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.

Designation: D5001 – 23

Standard Test Method for Measurement of Lubricity of Aviation Turbine Fuels by the Ball-on-Cylinder Lubricity Evaluator (BOCLE)[1]

This standard is issued under the fixed designation D5001; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 This test method covers assessment of the wear aspects of the boundary lubrication properties of aviation turbine fuels on rubbing steel surfaces.

1.1.1 This test method incorporates two procedures, one using a semi-automated instrument and the second a fully automated instrument. Either of the two instruments may be used to carry out the test.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.3 *This standard does not purport to address 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.*

1.4 *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]

D4175 Terminology Relating to Petroleum Products, Liquid Fuels, and Lubricants

D4306 Practice for Aviation Fuel Sample Containers for Tests Affected by Trace Contamination

D6708 Practice for Statistical Assessment and Improvement of Expected Agreement Between Two Test Methods that Purport to Measure the Same Property of a Material

2.2 *American Iron and Steel Institute Standard:*[3]

AISI E-52100 Chromium Alloy Steel

2.3 *ISO Standard:*[4]

ISO 3290-1 Rolling bearings -- Balls -- Part 1: Steel balls

2.4 *Society of Automotive Engineers Standard:*[5]

SAE 8720 Steel

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this test method, refer to Terminology D4175.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *lubricity, n*—qualitative term describing the ability of a fluid to minimize friction between, and damage to, surfaces in relative motion under load.

3.2.1.1 *Discussion*—In this test method, the lubricity of a fluid is defined in terms of a wear scar, in millimeters, produced on a loaded stationary ball from contact with a fluid-wetted rotating cylindrical test ring operating under closely defined and controlled conditions.

3.2.2 *wear scar, n—in the liquid fuels industry*, average diameter of a worn and abraded area, measured in two specified directions, produced on a test ball under defined conditions.

3.2.2.1 *Discussion*—The wear scar generated by Test Method D5001 is often referred to as the BOCLE wear scar.

3.3 *Abbreviations:*

3.3.1 *BOCLE*—Ball On Cylinder Lubricity Evaluator

3.3.2 *HRC*—Rockwell Hardness "C" scale.

3.3.3 *WSD*—Wear Scar Diameter

[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.J0.04 on Additives and Electrical Properties.

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[2] 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] Available from American Iron and Steel Institute (AISI), 1140 Connecticut Ave., NW, Suite 705, Washington, DC 20036, http://www.steel.org.

[4] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, http://www.iso.ch.

[5] Available from Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001, http://www.sae.org.

*A Summary of Changes section appears at the end of this standard

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4. Summary of Test Method

4.1 The fluid under test is placed in a test reservoir in which atmospheric air is maintained at 10 % relative humidity. A non-rotating steel ball is held in a vertically mounted chuck and forced against the outside diameter of an axially mounted cylindrical steel ring with an applied load. The test ring is rotated at a fixed speed while being partially immersed in the fluid reservoir. This maintains the ring in a wet condition and continuously transports the test fluid to the ball/ring interface. The wear scar generated on the test ball is a measure of the lubricating property of the fluid. For wear scar diameter (WSD) calibration and standardization, see Section 10.

5. Significance and Use

5.1 Wear due to excessive friction resulting in shortened life of engine components such as fuel pumps and fuel controls has sometimes been ascribed to lack of lubricity in an aviation fuel.

5.2 The relationship of test results to aviation fuel system component distress due to wear has been demonstrated for some fuel/hardware combinations where boundary lubrication is a factor in the operation of the component.

5.3 The wear scar generated in the ball-on-cylinder lubricity evaluator (BOCLE) test is sensitive to contamination of the fluids and test materials, the presence of oxygen and water in the atmosphere, and the temperature of the test. Lubricity measurements are also sensitive to trace materials acquired during sampling and storage. Containers specified in Practice D4306 shall be used.

