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Standard Test Method for Determining the Combustion Behavior of Metallic Materials in Oxygen-Enriched Atmospheres[1]

This standard is issued under the fixed designation G124; 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 test apparatus and techniques to determine the minimum test gas pressure and sample temperature that supports self-sustained combustion (the threshold pressure) burning and the average regression rate (apparent burn rate) of the melting surface of a standardized sample of a metallic material that has been ignited using a strong promoter.

1.2 The data obtained from this test method are dependent on the precise test sample configuration and provide a basis for comparing the combustion behaviorburning characteristics of metallic materials. No criteria are implied for relating these data tofor the suitability of a material's use in any actual system. The application of data obtained from this test method is discussed in Guides G88 and G94.

1.3 Requirements for an apparatus suitable for this test method are given, as well as an example of such an apparatus. example. The example, however, example is not required to be used.

1.4 This test method is for gaseous oxygen or any mixture of oxygen with inert diluents that will support combustion,burning, at any pressure or temperature within the capabilities of the apparatus used.

1.5 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.6 *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 hazards statements are given in Section 9.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

G63 Guide for Evaluating Nonmetallic Materials for Oxygen Service
G88 Guide for Designing Systems for Oxygen Service
G93 Practice for Cleaning Methods and Cleanliness Levels for Material and Equipment Used in Oxygen-Enriched Environments
G94 Guide for Evaluating Metals for Oxygen Service

2.2 *Federal Specification:*

BB-0-925 Oxygen, Technical, Gas and Liquid

2.3 *Military Standard:*

MIL-0-27210E Amendment 1—Oxygen, Aviator's Breathing, Liquid and Gas[3]

3. Terminology

3.1*Definitions of Terms Specific to This Standard:*

3.1 *Definitions:*

3.1.1 *average regression rate (apparent burn rate)*—the average rate at which the burning/solid-metal interface advances along the test sample length. burn length, *n*—the burn length is the length of the sample that has been consumed by combustion.

3.1.1.1 *Discussion*—The burn length is determined by subtracting the post-test sample length from the pretest sample length (which does not include the promoter length or region used by the test sample support.)

3.1.2 *igniter*—a material to ignite the promoter that can burn under an electrical influence, such as a small-diameter wire.

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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.

flammable material, *n*—a material is defined in this standard as flammable if a standard rod sample burns more than 3 cm (1.2 in.) above the promoter **(1, 2)**.[3]

3.1.3 ~~*promoter*—a material that can add supplemental heat and increase the temperature to start combustion of the material being tested.~~ highest no-burn pressure, *n*—the maximum gas pressure (at a specified oxygen concentration and fixed sample temperature) at which a material does not burn more than 3 cm (1.2 in.) above the promoter in a minimum of five tests.

3.1.4 ~~*self-sustained combustion*—combustion that consumes a sample to the point at which the sample holder affects further combustion (assuming sufficient oxygen).~~ highest no-burn temperature, *n*—the maximum sample temperature (at a specified oxygen concentration and pressure) at which a material does not burn more than 3 cm (1.2 in.) above the promoter in a minimum of 5 tests.

3.1.5 ~~*threshold pressure*—the minimum gas pressure (at a specified oxygen concentration and ambient temperature) that supports self-sustained combustion of the entire standard sample.~~ igniter, *n*—a material used to ignite the promoter that can burn under an electrical influence, such as a small-diameter wire.

3.1.6 *lowest burn pressure*, *n*—the minimum gas pressure (at a specified oxygen concentration and fixed sample temperature) at which a material burns more than 3 cm (1.2 in.) above the promoter for one or more tests specimens.

3.1.7 *lowest burn temperature*, *n*—the minimum sample temperature (at a specified oxygen concentration and pressure) at which a material burns more than 3 cm (1.2 in.) above the promoter for one or more tests specimens.

3.1.8 *promoter*, *n*—an optional material that can add supplemental heat and increase the temperature to start burning of the metallic material being tested.

3.1.9 *regression rate of the melting interface*, *n*—the average rate at which the solid-liquid metal (melting) interface advances along the test sample length during a test.

3.1.10 *sample temperature*, *n—the initial temperature of the test sample being evaluated.*

3.1.10.1 *Discussion*—Various methods of measuring sample temperatures are used. The method selected must be reported with test data.

