



Designation: G181 – 04

# Standard Practice for Conducting Friction Tests of Piston Ring and Cylinder Liner Materials Under Lubricated Conditions<sup>1</sup>

This standard is issued under the fixed designation G181; 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 practice covers procedures for conducting laboratory bench-scale friction tests of materials, coatings, and surface treatments intended for use in piston rings and cylinder liners in diesel or spark-ignition engines. The goal of this procedure is to provide a means for preliminary, cost-effective screening or evaluation of candidate ring and liner materials. A reciprocating sliding arrangement is used to simulate the contact that occurs between a piston ring and its mating liner near the top-dead-center position in the cylinder where liquid lubrication is least effective, and most wear is known to occur. Special attention is paid to specimen alignment, running-in, and lubricant condition.

1.2 This practice does not purport to simulate all aspects of a fired engine's operating environment, but is intended to serve as a means for preliminary screening for assessing the frictional characteristics of candidate piston ring and liner material combinations in the presence of fluids that behave as use-conditioned engine oils. Therefore, it is beyond the scope of this practice to describe how one might establish correlations between the described test results and the frictional characteristics of rings and cylinder bore materials for specific engine designs or operating conditions.

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:*<sup>2</sup>

D6838 Test Method for Cummins M11 High Soot Test

G40 Terminology Relating to Wear and Erosion

<sup>1</sup> This practice is under the jurisdiction of ASTM Committee G02 on Wear and Erosion and is the direct responsibility of Subcommittee G02.50 on Friction.

Current edition approved Nov. 1, 2004. Published November 2004. DOI: 10.1520/G0181-04.

<sup>2</sup> 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. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *conditioned oil*—a lubricating oil whose viscosity, composition, and other function-related characteristics have been altered by use in an operating engine, such that the oil's effects on friction and wear reflect those characteristic of the long-term, steady-state engine operation.

3.1.2 *conformal contact*—in friction and wear testing, any macro-geometric specimen configuration in which the curvature of one contact surface matches that of the countersurface.

3.1.2.1 *Discussion*—Examples of conformal contact include a flat surface sliding on a flat surface and a ball rotating in a socket that conforms to the shape of the ball. A pair of surfaces may begin a wear or friction test in a non-conforming contact configuration, but develop a conformal contact as a result of wear.

3.1.3 *lubrication regime*—in liquid-lubricated sliding contact, a certain range of friction coefficients that results from a combination of contact geometry, lubricant viscosity characteristics, surface roughness, normal pressure, and the relative speed of the bearing surfaces.

3.1.3.1 *Discussion*—Common designations for lubrication regimes are boundary lubrication, mixed film lubrication, elasto-hydrodynamic lubrication and hydrodynamic lubrication.

## 4. Summary of Practice

4.1 A reciprocating friction test apparatus is used to simulate the back-and-forth motion of a piston ring within a cylinder bore in the presence of a heated lubricant. Other types of motions, like ring rotation, ring-groove fretting motion, and ring rocking, are not simulated with this procedure. The contact geometry, selection of testing parameters, and the methods of specimen surface finishing and characterization are described. The lubricating fluid is selected to simulate the effects of used oil. A running-in procedure is used to increase the repeatability of results.

## 5. Significance and Use

5.1 The efficiency and fuel economy of spark ignition and diesel engines is affected in part to the friction between moving parts. Although no reliable, in situ friction measurements exist

for fired internal combustion engines, it has been estimated that at least half of the friction losses in such engines are due to those at the ring and liner interface. This practice involves the use of a reciprocating sliding arrangement to simulate the type of oscillating contact that occurs between a piston ring and its mating cylinder bore surface near the top-dead-center position in the cylinder where most severe surface contact conditions occur. There are many types of engines and engine operating environments; therefore, to allow the user the flexibility to tailor this test to conditions representative of various engines, a practice is considered more appropriate than a standard test method in which specific test parameters are prescribed. Variables that can be adjusted in this procedure include: normal force, speed of oscillation, stroke length, duration of testing, temperature of testing, method of specimen surface preparation, and the materials and lubricants to be evaluated. Guidance is provided here on the set-up of the test, the manner of specimen fixturing and alignment, the selection of a lubricant to simulate conditioned oil characteristics (for a diesel engine), and the means to run-in the ring specimens to minimize variability in test results.