5.4 The BOCLE test method may not directly reflect operating conditions of engine hardware. For example, some fuels that contain a high content of certain sulfur compounds can give anomalous test results.

6. Apparatus

6.1 For details of the *Ball-On-Cylinder Lubricity Evaluator (BOCLE)*, apparatus required for each method see: Annex A1 for the semi-automatic method, Annex A2 for the fully automatic method.

6.2 *Microscope,* capable of 100× magnification and suitable of measuring the wear scar on the ball to the nearest 0.01 mm.

6.2.1 *Method of Measuring the Wear Scar*—This may be either a Glass Slide Micrometer, with a scale ruled in 0.01 mm divisions, or a digital micrometer and slide assembly, having a resolution of at least 0.01 mm.[6,7]

6.3 *Cleaning Bath*—Ultrasonic seamless stainless steel tank with a capacity of 1.9 L and a cleaning power of 40W.

6.4 The test requirements are listed in Table 1.

TABLE 1 Standard Operating Conditions

Fluid Volume	50 mL ± 1.0 mL
Fluid Temperature	25 °C ± 1 °C
Conditioned Air	10 % ± 0.2 % relative humidity at 25 °C ± 1 °C
Fluid pretreatment	0.50 L/min flowing through and 3.3 L/min over the fluid for 15 min
Fluid test conditions	3.8 L/min flowing over the fluid
Applied Load	1000 g (500 g weight) (± l g)
Cylinder Rotational Speed	240 rpm ± 1 rpm
Test Duration	30 min ± 0.1 min

7. Reagents and Materials

7.1 *Test Ring,* of SAE 8720 steel, having a Rockwell hardness "C" scale, (HRC) number of 58 to 62 and a surface finish of 0.56 µm to 0.71 µm root mean square.[6,8] The dimensions are given in Fig. 1.

7.2 *Test Balls,* chrome alloy steel, made from AISI standard steel No. E-52100, with a diameter of 12.7 mm, Grade 5 to 10. The balls are described in ISO 3290-1. The HRC shall be 64 to 66, a closer limit than is found in the ISO requirement.

7.3 *Additional Equipment*—Details of additional items of test equipment specific to each test method are given in the appropriate annex.

7.4 *Compressed Air* (**Warning—**Compressed gas under high pressure. Use with extreme caution in the presence of combustible material, since the autoignition temperatures of most organic compounds in air are drastically reduced at

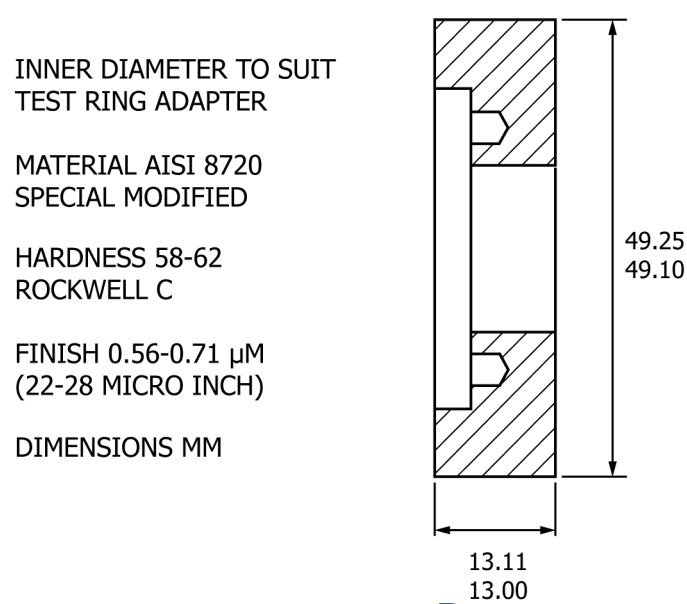

FIG. 1 Ball-on-Cylinder Test Ring

[6] 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.

