



Designation: ~~G114–14~~ G114 – 21

Standard Practices for Evaluating the Age Resistance of Polymeric Materials Used in Oxygen Service¹

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1. Scope

1.1 These practices describe procedures that are used to determine the age resistance of plastic, thermosetting, elastomeric, and polymer matrix composite materials exposed to oxygen-containing media.

1.2 While these practices focus on evaluating the age resistance of polymeric materials in oxygen-containing media prior to ignition and combustion testing, they also have relevance for evaluating the age resistance of metals, and nonmetallic oils and greases.

1.3 These practices address both established procedures that have a foundation of experience and new procedures that have yet to be validated. The latter are included to promote research and later elaboration in this practice as methods of the former type.

1.4 The results of these practices may not give exact correlation with service performance since service conditions vary widely and may involve multiple factors such as those listed in ~~subsection 5.8~~.

1.5 Three procedures are described for evaluating the age resistance of polymeric materials depending on application and information sought.

1.5.1 *Procedure A: Natural Aging*—This procedure is used to simulate the effect(s) of one or more service stressors on a material's oxygen resistance, and is suitable for evaluating materials that experience continuous or intermittent exposure to elevated temperature during service.

1.5.2 *Procedure B: Accelerated Aging Comparative Oxygen Resistance*—This procedure is suitable for evaluating materials that are used in ambient temperature service, or at a temperature that is otherwise lower than the aging temperature, and is useful for developing oxygen compatibility rankings on a laboratory comparison basis.

1.5.3 *Procedure C: Accelerated Aging Lifetime Prediction*—This procedure is used to determine the relationship between aging temperature and a fixed level of property change, thereby allowing predictions to be made about the effect of prolonged service on oxidative degradation.

1.6 *Units*—The values stated in SI units are to be regarded as the ~~standard~~ standard; however, all numerical values shall also be cited in the systems in which they were actually measured.

¹ These practices are under the jurisdiction of ASTM Committee G04 on Compatibility and Sensitivity of Materials in Oxygen Enriched Atmospheres and are the direct responsibility of Subcommittee G04.02 on Recommended Practices.

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1.7 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, safety, health, and health environmental practices and determine the applicability of regulatory limitations prior to use. Specific precautionary statements are given in Section 10.

1.8 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

- [D395 Test Methods for Rubber Property—Compression Set](#)
- [D412 Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension](#)
- [D454 Test Method for Rubber Deterioration by Heat and Air Pressure](#)
- [D572 Test Method for Rubber—Deterioration by Heat and Oxygen](#)
- [D573 Test Method for Rubber—Deterioration in an Air Oven](#)
- [D638 Test Method for Tensile Properties of Plastics](#)
- [D1349 Practice for Rubber—Standard Conditions for Testing](#)
- [D1708 Test Method for Tensile Properties of Plastics by Use of Microtensile Specimens](#)
- [D2240 Test Method for Rubber Property—Durometer Hardness](#)
- [D2512 Test Method for Compatibility of Materials with Liquid Oxygen \(Impact Sensitivity Threshold and Pass-Fail Techniques\)](#)
- [D2863 Test Method for Measuring the Minimum Oxygen Concentration to Support Candle-Like Combustion of Plastics \(Oxygen Index\)](#)
- [D3039 Test Method for Tensile Properties of Polymer Matrix Composite Materials](#)
- [D3045 Practice for Heat Aging of Plastics Without Load](#)
- [D4809 Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter \(Precision Method\)](#)
- [G63 Guide for Evaluating Nonmetallic Materials for Oxygen Service](#)
- [G72 Test Method for Autogenous Ignition Temperature of Liquids and Solids in a High-Pressure Oxygen-Enriched Environment](#)
- [G74 Test Method for Ignition Sensitivity of Nonmetallic Materials and Components by Gaseous Fluid Impact](#)
- [G86 Test Method for Determining Ignition Sensitivity of Materials to Mechanical Impact in Ambient Liquid Oxygen and Pressurized Liquid and Gaseous Oxygen Environments](#)
- [G94 Guide for Evaluating Metals for Oxygen Service](#)
- [G125 Test Method for Measuring Liquid and Solid Material Fire Limits in Gaseous Oxidants](#)
- [G126 Terminology Relating to the Compatibility and Sensitivity of Materials in Oxygen Enriched Atmospheres](#)

