



# Standard Test Method for Wear Rate and Coefficient of Friction of Materials in Self- Lubricated Rubbing Contact Using a Thrust Washer Testing Machine<sup>1</sup>

This standard is issued under the fixed designation D 3702; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This test method covers the determination of wear rate and coefficient of friction for self-lubricated materials in rubbing contact by a testing machine<sup>2</sup> that utilizes a thrust washer specimen configuration.

NOTE 1—This machine may also be used to measure coefficient of friction.

1.2 The values in SI units are to be regarded as the standard. In cases where materials, products, or equipment are available only in inch-pound units, SI values in parentheses are for information only.

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. Terminology

### 2.1 Definitions:

2.1.1 *coefficient of friction,  $\mu$  or  $f$* —in tribology—the dimensionless ratio of the friction force ( $F$ ) between two bodies to the normal force ( $N$ ) pressing these bodies together.

$$\mu \text{ or } f = (F/N) \quad (1)$$

2.1.1.1 *Discussion*—A distinction is often made between static coefficient of friction and kinetic coefficient of friction.

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

2.1.3 *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.

### 2.2 Definitions of Terms Specific to This Standard:

2.2.1 *torque*—reaction of a tendency to turn due to friction forces between specimens traveling in a circular path. It is the product of a restraining force and the radius at which it acts to balance the frictional torque.

## 3. Summary of Test Method

3.1 The test machine is operated with a test specimen rotating under load against a stationary steel washer. Each test consists of break-in for 40 h followed by a selected test duration, each at the same selected normal load and speed. Load is obtained by application of dead weights to the 10:1 lever arm. The contact area is 1.29 cm<sup>2</sup> (0.20 in.<sup>2</sup>). The mean rubbing velocity is related to spindle rotational speed: 1 rpm = 0.0848 m/min (0.278 ft/min).

3.2 The thickness change of the test specimen and torque during test are measured for each test.

3.3 Wear rate in centimetres per hour (inches per hour) and coefficient of friction is reported.

## 4. Significance and Use

4.1 This test method is used to determine the equilibrium rate of wear and coefficient of friction of materials in rubbing contact under useful operating conditions, that is, combinations of pressure and velocity that fall below the  $PV$  (pressure  $\times$  velocity) limit of the test material. The user of this test method should determine to his own satisfaction whether the results of this test procedure correlate with field performance or other bench test machines. If the test conditions are changed, the wear rates may change and the relative value of one material with respect to another may also change.

4.2 Test conditions may be selected from Table 1.

4.3 The precision of wear measurement is relatively independent of test duration or amount of wear, but the precision of wear rate (calculation) improves with test duration and amount of wear. It is generally believed that useful wear rate precision

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee D-2 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.L.05 on Solid Lubricants.

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<sup>2</sup> An example is the Falex Multispecimen Test Machine, available from Falex Corp., 1020 Airpark Drive, Sugar Grove, IL 60554. This manufacturer recommends a maximum test load of 808 lb (367 kg).

**TABLE 1 Test Conditions<sup>A</sup>**

Rotational speed, rpm	Rubbing Velocity, ft/min (m/min)	Load, lb(kg), to Obtain PV, psi × ft/min (kg/cm <sup>2</sup> × m/min) at Selected Speeds			
		PV <sub>1</sub> 1250 (26.8)	PV <sub>2</sub> 2500 (53.6)	PV <sub>3</sub> 5000 (107.1)	PV <sub>4</sub> 10 000 (214.3)
36	10 (3.05)	25.0 (11.3)	50.0 (22.7)	100 (45.4)	200 (90.7)
180	50 (15.2)	5.0 (2.3)	10.0 (4.5)	20.0 (9.1)	40.0 (18.1)
900	250 (76.2)	1.0 (0.5)	2.0 (0.9)	4.0 (1.8)	8.0 (3.6)

<sup>A</sup>For many applications a wear rate exceeding  $1.0 \times 10^{-5}$  in./h ( $2.5 \times 10^{-7}$  m/h) is considered excessive. Typical wear rates for some commonly used materials at different PV levels are:

Acetal homopolymer at PV <sub>1</sub> :	$5 \times 10^{-6}$ to $1 \times 10^{-5}$ in./h ( $1.3 \times 10^{-7}$ to $2.5 \times 10^{-7}$ m/h)
Acetal homopolymer at PV <sub>2</sub> :	$1 \times 10^{-5}$ to $3 \times 10^{-5}$ in./h ( $2.5 \times 10^{-7}$ to $7.5 \times 10^{-7}$ m/h)
22 % PTFE-filled acetal homopolymer at PV <sub>2</sub> :	$3 \times 10^{-6}$ to $6 \times 10^{-6}$ in./h ( $7.5 \times 10^{-8}$ to $1.5 \times 10^{-7}$ m/h)
Polyamide (Type 6-6) at PV <sub>2</sub> :	$1 \times 10^{-5}$ to $5 \times 10^{-5}$ in./h ( $2.5 \times 10^{-7}$ to $1.3 \times 10^{-6}$ m/h)
15 % graphite filled polyimide resin at PV <sub>3</sub> :	$1 \times 10^{-5}$ to $2 \times 10^{-5}$ in./h ( $2.5 \times 10^{-7}$ to $5 \times 10^{-7}$ m/h)

requires the selection of a test duration sufficient to produce 0.1 mm (0.004 in.) of wear. Test durations will often be in the 50 to 4000-h range.

## 5. Apparatus

5.1 *Falex Multispecimen Test Machine*, Fig. 1, shown schematically in Fig. 2 and described in Annex A1.

5.2 *Test Specimen or Rotating Wafer*, shown in Fig. 3.

5.3 *Stationary Washer*, AISI C-1018 steel, shown in Fig. 4. The surface finish should be  $16 \pm 2 \mu\text{in. AA}$ , the hardness Rc20  $\pm$  5.

5.4 *Micrometer* (Note 4), capable of measuring to the nearest 0.003 mm (0.0001 in.).

## 6. Reagents and Materials

6.1 *Solvent*, safe, non-film forming, nonchlorinated.

NOTE 2—Petroleum distillates, formerly used as solvents, have been eliminated due to possible toxic effects. Each user should select a solvent that can meet applicable safety requirements and thoroughly clean machine parts.

6.2 Appropriate reagents for cleaning the test specimen as recommended by the manufacturer of the test material.

## 7. Preparation of Apparatus

7.1 Measure the finish of the steel mating surface perpendicular to the finishing direction.

7.2 Before each test, thoroughly clean the steel washer and both specimen holders using the solvent per 5.1.

NOTE 3—Remove all solvents from the washer before testing.

7.3 Clean the test specimen as recommended by the manufacturer of the test material.

7.3.1 Store cleaned test specimens prior to testing in a glass jar.

7.3.2 Following the cleaning, do not handle the test specimens with bare hands. It is recommended that clean cotton gloves or clean tweezers or tongs be used.

NOTE 4—Check compatibility of the test specimen cleaning procedure and reagents with the specific material to be tested.

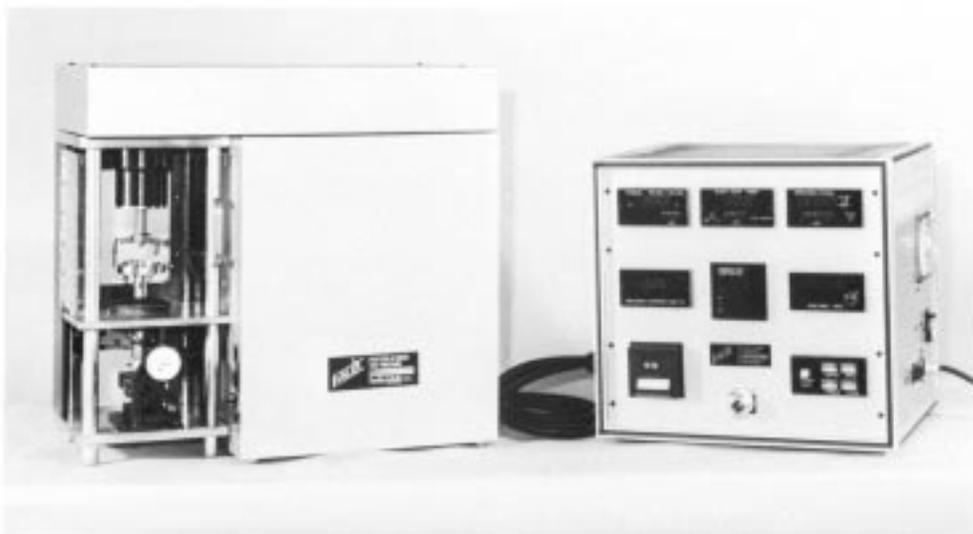
7.4 Preset the speed control to provide the desired speed as measured in revolutions per minute using the built-in tachometer. Refer to Table 1 to convert the specified velocity to revolutions per minute.

