



Designation: G115 – 24

Standard Guide for Measuring and Reporting Friction Coefficients¹

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1. Scope

1.1 This guide covers information to assist in the selection of a method for measuring the frictional properties of materials. Requirements for minimum data and a format for presenting these data are suggested. The use of the suggested reporting form will increase the long-term usefulness of the test results within a given laboratory and will facilitate the exchange of test results between laboratories. It is hoped that the use of a uniform reporting format will provide the basis for the preparation of handbooks and computerized databases.

1.2 This guide applies to most solid materials and to most friction measuring techniques and test equipment.

1.3 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 ASTM Standards:²

- C808** Guide for Reporting Friction and Wear Test Results of Manufactured Carbon and Graphite Bearing and Seal Materials
- C1028** Test Method for Determining the Static Coefficient of Friction of Ceramic Tile and Other Like Surfaces by the

Horizontal Dynamometer Pull-Meter Method (Withdrawn 2014)³

D1894 Test Method for Static and Kinetic Coefficients of Friction of Plastic Film and Sheet (Withdrawn 2023)³

D2047 Test Method for Static Coefficient of Friction of Polish-Coated Flooring Surfaces as Measured by the James Machine

D2394 Test Methods for Simulated Service Testing of Wood and Wood-Based Finish Flooring

D2534 Test Method for Coefficient of Kinetic Friction for Wax Coatings

D2714 Test Method for Calibration and Operation of the Falex Block-on-Ring Friction and Wear Testing Machine

D3108/D3108M Test Method for Coefficient of Friction, Yarn to Solid Material

D3412/D3412M Test Method for Coefficient of Friction, Yarn to Yarn

D3702 Test Method for Wear Rate and Coefficient of Friction of Materials in Self-Lubricated Rubbing Contact Using a Thrust Washer Testing Machine

D4103 Practice for Preparation of Substrate Surfaces for Coefficient of Friction Testing

D4917 Test Method for Coefficient of Static and Kinetic Friction of Uncoated Writing and Printing Paper by Use of the Horizontal Plane Method (Withdrawn 2010)³

D4918 Test Method for Coefficient of Static Friction of Uncoated Writing and Printing Paper by Use of the Inclined Plane Method (Withdrawn 2010)³

D5183 Test Method for Determination of the Coefficient of Friction of Lubricants Using the Four-Ball Wear Test Machine

D6078 Test Method for Evaluating Lubricity of Diesel Fuels by the Scuffing Load Ball-on-Cylinder Lubricity Evaluator (SLBOCLE) (Withdrawn 2021)³

D6079 Test Method for Evaluating Lubricity of Diesel Fuels by the High-Frequency Reciprocating Rig (HFRR)

D6425 Test Method for Measuring Friction and Wear Properties of Extreme Pressure (EP) Lubricating Oils Using SRV Test Machine

¹ This guide is under the jurisdiction of ASTM Committee G02 on Wear and Erosion and is the direct responsibility of Subcommittee G02.50 on Friction.

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at www.astm.org/contact. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

³ The last approved version of this historical standard is referenced on www.astm.org.

- E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process
- E303 Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester
- E670 Test Method for Testing Side Force Friction on Paved Surfaces Using the Mu-Meter
- E1911 Test Method for Measuring Surface Frictional Properties Using the Dynamic Friction Tester
- E2100 Practice for Calculating the International Runway Friction Index (Withdrawn 2019)³
- E2101 Test Method for Measuring the Frictional Properties of Winter-Contaminated Pavement Surfaces Using an Averaging-Type Spot Measuring Decelerometer
- F609 Test Method for Using a Horizontal Pull Slipmeter (HPS) (Withdrawn 2022)³
- F695 Practice for Ranking of Test Data Obtained for Measurement of Slip Resistance of Footwear Sole, Heel, and Related Materials (Withdrawn 2018)³
- F732 Test Method for Wear Testing of Polymeric Materials Used in Total Joint Prostheses
- G40 Terminology Relating to Wear and Erosion
- G77 Test Method for Ranking Resistance of Materials to Sliding Wear Using Block-on-Ring Wear Test
- G99 Test Method for Wear and Friction Testing with a Pin-on-Disk or Ball-on-Disk Apparatus
- G133 Test Method for Linearly Reciprocating Ball-on-Flat Sliding Wear
- G137 Test Method for Ranking Resistance of Plastic Materials to Sliding Wear Using a Block-On-Ring Configuration
- G143 Test Method for Measurement of Web/Roller Friction Characteristics
- G163 Guide for Digital Data Acquisition in Wear and Friction Measurements (Withdrawn 2016)³
- G164 Test Method for Determination of Surface Lubrication on Flexible Webs
- G176 Test Method for Ranking Resistance of Plastics to Sliding Wear Using Block-on-Ring Wear Test—Cumulative Wear Method
- G181 Test Method for Conducting Friction Tests of Piston Ring and Cylinder Liner Materials Under Lubricated Conditions
- G182 Test Method for Determination of the Breakaway Friction Characteristics of Rolling Element Bearings
- G194 Test Method for Measuring Rolling Friction Characteristics of a Spherical Shape on a Flat Horizontal Plane
- G203 Guide for Determining Friction Energy Dissipation in Reciprocating Tribosystems
- G204 Test Method for Damage to Contacting Solid Surfaces under Fretting Conditions
- G219 Guide for Determination of Static Coefficient of Friction of Test Couples Using an Inclined Plane Testing Device

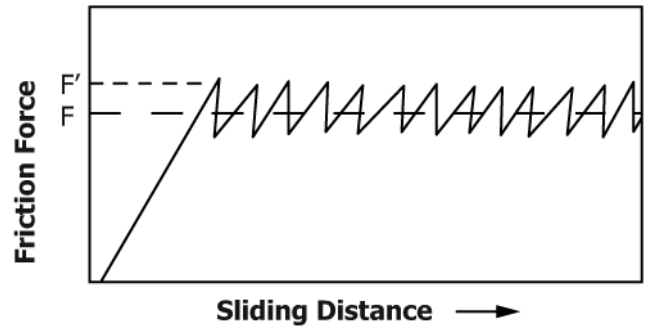


FIG. 1 Idealized Friction Force versus Distance Relationship for a System that Exhibits Stick-Slip Behavior (Long dashes indicate mean friction (kinetic) force (F) and short dashes indicate maximum (static) friction force (F').)