[7] The sole source of supply of the apparatus known to the committee at this time is Microscope part number ABSMIC from PCS Instruments, 78 Stanley Gardens, London, W3 7SZ, U.K. A certificate of traceability from the National Institute of Standards and Technology is available.

[8] The sole source of supply of the apparatus known to the committee at this time is (for the semi-automatic method) Test Rings Part No. F25061, Falex Corp., 2055 Comprehensive Drive, Aurora, IL 60505 and (for the fully automatic method) Test Rings, Part No. ABSRING, PCS Instruments, 78 Stanley Gardens, London, W3 7SZ, U.K.

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elevated pressures. See A3.1.), containing less than 0.1 ppm hydrocarbons and 50 ppm water.

7.5 *Desiccator,* containing a non-indicating drying agent, capable of storing test rings, balls, and hardware.

7.6 *Gloves,* clean, lint-free, cotton, disposable.

7.7 *Wiper,* wiping tissue, light duty, lint free, hydrocarbon free, disposable.

7.8 *Isooctane* (**Warning—**Extremely flammable. Harmful if inhaled. Vapors may cause flash fires. See A3.2.), conforming to American Chemical Society (ACS) Reagent/General Purpose Reagent (GPR) grade standards, 95 % purity minimum, 2,2,4-trimethylpentane.

7.9 *Isopropyl Alcohol* (**Warning—**Flammable. See A3.3.), conforming to ACS Reagent/GPR grade standards.

7.10 *Acetone* (**Warning—**Extremely flammable. Vapors may cause flash fire. See A3.4.), conforming to ACS Reagent/GPR grade standards.

7.11 *Reference Fluids:*

7.11.1 *Fluid JFA*[9]—High lubricity reference (**Warning—**Flammable). The URL of this webpage is http://webstore.astmtmc.cmu.edu/webstore/ProductDetail.aspx?ProductID=50. Store in clean, borosilicate glass with an aluminum foil-lined insert cap or a fully epoxy-lined metal container. Store in dark area.

7.11.2 *Fluid JFB*[9]—Low lubricity reference (**Warning—**Flammable. Vapor harmful). The URL of this webpage is https://www.astmtmc.org/ftp/docs/sds/fuel/JFB10_CofA.pdf. Store in clean, borosilicate glass with an aluminum foil-lined insert cap or a fully epoxy-lined metal container. Store in a dark area.

7.11.3 The reference fluids shall be stored in epoxy lined containers or borosilicate glass bottles with aluminum foil or PTFE lined insert caps. Borosilicate glass bottles shall be stored in a dark area.

8. Sampling, Test Specimens, and Test Units

8.1 *Cleaning of Apparatus and Test Components:*

8.1.1 *Test Rings, as Received:*

8.1.1.1 The test rings shall be partially stripped of any protective coatings by manually rubbing them with rags or paper towels saturated with isooctane.

8.1.1.2 Place partially cleaned rings in a clean 500 mL beaker. Transfer a sufficient volume of a 1 to 1 mixture of *iso*octane (2,2,4-trimethyl pentane) and isopropyl alcohol to the beaker such that the test rings are completely covered.

8.1.1.3 Place beaker in ultrasonic cleaner and turn on for 15 min.

8.1.1.4 Remove test rings and repeat ultrasonic cleaning cycle of 8.1.1.3 with a clean beaker and fresh solvents.

8.1.1.5 Handle all clean test rings with clean forceps or disposable gloves. Remove test rings from beaker and rinse with isooctane, dry, and rinse with acetone.

NOTE 1—Drying operations can be accomplished using a compressed air jet at 140 kPa to 210 kPa pressure.

8.1.1.6 Dry and store in a desiccator.

8.1.2 *Test Balls, as Received.*

8.1.2.1 Place balls in 300 mL beaker. Transfer a sufficient volume of a 1 to 1 mixture of isooctane and isopropyl alcohol to the beaker such that the test balls are completely covered by the cleaning solvent.

