimen, a lever-arm device to hold the nonrotating specimen and attachments to allow the nonrotating specimen to be forced against the rotating specimen with a controlled load. The commercially available unit has an optional friction force measuring system that allows coefficient of friction to be calculated.[4,5]

6.2 *Rotating Specimen Holder*—This critical part of the test device consists of a chuck or collet and an accurate bearing system. A three-jaw chuck has been found to be unsatisfactory and its use is not recommended.

6.3 *Motor Drive*—A variable speed motor, capable of maintaining constant speed under load is required. A minimum

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[4] Original users of this test method designed and fabricated their own test machines.

[5] The sole source of supply of a commercially built apparatus known to the committee at this time is Falex Corp., 2055 Comprehensive Dr., Aurora, IL 60505. If you are aware of alternative suppliers, please provide this information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend.

motor size should be 0.56 kW (¾ hp). The motor should be mounted in such a manner that its vibration does not affect the two cylinders. The drive system between the rotating specimen and the motor should be positive so that there is no slippage. A variable test speed up to 400 r/min (41.9 rad/s) should be obtainable. The test speed should be accurately set, preferrably with a digital speed readout.

6.4 *Revolution Counter*—The machine shall be equipped with a revolution counter that will record the number of specimen revolutions as specified in the procedure. It is recommended that the cycle counter have the ability to shut off the machine after a preselected number of revolutions is obtained.

6.5 *Nonrotating Specimen Holder and Lever Arm*—The specimen holder is attached to the lever arm which has a pivot. If the lever is unbalanced, it is necessary to check the loading at the specimens with a direct-force measurement. The commercial design utilizes a calibrated lever that is balanced and the weights produce a test force proportional to the weights applied.

6.6 *Analytical Balance*—The balance used to measure the loss in mass of the test specimen shall have a sensitivity of 0.1 mg.

7. Test Specimens and Their Preparation

7.1 *Materials*—This test may be applied to a variety of metallic materials, such as wrought metals, castings, plasma spray deposits, and powder metals. 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 composition, heat treatment, product form, and hardness.

7.2 *Specimen Specifications*—The typical specimen is cylindrical in shape having dimensions 12.7-mm diameter times 102-mm long (0.5-in. diameter times 4.0-in. long) as shown in Fig. 2. Since the runout is critical all specimens shall be ground on centers capable of maintaining cylindricity of the specimen outside diameter within 0.0025 mm (0.0001 in.).

7.3 *Specimen Finish*—Test specimens shall be straight and free from scale. Surface roughness of 1.25 µm (32 µin.) arithmetic average or less is acceptable. Measurements shall be made with the trace parallel to the cylinder axis. State the type of surface or surface preparation in the data sheet.

8. Test Parameters

8.1 Table 1 specifies the applied force, the number of revolutions, and the test speed for the three test procedures.

TABLE 1 Test Parameters

Specified Procedure	Applied Force[A]			Revolutions	Speed, r/min[B]
	Equivalent (Newtons)	Force kgf	(Pounds Equivalent)		
A	71.2	7.26	16	80 000	400
B	71.2	7.26	16	40 000	400
C	71.2	7.26	16	10 000	100

[A] Force Tolerance is ±3 %.

[B] Speed Tolerance is ±2 %.

8.2 *Duration*—The duration of the test will be approximately 200 min for Procedure A, and 100 min for Procedures B and C. The number of revolutions and not the time shall be the controlling parameter.

9. Procedure

9.1 *Cleaning*—Immediately prior to weighing, the specimens must be cleaned and dried. Care must be taken to remove all dirt and foreign matter from the specimen. Materials with open grains (some powder metals) must be dried to remove all traces of the cleaning solvent which may be entrapped in the material. Demagnetize steel specimens having residual magnetism. Record the methods used for cleaning.

9.2 Weigh the specimens to the nearest 0.0001 g.

9.3 The rotating cylinder is inserted in the chucking device. A dial gage is placed perpendicular to the rotating cylinder on the likely location of the wear track. The dial indicator is read continuously as the rotating cylinder goes through one or more complete revolutions. The deviation from the center reading on the dial gage shall be less than 0.0051 mm (0.0002 in.). The final determination of concentricity shall be determined at the speed of the desired test.