3. Terminology

3.1 For definitions relating to friction as a characteristic of a tribosystem, refer to Terminology G40.

3.2 Definitions:

3.2.1 *stick-slip, n*—relaxation oscillation usually associated with a decrease in the coefficient of friction as the relative velocity increases.

3.2.1.1 *Discussion*—The usual manifestation is a cycling decrease and subsequent increase in the friction force as sliding proceeds (Fig. 1).

4. Summary of Guide

4.1 A number of ASTM International standard test methods and guides (referred to here as simply “test methods” for brevity) that consider friction are tabulated here (Table 1) so that users can review available likely test methods and determine which may be most applicable for a particular application. Any of the listed tests or another accepted test may be used. Due to the ongoing nature of standards development, it should be noted that while this table cannot be exhaustive, its content has been selected to balance breadth, detail, and utility. Similarly, users are encouraged to review the most recent version of any test method cited as they may have been revised since this guide was published. Some test methods that have been “withdrawn” have been included for reference.

4.2 General friction testing precautions are cited and a prescribed method of recording friction data is recommended. This guide is intended to promote the use of this standard reporting system and standard friction test methods.

4.3 The use of one of the test methods cited in this guide will give assurance of a testing procedure that has been agreed-to for a particular application. In addition, it is important to keep in mind that friction is a system property. For example, the coefficient of friction of polystyrene against mild steel measured on a sled test (Test Method D1894) will probably be different than the coefficient of the same couple measured on a block-on-ring tester (Test Method G176) *since the coefficient of friction is a system property.*

TABLE 1 Selected ASTM Guides and Test Methods that Consider Friction

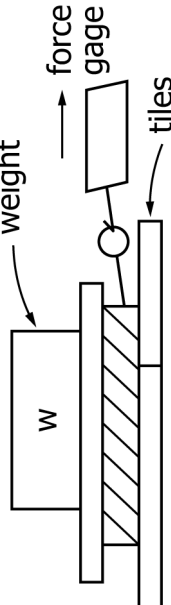
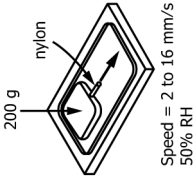
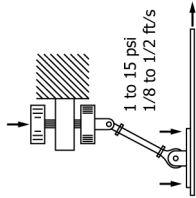
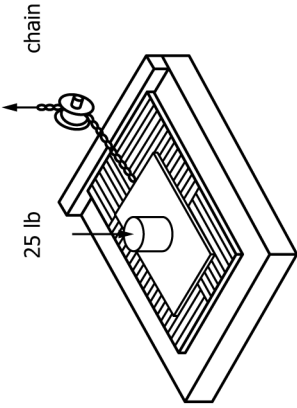
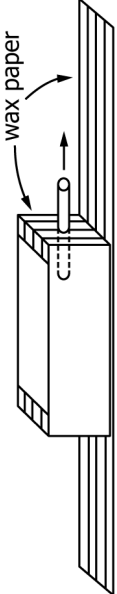
Standard/Committee	Title	Measured Parameters	Test Configuration
C808 /D02.F0 on Manufactured Carbon and Graphite Products	Guide for Reporting Friction and Wear Test Results of Manufactured Carbon and Graphite Bearing and Seal Materials	Carbon versus other materials (μ_s and μ_k)	any
C1028 /C21 on Ceramic Whitewares and Related Products (Withdrawn 2014)	Test Method for Determining the Static Coefficient of Friction of Ceramic Tile and Other Like Surfaces by the Horizontal Dynamometer Pull-Meter Method	Static COF wet and dry	
D1894 /D20 on Plastics (Withdrawn 2023)	Test Method for Static and Kinetic Coefficients of Friction of Plastic Film and Sheet	Plastic film versus stiff or other solids (μ_s and μ_k)	
D2047 /D21 on Polishes	Test Method for Static Coefficient of Friction of Polish-Coated Flooring Surfaces as Measured by the James Machine	Walking materials versus shoe heels and soles (μ_s and μ_k)	
D2394 /D07 on Wood	Test Methods for Simulated Service Testing of Wood and Wood-Base Finish Flooring	Wood and wood base flooring versus sole leather (μ_s and μ_k)	
D2534 /D02 on Petroleum Products and Lubricants	Test Method for Coefficient of Kinetic Friction for Wax Coatings	Kinetic coefficient of friction	

TABLE 1 Continued

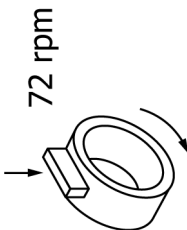
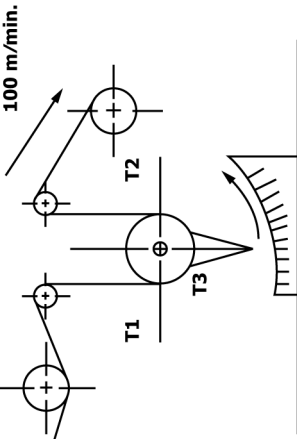
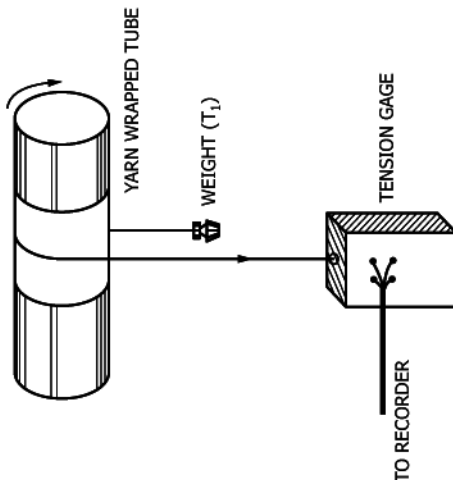
Standard/Committee	Title	Measured Parameters	Test Configuration
D2714/D02 on Petroleum Products and Lubricants	Test Method for Calibration and Operation of the Falex Block-on-Ring Friction and Wear Testing Machine	Steel ring versus steel block (lubricated with standard oil) (μ_k)	
D3108/D3108M/D13 on Textiles	Test Method for Coefficient of Friction, Yarn to Solid Material	Textile yarn versus solids (μ_k)	 $\mu = (\ln T_2 - \ln T_1) / \phi$
D3412/D3412M/D13 on Textiles	Test Method for Coefficient of Friction, Yarn to Yarn	Continuous filament and spun yarns self-mated (μ_s and μ_k)	 YARN WRAPPED TUBE WEIGHT (T_1) TENSION GAGE TO RECORDER