3.1.11 *standard rod test sample*, *n*—a 3.2 mm (0.125 in.) diameter rod with a minimum length of 101.6 mm (4 in.).

3.1.12 *threshold pressure*, *n*—This term is historically used to represent the definitions of either the lowest burn pressure or the highest no-burn pressure.

3.1.12.1 *Discussion*—In this standard, it represents the lowest burn pressure, which is used as the new term throughout.

3.1.13 *valid test*, *n*—a test in which the igniter and/or promoter combination has melted the bottom section of the test sample where the igniter and/or promoter is located.

4. Summary of Test Method

~~4.1A small rod of the material is suspended in a chamber filled with pressurized test gas. The chamber contains sufficient oxygen so that not more than 10% of the oxygen will be consumed when the material combusts completely. A promoter (typically aluminum or magnesium) applied to the bottom of the rod starts combustion of the material. The test pressure is reduced and another rod is tested if combustion of the entire rod occurs. This continues until self-sustained combustion of the rod does not occur for at least five tests at one pressure. The lowest pressure at which self-sustained combustion occurred is the threshold pressure for the material, and the difference between it and the highest pressure level that produced only incomplete combustion is the margin of potential error. Astute initial estimates of the threshold can reduce the amount of testing necessary to demonstrate the threshold to within the required uncertainty.~~

4.1 A standard rod sample of the material to be tested is vertically suspended in a chamber filled with pressurized test gas. The chamber contains sufficient oxygen so that not more than 10 % of the oxygen will be consumed if the sample completely burns. A promoter (aluminum is most common, however titanium, carbon steel and magnesium are also used) may be applied to the bottom of the rod to start burning of the material in conjunction with the igniter (typically Pyrofuse or Nichrome wire)[4]. The test chamber is pressurized to the required test pressure and the sample is heated to the required test temperature (if elevated temperature is one of the parameters).

4.2 The test is initiated by ignition of the igniter wire/promoter (typically through resistive heating) so that the end of the test sample is melted away to produce a valid test with relevant data collected, as specified.

NOTE 1—In 4.3 as subsequent samples are tested, only one parameter of temperature or pressure is varied and the other held constant within the tolerance allowed by this test method. It is up to the user to determine if the purpose of the test is to determine burn/no-burn pressure or burn/no-burn temperature. Only one of these variables should be changed during a series of tests.

4.3 If the sample is flammable, another standard sample rod is tested at a reduced test pressure or temperature. If the sample is not flammable, testing continues until the sample is not flammable in a minimum of fivetests at one set of conditions. It has been

~~[3] Available from Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098, http://dodssp.daps.dla.mil.~~

[3] The boldface numbers in parentheses refer to a list of references at the end of this standard.

~~[4] The boldface numbers in parentheses refer to the list of references at the end of this test method.~~

[4] The trade name for aluminum-palladium wire is Pyrofuze. It is a registered trademark of the Pyrofuze Corp., 121 S. Columbus Ave., Mt. Vernon, NY 10553, and is available from them.

shown, for a burn probability of less than 10 %, 5 no burn results provides a 41 % confidence level in the (no burn) result, whereas twenty-two no burn results provides a 90 % confidence level (for the same burn probability of 10 %). A thorough discussion of the burn probabilities and associated confidence levels is given in Ref **(3)**.

NOTE 2—Increasing the number of samples will always give a higher level of confidence and is recommended when possible. This method defines the highest no-burn pressure or temperature and the lowest burn pressure or temperature. The maximum no-burn (and burn) temperature and pressure and regression rate of the melting interface can be determined from the test data.

5. Significance and Use

5.1This test method will allow comparisons of the combustion characteristics of various metallic materials. The combustion characteristics that can be evaluated include (*1*) threshold pressure and (*2*) average regression rate (apparent burn rate) of the sample.

5.1 This test method will allow comparisons of the burning characteristics of various metallic materials. The burning characteristics that can be evaluated include (*1*) burn and no-burn pressure, (*2*) burn and no-burn temperature, (*3*) regression rate of the melting interface, and (*4*) visual evaluation of the burning process of the test sample.

6. Interferences

6.1Any internal materials that may bake out or vaporize during the combustion process at test temperature/pressure may interfere with the chemistry of the fire propagation.

6.2The specific atmosphere in the test chamber can have a severe effect. Therefore, alien air, argon, nitrogen, carbon dioxide, moisture, and others can be important interfering gases.