9.4 Insert the nonrotating specimen securely in its holder and add the proper mass to develop the prescribed force pressing the nonrotating specimen against the rotating specimen. The force may be measured by means of an accurate spring scale that is hooked around the specimen and pulled back to lift the specimen away from the wheel.

9.5 Set the revolution counter to the prescribed number of revolutions.

9.6 Start the rotation, adjust the speed to within the ± 2 r/min at 100 r/min and ±8 r/min at 400 r/min.

9.7 When the test has run the desired number of revolutions, lift the stationary specimen away from the rotating specimen.

9.8 Remove the specimens and clean the specimen of wear debris. Note the existence of any lip, displaced metal, retained oxide, discoloration, microcracking, or spotting.

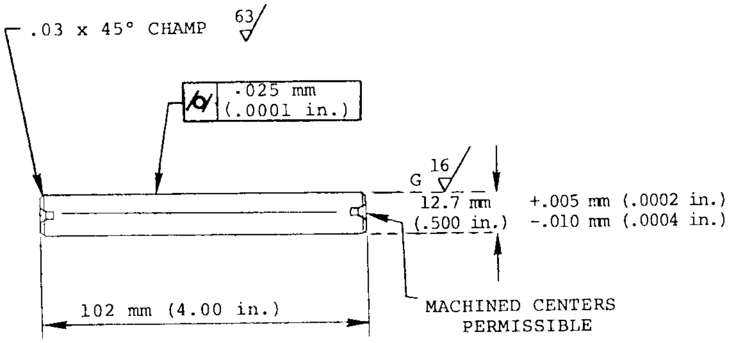

FIG. 2 Typical Test Specimen

9.9 Reweigh the specimens to the nearest 0.0001 g.

10. Report

10.1 The wear test results should be reported as the total volume loss in cubic millimetres for like couples per the specified procedure used in the test. The volume loss for each bar in each position should be reported for dissimilar couples.

10.1.1 For example, ______mm^3 per ASTM ______, Procedure______ . While mass loss results may be used internally in test laboratories to compare materials of equivalent densities, it is essential that all users of this test procedure report their results uniformly as volume loss in publications or reports so that there is no confusion caused by variations in density. Care should be taken to use the best available density value for the specific materials(s) tested.

10.1.2 The following equation for conversion of mass loss to volume loss shall be used:

$$\text{Volume loss, mm}^3 = \frac{\text{Mass loss, g}}{\text{Density, g/cm}^3} \times 1000$$

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

10.3 If the materials being tested exhibit physical deformation during the test and the displaced metal increases the specimen diameter by more than 0.002 in. (0.051 mm) then this test method should not be used.

11. Precision and Bias

11.1 The precision and bias of the measurements obtained with this test procedure will depend upon strict adherence to the specified test parameters.

11.2 The reproducibility of repeated tests on the same material will depend upon material homogeneity, machine and material interaction, and careful adherence to the specified test procedure by a competent machine operator.

11.3 Normal variations in the procedure will tend to reduce the accuracy of the method as compared to the accuracy of such material property tests as hardness, density, or thermal expansion rate. Properly conducted tests will, however, maintain a within laboratory coefficient of variation of 15 % or less for the volume-loss values. Interlaboratory tests have shown a coefficient of variation of 30 % between laboratories.

11.4 *Initial Machine Operation and Qualification*—The number of tests required to establish the precision of the machine for initial machine operations shall be at least five for each of the Test Procedures A, B, and C. The test samples shall be taken from the same homogeneous material.

11.5 The standard deviation from the mean average shall be calculated from the accumulated test results and reduced to the coefficient of variation. The coefficient of variation shall not exceed 15 %. If this value is exceeded, the machine operation shall be considered out of control and steps taken to eliminate erratic results.

11.6 In any test series, all data must be considered in the calculation, including *outliers* (data exceeding the obvious range). For example, an exceedingly high- or low-volume loss must not be disregarded except in the case of obvious faulty machine operation.