7.5 Install the test specimen in the upper specimen holder with the bolt and washer provided. Torque the bolt to  $2.8 \pm 0.6$  J ( $25 \pm 5$  in.·lbf).

7.6 Place the steel washer in the lower specimen holder.

7.7 Balance the load lever arm with the bale rod attached.

7.8 Mount the test specimen together with its specimen holder in the rotary spindle so that the drive pins of the spindle



**FIG. 1 The Falex Multispecimen Test Machine**

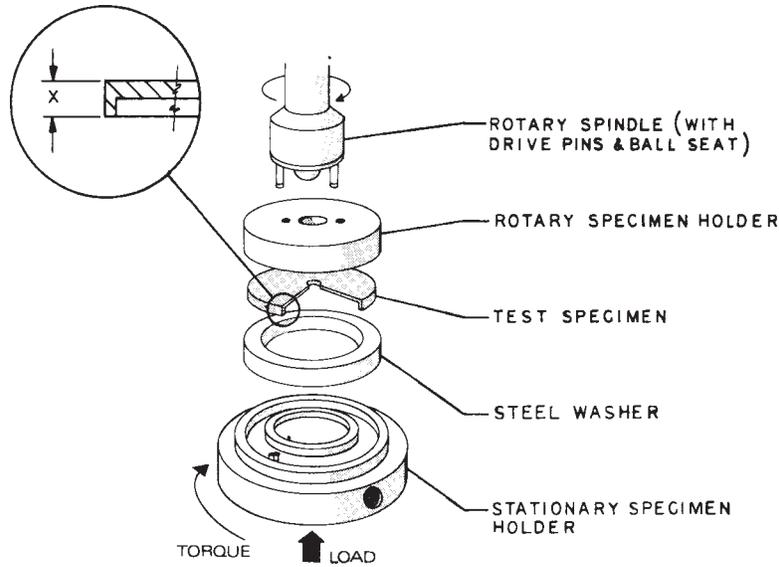


FIG. 2 Thrust Washer Test Specimen Arrangement

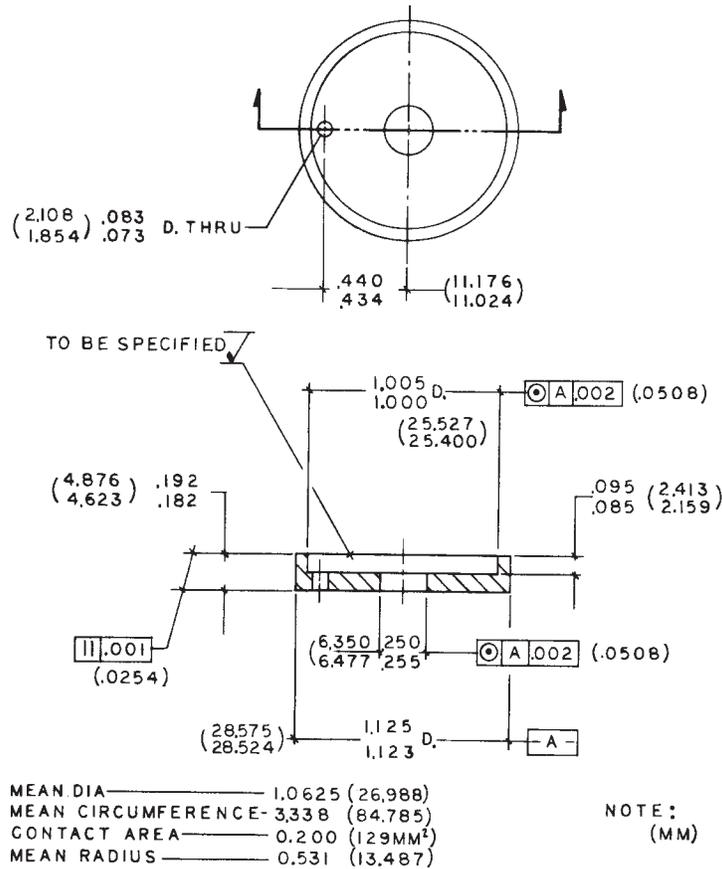


FIG. 3 Rotating Test Specimen

are inserted in the drive pin holes of the specimen holder and the specimen holder is free to pivot on the ball seat.

7.9 Determine the dead weight,  $w$ , to be applied to the bale rod as follows:

$$W = \frac{F}{10} \quad (2)$$

where  $F$  = normal force.

7.10 If coefficient of friction is to be determined, check calibration of torque meter and adjust, if required, according to equipment manufacturer's instructions.

NOTE 5—Calibrate torque meter such that the anticipated test torque is approximately two-thirds of calibration value.

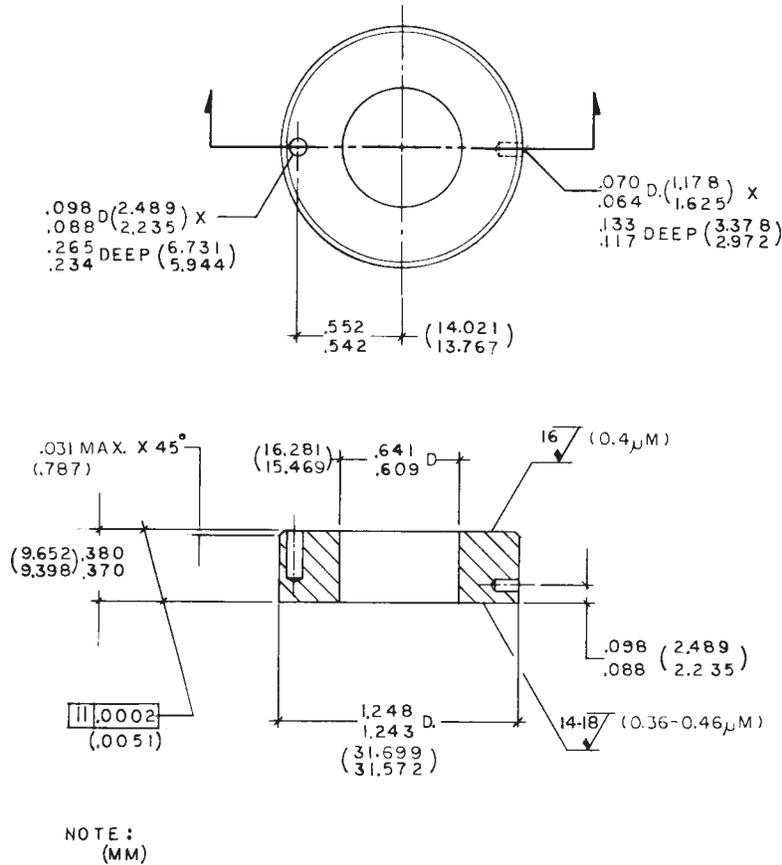


FIG. 4 Stationary Steel Washer Specimen

NOTE 6—A chart recorder can be used to continuously record torque throughout the test. Zero and span the recorder according to manufacturer's instructions.

## 8. Procedure

8.1 With the specimens and bale rod in position, gently apply the appropriate weight to the bale rod.

8.2 Turn on the machine.

8.3 When the prescribed break-in interval duration (40 h) has been completed, stop the machine, remove the weights from the bale rod and carefully lower the stationary specimen holder to its lowest position.

8.4 Remove the test specimen together with its specimen holder and clean with a lint-free wiper.

8.5 Condition the specimens for a minimum of 1 h at room temperature prior to measuring thickness.

8.6 Measure the thickness of the test specimen together with its specimen holder at four places, 90° apart. Mark the test specimen (inside the raised test surface) so subsequent measurements can be made at the same places.

8.7 Balance the load lever arm with the bale rod attached.

8.8 Mount the test specimen together with its specimen holder in the rotary spindle so that the drive pins of the spindle are inserted in the drive pin holes of the specimen holder and the specimen holder is free to pivot on the ball seat.