TABLE 1 Continued

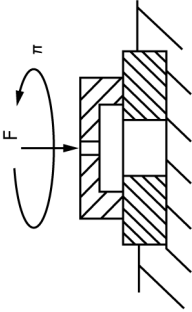
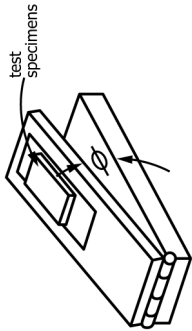
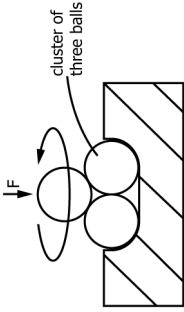
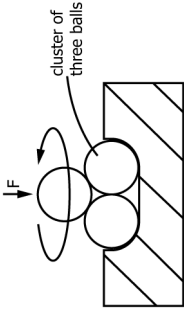
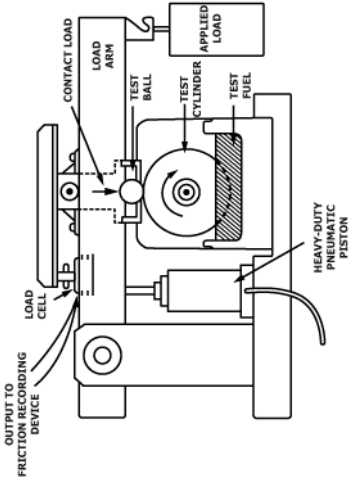
Standard/Committee	Title	Measured Parameters	Test Configuration
D3702/D02 on Petroleum Products and Lubricants	Test Method for Wear Rate and Coefficient of Friction of Materials in Self-Lubricated Rubbing Contact Using a Thrust Washer Testing Machine	Kinetic COF	
D4103/D21 on Polishes	Practice for Preparation of Substrate Surfaces for Coefficient of Friction Testing	Vinyl and wood tiles (preparation)	any
D4917/D06 on Paper and Paper Products (Withdrawn 2010)	Test Method for Coefficient of Static and Kinetic Friction of Uncoated Writing and Printing Paper by Use of the Horizontal Plane Method	μ_s and μ_k	
D4918/D06 on Paper and Paper Products (Withdrawn 2010)	Test Method for Coefficient of Static Friction of Uncoated Writing and Printing Paper by Use of the Inclined Plane Method	Static COF	
D5183/D02 on Petroleum Products and Lubricants	Test Method for Determination of the Coefficient of Friction of Lubricants Using the Four-Ball Wear Test Machine	Coefficient of force for each increment of 10 kgf	
D6078/D02 on Petroleum Products and Lubricants (Withdrawn 2021)	Standard Test Method for Evaluating Lubricity of Diesel Fuels by the Scuffing Load Ball-on-Cylinder Lubricity Evaluator (SLBOCLE) (withdrawn in 2021, but may still be used)	Tangential friction force (friction coefficient) Minimum applied load required to produce a friction coefficient greater than 0.175	

TABLE 1 Continued

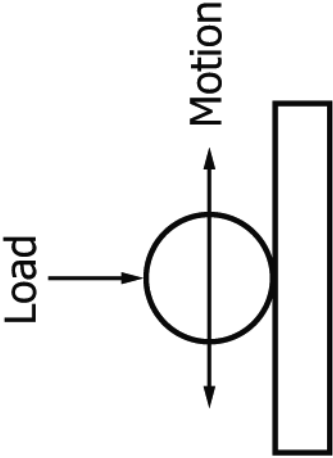
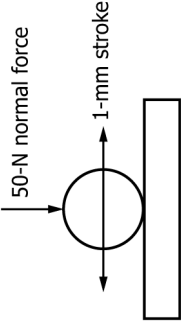
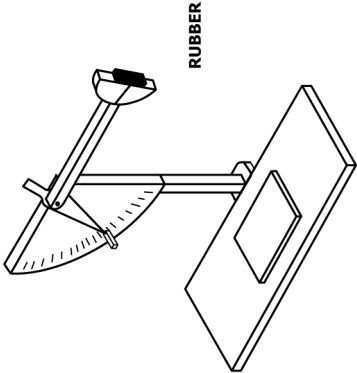
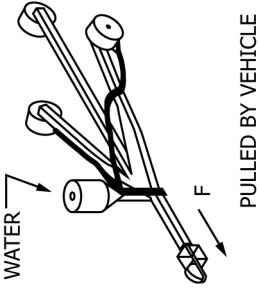
Standard/Committee	Title	Measured Parameters	Test Configuration
D6079/D02 on Petroleum Products and Lubricants	Standard Test Method for Evaluating Lubricity of Diesel Fuels by the High-Frequency Reciprocating Rig (HFRR)	Wear scar diameter (as a proxy for lubricity)	
D6425/D02 on Petroleum Products and Lubricants	Test Method for Measuring Friction and Wear Properties of Extreme Pressure (EP) Lubricating Oils Using SRV Test Machine	Coefficient of friction for test (min, max, and at increments <i>throughout the</i> test)	
E303/E17 on Vehicle-Pavement Systems	Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester	Rubber versus pavement (BPN British Pendulum Number)	
E670/E17 on Vehicle-Pavement Systems	Test Method for Testing Side Force Friction on Paved Surfaces Using the Mu-Meter	Tires versus pavement Mu Number (F dry – F wet)	