5.2 Engine oil spends the majority of its operating lifetime in a state that is representative of use-conditioned oil. That is, fresh oil is changed by exposure to the heat, chemical environment, and confinement in lubricated contact. It ages, changing viscosity, atomic weight, solids content, acidity, and chemistry. Conducting piston ring and cylinder liner material evaluations in fresh, non-conditioned oil is therefore unrealistic for material screening. But additive-depleted, used oil can result in high wear and corrosive attack of engine parts. The current test is intended for use with lubricants that simulate tribological behavior after in-service oil conditioning, but preceding the point of severe engine damage.

### 6. Reagents

6.1 *Cleaning Solvents*—Suitable solvents may be used to degrease and clean specimens prior to conducting the described procedure. No specific solvents are recommended here, except

that they should not chemically attack the test surfaces, nor leave a residual film or stain after cleaning.

6.2 *Lubricants*—Lubricants shall be handled appropriately with awareness of, and precautions taken against, any hazards indicated in the Material Safety Data Sheets for those lubricants. A further description of simulated used engine oil is further described in an appendix to this standard.

### 7. Apparatus and Specimen Preparation

7.1 *Description of the Test Apparatus*—A schematic representation of the reciprocating contact geometry is shown in Fig. 1. Two versions of this test are shown. In the first case (Fig. 1, bottom left), the lower specimen conforms to the shape of the ring segment. In the second case (Fig. 1, bottom right), the ring segment slides on a flat lower specimen. Specimens are placed in a heated, temperature-controlled bath of lubricant. Alternate means of supplying the lubricant, such as drip feed, may be used.

7.1.1 *Motion*—The test apparatus shall be capable of imparting a back-and-forth (herein called reciprocating) motion of constant stroke length and repeatable velocity profile to the simulated piston ring specimen which slides against the simulated cylinder bore under a controlled normal force. The motor shall be sufficiently powered so that the velocity profile and constancy of operation shall be unaffected by the friction force developed between the test specimens. The velocity versus time response of crank-driven devices tends to be approximately sinusoidal, and this type of motion is appropriate to simulate a piston driven by a crankshaft. The frequency of reciprocation, given in cycles per second, shall be selected to induce the appropriate lubrication regime experienced by the piston ring during its slow down and reversal of direction in the engine of interest. Typical frequencies for slider-crank testing equipment of this type range between 5 and 40 cycles per second. The average sliding speed for each stroke,  $s$ , in metres per second, is calculated as follows:

$$s = 2fL \tag{1}$$

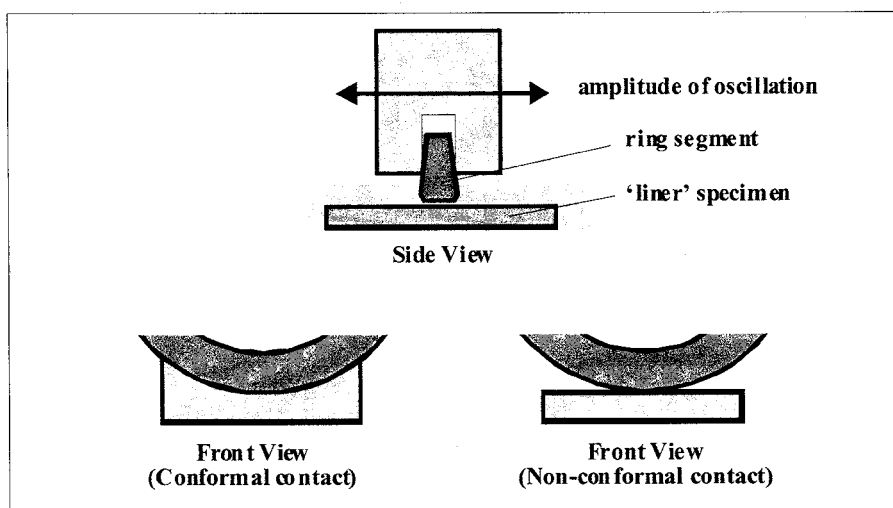


FIG. 1 Schematic Drawing of the Test Configuration Showing Conformal and Non-conformal Contact

where:

$f$  = frequency of reciprocation in cycles per second, and  
 $L$  = stroke length in meters.

**7.1.2 Stroke Length Selection**—It is unnecessary to set the stroke length equal to the full stroke of the piston in the engine because the greatest frictional influence of the materials is experienced at the ends of the ring travel where operation in the boundary lubrication regime increases the likelihood that contact will occur between the surfaces of the ring and cylinder materials. The stroke length should typically range between 5 and 10 times the width of the worn-in contact face of the piston ring specimen.

**NOTE 1**—The design of certain testing machines and motor drive systems limits the maximum frequency achievable for a given stroke length. Therefore, a compromise may be necessary between the highest desired stroke length and the desired reciprocating frequency.

**7.1.3 Specimen Fixturing**—A means shall be provided to clamp the ring specimen to the reciprocating portion of the machine in such a way as to ensure correct alignment during sliding. Likewise, the cylinder bore specimen shall be mounted in a suitable, heated lubricant container such that no loosening or other misalignment occurs during the test. For ring segments with a rectangular cross-section, a suitable flat-faced ring-segment grip may be used. For non parallel-sided piston rings (for example, those with keystone-like cross-sections), it may be necessary to prepare a holder from an actual piston or design a holder that clamps the inclined sides of the ring firmly.

**7.1.4 Specimen Alignment**—Proper alignment and centering between sliding surfaces is a critical factor for ensuring repeatable friction test results. Alignment affects the distribution of normal forces on the contact surface as well as the lubrication regimes that change as the ring specimen moves back and forth. Two approaches are used together to ensure proper alignment: (1) mechanical alignment of the test fixtures during the initial test set-up, and (2) running-in of the ring specimen against the counterface surface. The former approach addresses macro-contact aspects of alignment and the latter micro-scale aspects of alignment. A method for running in specimens is given in [Appendix X1](#).

**NOTE 2**—Mechanical specimen alignment tends to be difficult to achieve with conformal starting geometry. When testing ring and cylinder materials from the same type of engine, the ring curvature in the actual engine is produced by elastically confining the ring in its groove. The same ring, out of the engine, will tend to have a larger curvature, and hence rest on the edges of the corresponding cylinder bore specimen unless the ring can be pre-stressed or in some other way forced into a radius of curvature that precisely matches that of the opposing specimen cut from the cylinder. A non-conformal, ring-on-flat geometry with a suitable running-in procedure, has been shown to produce a more repeatable worn-in condition for friction testing.

**7.1.5 Normal Force Application**—The apparatus shall have the ability to apply a controlled normal force to the ring and cylinder specimens. The loading mechanism can be a dead-weight system, a levered type of device, or a hydraulic or electromagnetic actuator. The loading system shall have sufficient rigidity and damping capacity to avoid excessive deflections or vibrations during testing, and to maintain the desired normal force within 2 % of the intended value.

**7.2 Specimen Preparation**—Test specimens are herein referred to as the ‘ring specimen’ and the ‘cylinder bore specimen.’ The precise manner of preparing test specimens depends in part on the kinds of materials, coatings, or surface treatments to be evaluated.

**7.2.1 Ring Specimen**—The ring specimen shall be prepared by cutting a segment from a production piston ring, or machining a test piece of equal dimensions and finish to a production piston ring. The ring specimen may be used in its original, factory-finished condition or it may be altered by applying a coating or surface treatment. The surface shall be prepared to simulate that for a particular engine or class of engines. The surface roughness of the ring specimen, in the area of the contact, shall be measured by a suitable method and included in the test record. All pertinent descriptors (type of profiling method, surface finish parameters, and measuring conditions) shall be reported.

