Designation: D5183 – 05

Standard Test Method for Determination of the Coefficient of Friction of Lubricants Using the Four-Ball Wear Test Machine[1]

This standard is issued under the fixed designation D5183; 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 procedure for determining the coefficient of friction by means of the Four-Ball Wear Test Machine.[2]

1.2 The values stated in either SI units or in the former cm-kgf metric units are to be regarded separately as the standard. Within the text the cm-kgf units are shown in parentheses. The values stated in each system are not exact equivalents, therefore each system must be used independently of the other. Combining values from the two systems can result in nonconformance to specification.

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.* Specific warning statements are given in 7.3, 7.4, 7.5, and 7.6.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D4172 Test Method for Wear Preventive Characteristics of Lubricating Fluid (Four-Ball Method)

2.2 *ANSI Standard:*

B3.12 Specification for Metal Balls[4]

3. Terminology

3.1 *Definitions:*

3.1.1 *coefficient of friction, (μ)*—the ratio of the tangential force that is needed to start or to maintain uniform relative motion between two contacting surfaces to the perpendicular force holding them in contact.

4. Summary of Test Method

4.1 Three 12.7 mm (0.5 in.) diameter steel balls are clamped together and covered with 10 mL of the wear-in lubricant. A fourth 12.7 mm diameter ball, referred to as the "top ball" is pressed with a force of 392 N (40 kgf) into the cavity formed by the three clamped balls for three-point contact. The temperature of the wear-in lubricant is regulated at 75°C (167°F), and then, the top ball is rotated at 600 rpm for 60 min.

4.2 Fluid is discarded and balls cleaned. The wear scar diameter on each of the lower three balls is examined. If the wear scars average 0.67 ± 0.03 mm, (0.026 ± 0.001 in.) then the 10 mL of test fluid is added to the ball cup with the worn-in test balls in place. The temperature of the test lubricant is regulated at 75°C (167°F) and the top ball is rotated at 600 rpm at 98.1 N (10 kgf) for 10 min.

4.3 The load is then increased by 98.1 N (10 kgf) at the end of each successive 10 min interval up to the point where the frictional trace indicates incipient seizure. The coefficient of friction is measured at the end of each 10 min interval.

5. Significance and Use

5.1 This test method can be used to determine the coefficient of friction of lubricating fluids under the prescribed test conditions. The user of this test method should determine to his own satisfaction whether results of this test method correlate with field performance or other bench test machines.

6. Apparatus

6.1 *Four-Ball Test Machine*[5]—See Fig. 1, Fig. 2, and Fig. 3.

NOTE 1—It is important to distinguish between the Four-Ball E.P. and

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[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.L0 on Industrial Lubricants.

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[2] The sole source of supply of the Four-Ball Wear Test Machine known to the committee at this time is Falex Corp., 1020 Airpark Dr., Sugar Grove, IL 60554. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

[3] 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.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

[5] The Four-Ball Wear Test Machine and the Falex Multi-Specimen Friction and Wear Test Machine, both made by Falex Corp., 1020 Airpark Dr., Sugar Grove, IL 60554 have been found satisfactory for this purpose. This company can also furnish a microscope with a special base to measure the wear scars without removing the balls from the test-oil cup. Discontinued models of the Four-Ball Wear Test Machine made by Precision Scientific Co. and Roxana Machine Works are also satisfactory.

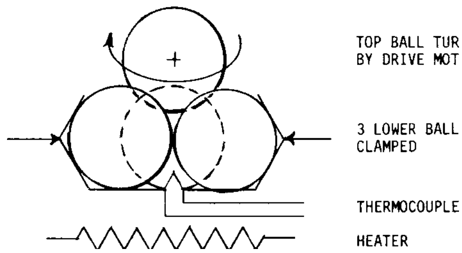


FIG. 1 Schematic of a Four-Ball Wear Test Machine

FIG. 2 Falex Variable—Speed Four-Ball Wear Test Machine

the Four-Ball Wear Test Machine (see Test Method D4172). The Four-Ball E.P. Test Machine is designed for testing under heavier loads and lacks the sensitivity necessary for wear tests.

6.2 *Microscope,*[5] capable of measuring the diameters of the scars produced on the three balls to an accuracy of 0.01 mm without removal from the ball test cup.