TABLE 1 Continued

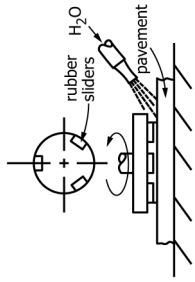
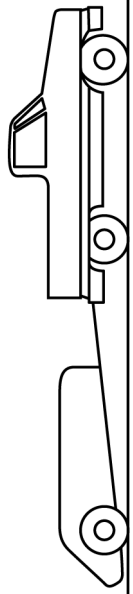
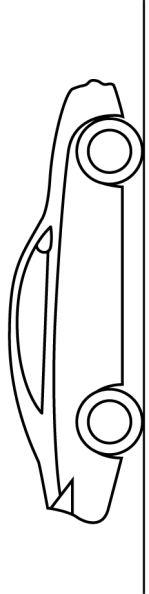
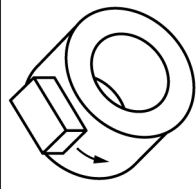
Standard/Committee	Title	Measured Parameters	Test Configuration
E1911/E17 on Vehicle-Pavement Systems	Test Method for Measuring Paved Surface Frictional Properties Using the Dynamic Friction Tester	Dynamic friction numbers (DNF) at 12 mph, 24 mph, 36 mph, and 48 mph	
E2100/E17 on Vehicle-Pavement Systems (Withdrawn 2019)	Practice for Calculating the International Runway Friction Index	Friction index for snow on a runway	 special trailer
E2101/E17 on Vehicle-Pavement Systems	Test Method for Measuring the Friction Properties of Winter Contaminated Pavement Surfaces Using an Averaging-Type Spot Measuring Decelerometer	Friction index for pavement	 braking deceleration
F609/F13 on Pedestrian/Walkway Safety and Footwear (Withdrawn 2022)	Test Method for Using a Horizontal Pull Slipmeter (HPS)	Footwear materials versus walking surfaces (μ_s)	Same as D2047
F695/F13 on Pedestrian/Walkway Safety and Footwear (Withdrawn 2018)	Practice for Ranking of Test Data Obtained for Measurement of Slip Resistance of Footwear Sole, Heel, and Related Materials	Footwear materials versus walking surfaces (reliable ranking of footwear for slip resistance) (μ_k)	Same as D2047
F732/F04 on Medical and Surgical Materials and Devices	Test Method for Wear Testing of Polymeric Materials Used in Total Joint Prostheses	Materials for human joints (μ_k)	Same as D6079 (with cylindrical pin)
G77/G02 on Wear and Erosion	Test Method for Ranking Resistance of Materials to Sliding Wear Using Block-on-Ring Wear Test	μ_s initial μ_k final μ_k final	 user-specified test conditions

TABLE 1 Continued

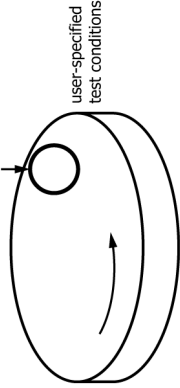
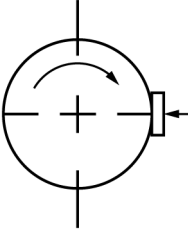
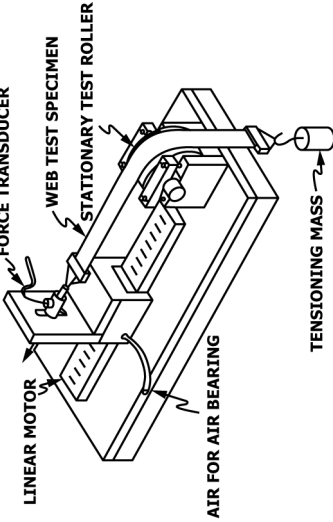
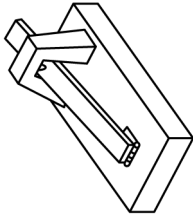
Standard/Committee	Title	Measured Parameters	Test Configuration
G99/G02 on Wear and Erosion	Test Method for Wear Testing with a Pin-on-Disk Apparatus	COF	
G133/G02 Wear and Erosion	Test Method for Linearly Reciprocating Ball-on-Flat Sliding Wear	μ_k	Same as D6079
G137/G02 Wear and Erosion	Test Method for Ranking Resistance of Plastic Materials to Sliding Wear Using a Block-On-Ring Configuration	μ_k	
G143/G02 on Wear and Erosion	Test Method for Measurement of Web/Roller Friction Characteristics	μ_s μ_k	
G163/G02 on Wear and Erosion	Guide for Digital Data Acquisition in Wear and Friction Measurements	Guidelines on data acquisition	Any rig
G164/G02 on Wear and Erosion	Test Method for Determination of Surface Lubrication on Flexible Webs	μ_s	

TABLE 1 Continued

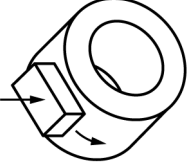
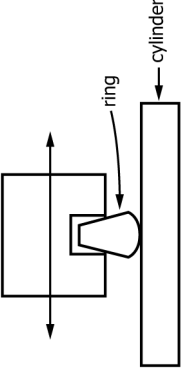
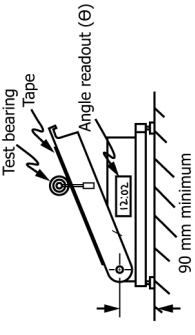
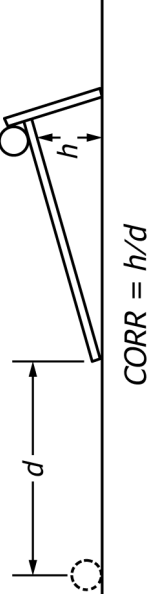
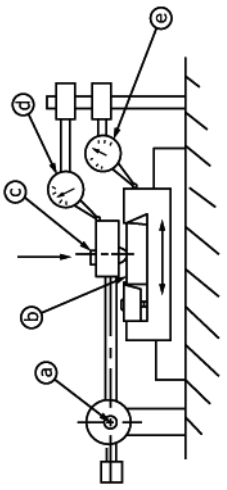
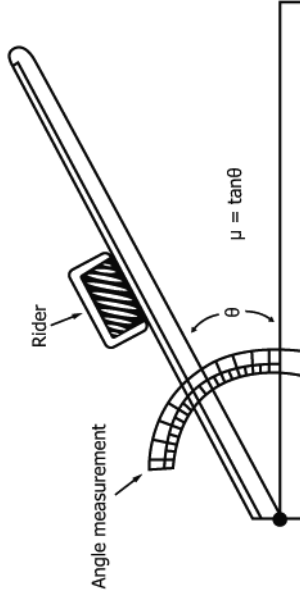
Standard/Committee	Title	Measured Parameters	Test Configuration
G176/G02 on Wear and Erosion	Test Method for Ranking Resistance of Plastics to Sliding Wear using Block-on-Ring Wear Test—Cumulative Wear Method	μ_s μ_k initial μ_k final	
G181/G02 on Wear and Erosion	Practice for Conducting Friction Tests of Piston Ring and Cylinder Liner Materials Under Lubricated Conditions	Average coefficient of friction	
G182/G02 on Wear and Erosion	Test Method for Determination of the Breakaway Friction Characteristics of Rolling Element Bearings	μ_s	
G194/G02 on Wear and Erosion	Test Method for Measuring Rolling Friction Characteristics of a Spherical Shape on a Flat Horizontal Plane	Coefficient of rolling resistance (CORR)	
G203/G02 on Wear and Erosion	Standard Guide for Determining Friction Energy Dissipation in Reciprocating Tribosystems	N/A	N/A
G204/G02 on Wear and Erosion	Standard Test Method for Damage to Contacting Solid Surfaces under Fretting Conditions	Friction force	