6.3The test is conducted under stagnant conditions. A flowing system or one that facilitates buoyant convective currents may be a significantly more severe climate.

6.4The specific temperature of the test sample prior to ignition can have an important effect.

NOTE1—The promoters discussed in this test method have produced favorable results over a wide range of metal test specimens with the degree of precision sought to date. As the threshold is approached or when interaction between promoter and metal occur promoter can thwart the ignition process. Hence the prospect that future work may refine the promoter and enable the measurement of lower thresholds than are measurable today cannot be ruled out.

6.1 Any materials inside the test chamber that may bake out, ignite/burn, or vaporize during the burning process at test temperature/pressure may interfere with the chemistry of the fire propagation and subsequently affect burning.

6.2 The specific atmosphere in the test chamber can have a severe chemical or thermodynamic effect, or both. Therefore, test gas contamination or diluents (such as argon, nitrogen, carbon dioxide, water vapor, and others) can be important factors, so the oxygen gas purity and quantities and types of diluents should be specified in the data sheet.

6.3 The standard test is conducted under non-flowing conditions. Depending on the final gas velocity, tests conducted under flowing oxygen conditions may dramatically affect the test results.

7. Apparatus

7.1 *System*—A schematic of a typical system is shown in Fig. 1. Other designs may also be used,used if they fulfill the requirements below. following requirements.

7.2 *Test Chamber*—A cross-section of a typical stainless steel test chamber is shown in Fig. 2. No more than 10% of the available oxygen should be consumed during a test. . Appendix X1 provides criteria for establishing the lowest test pressures that meet this criterion for various vessel volumes. If the chamber cannot be made sufficiently large, an accumulator can be attached that contains more test gas if the chamber cannot be made sufficiently large; however, this is not as severe a test environment as in the larger vessel. The test chamber shall not contribute any chemical interference to testing.

NOTE2—The addition of an accumulator can act as a snubber to suppress pressure rises that occur due to temperature rises and pressure drops that result from oxygen consumption, but it will have a much smaller effect in preventing local buildup of diluents in the oxygen. Each of these influences will exhibit a progressively greater effect and consequence in smaller vessels.

NOTE3—The significance of ensuring an adequate oxygen inventory is to avoid the observation of apparently negative test results at conditions that are above the threshold but for which extinguishment may, nonetheless, occur due to depletion of oxygen, consequential reduction of pressure, or concentration of diluents. However, in any test in which complete combustion of the specimen occurs, the result is valid, regardless of whether the test conditions met the minimum recommended requirement for oxygen inventory. provides criteria for establishing the lowest test pressures that meet the stated criterion of using no more than 10 % of the available oxidizer for various vessel volumes. If the chamber cannot be made sufficiently large, an accumulator can be attached between the test chamber and the chamber isolation valve that contains more test gas. The test chamber (and accumulator if used) shall not contribute any chemical interference to testing.

7.3 *Sample holder*, capable of securing the sample at the top and supporting it in a vertical position. There shall be sufficient space beneath the sample for the igniter and any drops of liquid material that may fall during the test. Sample Holder—capable of securing the sample at the top and supporting it in a vertical position.

7.4 *Thermocouple*, used to measure gas temperature in the chamber. Temperature Sensor—used to measure gas or sample temperatures in the chamber, accurate to within ±1 % of reading or accuracy otherwise noted.

7.5 *Pressure Transducer*, used to measure gas pressure in the chamber, accurate to within ±1% of reading. —used to measure