NOTE 2—Approximately a five-day supply can be processed at one time.

8.1.2.2 Place beaker in ultrasonic cleaner and turn on for 15 min.

8.1.2.3 Repeat the cleaning cycle of 8.1.2.2 with a clean beaker and fresh solvent.

8.1.2.4 Remove and rinse with *iso*octane, dry, and rinse with acetone.

8.1.2.5 Dry and store in a desiccator.

8.1.3 *Reservoir, Reservoir Cover, Ball Chuck, Lock Ring, Mandrel Assembly (Method A, Semi Automatic Method) Test Ring Assembly (Method B, Fully Automatic Method),* and all other parts which come into direct contact with the test fuel (refer to the appropriate annex).

8.1.3.1 Rinse with isooctane.

8.1.3.2 Clean in an ultrasonic cleaner with a 1:1 mixture of isooctane and isopropyl alcohol for 5 min.

8.1.3.3 Remove and rinse with isooctane, dry, and rinse with acetone.

8.1.3.4 Store in a desiccator until required.

8.1.4 *Hardware:*

8.1.4.1 The hardware and utensils, that is, any part that comes in contact with the test fluid shall be cleaned by washing thoroughly with isooctane and wiped with a wiper.

8.1.4.2 Store parts in desiccator when not in use.

8.1.5 *After Test:*

8.1.5.1 Remove reservoir and test ring.

8.1.5.2 Disassemble components and clean in an ultrasonic cleaner using a 1 to 1 mixture of isooctane and isopropyl alcohol for 5 min. Rinse with isooctane, dry, and rinse with acetone. Reassemble components.

8.1.5.3 Dry and store in a desiccator.

NOTE 3—When testing the same fluid, it is permissible to clean the reservoir by hand. The reservoir is rinsed with isooctane. Wipe with disposable wiper to remove residual fuel related deposits and test debris. The reservoir is rinsed again with isooctane. Dry and final rinse with acetone, dry.

8.1.5.4 Store parts in desiccator when not in use.

8.1.5.5 *Semi-Automatic (Method A) Only*—Care shall be taken to ensure that the fuel aeration tube is rinsed and dried during the cleaning procedure. Store parts in desiccator when not in use.

9. Preparation of Apparatus

9.1 Use the following procedures, where applicable:

Annex A1 for the semi-automatic method.

Annex A2 for the fully automatic method.

[9] Reference Fluids JFA and JFB are available from ASTM Test Monitoring Center, 203 Armstrong Dr., Freeport, PA 16229.

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10. Calibration and Standardization

10.1 Visually inspect test balls before each test. Discard balls that exhibit pits, corrosion, or surface abnormalities.

10.2 *Reference Fluids:*

10.2.1 Conduct three tests on each new batch of the reference fluids in accordance with Section 11 using a test ring previously standardized by reference fluid testing.

10.2.2 Repeat the three tests if the wear scar diameters differ by more than 0.04 mm for Reference Fluid A or by more than 0.08 mm for Reference Fluid B.

10.2.3 Reject the reference fluid concerned if the wear scar diameters for the repeat tests (10.2.2) again differ by more than the values obtained in 10.2.1.

10.2.4 Calculate the average wear scar for the three results that are within the values of 10.2.2 for the appropriate Reference Fluid.

10.2.5 Compare the average results with the WSD of the Reference Fluid values provided by the ASTM Test Monitoring Center Certificate of Analysis. The TMC issues COAs for both JFA and JFB posted on the website: https://www.astmtmc.org/ftp/docs/sds/

10.2.6 Reject the new Reference Fluid batch if the average results obtained at 10.2.4 differ by more than 0.04 mm for Reference Fluid A or by more than 0.08 mm for Reference Fluid B from the Reference Fluid values given in 10.2.5.