11.7 While two or more laboratories may develop test data which 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 method for establishing the significance of the difference in averages shall be agreed upon between laboratories and shall be based on established statistical method of Practice E 122, Practice E 177, and STP 15D.[6]

11.8 Table 2 shows volume loss ranges of typical materials established in interlaboratory testing by the sub-Committee. They may be used as a general indication of the bias of test results.

TABLE 2 Typical Volume Loss Ranges

NOTE 1—All Samples Were Self-Mated

	Material		
	M4	1020	304
Condition	hardened, tempered	hot rolled	hot rolled, annealed
Microstructure	alloy carbides and tempered martensite	pearlite and ferrite	austenite
Hardness	64 HRC	69 HRB	78 HRB
Volume Loss:			
Procedure A, mm^3	1.00 ± 0.30	...	...
Procedure B, mm^3	0.5 ± 0.15	...	24.5 ± 2
Procedure C, mm^3	...	210 ± 20	9 ± 2

12. Typical Volume Loss Values

12.1 The crossed-cylinder wear test will produce volume losses in metallic materials. The more wear resistant materials will develop the least volume loss. Table 2 shows typical volume loss ranges which can be expected in the metals listed. They are offered as guidelines only and not as purchasing specifications.

12.2 Any material specifications involving this test method must be agreed upon between the material vendor and the purchaser.

13. Keywords

13.1 crossed-cylinder apparatus; metallic couples; nonabrasive wear; sliding wear; tribology; wear resistance ranking; wear test

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[6] *Manual on Quality Control of Materials, ASTM STP 15D*, ASTM, 1951.

APPENDIX

(Nonmandatory Information)

X1. SOME STATISTICAL CONSIDERATIONS FOR CROSSED CYLINDER WEAR TESTING

X1.1 *Background*—This method has been in various stages of evolution and use over the last two or more decades. A number of variations of the test procedure have been used by several research and industrial laboratories in the United States who were faced with the problem of evaluating hardsurfacing alloys, powdered metal tool steels, and wrought products for their resistance to wear. Individual laboratories set their own test parameters with the goal being the generation of reproducible test data within the laboratory. As the need for standardization became apparent, ASTM subcommittee G02.40 formed a task group to study the effect of each test parameter on the overall results within individual laboratories and among all laboratories, as a group. While standardization of test parameters was attained, it became evident that the variability or experimental error inherent in each laboratory was a factor which must be considered. Not only must the test method, apparatus, and individual operator generate correct results (bias), but the test results must be consistently reproducible (precision) within an acceptable narrow range. Another important consideration in developing accurate and precise test results was the selection of adequate sample size. More specifically, there was the need for laboratories to agree on the number of times a test should be repeated on a given homogeneous material in order to obtain a meaningful average result. While single test results and simple arithmetic averaging may in some few cases be useful in individual laboratories, it is essential that statistical techniques and multiple testing of specimens be utilized for the qualification of each test apparatus, and for the comparison of materials. Further information on statistical methods may be found in Practice E 122, STP 15D, and in the references.

X1.2 *Statistical Equations*—Several equations for the calculation of optimum sample size, standard deviation, and coefficient of variation are used in the statistical analysis of data. To ensure uniformity among laboratories using this method, the standard deviation and coefficient of variation of results produced from a series of tests shall be calculated by the following:

$$s = \text{standard deviation (small sample size, 2 to 10)} = R/d_2 \quad \text{(X1.1)}$$

$$s = \text{standard deviation (any sample size)} = [\Sigma (x - \bar{x})^2/(n - 1)]^{1/2} \quad \text{(X1.2)}$$

$$v = \text{\% coefficient of variation} \quad v = (s/\bar{x})\cdot 100 \quad \text{(X1.3)}$$

$$n = \text{sample size (95 \% Confidence level)} = (1.96\, v/e)^2 \quad \text{(X1.4)}$$

where:

s = standard deviation from the mean,
v = variability of the test procedure expressed in %,
x = value of each test result (volume loss in mm^3),
$\bar{x}$ = mean or arithmetic average for n tests,
n = number of tests or observations,
e = allowable sampling error expressed in %,
R = difference between the highest and lowest test value, and
d_2 = deviation factor which varies with sample size (see Table X1.1).