2.2 CGA Standard:³

- [CGA G-4.3 Type I QVL-E Commodity Specification for Oxygen](#)

2.3 Military Standard Standards:⁴

- [MIL-PRF-27210 Amendment 1—Oxygen, Aviator’s Breathing, Liquid and Gas](#)
- [MIL-PRF-25508 Performance Specification: Propellant, Oxygen](#)

2.4 ISO Standards:⁵

- [ISO 2578 Plastics — Determination of time-temperature limits after prolonged exposure to heat](#)
- [ISO 9080 Plastics Piping and Ducting Systems — Determination of the Long-term Hydrostatic Strength of Thermoplastics Materials in Pipe Form by Extrapolation](#)

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 *aging*—*aging*, *n*—see Terminology [G126](#).

3.1.2 *accelerated aging*—*aging*, *n*—a type of artificial aging whereby the effect of prolonged exposure during service is simulated by aging at elevated temperature.

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 Compressed Gas Association (CGA), 4221 Walney Rd., 5th Floor, Chantilly, VA 20151-2923, <http://www.cganet.com>.

⁴ Available from Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098, <http://www.dsp.dla.mil>.

⁵ Wegener, W., Binder, C., Hengstenberg, P., Herrmann, K. P., and Weinert, P., “Tests to Evaluate the Suitability of Materials for Oxygen Service,” Available from International Organization for Standardization (ISO), *Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: Third Volume, ASTM-STP 986*, ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, <https://www.iso.org>. D. W. Schroll, Ed. ASTM, 1988, pp. 268–278.

3.1.3 *artificial aging*—*aging, n*—see Terminology **G126**.

3.1.4 *oxidative degradation*—*degradation, n*—physical or mechanical property changes occurring as a result of exposure to oxygen-containing media.

3.1.5 *oxygen-containing media*—*media, n*—air media containing greater than 21 mole % oxygen, or oxygen-enriched media containing greater than 25 mole % oxygen.

3.1.6 *oxygen resistance*—*resistance, n*—resistance of a material to ignite spontaneously, propagate by sustained combustion, or undergo oxidative degradation.

3.1.7 *oxygen service*—*service, n*—applications involving the production, storage, transportation, distribution, or use of oxygen-containing media.

3.1.8 *natural aging*—*aging, n*—see Terminology **G126**.

3.1.9 *physical aging*—*aging, n*—aging that occurs during normal storage and which is a function of time after molding or curing.

4. Summary of Practice

4.1 These practices can be used to evaluate systematically the effect of natural aging (Procedure A) or accelerated aging (Procedures B and C) on oxygen resistance. To apply its principle, the user first characterizes the material, then subjects the material to an aging stressor or stressors, followed by re-characterizing the material. Caution must be taken in interpreting results because interactions occurring in service may be different from those simulated during aging.

4.2 It is always more accurate, although not always practical, to determine the effect of natural aging (Procedure A) without resorting to accelerated aging (Procedures B and C). Accelerated aging procedures are more useful for determining material rankings (Procedure B) or for making lifetime predictions (Procedure C).

4.3 In the procedures mentioned, specimens are exposed to a deteriorating influence at a specified elevated temperature at ambient pressure known periods of time. When aging exposures are also conducted at elevated oxygen or air pressure, guidance contained in Test Methods **D572** or **D573**, respectively, must also be followed in addition to the guidance in the standard.

4.4 *Summary of Practice for Evaluating the Effect of Aging in Incident Studies:*

4.4.1 In incident studies, in which initial characterization data are not available, historical or average property data may be used to draw coarser conclusions about the effect of aging on oxygen resistance.