TABLE 1 Continued

Standard/Committee	Title	Measured Parameters	Test Configuration
G219/G02 on Wear and Erosion	Standard Guide for Determination of Static Coefficient of Friction of Test Couples Using an Inclined Plane Testing Device	Angle of incline	

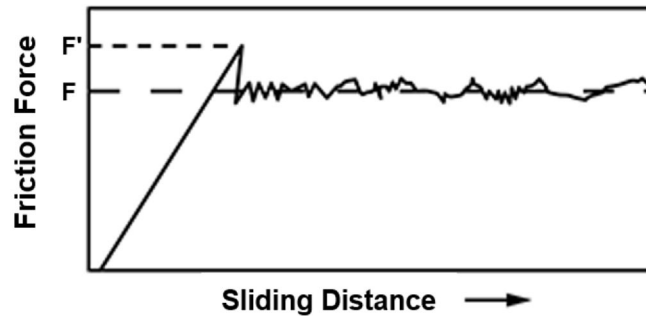


FIG. 2 Typical Force versus Distance Recording for a System that has a Static Friction (F') that is Higher than its Kinetic Friction (F)

4.4 Data developed by others can be useful if sufficient information is presented to characterize the tribosystem used in testing. Conformance with this guide in testing and reporting should produce data that can be reviewed for applicability to a particular tribosystem. Care should be particularly taken in comparing test configuration, especially where the measured friction force sensor is not colinear with the interface of interest.

5. Significance and Use

5.1 In this guide, factors that shall be considered in conducting a valid test for the determination of the coefficient of friction of a tribosystem are covered, and the use of a standard reporting format for friction data is encouraged.

5.2 The factors that are important for a valid test may not be obvious to non-tribologists, and the friction tests referenced will assist in selecting the apparatus and test technique that is most appropriate to simulate a tribosystem of interest.

5.3 The tribology literature is replete with friction data that cannot readily be used by others because specifics are not presented on the tribosystem that was used to develop the data. The overall goal of this guide is to provide a reporting format that will enable computer databases to be readily established. These databases can be searched for material couples and tribosystems of interest. Their use will significantly reduce the need for each laboratory to do its own testing. Sufficient information on test conditions will be available to determine applicability of the friction data to the engineer's specific needs.

6. Test Method Selection

6.1 The appropriate device to use is the one that closely simulates a tribosystem of interest, however doing so often produces results with substantial scatter and this is especially true where contamination is present. This scatter should be considered a property of the system and the magnitude of the variation can be greater than the mean value of the coefficient of friction.

6.1.1 *Discussion*—For example, compare a floor material with a mean coefficient of friction of 0.4 and a standard deviation of 0.01 with an alternate material with a mean coefficient of friction of 0.5 and a standard deviation of 0.25. Reporting only the mean values of coefficient of friction would

conclude that the alternate is safer, however it would disguise the fact that dangerously low friction was also statistically more likely. The closer to reality a system is, more repeated tests will likely be required to reach the same confidence in the mean results. Special care should be taken not to bias the results by using techniques such as randomisation and blinding.

6.2 Specimen geometries that resemble the components in the system of interest should be used. Entry geometry and specimen alignment are especially important in lubricated tests. Similarly, the geometry (radius and so forth) of leading edges and application of force are very important. Other important factors to simulate are normal force (contact pressure), velocity, type of motion (reciprocating versus unidirectional), and environment. For example, if an application involves flat surfaces in contact under relatively light loads and with low slip velocities, a sled device may be applicable. If an application involves materials such as friction composites, one of the brake-type dynamometer tests may be appropriate.

6.3 Stiffness of the friction force-measuring system can be important in some tests. If the sliding member in a test couple is set into motion by a metal rod, chain, or similar device, there will be very little elastic strain in the pulling device before initiation of motion, and the force-measuring transducer may not record a “breakaway” force, a force spike that is higher than the mean force measured during steady state sliding. This breakaway force is commonly used to calculate static friction (Fig. 2). If initial friction is of interest in a test, it is advisable to use a force-measuring system with substantial elasticity.

6.3.1 *Discussion*—For example, when pulling plastic film over a roll in sled-type devices, a nylon or similar plastic filament would be best to produce motion of the sliding member. Conversely, when pulling a steel cable over the same roll, it would be more appropriate to use a stiff testing system. (**Warning**—More “elastic” systems may be more prone to produce stick-slip behavior. In addition, elastic beams containing strain gauges may produce different friction responses than a more rigid load cell even if used on the same friction testing machine.)

6.4 Initial friction force spikes will occur in many test systems. Test surfaces that are prone to blocking or interlocking of surface features are particularly prone to showing a

breakaway force spike. Blocking is a term used to describe the tendency of some plastic materials to stick to each other after long periods of contact, for example, plasticized vinyl materials often block when self mated.

7. Considerations When Selecting Tests

7.1 The precautions listed in 7.1.1 – 7.1.10 are provided to supplement those included in any ASTM International or other friction test method.

7.1.1 Avoid skin contact with the test surfaces. Fingerprints can leave a film several micrometres thick that can affect results. The method of cleaning the test surfaces and the elapsed time between surface cleaning and friction testing should be documented.

7.1.2 Test in ambient conditions (atmosphere, temperature, and humidity) that are the same as the tribosystem of interest. Samples should be in equilibrium with their environment. It is advisable to incubate test samples that can be affected by humidity (plastics and other non-metals) for 24 h in the desired ambient conditions prior to testing.

7.1.3 Use test samples with the same surface texture and directionality as the tribosystem of interest. A nondirectional lapped surface is sometimes preferred for research studies. The test report should indicate how the test surface textures were produced (for example, lapping, longitudinal grinding, and so forth), the orientation of surface lay to the sliding direction, and the relative alignment of the surfaces both when in contact and at the point of engagement/disengagement of the contact.