6.3 *Test Balls*, chrome alloy steel, made from AISI Standard Steel No. E-52100, with diameter of 12.7 mm (0.5 in.) Grade 25 EP (extra polish). Such balls are described in ANSI Specifications B3.12. The extra-polish finish is not described in that specification. The Rockwell C hardness shall be 64 to 66, a closer limit than is found in the ANSI requirement.

7. Reagents and Materials

7.1 *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society where such specifications are available.[6] Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

7.2 *Wear-In Lubricant*, white oil having a viscosity at 40°C of 24.3 to 26.1 cSt (100°F of 125/135 SUS). It should be percolated through activated alumina to remove any residual impurities.

7.3 *Acetone*. (**Warning**—Flammable. Health hazard.)

7.4 *n-Heptane*. (**Warning**—Flammable. Health hazard.)

7.5 *Methyl ethyl ketone*. (**Warning**—Flammable. Health hazard.)

7.6 *Pyridine*. (**Warning**—Flammable. Health hazard.)

8. Preparation of Apparatus

8.1 Set up the drive of the machine to obtain a spindle speed of 600 ± 30 rpm.

8.2 Set temperature regulator to produce a test-oil temperature of 75 ± 2°C (167 ± 4°F).

8.3 If an automatic timer is used to terminate a test, it should be checked for the required ±1 min accuracy at 60 min elapsed time, and ±10 s at 10 min elapsed time.

8.4 The loading mechanism should be balanced to a zero reading with all parts and test oil in place. To demonstrate proper precision an addition or subtraction of 2.0 N (0.2 kgf) should be detectable in imbalance. Determination of accuracy of loading at 147 and 392 N (15 and 40 kgf) is difficult and generally limited to careful measurement of lever-arm ratios and weights or piston diameter and pressure gage calibration.

NOTE 2—Because of differences in the construction of the various machines on which the four-ball can be made, the manufacturer's instructions should be consulted for proper machine set up and operation.

9. Conditioning

9.1 *Test Conditions*—See Table 1.

10. Procedure

10.1 Thoroughly clean four test balls, clamping parts for upper and lower balls and the ball cup by first soaking in heptane for 1 min and then with sonic agitation for 10 s. Drain and rinse with fresh heptane.

10.1.1 Repeat 10.1 using acetone. Blow dry under a stream of nitrogen gas. After cleaning, handle all parts using only a fresh wipe. No trace of solvent should remain when wear-in lubricant is introduced and the machine assembled.

10.2 Tighten one of the clean balls into the spindle of the test machine.

10.3 Assemble three of the clean balls in the test-oil cup.

10.4 Pour the wear-in lubricant indicated in 7.2 into the test-oil cup to a level at least 3 mm (⅛ in.) above the top of the balls. Observe that this oil level still exists after the lubricant fills all of the voids in the test oil cup assembly.

[6] *Reagent Chemicals, American Chemical Society Specifications*, American Chemical Society, Washington, DC. For Suggestions on the testing of reagents not listed by the American Chemical Society, see *Annual Standards for Laboratory Chemicals,* BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary,* U.S. Pharmacopeial Convention, Inc. (USPC), Rockville, MD.