X1.3 *Use of Statistical Methods*—In evaluating the precision and bias of any test procedure, new users must deal with the concepts of mean, average, standard deviation from the mean, variability of test results, range of results, allowable sampling error, and particularly the effect of sample size. While it is obvious that a large number of tests on the same material is desirable and will yield a high confidence level in evaluating test results, many wear-test evaluations are made on a small number of samples. This is due to the fact that in much wear-resistance testing, large numbers of test specimens are just not available. In addition to this, a new user is concerned with evaluating the bias of his first few (two or three) test results during the initial test campaign which certainly should not inspire much confidence because of the small number of tests. However, even with this admittedly small sample size, the user may calculate the variability of results, which may give a general indication of precision of the apparatus and test method. As more data is accumulated from the same homogeneous material and new data is accumulated from different materials, the accumulated variability values may be averaged to provide a better estimate of the precision of the apparatus and procedure.

X1.4 *Small Sample Size (2 to 10)*—In statistical analysis, the estimated standard deviations of large sample sizes (over ten) are derived from the square root of the mean square of deviations from the average. A typical user of this test procedure will more likely start out with less than ten test results. In these cases, the standard deviation (s) is more accurately derived by the range (R) of the sample observation than from the root mean square. For such samples, the standard deviation is obtained by multiplying the range of available observations (the difference between the highest and the lowest

TABLE X1.1 Factors for Estimating Standard Deviation from the Range on the Basis of Sample Size

Sample Size (n)	d_2	$1/d_2$
2	1.128	0.8865
3	1.693	0.5907
4	2.059	0.4857
5	2.326	0.4299
6	2.534	0.3946
7	2.704	0.3698
8	2.847	0.3512
9	2.970	0.3367
10	3.078	0.3249

numerical value) by a deviation factor (Eq X1.1) that varies with the sample size. Once the standard deviation is obtained, the percent coefficient of variation is attained by dividing the standard deviation by the average test value and multiplying by 100. The deviation factor is obtained from Table X1.1:

X1.5 *Example*—Table X1.2 shows a typical analysis for standard deviation of six tests (Procedure A) made upon hardened tool steel. This data, as well as subsequent data shown in the table, is taken from actual interlaboratory test data obtained in the early stages of the standardization of this test procedure.

TABLE X1.2 Results of Typical Analysis

NOTE 1—Sample Size (2 to 10), M2 Tool Steel—400 r/min, (16 lbs.) is 71.2 N, 80 000 Cycles

Test No.	Fixed Specimen		Moving Specimen, Weight Loss, mg, mils	Total Wear, mg
	Weight Loss, mg	Scar Diameter, 64^{ths} in., mm		
1	6.7	8 (3.2)	4.6 (1.6)	11.3
2	6.3	8 (3.2)	4.5 (0.4)	10.8
3	7.2	8.5 (3.4)	6.0 (2.5)	13.2
4	6.9	8 (3.2)	5.0 (4.5)	11.9
5	8.3	8.5 (3.4)	4.3 (3.0)	12.6
6	7.6	8.5 (3.2)	4.6 (3.5)	12.2
	$\bar{x} = 7.17$		$\bar{x} = 4.83$	$\bar{x} = 12.0$
	$R = 8.3 - 6.3 = 2.0$		$R = 6.0 - 4.3 = 1.7$	$R = 13.2 - 10.8 = 2.4$
	$d_2 = 2.534$		$d_2 = 2.534$	$d_2 = 2.534$
	$s = R/d_2 = 2.0/2.534$		$s = R/d_2 = 1.7/2.534$	$s = R/d_2 = 2.4/2.534$
	$s = 0.7893$		$s = 0.6709$	$s = 0.9471$
	$v = s/\bar{x} = 0.7893/7.17$		$v = s/\bar{x} = 0.6709/4.83$	$v = s/\bar{x} = 0.9471/12.0$
	$v = 11.0$ %		$v = 13.9$ %	$v = 7.9$ %

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