**7.2.2 Cylinder Bore Specimen**—The specimen intended to simulate the cylinder bore surface shall constitute either a cut section of a production-finished cylinder or a flat specimen whose form and finish is similar to that of the cylinders used in the engine of interest. Methods have been developed to simulate the roughness and lay of production cylinder liners on flat cast iron test coupons.<sup>3</sup> Alternatively, a polished surface may be used to simulate the worn condition of a cylinder bore near at the top-dead-center position. In certain cases, the cylinder bore specimen may be fabricated from experimental materials, coated, or surface-treated. The surface roughness of the cylinder bore specimen shall be measured by a suitable method and included in the test record. With stylus-type instruments, it is traditional to measure and report the surface roughness profile parallel to the direction of motion of the ring, that is, parallel to the cylinder axis. All pertinent descriptors (type of profiling method, surface finish parameters, and measuring conditions) shall be reported.

**7.3 Lubricant Selection**—The lubricant should be in a condition that is representative of that found in the engine of interest after a period of running. Studies of experimental piston ring and liner materials have shown that fresh engine lubricants do not in general produce friction and wear test results equal to those obtained with used engine oils under otherwise similar testing conditions.<sup>4</sup> A guide to formulating fluids with characteristics similar to those of used diesel engine oil is given in [Appendix X2](#).

**7.4 Friction Force Measurement and Calibration:**

**7.4.1 Friction Force Measurement and Recording**—A means shall be provided for measuring and recording the magnitude of the friction force. This can involve a tension/compression load cell, strain gauged beam, piezoelectric force sensor, or similar. The friction force sensor should be as close to the line of action of the friction force at the contact point as

<sup>3</sup> Blau, P. J., “Simulation of Cylinder Bore Surface Finish Parameters to Improve Laboratory-Scale Friction Tests in New and Used Oil,” *Engine Systems: Lubricants, Components, Exhaust and Boosting System, Design and Simulation*, Amer. Soc. of Mech. Engr., New York, ASME ICE Vol. 37-3, 2001, pp. 57-63.

<sup>4</sup> Naylor, M. G. S., “Development of Wear-Resistant Ceramic Coatings for Diesel Engine Components,” Vol 1, Oak Ridge National Laboratory, Oak Ridge, Tennessee, report ORNL/Sub/87-SA581/1, 1992, 195 pp.



practical on the test apparatus. The sampling rate should be at least 10 readings per stroke in each direction. Thus, a sampling rate of at least 200 readings per second would be required with a frequency of 10 Hz (10 cycles per second having 1 forward and 1 reverse stroke per cycle). The sign of the friction force is positive when it opposes the direction of relative motion; therefore, the friction data should be corrected to account for the reversal of direction during reciprocating sliding. Data collected during the period of direction reversal should be discarded. The quotient of the instantaneous friction force divided by the normal force is defined as the kinetic friction coefficient.

**7.4.2 Calibration**—Since mechanical assembly stresses and asymmetry can exist in the design of friction testing apparatus, the friction force shall be calibrated in both directions of reciprocating sliding using a pulley system or similar method for applying a known weight in line with the sliding contact and parallel to the friction force that occurs during testing. The calibration weights shall be chosen to cover the full range of friction forces typically experienced during the testing.

## 8. Procedure

8.1 Turn on the testing machine and recording equipment and allow the electronics to stabilize for 30 minutes.

8.2 Measure the surface finish of the ring and liner specimens. This shall include at least the arithmetic average roughness of the liner profiled parallel to the direction of reciprocating motion.

8.3 Mount the ring and liner specimens in the testing machine. Verify proper specimen alignment.

8.4 Conduct a running-in procedure to ensure proper fitting of the ring and liner specimen. (See [Appendix X1](#) for a description of the recommended running-in practice.)