4.5 *Practices for Natural Aging (Procedure A) and Accelerated Aging for Comparative Oxygen Resistance (Procedure B):*

4.5.1 The effect of aging is reported as positive or negative depending upon whether the property used to evaluate oxygen resistance increases or decreases, and the magnitude of the effect is reported as the degree to which the measured property changes relative to that of the unaged material.

4.6 *Practice for Accelerated Aging for Lifetime Prediction (Procedure C):*

4.6.1 The time necessary to produce a fixed level of property change is determined at a series of elevated aging temperatures, and the time necessary to produce the same level of property change at some lower temperature is then determined by linear extrapolation.

4.6.2 A practice for evaluating the effect of accelerated aging on physical and mechanical properties under conditions of variable time and temperature has been validated for significance and is described in detail. This practice is similar to that given in Practice **D3045** but is specific to aging in oxygen-containing media.

4.6.3 A practice for evaluating the effect of accelerated aging on ignition and combustion properties under conditions of variable time and temperature has not been validated for significance, but may yield meaningful results. The practice described is included to promote research and possible development into an established method.

4.6.4 There can be very large errors when accelerated aging Arrhenius approaches are and other pitfalls associated with accelerated aging at elevated temperature (Arrhenius approaches) used to estimate the time necessary to produce a fixed level of property change at some a lower temperature. This temperature (1).⁶ The estimated time to produce a fixed level of property change or “failure” at the lower temperature is often called the “service life.” Because of the errors associated with these calculations, this time should be considered to be the “maximum expected” rather than “typical.”

NOTE 1—Errors in accelerated aging Arrhenius approaches arise from changes in this oxidative degradation mechanism at elevated temperature.

5. Significance and Use

5.1 This practice allows the user to evaluate the effect of service or accelerating aging on the oxygen resistance of polymeric materials used in oxygen service.

5.2 The use of this practice presupposes that the properties used to evaluate the effect of aging can be shown to relate to the intended use of the material, and are also sensitive to the effect of aging.

5.3 Polymeric materials will, in general, be more susceptible than metals to aging effects as evidenced by irreversible property loss. Such property loss may lead to catastrophic component failure, including a secondary fire, before primary ignition or combustion of the polymeric material occurs.

5.4 Polymers aged in the presence of oxygen-containing media may undergo many types of reversible and irreversible physical and chemical property change. The severity of the aging conditions determines the extent and type of changes that take place. Polymers are not necessarily degraded by aging, but may be unchanged or improved. For example, aging may drive off volatile materials, thus raising the ignition temperature without compromising mechanical properties. However, aging under prolonged or severe conditions (for example, elevated oxygen concentration) will usually cause a decrease in mechanical performance, while improving resistance to ignition and combustion.

5.5 Aging may result in reversible mass increase (physisorption), irreversible mass increase (chemisorption), plasticization, discoloration, loss of volatiles, embrittlement, softening due to sorption of volatiles, cracking, relief of molding stresses, increased crystallinity, dimensional change, advance of cure in thermosets and elastomers, chain scissioning, and crosslinking.

5.6 After a period of service, a material’s properties may be significantly different from those when new. All materials rated for oxygen service should remain resistant to ignition and combustion (primary fire risk). Furthermore, all materials rated for oxygen service should be resistant to oxidative degradation and retain relevant physical and mechanical properties during service, because part failure can indirectly lead to an unacceptable ignition or combustion risk (secondary fire risk).

5.7 In cases where aging makes a material more susceptible to fire or causes significant oxidative degradation, aging tests may be used to evaluate whether the material will become unacceptable during service. In cases where aging makes a material less susceptible to fire, aging tests may be used to evaluate whether a material can be conditioned (artificially aged) to prolong its service lifetime.