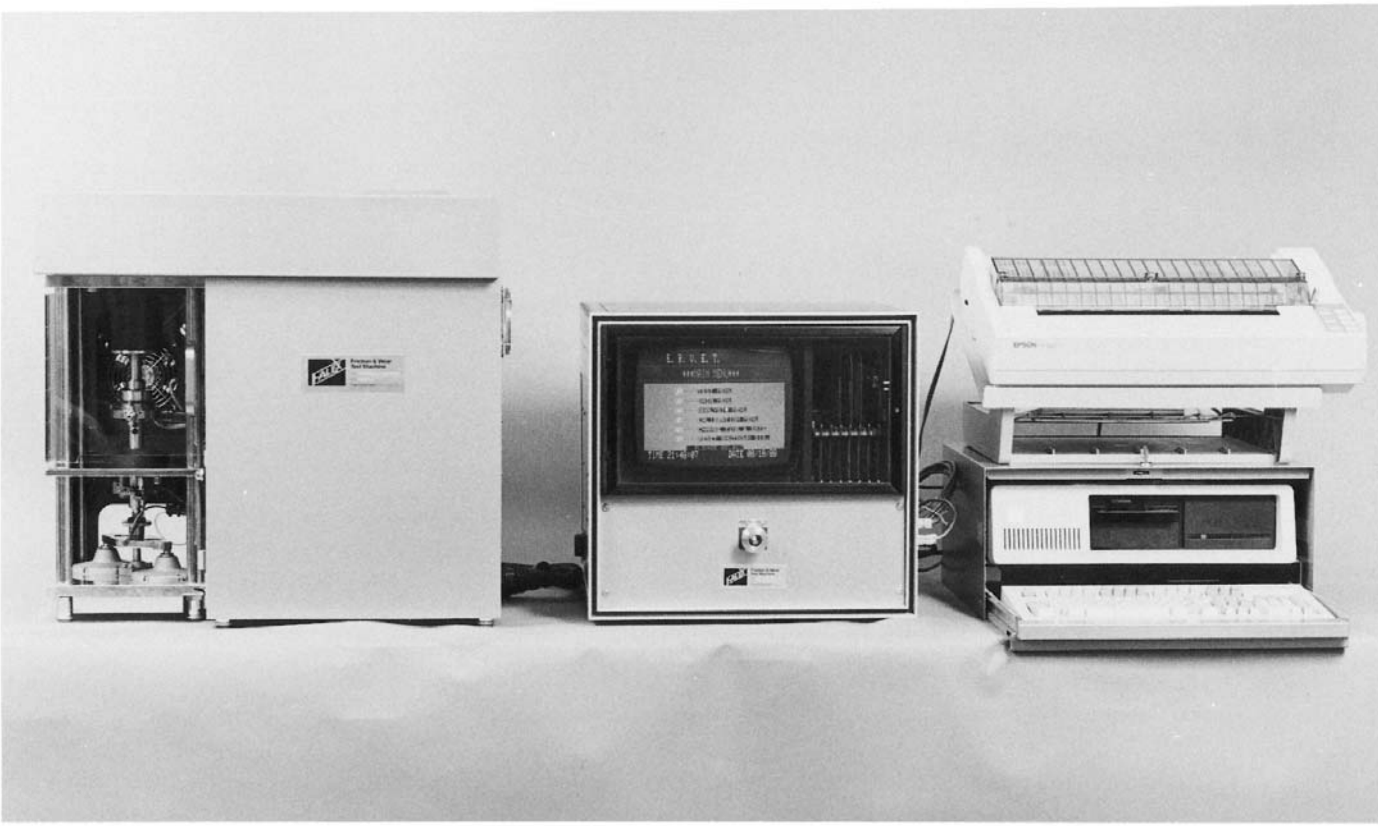


FIG. 3 Falex Multi-Specimen Friction and Wear Test Machine

TABLE 1 Test Conditions

	Wear-In	Test
Temperature	75 ± 2°C (167 ± 4°F)	75 ± 2°C (167 ± 4°F)
Speed	600 r/min	600 r/min
Duration	60 min	10 min
Load	392 N (40 kgf) per 60 min	98.1 N (10 kgf) per 10 min increment to a load that indicates incipient seizure (sudden increase in friction force value over steady state) on the friction trace

10.5 Install the test-oil cup/three balls in the machine and avoid shock loading by slowly applying the test load 392 N (40 kgf).

10.6 Turn on the heaters and set controls to obtain 75± 2°C (167 ± 4°F). Heater voltage or offset on proportional controllers should be capable of bringing stabilized temperature within the prescribed limits.

10.7 When the test temperature is reached, start the drive motor that was previously set to drive the top ball at 600 ± 30 rpm. Machines with automatic start using a proportional controller will start below the set temperature. Set the proportional band so that test machines start at temperatures 2°C (4°F) below the set point temperature.

10.8 After the drive motor has been on for 60 ± 1 min, turn off the heaters and drive motor and remove the test-oil cup and three-ball assembly.

10.9 Measure the wear scars on the three lower balls to an accuracy of ±0.01 mm by the following method described in 10.10.