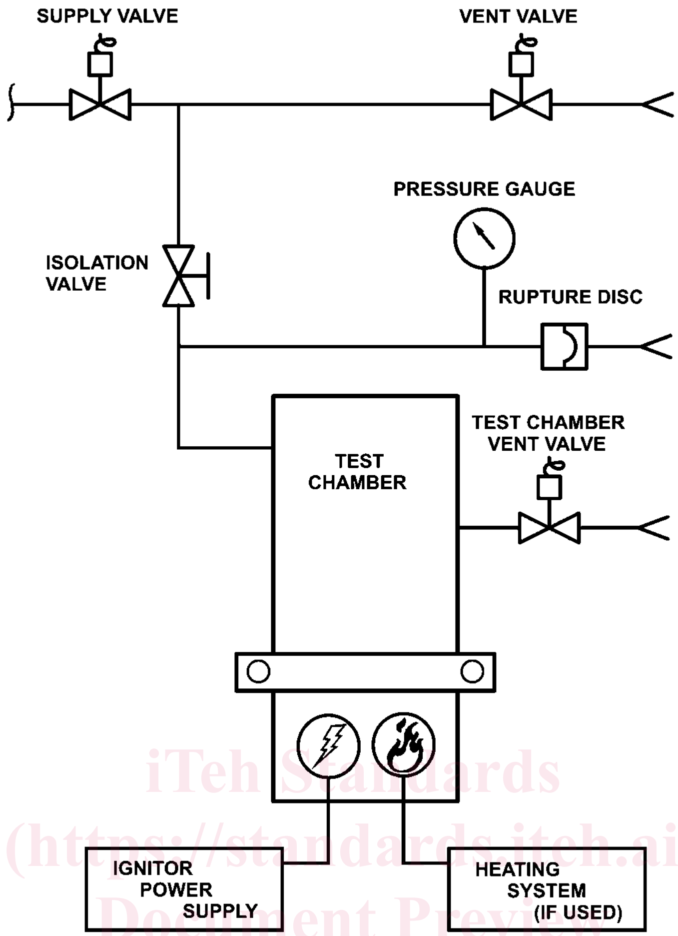

FIG. 1 Schematic of Typical System

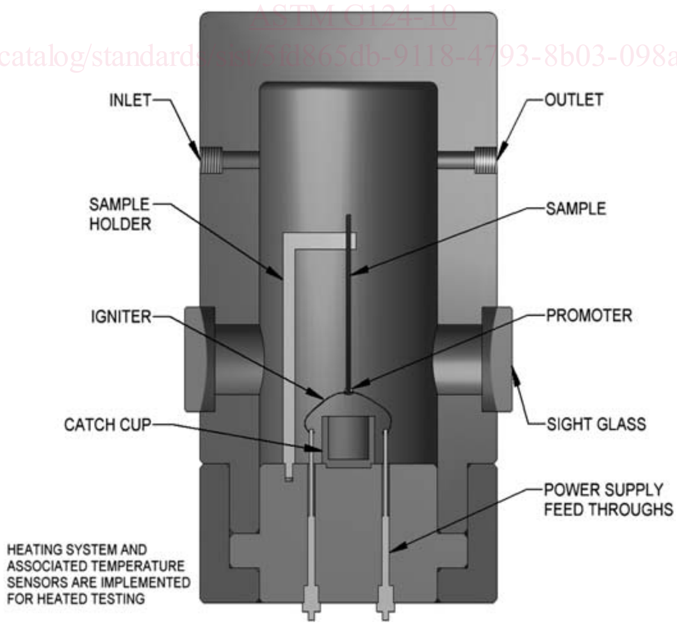

FIG. 2 Typical Stainless Steel Test Chamber Cross-Section

gas pressure in the chamber, accurate to within ±1 % of reading or accuracy otherwise noted.

7.6 ~~*Liner and Base Plate*—A burn-resistant (for example, copper) liner and base plate in the test chamber serve as an internal shield to protect the components from combustion products, molten slag, and so forth.~~ Liner (optional)—a burn-resistant (for example, copper or ceramic) liner is recommended in the test chamber to serve as an internal shield to protect the chamber and components from the burning, molten slag, and other reaction products produced during sample burning.

7.7 *Sight Glass*~~, capable of withstanding the maximum test pressure anticipated. If video or film recording of the burning event contained in the test chamber is desired, the sight glass shall transmit compatible light.~~ —(optional for tests not determining either the regression rate of the melting interface or visual evaluation of the burning process), capable of withstanding the maximum test pressure anticipated (initial pressure plus pressure rise due to heating during burning). Other methods of observing the test may be possible, though direct observation is most common.

7.8 *Igniter Power Supply*~~,~~—electrically isolated and capable of providing adequate current to initiate the ~~igniter wire~~ ignition within ~~a few seconds~~3 s of the application of power.