5.8 Oxygen resistance as determined by this practice does not constitute grounds for material acceptability in oxygen service. Determination of material acceptability must be performed within the broader context of review of system or component design, plausible ignition mechanisms, ignition probability, post-ignition material properties, and reaction effects such as are covered by Guide G63.

⁶ ASME, 2004. The boldface Boiler and Pressure Vessel Code, numbers in parentheses refer to Section VIII, Division 1, New York, New York. the list of references at the end of this standard.

5.9 The potential for personnel injury, facility damage, product loss, or downtime occurring as a result of ignition, combustion, or catastrophic equipment failure will be least for systems or components using air and greatest for systems or components using pure oxygen.

5.10 In terms of physical and mechanical properties, aging is expected to have a greater influence on a polymer's ultimate properties such as strength and elongation, than bulk properties such as modulus.

5.11 In terms of fire properties, aging is expected to have a greater influence on a polymer's ignition properties (for example, autogenous ignition temperature (AIT), mechanical and pneumatic impact) than its propagation properties (for example, upward and downward flame propagation). To date, the only background on aging influences is that of the Bundesanstalt für Materialforschung und -prüfung (BAM) which has assessed the effect of aging at elevated pressure and temperature on a material's AIT. BAM has used the AIT test results to establish maximum constraints on the use of materials at elevated pressure and temperature:temperature (2).

6. Rationale for Aging Tests

6.1 The body of information on the effect of natural aging on oxygen resistance under conditions of multiple stressors is small, and so, this practice is intended to promote testing towards the goal of developing better practices to evaluate the competing effects of multiple stressors.

6.2 The body of information on the effect of accelerated aging on ignition and combustion is small, and so, this practice is intended to promote testing towards the goal of developing potential practices to evaluate the effect of accelerated aging on ignition and combustion.

7. Apparatus

7.1 General Considerations:

7.1.1 The apparatus used for aging can vary widely. Aging in ambient pressure air, gravity-convection ovens or forced-ventilation ovens may be used. When aging in pressurized oxygen-enriched media, pressure-rated cell-type ovens or oxygen pressure chambers that provide a greater margin of safety must be used because of the increased risk of ignition or combustion.

7.1.2 This practice focuses on small-scale aging methods involving a requisite number and type of specimens in accordance with the ASTM test method for the specific property being determined. The scale of the aging procedure can be increased in numerous ways, provided care is taken to ensure safety.

7.1.3 A provision shall be made for suspending specimens vertically without touching each other or the sides of the aging chamber. If possible, maintain at least a 5 cm (2 in.) separation between specimens and the sides of the aging oven, cell, or chamber.

7.1.4 The temperature, and pressure, if different than ambient, should be recorded.

7.1.5 Temperatures shall be measured in close proximity to the test piece.

7.1.6 Uniform heating shall be accomplished by mechanical agitation or forced circulation whenever possible or practical. Baffles or other design features shall be used to ensure uniform heating is attained in all parts of the chamber and to prevent local overheating or dead spots.

7.1.7 In cases where circulated air is used, increasing the air flow rate, will improve temperature uniformity. However, while low air speed will promote accumulation of degradation products and volatilized ingredients, as well as oxygen depletion, high air speed will increase the rate of deterioration due to reduced oxygen depletion, higher oxygen diffusion or mass transport rates, and increased volatilization of plasticizers and antioxidants.

7.1.8 Specimen preparation for larger scale experiments or unique combinations of stressors that qualify as research may utilize other hardware that allows safe aging. Safety must be carefully evaluated for any aging arrangement.

NOTE 2—The effects of aging may be quite variable, especially when specimens are aged for long intervals. Factors that may affect reproducibility of

data include temperature uniformity and control and humidity within the aging apparatus. For example, materials susceptible to hydrolysis may undergo degradation not directly attributable to the effects of oxygen.