8.9 With the specimens and bale rod in position, gently apply the appropriate weight to the bale rod.

8.10 Turn on the machine and chart recorder if torque is to be recorded.

8.11 When the prescribed test interval duration has been completed, stop the machine, remove the weights from the bale rod, and carefully lower the stationary specimen holder to its lowest position.

8.12 Remove the test specimen together with its specimen holder and clean with a lint-free wiper.

8.13 Condition the specimens for a minimum of 1 h at room temperature prior to measuring thickness.

8.14 Measure the thickness of the test specimen together with its specimen holder at the same four places, 90° apart, previously marked.

## 9. Calculation

9.1 *Wear:*

9.1.1 Record the (four) thickness measurements for the test specimen before and after test, and actual test duration in hours.

9.1.2 Calculate the wear rate as follows:

$$WR = \frac{(X_{1a} + X_{1b} + X_{1c} + X_{1d}) - (X_{2a} + X_{2b} + X_{2c} + X_{2d})}{4T} \quad (3)$$

where:

WR = wear rate, in./h (m/h),  
X = thickness, in., (m), and  
T = test duration, h.

9.1.3 Subscripts 1a, 1b, 1c, and 1d are the initial four thickness measurements taken 90° apart on the upper rotating specimen. Subscripts 2a, 2b, 2c, and 2d are the corresponding final thickness measurements.

## 9.2 Coefficient of Friction:

0.019 mm (0.00075 in.) (5)

9.2.1 Calculate the coefficient of friction from the torque values as follows:

$$f = T/rW \quad (4)$$

where:

$f$  = coefficient of friction,

$T$  = specimen torque, N·m (lb·in.),

$r$  = test specimen radius, 13.49 mm (0.531 in.), and

$W$  = normal force, kg (lbs).

10.1.2 *Reproducibility*—The difference between two single and independent results obtained by different operators working in different laboratories on identical test material would, in the long run, exceed the following values only in one case in twenty.

0.030 mm (0.00118 in.) (6)

10.2 The tests on which the precision statement is based were all conducted at  $PV_3$ , with 180 rpm used in round robin 1, 2a, and 3, and 720 rpm in round robin 2b. Test durations were 100 h, except for round robin 1 where they ranged from 118 to 313 h. Wear in 100 h round robins averaged 0.00027 to 0.00049 in., and in no test did wear exceed 0.0017 in.

10.3 *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedure for measuring wear rate, bias has not been determined.

## 10. Precision and Bias

10.1 *Precision*—The precision<sup>3</sup> of this test method for wear as determined by the statistical examination of interlaboratory test results is as follows:

10.1.1 *Repeatability*—The difference between successive results obtained by the same operator with the same apparatus under constant operating conditions on identical test material would, in the long run, in the normal and correct operation of the test method exceed the following values only in one case in twenty.

## 11. Keywords

11.1 coefficient of friction; self-lubricated; torque; wear; wear-rate

<sup>3</sup> The results of cooperative test programs, from which these values have been derived can be obtained from ASTM Headquarters by requesting RR: D02-1054.

## ANNEX

### (Mandatory Information)

#### A1. DESCRIPTION OF THE THRUST WASHER TESTING MACHINE<sup>2</sup> (FIG. 1)

A1.1 Dead weights are attached to a bale rod, and act through a 10:1 lever arm to load the stationary (lower) washer axially upward against a rotating (upper) test specimen. The lever arm may be balanced to compensate for the weight of the stationary washer. Optional controlled pneumatic loading systems are available to replace applications of dead weight.

A1.2 The rotary spindle is driven by a variable-speed d-c motor with feed back speed control, controlled by a 10-turn potentiometer, acting through dual-range step pulleys. Typical

spindle speed range is 10 to 7200 rpm. A built-in tachometer provides speed indication. An elapsed time indicator with reset feature to indicate motor running time should be included.

A1.3 In rotation at motion, torque is indicated throughout the test by a digital indicator.

A1.4 Optional features include an assortment of torque measurement devices; apparatus for the application, control, and readout of various test environment conditions; and devices to accommodate alternative test sample configurations.

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