7.1.4 Be meticulous in cutting test samples, and eliminate burred edges and errors of form (dents, scratches, bow, and so forth).

7.1.5 Thoroughly document the test specimens: material designation, composition, heat treatment, processing, and manufacturer.

7.1.6 If friction is measured in a wear test, be aware that the measured friction coefficient is for altered counterfaces, rather than as if they were (unworn) at the start of the test. In addition to surface topology changes due to material removal or movement, the surfaces may be separated by wear debris. This may change throughout the test as wear debris is accumulated and will depend on the test apparatus design. For example, a design that includes a simple oil bath is more likely to have debris being entrained into the contact being investigated than a design with oil circulating through a filter and a gravity or magnetic debris trap in a sump reservoir. If worn surfaces are likely in the tribosystem of interest, then it is appropriate to measure friction coefficients in a wear test.

7.1.7 The frictional characteristics of many couples can be affected by sliding velocity and normal force. It is advisable to check systems for sensitivity to these factors. Hold normal force constant and vary velocity and vice versa.

7.1.8 Run-in may cause friction force transitions. Therefore, a steady-state value of friction force may or may not be achieved under given test conditions. The reported friction coefficient (μ_k) should be the steady-state value unless specific reference to transient behavior is to be reported.

7.1.9 Inspect surfaces after testing to determine if the surfaces are altered by the test (are they scratched, worn,

deformed, and so forth). If the test goal is to test virgin surfaces, it may be necessary to use less severe test conditions. If unexpected damage occurs under all test conditions of interest, note this in the test results. The occurrence of surface damage may be a significant test output.

7.1.10 When using a digital data acquisition system to record friction force, results can be affected by the sampling rate or the duration of the sampling period (see Guide G163).

8. Test Specimens and Sample Preparation

8.1 Friction measurements are extremely dependent on the condition of the contacting surfaces on the test specimens. The surfaces should be in exactly the same condition as the tribosystem under study or as prescribed in an applicable ASTM International or test standard. Where real world variation is small, test samples should exactly match the expected conditions. For example, if the subject tribosystem involves molded surfaces, do not test with machined surfaces. Where real world variation is large, if practical, test samples should reflect this variation and enough repeats carried out to well characterize the response. If not practical, variation must be idealised away. For example, by testing a single “ideal” shoe molding against multiple floors or tightly controlling the temperature of the environment in which the test is occurring. In these situations, it is important to select an ideal that is relevant to the use cases of interest.

8.2 Cleaning:

8.2.1 Avoid cleaning surfaces with solvents that may leave films that may not be present in the tribosystem of interest. If perfectly clean metal surfaces are to be tested for friction characteristics, cleaning with refluxed solvent vapors is very effective. Trichlorethylene is commonly used in a vapor degreaser for this purpose. There is some evidence that cleaning in chlorinated solvents can leave films that affect friction results. If this is a consideration, acetone or a similar non-chlorinated solvent can be used. Cleaning details should be included in the test report.

8.2.2 Plastics, ceramics, and other non-metals can have their surface characteristics significantly affected by solvent cleaning. Many plastics can be effectively cleaned with commercial glass detergents (except those containing wax) followed by a distilled water rinse. This same procedure will work on many ceramics. Alcohols should be avoided on ceramics since there is some evidence that they alter surface properties. Alcohols should be avoided for cleaning in general because they may not effectively remove common surface contaminants such as fingerprints and oil.

8.2.3 The cleaning method that has shown to produce uniformly clean surfaces on metals and most rigid materials is abrasive cleaning with bonded abrasive. Abrading with a fresh sheet of abrasive paper on a flat surface plate (use a grit size that will produce the desired surface roughness) will usually be sufficient to produce a surface that is free of contaminating films. Frequent changes in sample orientation can be used to generate a multidirectional scratch pattern. Debris from abrasion should be removed by a blast from an aerosol can of laboratory grade, clean, dry air. Abrasion is the only effective way of removing silicones, graphite, molybdenum disulfide,

and similar materials. Any abrasion or lapping produces some risk of embedding abrasive. If it is felt that a test material is prone to embedding, surface analysis techniques (X-ray fluorescence and the like) can be used to confirm if a particular surface preparation process is producing embedding. Usually embedding is not a concern unless fine abrasives ($<10\ \mu\text{m}$) are used. In any case, specimens shall be checked for embedding.

8.2.4 In summary, cleaning of friction test surfaces is one of the most important considerations, and the best system to use is the one that produces surface conditions that will be present in tribosystems of interest. For research studies, freshly abraded surfaces are likely to be clean and free from the contaminant films that may affect results.

9. Procedure

9.1 Simulate the velocity, type of motion, normal force, and environment of the tribosystem of interest. If a standard test is being used (ASTM International and so forth), use designated test conditions. Try to use fresh samples for replicate tests. If this is impractical, examine samples for wear after each test; discontinue testing if there is an upward or downward trend or if the surface texture is altered in any way (unless worn surfaces are of interest). In this case, the samples should also be randomised or systematically varied between test conditions; if two types of oil are to be tested you should not keep one sample in one type of oil and the other in the other type as this confounds the results. For example, it may be possible to do many replicate tests on hard steel samples without alteration of surfaces, but plastic samples may wear (by surface deformation, scratching, and so forth) after only one test. Statistical techniques can be used to determine the number of replicates required (Practice E122) but usually a minimum of five replicates is required. The expected variability of the test, the number of different test conditions, and the desired quality of results determine how many replicates are needed, but it is usually desirable to achieve a standard error of less than 5 % of the mean value for a valid test.

9.2 Control tests should be completed alongside the tests of interest. Otherwise it is not possible to formally compare results directly as effects of interest are confounded with particulars of sample preparation, lab environment etc. If there are no standard controls (for example, a stated material grade as described in a standard test method), they should be selected to be relevant, ideally reflecting current best practice. For example, if an oil additive is being tested, the best control would be an alternative, established additive of the same type used in its recommended quantity (that is, do not match quantities). Alternatively, the plain oil could be used. A dry control would not be relevant. The order of these tests should also be randomised as testing in blocks (for example, all control tests in the morning and others in the afternoon) may unnecessarily introduce bias into the results.