10.10 Drain the test oil from the three-ball assembly and wipe the scar area with a tissue. **Leave the three balls clamped** and set the assembly on a special base of a microscope that has been designed for the purpose. Make two measurements on each of the wear scars. Take one measurement of the scar along a radial line from the center of the holder. Take the second measurement along a line 90° from the first measurement. If a scar is elliptical take one measurement with the striations and the other across the striations. Take care to ensure that the line of sight is perpendicular to the surface being measured. Average the six readings and report as wear-in scar diameter in millimetres. If the wear-in scar measures 0.67 ± 0.03 mm, the following test sequence is performed; otherwise, the wear-in sequence is repeated using new specimen balls. (The wear-in scar can measure outside this range in different machines, but for a given machine, repeated result should be ±0.03 mm. The user should first determine the wear-in average for the machine.)

10.11 Add heptane to test-cup and let soak for 1 min with occasional agitation. Drain off heptane. Rinse inside of the cup with heptane using a squeeze bottle to remove entrained oil. Repeat soak and rinse stages twice. Rinse inside of the cup with two successive rinses of acetone using a squeeze bottle. Blow dry with nitrogen.

10.12 Wipe surface of top ball and entire surface of ball chuck assembly using a clean tissue dampened with heptane. Repeat with a tissue dampened with acetone. Blow dry with nitrogen.

10.13 Wipe wear scars on the bottom three balls and wear track on the top ball with a tissue dampened with methyl ethyl ketone.

10.14 Pour the sample to be tested into the clean test oil cup assembly, containing the worn-in test balls, to a level at least 3 mm (⅛ in.) above the top of the balls. Observe that this oil level exists after the lubricant fills all of the voids in the test-oil cup assembly.

10.15 Install the test-oil cup containing three balls in the machine and avoid shock loading by slowly applying a test load of 98.1 N (10 kgf).

10.16 Turn on the heater and set controls to obtain 75± 2°C (167 ± 4°F).

10.17 When the test temperature is reached, start the drive motor that was previously set to drive the top ball at 600 ± 30 rpm. Run for 10 min. Do not allow test machine to stop. At the end of the 10 min interval, record the torque value. Increase the load 98.1 N (10 kgf) every 10 min until the friction trace indicates incipient seizure is occurring. Record the torque value at the end of each 10 min interval.

10.18 Measure the final wear scars on the three lower balls to an accuracy of 0.01 mm as described in 10.10 and note the appearance of the wear scar.

11. Calculation

11.1 Determine the coefficient of friction using one of the two following equations:

$$\mu = 0.00223\, fL/P \tag{1}$$

where:

μ = coefficient of friction,
f = friction force, grams force,
L = length of friction lever arm, cm, and
P = test load, kg.

NOTE 3—Current test machines are supplied with a friction lever arm having a length of 7.62 cm (3 in.), and friction force is displayed in units of grams force. Therefore, for these instruments, $\mu = 0.0170\, f/P$ can be used.

or

$$\mu = 0.00227\, fL/P \tag{2}$$

where:

μ = coefficient of friction,
f = friction force, N,
L = length of friction lever arm, cm, and
P = test load, kg.

NOTE 4—For test instruments with a lever arm of 7.62 cm (3 in.) and friction force displayed in Newtons, $\mu = 1.73\, f/P$.

NOTE 5—Friction force is read directly from the test machine and is the force measured at a distance equal to the length of the friction lever arm from center of rotation. Test machines may have friction force displayed as grams force or Newtons. Users should consult their operating manuals for their equipment to verify the calculation equation.

12. Report

12.1 Report the following information:
12.1.1 Average wear-in scar, mm,
12.1.2 Coefficient of friction for each increment of 10 kgf,
12.1.3 Incipient seizure load, kilogram force, and
12.1.4 Final average wear scar, mm.

13. Precision and Bias

13.1 *Precision*—The precision of this test method as determined by the statistical examination of interlaboratory test results is as follows:[7]

13.1.1 *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.

$$\text{Repeatability} = 0.20 \times \bar{x} \tag{3}$$

where:
$\bar{x}$ = average of successive results.

13.1.2 *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.

$$\text{Reproducibility} = 0.49 \times \bar{x} \tag{4}$$

where:
$\bar{x}$ = average of successive results.

NOTE 6—Precision data is based on the coefficient of friction values determined according to this test method at 40 kg load using balls from random lots.

13.2 *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedure in Test Method D5183 for measuring coefficient of friction, bias has not been determined.