NOTE 3—Aging apparatuses must be designed so that specimens, especially vulcanized elastomers, natural rubber (NR), do not come in contact with copper or copper-containing alloys, alloys such as brass, which can accelerate aging-aging (3). For example, NR has been reported (4) to react with copper to form cuprous sulfide, which may lead to depolymerization. For polymers in general, trace quantities of transition metals such as Co, Cu, Fe, and Mn have also been reported to accelerate oxidation because they are potent catalysts for hydroperoxide decomposition and, thus, greatly reduce the activation energy for oxidative aging (5).

7.1.9 Selection of metallic materials of construction used in aging apparatuses should follow recommendations set forth in Guide G94. In general, metallic materials used in the aging apparatus are evaluated based on the flammability properties and the ignition energy sources within the apparatus including polymeric materials aged therein. In addition to potential kindling chain reactions initiated by polymeric materials susceptible to rapid aging, cleanliness of the apparatus should also be considered.

7.2 Gravity-Convection Air Ovens:

7.2.1 Gravity convection ovens are recommended for film specimens having a nominal thickness not greater than 0.25 mm (0.010 in.). In order to maintain a constant, evenly distributed temperature throughout the heating interval, automatic temperature control by means of thermostatic regulation shall be used. Aluminum chamber or cell walls will help maintain temperature consistency. The air shall circulate at not less than 3 or more than 10 changes per hour.

7.3 Forced-Ventilation Air Ovens:

7.3.1 Forced ventilation ovens are recommended for specimens having a nominal thickness greater than 0.25 mm (0.010 in.). The source of heat is optional, but shall be located outside the aging chamber proper. The air shall be preheated to the target aging temperature. The air shall circulate at not less than 3 or more than 10 changes per hour, and the flow shall be as laminar and uniform as possible. Specimens shall be placed with the smallest surface facing the air flow so as to avoid disturbing the air flow.

NOTE 4—During forced-ventilation air aging and in cases where a motor driven fan is used, in order to avoid ozone contamination, the aging media must not come into contact with the fan motor brush discharge in order to avoid ozone contamination. Accordingly, it is not permissible to use motor-driven fans inside the oven, for example.

7.4 Cell-type Air Ovens:

7.4.1 Cell-type ovens shall consist of one or more unconnected cylindrical cells having a minimum height of 300 mm (12 in.) in which the temperature can be kept constant and the air circulates at not less than 3 or more than 10 changes per hour. Cells shall be surrounded by a good heat transfer medium (aluminum block, liquid bath, or saturated vapor). The air passing through one cell shall not enter into other cells. Cells are especially useful when aging dissimilar types of polymers (see [Note 79](#)).

7.5 Pressure Chambers:

7.5.1 A pressure chamber shall consist of a metal vessel made of stainless steel or other suitable material. When aging in oxygen-containing media, both the chamber and the heat transfer medium surrounding the chamber shall be made of materials that do not react with oxygen.

7.5.2 Oxygen pressure and concentration are important considerations when aging polymeric materials and avoiding potential adverse effects on metallic materials of construction used in pressure chambers. Per Guides G63 and G94, oxygen pressure effects on nonmetals and metals can range from relatively mild below 70 kPa (10 psi) to extremely severe above 20 000 kPa (3000 psi). Furthermore, per Guide G63, when evaluating polymeric materials, any mixture with oxygen exceeding atmospheric concentration at pressures higher than 101 kPa (14.7 psi) should be evaluated from the hazard point of view for possible significant increase in material combustibility. Conversely, as oxygen concentration decreases from 100 %, the likelihood of rapid or catastrophic aging of polymeric test materials and accompanying adverse effects on metallic pressure chamber or aging oven materials of construction will diminish.

7.5.3 A-Per Test Method D572, pressure chamber shall consist of a vessel made, pressure chambers used for aging of rubbers shall be equipped with a reliable safety valve or rupture diaphragm set for release at 3450 kPa (500 psi) of pressure. Also, per Note 3 of stainless steel or other suitable material. When aging in oxygen-containing media, both the chamber and the heat transfer medium surrounding the, when aging rubber and its vulcanizates, especially NR, no copper or brass parts shall be exposed to the

atmosphere, nor used in the pressure chamber and tubing or valves leading to it. Finally, the pressure of oxygen supplied to the aging chamber shall be ~~made of materials that do not react with oxygen~~ measured by a calibrated pressure gauge.