9.3 The sliding distance used in a friction test should be adequate to ensure equilibrium friction conditions. If the friction force increases and decreases continuously through a test, this may be an indication that a longer sliding distance is needed. If friction is measured in a wear test, this should be stated in the data sheet.

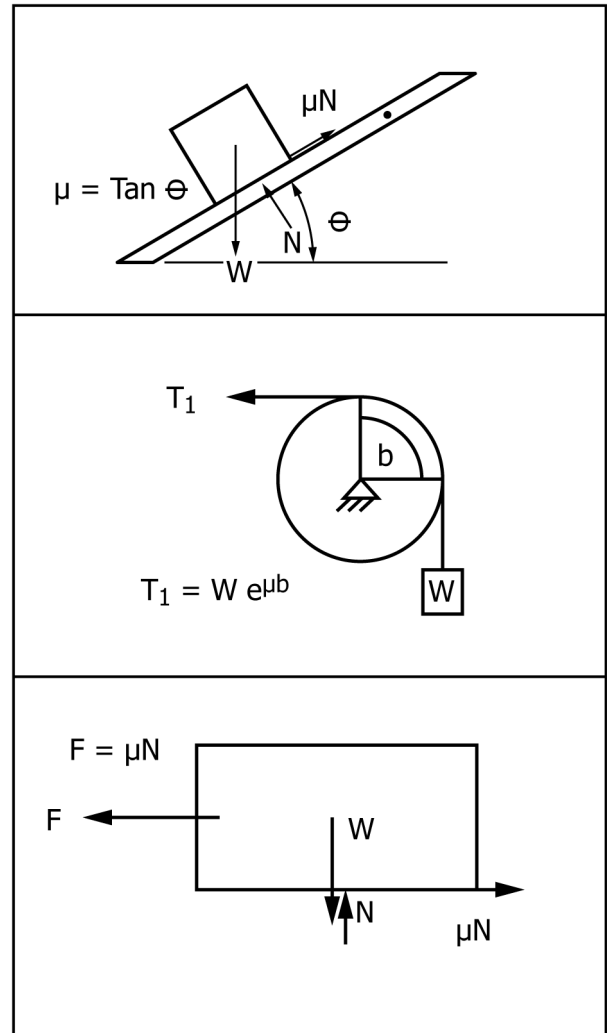


FIG. 3 Formulas for Calculation of Friction Coefficients, μ

F = Friction force, w = mass, N = Normal force, b = angle of wrap (radians), e = Euler's number = 2.718

10. Calculation of Coefficient of Friction

10.1 The equations commonly used to calculate coefficients of friction are shown in Fig. 3. The inclined plane test (Fig. 3) only yields the static coefficient of friction. It is recommended that the term static friction coefficient, μ_s , be used to describe a coefficient calculated using a breakaway force in a friction test rig that moves a specimen with a mechanism other than gravity.

10.2 The kinetic coefficient of friction, μ_k , may not be constant for a given time of sliding. It is common to calculate μ_k from averaged force readings for the duration of sliding, but other techniques may be used. If non-continuous readings are desired, it is common to measure the friction towards the end of the test (for example, for the last 60 s) to record and report the “End of Test Friction” (EOT). It is important to report the trend of EOT (for example, stable, erratic, rising, falling) in addition to the numerical value. The standard deviation of the time series should also be reported for each test and plots of the raw data made available to indicate the range (“windows”) of

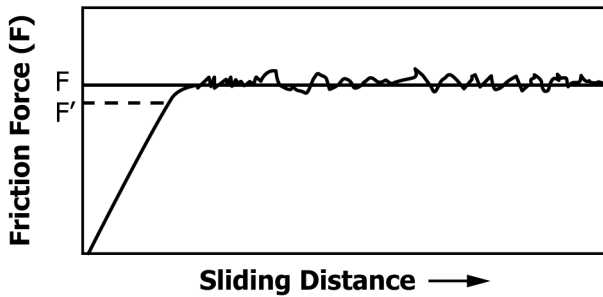


FIG. 4 Typical Force versus Distance Recording for a System that Does Not Exhibit a High Breakaway Force

values used in the calculations. The slope and gradient of the line of best fit, if significantly non-zero, can provide an indication of a test being steady-state or not. However, raw data plots provide the same information and also highlight other issues. It is strongly recommended that friction force readings be taken from continuously recorded (analog or digital) force data. Consideration of data acquisition frequency must be made, particularly if the test itself is cyclic in nature and is likely to require the capture of friction force data that varies in a near-repeatable manner with time within each cycle (for example, the periodic reversing in direction of a ball on flat reciprocating test such as defined by Test Method G133). If a test is very fast and initial friction is of concern, a recording oscilloscope or high-speed data acquisition system should be used to optimize recorder response. If suitable equipment is available to record friction force and normal force at preset time intervals (instantaneously), these values can be averaged to yield a μ_k for a test, but cannot be used as repeat tests. Whatever the method used, the technique should be described in sufficient detail so that it can be reproduced by others.

10.3 Interpretation of Friction Force Recordings:

10.3.1 Stick-slip behavior occurs in many sliding systems, and when it does, the coefficient of friction of the system is so variable that it is common practice to simply report “stick-slip behavior” for the test result rather than a numerical result. Typical friction-force-versus-time (distance) recordings are presented in Fig. 1, Fig. 2, and Fig. 4.

10.3.2 In the examples of typical friction force tracers (Fig. 1, Fig. 2, and Fig. 4), the kinetic coefficient of friction is usually calculated from the friction force, F . The static coefficient is usually calculated from force, F' ; the behavior in the example in Fig. 1 is usually reported as stick-slip. This type of behavior may not be apparent if the moving body is translated by a rigid screw mechanism or similar device. Tribosystems that display stick-slip behavior often produce vibration or noise. Stick-slip usually occurs in tribosystems in which there is considerable elasticity. It usually does not occur if the static coefficient of friction (μ_s) is equal to the kinetic coefficient of friction (μ_k), and it often occurs in systems in which there is a negative slope to the coefficient of friction versus velocity curve.