10.3 *Test Ring Calibration:*

10.3.1 Test each new ring with Reference Fluid A as per Section 11.

10.3.2 The ring is acceptable if the wear scar diameter result is within 0.04 mm WSD of the Reference Fluid A value shown in 10.2.5.

10.3.3 Repeat the test if the wear scar diameter does not agree within 0.04 mm WSD of the Reference Fluid A value shown in 10.2.5.

10.3.4 Reject the ring if the two values obtained in 10.3.1 and 10.3.3 differ by more than 0.04 mm WSD from each other or if both of the values differ by more than 0.04 mm WSD from the Reference Fluid A value shown in 10.2.5.

10.3.5 Test each new ring with Reference Fluid B as per Section 11.

10.3.6 The ring is acceptable if the wear scar diameter result is within 0.08 mm WSD of the Reference Fluid B value shown in 10.2.5.

10.3.7 Repeat the test if the wear scar diameter does not agree within 0.08 mm WSD of the Reference Fluid B value shown in 10.2.5.

10.3.8 Reject the ring if the two values obtained in 10.3.5 and 10.3.7 differ by more than 0.08 mm WSD from each other or if both of the values differ by more than 0.08 mm WSD from the Reference Fluid B value shown in 10.2.5.

NOTE 4—The BOCLE test result is very sensitive to contamination of the reference fluids, test rings, balls and hardware.

11. Procedure

11.1 The procedure for testing using the semi automatic method is described in Annex A1.

11.2 The procedure for testing using the fully automatic method is described in Annex A2.

12. Calculation and Interpretation of Results

12.1 *Wear Scar Measurement:*

12.1.1 Turn on the microscope light and position test ball under the microscope at 100× magnification.

12.1.2 Focus the microscope and adjust the stage such that wear scar is centered within the field of view.

12.1.3 Align the wear scar to either a divisional point of reference on the numerical scale with the mechanical stage controls, or the cross hair graticule. Measure the major axis to the nearest 0.01 mm. Ensure that the measurement is taken to include the outermost edge of the wear scar (i.e. include all the wear scar region). Repeat the procedure for the minor axis. Record the readings on the data sheet. Typical wear scars are illustrated in Fig. 2 showing the measurement points.

12.1.4 Record condition of wear area if different from the reference standard test, that is, debris color, unusual particles or wear pattern, visible galling, etc., and presence of particles in the reservoir.

12.2 *Wear Scar Calculation:*

12.2.1 Calculate the wear scar diameter as follows:

$$WSD = (M+N)/2 \quad (1)$$

where:

WSD = wear scar diameter, mm,
M = major axis, mm, and
N = minor axis, mm.

13. Report

13.1 Report the following information:

13.1.1 Wear scar diameter to the nearest 0.01 mm (from 12.2),

13.1.2 Description of the wear scar area, and

13.1.3 Deviations from the standard conditions of the test load, relative humidity, and fuel temperature, etc. (Fig. 3).

14. Precision and Bias[10]

14.1 *Precision*—The precision of this test method as obtained by statistical analysis of interlaboratory test results should be used for judging the acceptability of results (95 % of confidence).[6,10,11] The interlaboratory study was carried out on both the semi-automatic and fully automatic instruments, using 10 fuel samples and 8 participating laboratories.

14.2 *Repeatability*—The difference between successive test results, obtained by the same operator with the same apparatus

[10] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1639. The following equipment, as listed in RR:D02-1639 was used to develop the precision statement and no statistically significant differences were found between these pieces of equipment (Semi-automatic method: BOCLE units, BOC 100, made by Inter Av, Inc., P.O. Box 792228, San Antonio, TX 78279. Fully automatic method: Automated BOCLE System, ABS, made by PCS Instruments, 78 Stanley Gardens, London, W3 7SZ, U.K.) This listing is not an endorsement or certification by ASTM International.

[11] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1256. Contact ASTM Customer Service at service@astm.org.

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