7.5.3.1 The chamber shall be equipped with a burst disk to prevent the maximum allowable water pressure (MAWP) for the chamber from being exceeded in the case of an extreme reaction between the test material and oxygen. Additionally, an engineering design safety factor can be used to further reduce the possibility of catastrophic over-pressurization.

7.5.3.2 The size of the chamber is optional, but shall be such that (1) the total volume of the specimens does not exceed ~~10 percent~~ 10 % of the free space in the chamber, and (2) the maximum expected operating pressure (MEOP) produced by a worst-case combustion to form completely oxidized gaseous by-products does not exceed eighty percent of the MAWP for the chamber. For example, in a typical isothermal combustion in ~~100 percent~~ 100 % oxygen, and assuming oxygen is the limiting reactant (that is, all oxygen originally present is consumed), the MEOP can be estimated as: (6):

$$MEOP = \frac{n_{gas} \cdot R \cdot T_f}{V_c} \leq 0.8 \text{ MAWP} \quad (1)$$

where:

n_{gas} = number of moles of gas produced by the combustion (assumes all moles of gas originally present in the aging medium were consumed),
 R = ideal gas constant, and
 V_c = pressure chamber volume.

And where T_f is the final temperature inside the chamber after 100 % combustion as determined by:

$$T_f = T_i + \left(\frac{\Delta H_c \cdot m_{sample}}{C_p \cdot m_{chamber}} \right) \quad (2)$$

where:

T_i = initial aging temperature,
 ΔH_c = heat of combustion of the specimen as determined under isothermal conditions per Test Method **D4809**,
 m_{sample} = mass of the combusted specimens,
 C_p = heat capacity of the metal or metal alloy used to construct the pressure chamber, and
 $m_{chamber}$ = mass of pressure chamber.

NOTE 5—Warning: The pressure chamber shall be constructed of materials that are known to be resistant to ignition and combustion in the aging medium used, and at the aging temperatures and pressures used.

NOTE 6—Warning: Precautions must be taken to ensure that the pressure chamber is not overloaded, or aging temperatures and pressures used that would cause the safety margins for the chamber to be ~~exceeded~~ exceeded are not used.

NOTE 7—Warning: Adequate safety provisions are important when heating oxidizable organic materials in oxygen since the rate of reaction may become very rapid in some cases, particularly if large surface area is exposed, and very high pressures may be developed. If the same equipment is used for the oxygen-pressure test and the air-pressure heat test, Test Method **D454**, care must be exercised to see that the thermostatic controls are properly set, since the specimens may react very rapidly with oxygen at or below the temperature of the air-pressure heat test.

7.5.4 In cases where the effect of aging on ignition or combustion properties is being examined, the vessel used to perform the ignition test (AIT reaction vessel and mechanical impact test chamber, or pneumatic impact test chamber subassembly) or combustion test (calorimeter bomb) may also serve as the apparatus for the aging procedure.

7.5.4.1 To examine the effect of aging on the autogenous ignition sensitivity, specimens would be placed into the AIT reaction vessel of Test Method **G72**, and aged at the desired pressure(s) and temperature(s).

7.5.4.2 To examine the effect of aging on gaseous pneumatic impact ignition sensitivity, specimens should be placed in the test chamber subassembly of Test Method **G74**, and aged at the desired pressure(s) and temperature(s).

7.5.4.3 To examine the effect of aging on pressurized oxygen mechanical impact ignition sensitivity, specimens should be placed in the test chamber of Test Method **G86**, and aged at the desired pressure(s) and temperature(s).

7.5.4.4 To examine the effect of aging on heat of combustion, specimens should be placed in the calorimeter bomb Test Method **D4809**, and aged at the desired pressure(s) and temperature(s).