7.9 *Test Cell*~~, (a room to house the test chamber), constructed of noncombustible material (such as concrete or metal) with sufficient strength to provide protection from explosion or fire hazards. A continuous ventilation system shall circulate fresh air in the test cell. The cell shall provide a facility that can be maintained at a high level of good housekeeping. The test cell shall be cleaned periodically to avoid contamination of the sample and equipment.~~ —a room to house the test chamber, constructed of non-flammable material (such as concrete or metal) with sufficient strength to provide protection from explosion, pneumatic release or fire hazards. A continuous ventilation system shall circulate fresh air in the test cell. The test cell shall be cleaned periodically to avoid contamination of the sample and equipment and minimize fire hazards.

7.10 *Piping System*~~, which purges, pressurizes, and vents the test chamber. The piping system shall be designed to permit remote test chamber purge, pressurization, and venting without unsafe exposure of personnel. The chamber shall be purged and pressurized through one line and vented through a separate line to minimize the chances of contaminant migrating into the pressurization line, which might influence subsequent tests. A typical piping system for this test is shown in~~ — which purges, pressurizes, and vents the test chamber. The piping system shall be designed to permit remote test chamber purge, pressurization, and venting without unsafe exposure of personnel. It is recommended the test chamber be purged and pressurized through one line and vented through a separate line to minimize the chances of a contaminant migrating into the pressurization line, which might influence subsequent tests. It is also recommended that a pressure relief device with an appropriate setting be fitted to the piping system and be able to communicate to the test chamber.

NOTE 3—Although the use of separate lines is preferred it is not a requirement. Periodic inspection and cleaning of lines and valves should be done to decrease the risk of cross contamination. A typical piping system for this test is shown in Fig. 1.

7.11 *Control Area*~~, which~~—which will isolate test personnel from the test cell during tests. This control area shall be provided with the necessary control and instrumentation features to perform test chamber purge, pressurization and venting operations, and monitoring of the test chamber instrumentation during the test.

7.12 ~~*Data Acquisition System (Optional)*, capable of recording, storing, and accessing the pressure and temperature data at a rate of ten samples/s (minimum). It shall also include a video recording device that displays the "real-time" burn phenomenon. The video recording can be used for regression rate determination.~~ Data Acquisition System—capable of recording, storing, and accessing the pressure, temperature and regression rate data at a rate of ten samples per second (minimum). It may also include a video recording device that displays the "real-time" burn phenomenon. The video recording with embedded timer, thermocouple sensor arrays, and ultrasonic rod length measurements are some of the methods available for determination of the regression rate of the melting interface (see Annex A1).

7.13 *Heating System (for elevated temperature testing only)*—which will heat the sample to the required initial test sample temperature range, without interfering with the other functions of the test system or the test chamber integrity. The heating system is required to evaluate burning characteristics at elevated temperatures above ambient. (No heating system is required if testing is to be done at ambient temperature only.) The method used can include, but is not limited to, localized heating methods including induction heating, resistive heating, and radiant heating. Heating of the entire system has also been successfully used, however the vessel pressure rating must be considered due to the temperature dependency of the chamber material strength (see 9.4) and any non-metallic materials exposed to elevated temperatures should be used in accordance with Guide G63.

8. Reagents and Materials

8.1 *Gaseous Oxygen*~~—Oxygen purity equal to or greater than that of practical systems is preferred, especially when testing alloys containing aluminum, magnesium, zirconium, etc. (that is, metals believed to burn at least in part in the vapor phase). An analysis of the test oxidant is required. The use of oxygen greater than 99.5% pure may affect the test results significantly (1~~**—Oxygen purity equal to or greater than that of practical systems is preferred for the standard test, and an analysis of the test oxidant is required. Other oxygen/diluents mixtures may be used and it is recommended that the exact oxygen purity used be specified with the test results. (4)** ~~**, and its use shall be noted on the data sheet.**~~

NOTE ~~4—Some applications involve the use of oxygen mixed with other gases, and data in the literature **(1, 2**~~ **4—Oxygen purity has been shown, for certain materials to significantly affect the results. Extremely high purity or low purity oxygen (with diluents present) should be avoided unless conducting special studies using gas mixtures (5)** ~~**indicate that the rankings of materials can be different depending on the amount and kind of diluents present. Although the basic apparatus and principle of this test are valid when used with oxygen mixed with other gases, alterations to the test method may be necessary. At present, these alterations have not been studied sufficiently for inclusion in this test method.**~~ **and in all cases the purity should be specified along with any diluents present**