8.5 **Lubrication Methods**—Several methods are possible, depending on the objective of the test and the type of simulation desired. (See [Appendix X2](#) for a description of lubricant preparation to simulate engine-conditioned oil.)

8.5.1 **Fully-flooded**—Fill the lubricant bath to cover the contact surface with at least 2 mm of the selected lubricant.

8.5.2 **Drip-feed Lubrication**—A metered drop of lubricant is introduced into the contact periodically, in accordance with an established flow rate or delivery schedule.

8.5.3 **Starved Lubrication**—A specific quantity of lubricant is placed on the surface before the test is started and no additional lubricant is added for the duration of the test.

8.6 **Lubricant Heating**—For fully-flooded tests, with no normal load applied, slowly oscillate the upper specimen while the bath heats to the desired temperature. After the test temperature is reached, allow the temperature to equilibrate for 10 min ( $\pm 2^\circ\text{C}$ ), then stop the motor. For drip-feed tests or starved lubrication tests, ensure the specimens and lubricant are at the correct test temperature before proceeding.

8.7 Adjust the speed setting to the desired reciprocation frequency, raise the load to the desired test load.

8.8 Run the test for the desired period of time, while monitoring and recording friction force. When running a step loaded test, increase the load to the next level and run for the desired period of time. Repeat the step loading sequence as needed to reach the maximum desired load.

8.9 After completing the test allow specimens to cool with the load removed.

8.10 Remove the test specimens and inspect both contact surfaces. Record observations of ring or bore specimen surface damage, including the dimensions of the wearing contact area on the ring.

## 9. Report

9.1 **Materials**—Provide a description of the composition, heat treatment, surface coating, and/or other identifying designations for the test materials. Indicate the dimensions of the ring segment, particularly the contact width (mm). Describe the surface finish of the liner and ring, including the arithmetic average surface roughness of the liner specimen taken parallel to the direction of ring motion. Additional measures of roughness may also be used. Identify the type and make of apparatus, and stylus radius if applicable, that is used to measure surface roughness. Optional characterization may include the hardness of the ring and liner specimen surfaces.

9.2 **Running-in Procedure**—Describe the procedure used to run in the ring specimen prior to testing. This should include the sequence of loads and speeds such as those described in the example in [Appendix X1](#).

9.3 **Lubrication**—Report the type or grade, source, and viscosity of the oil, as well as the method used to prepare the oil to simulate an engine-conditioned lubricant, or the engine duty cycle if using engine-conditioned oil. Describe the method used to apply the lubricant during testing.

9.4 **Applied Test Parameters**—Report the stroke length (mm), frequency of oscillation (cycles/s), applied load (N), and test duration (h:min:s). If step loading, describe the times and loading sequence applied. Test duration may also be reported in terms of cumulative sliding distance. Also report the test temperature and its typical variation ( $\text{deg C} \pm \text{deg C}$ ).

9.5 **Data**—Report the time required for the friction force to reach a relatively stable value (running-in period). Report the time-averaged (at least 60 s sampling interval), post running-in friction coefficient. Report the average friction coefficient (at least 60 s sampling interval) at the mid-point of the test and then at the end of the test. A typical friction force trace for a constant applied load is shown schematically in [Fig. 2](#) including the approximate time to reach steady-state conditions.

9.6 **Observations**—Report the occurrence of any unusual sounds or vibrations. Report the appearance of the ring and liner specimens after testing and cleaning. Observe the condition of the lubricant, and report any changes from the initial condition. Additional lubricant analysis or specimen characterization, such as change in roughness, photographs, or the like, may be included.

9.7 **Reporting Form**—A sample reporting form is shown in [Fig. 3](#).

## 10. Precision and Bias

10.1 Since the precision and bias of this practice is dependent on the type of testing machine used and the selection of load, oscillation length, oscillation frequency, and lubricant, precision and bias have not been established. It is advisable to report the friction coefficient to not more than three significant