11. Report

11.1 The minimum data for tabulation in friction database is included in items 11.1.1 to 11.1.9.

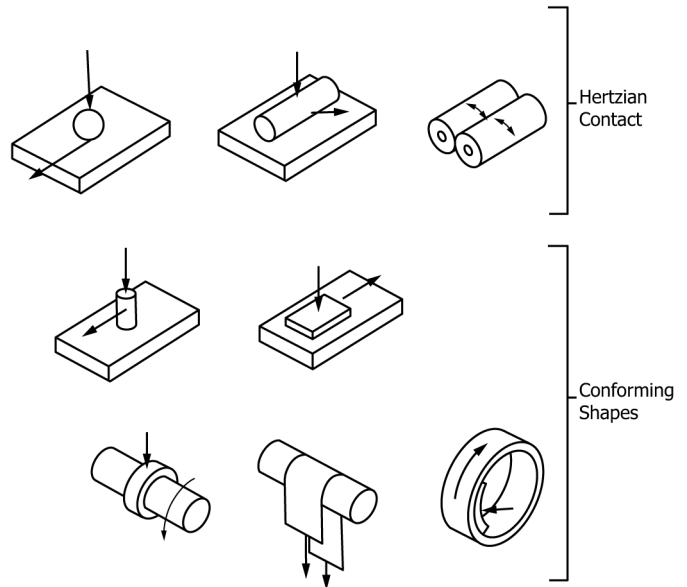


FIG. 5 Friction Testing Specimen Configuration Options

- 11.1.1 Material Couple (A) _____
(B) _____ (generic names of materials).

NOTE 1—Many plastics, ceramics, and cermets are proprietary in nature; for these materials, use trade names but reference the manufacturer.

11.1.2 Specimen Description (pin, disk, shaft, bushing, block, and so forth).

11.1.3 Kinetic Coefficient of Friction, μ_k _____, including the standard deviation, the number of tests completed, the period of which the data is averaged (for example, full or part test, and, if the latter which parts). (Refer to Note 2.)

11.1.4 Static Coefficient of Friction, μ_s _____, including the standard deviation, the number of tests completed, the period of which the data is averaged (for example full or part test, and, if the latter which parts). (Refer to Note 2.)

NOTE 2—Ideally, also report the “raw” value for each test carried out, then these can be combined later from multiple reports to add value to the wider dataset, and provide a plot of the raw data (for example, a x-y scatter plot where each test, averaged over time if needed, is a single point) to show the variation in the data.

11.1.5 System Configuration (see Fig. 5 for options) _____.

11.1.6 ASTM International or other procedure _____.

11.1.7 Comments—In addition to 11.1.1 through 11.1.6, it is always advisable to include a “comments” section in a data sheet to prompt inclusion of important tribological behavior that may not show up in making the measurements in 11.1.1 through 11.1.6. For example, some couples may show stick-slip behavior, some may squeal, some materials may deform, and so forth. Note here if sample surfaces were visibly altered during the friction test.

11.1.8 Test Conditions (Starting)—For conforming surfaces (Fig. 5), this is the normal force/apparent area of contact; Hertz stress equations can be used for nonconformal geometries.

11.1.8.1 Apparent contact pressure, MPa _____.

11.1.8.2 Normal force, N _____.

11.1.8.3 Velocity, m/s _____.

11.1.8.4 Type of motion (reciprocating, steady sliding, and so forth) _____.

11.1.8.5 Total sliding distance, m _____.

11.1.8.6 Sample bulk temperature, °C _____.

11.1.8.7 Temperature measurement technique (location of sensor, and so forth).

11.1.8.8 Test atmosphere (surrounding gases, ambient pressure, and so forth) _____.

11.1.8.9 Relative humidity, % _____.

11.1.8.10 Lubricant _____.

11.1.8.11 *Generic Type (Petroleum Oil) Specifies*—Mobil 10/60, and so forth.

11.1.8.12 Friction measured as part of a wear test ____yes
____no.

11.1.8.13 *Comments*—In addition to 11.1.1 through 11.1.6, it is always advisable to include a record of any changes to the testing conditions that were observed during and at the end of the test.

11.1.9 *Test Materials*—Complete description of stationary members and moving members should include:

11.1.9.1 *Generic Name*—(1020) steel, acetal homopolym-
er, aluminum oxide, and so forth.

11.1.9.2 *Specification*—AISI, ASTM, UNS.

11.1.9.3 *Form*—Wrought, cast, extruded, hot pressed, and so forth.

11.1.9.4 *Treatments*—Hardened to 60 HRC, annealed, as extruded, carburized, plated with 1 µm-thick hard chromium, and so forth.

11.1.9.5 *Surface Texture*— R_A , R_Z , lay, method of surface preparation, relationship of lay to sliding direction, and so forth. If R_Z is reported, the calculation method should be stated (for example, $R_{z(DIN)}$, $R_{z(ISO)}$).

11.1.10 *Cleaning*—Solvent type, how performed, number of times cleaning process was carried out, elapsed time before testing, and so forth.

NOTE 3—If one or both members are coated or subject to some surface treatment, the details of this process should be noted. If a coating is the subject of a friction test, the coating(s) may be listed as a test member(s).

12. Precision and Bias

12.1 Since this guide encompasses the use of many types of test methods and types of apparatus, no specific data for

precision and bias can be given. Some general comments on values that might be expected and on factors that can affect precision are given in the following paragraphs.

12.2 The repeatability of 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.

12.3 Industrial experience has shown that carefully conducted unlubricated inclined plane and sled friction tests have produced within-laboratory coefficient of variation of 10 % or less for friction coefficients on an identical tribosystem. Coefficients of variation may be 25 % or higher when friction measurements are derived from wear tests. Variation is largest in systems with high wear (surface damage), contamination, or strong sensitivity to environmental conditions. It is the responsibility of the user to determine what is an acceptably low enough coefficient of variation to yield meaningful results. The above sentences reflect observations made in unlubricated metal-to-metal and metal-to-plastic friction tests and highlight the importance of not idealising away so much of the real-world variation that the results become irrelevant to the application.

12.4 Sample wear during friction tests can result in unacceptable test variability. Care should be taken to prevent surface alteration during friction testing caused by wear unless wear is part of the tribosystem of interest.

12.5 Friction coefficients of material couples obtained on one type of test apparatus may be significantly different from coefficients of the same material couples tested on a different apparatus. A friction coefficient is a system effect, so appropriate caution shall be used when comparing or using data from different sources and systems. If direct comparison is required, include the subject as a control.

13. Keywords

13.1 coefficient of friction; data analysis; friction coefficients; friction/frictional properties; kinetic coefficient of friction; static coefficient of friction; triboelements

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