14. Keywords

14.1 coefficient of friction; Four-Ball Wear test machine; friction

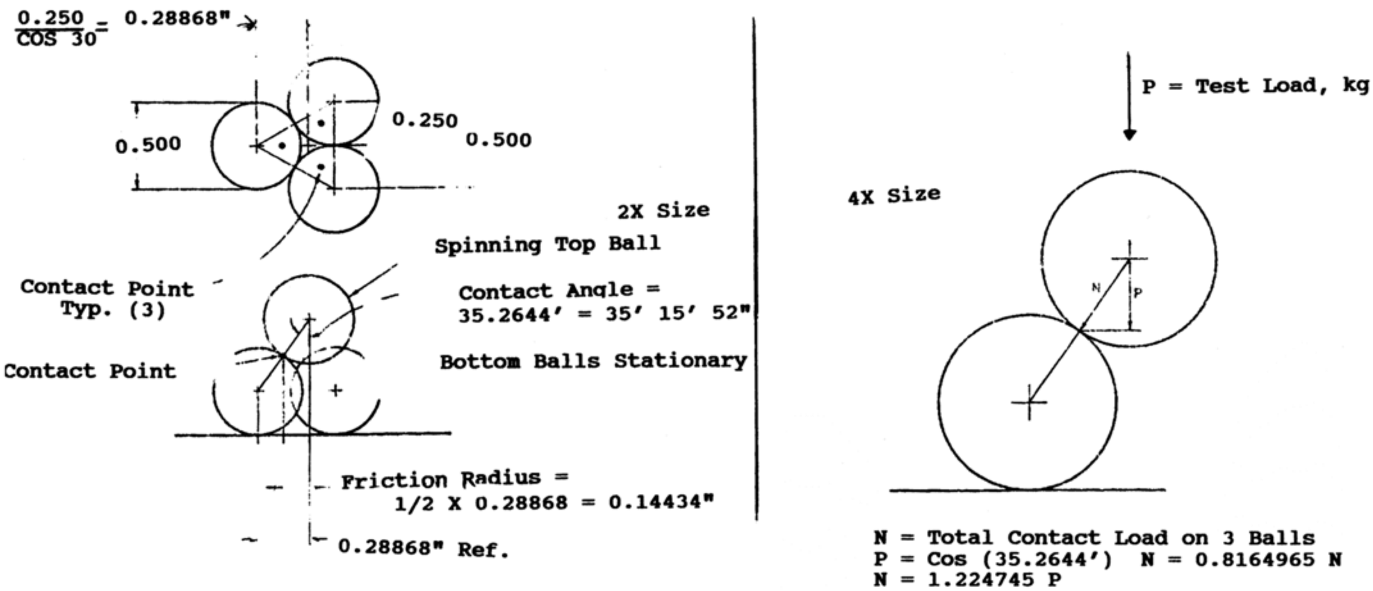
[7] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report D02-1352.

APPENDIX

(Nonmandatory Information)

X1. SCHEMATIC

X1.1 See Fig. X1.1.



METRE UNITS
TOTAL CONTACT FRICTION FORCE = $f = \mu N$, WHERE μ IS THE COEFFICIENT OF FRICTION
T = TORQUE (kg—cm) = $fL = \mu NL = \mu(1.224745\ P)$. 36662 = .44902μP

$$\mu = 2.22707 \frac{T}{P} \frac{(\text{kg—cm})}{(\text{kg})} = 0.0008164965 \frac{f(\text{gram})}{P(\text{kg})}$$ READ FROM CURRENT DISPLAYS ON MACHINE

ENGLISH UNITS
TOTAL CONTACT FRICTION FORCE = $f = \mu N$, WHERE μ IS THE COEFFICIENT OF FRICTION
T = TORQUE IN LBS = $fr = \mu Nr = \mu(1.224745\ P)\ 0.14434 = 0.1767797\ \mu P$

$$\mu = 5.656 \frac{T}{P}$$

RUBBING DISTANCE PER REVOLUTION OF THE TOP BALL = $2\pi R = 2\pi .14434 = 0.9069''$ OR 0.075576 ft.
ALL DIAGRAM DIMENSIONS ARE IN INCHES
DO NOT USE THE ABOVE DATA FOR
THE ROLLING 4 BALL TEST

FIG. X1.1 Schematic of Technical Calculation for Four-Ball Coefficients of Friction

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