8.2 *Promoter*~~—The promoter shall consist of a sufficient quantity of material to ignite the test specimens. Some examples of promoter material are aluminum and magnesium (~~**3—The promoter shall provide sufficient energy to melt the end of the test sample to produce a valid test and, if flammable at test conditions, ignite the test specimens. Some examples of promoter material include aluminum, Pyrofuze,[4] magnesium, titanium and carbon steel (6)**~~**. No promoter may be necessary at all at times; the igniter wire itself may provide sufficient energy to ignite the sample. Nonmetallic promoters may be used; however, the combustion products of such promoters might contaminate the test media.**~~ **. In some cases, a promoter may not be necessary when the igniter itself can provide sufficient energy to produce a valid test. Nonmetallic promoters may be used; however, the combustion products of such promoters might contaminate the test media and care must be taken to ensure that the use of nonmetallic promoters produces a valid test result. Other ignition sources, such as laser or electrical, may also be used. In selecting the promoter material, the possibility of a chemical reaction between the test material and the promoter should be considered.**

8.3 *Igniter*—The igniter shall have sufficient energy to ignite the promoter or the sample and produce a valid test result. Some examples of the igniter wire material are nickel/chromium (Nichrome) or aluminum/ palladium (Pyrofuze).[4] The electrical system that supplies current to the wire should provide sufficient current to melt and ignite the igniter in 1-2 s. A slow heat-up can increase the amount of pre-ignition energy loss to the sample rod, which will increase the heat affected zone of the sample and potentially produce an invalid test.

NOTE~~5—In selecting the promoter material, the possibility of a chemical reaction between the test material and the promoter should be considered. Also, for certain metals, the chemical energy released from the combustion of promoter might be insufficient to ignite the metal. Other ignition sources, for example, electrical or laser, may be used in such cases.~~

~~8.3*Igniter Wire*—The igniter wire shall be made of a material capable of igniting the promoter. Some examples of the igniter wire material are nickel/chromium or aluminum/palladium.~~ 5—Rapid heating of the sample may result in damage to, or ignition of, the igniter wire and either prevent ignition of the promoter or ignite it prior to establishment of required test conditions.

9. Hazards

9.1 *High-Pressure Oxygen System*—**Warning:** There are hazards involving the use of a ~~high-pressure oxygen system.~~enriched-oxygen systems. The following guidelines will reduce the dangers:

9.1.1 Personnel should be isolated from the test system when it is pressurized. Preferably, personnel should be shielded by both physical protection (for example, the test cell) and distance.

9.1.2 The test system itself should be isolated to prevent danger to people not involved in the test.

9.1.3 The test system should incorporate equipment able to handle the maximum operating pressure safely, including an appropriate safety-factor.

9.1.4 The test system should be kept clean to prevent unintentional ignition.

9.1.5 The test system should be double-isolated from the test gas supply system.

9.1.6 Remote readout devices should be provided so personnel do not have to approach the test system to obtain operating data or test results, or both.

9.2 *Oxygen*—**Warning:** Oxygen enrichment accelerates combustion vigorously. Care should be taken at all times when working

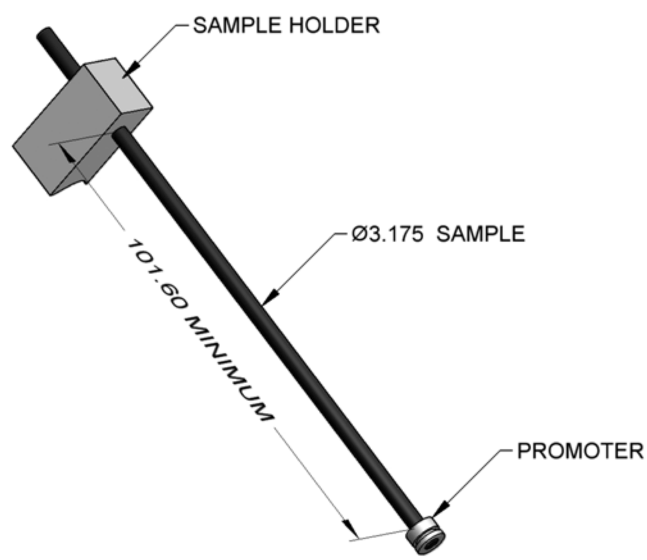

FIG. 3 Typical Test Sample Dimensions