Designation: G127 – 15

Standard Guide for the Selection of Cleaning Agents for Oxygen-Enriched Systems[1]

This standard is issued under the fixed designation G127; 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 The purpose of this guide is to establish a procedure to select cleaning agents, both solvents and water-based detergents, for oxygen-enriched systems. This includes laboratory-scale tests for cleaning effectiveness, materials compatibility, and oxygen compatibility.

1.2 The effectiveness of a particular cleaning agent depends upon the method by which it is used, the nature and type of the contaminants, and the characteristics of the article being cleaned, such as size, shape, and material. Final evaluation of the cleaning agent should include testing of actual products and production processes.

1.3 Different cleaning agents may be required for different cleaning activities, such as aqueous ultrasonic cleaning, spray cleaning, hand wiping, and flushing of oxygen lines in field applications.

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D471 Test Method for Rubber Property—Effect of Liquids

D543 Practices for Evaluating the Resistance of Plastics to Chemical Reagents

D1193 Specification for Reagent Water

D1460 Test Method for Rubber Property—Change in Length During Liquid Immersion

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)

D4809 Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Precision Method)

F483 Practice for Total Immersion Corrosion Test for Aircraft Maintenance Chemicals

G5 Reference Test Method for Making Potentiodynamic Anodic Polarization Measurements

G31 Guide for Laboratory Immersion Corrosion Testing of Metals

G59 Test Method for Conducting Potentiodynamic Polarization Resistance Measurements

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

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

G121 Practice for Preparation of Contaminated Test Coupons for the Evaluation of Cleaning Agents

G122 Test Method for Evaluating the Effectiveness of Cleaning Agents

2.2 *CGA Document:*

CGA Pamphlet G-4.1 Cleaning Equipment for Oxygen Service

2.3 *Other ASTM Documents:*

MNL36 Safe Use of Oxygen and Oxygen Systems: Handbook for Design, Operation, and Maintenance[2]

3. Significance and Use

3.1 The purpose of this guide is to provide information that may be considered when selecting and qualifying a cleaning agent for oxygen-enriched systems.

---

[1] This guide is under the jurisdiction of ASTM Committee G04 on Compatibility and Sensitivity of Materials in Oxygen Enriched Atmospheres and is the direct responsibility of Subcommittee G04.02 on Recommended Practices.

Current edition approved Oct. 1, 2015. Published October 2015. Originally approved in 1995. Last previous edition approved in 2008 as G127 – 95 (2008). DOI: 10.1520/G0127-15.

[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.

3.2 Insufficient cleanliness can result in the ignition of contaminants or components by a variety of mechanisms. Therefore, an acceptable level of contamination for each condition of use in oxygen-enriched service should be defined. The acceptable level of contamination may depend on various factors, such as:

3.2.1 The nature and type of the contaminants,

3.2.2 The location and degree of contamination,

3.2.3 The type of substrate material,

3.2.4 The configuration and end use of the equipment or part to be cleaned, and

3.2.5 The operating parameters of the oxygen-enriched system (pressure, temperature, phase, concentration, fluid velocity, etc.).

4. Selection of Cleaning Agent

4.1 Before a specific cleaning agent is selected for testing, the following attributes should be considered.

4.1.1 Toxicity,

4.1.2 Carcinogenicity,

4.1.3 Stability and recyclability,

4.1.4 Waste disposal,

4.1.5 Environmental impacts and associated regulatory restrictions (ozone depletion potential, global warming potential, volatile organic compound contribution to ground level ozone, etc.),

4.1.6 Inertness (flammability and combustibility),

4.1.7 Corrosivity and compatibility with metallic and nonmetallic engineering materials,

4.1.8 Availability and technical support from supplier,

4.1.9 Cost effectiveness, and

4.1.10 Compliance with local, state and federal regulations.

4.2 It is desirable that the cleaning agent could be applied by a variety of methods, such as wiping, immersion, spraying, etc. Consequently, the cleaning agent manufacturer's instructions for applying the cleaner should be considered.

5. Selection of Substrate Materials

5.1 Substrate materials used for cleaning effectiveness and compatibility tests should be representative of those used in the end application, including both the parts to be cleaned and the cleaning system itself.

5.2 *Metallic Materials:*

5.2.1 Metallic materials commonly used in oxygen-enriched systems are listed in Guide G94 and Handbook MNL36.

5.2.2 Materials compatability tests should include those metals used in the oxygen-enriched system that are expected to come in contact with the candidate cleaning agent. As a minimum, alloys representative of each family of metals used in the system should be tested. The alloy and finish expected to be used in the oxygen-enriched system that is most susceptible to corrosion within the metal family should be tested.

5.3 *Nonmetallic Materials:*

5.3.1 Nonmetallic materials commonly used in oxygen-enriched systems are discussed in Guide G63 and Handbook MNL36.

5.3.2 Materials compatibility tests should include those nonmetallic materials used in the oxygen-enriched system that are expected to come in contact with the candidate cleaning agent. As a minimum, materials representative of each family of these nonmetals should be tested.

6. Cleaning Effectiveness Tests

6.1 *Selection of Test Contaminants:*

6.1.1 Numerous contaminants encountered in oxygen-enriched systems that could result from manufacturing, assembly, fabrication, and construction processes are listed in Practice G93. Typical contaminant types include:

6.1.1.1 Hydrocarbon oils and greases (mineral oil, hydraulic fluids, lubricants, water-displacing compounds),

6.1.1.2 Fluorinated fluids and greases,

6.1.1.3 Inks,

6.1.1.4 Machine cutting oils (hydrocarbon- or water-based),

6.1.1.5 Carbon deposits,

6.1.1.6 Silicone oils and greases,

6.1.1.7 Phosphate esters (fire-resistant hydraulic fluids),

6.1.1.8 Waxes,

6.1.1.9 Dye penetrants,

6.1.1.10 Chlorotrifluoroethylene based oils and greases,

6.1.1.11 Pariculate (sand, metal shavings, fibers, etc.), and

6.1.1.12 Tape residue.

NOTE 1—Some contaminants are more difficult to remove after aging or exposure to heat. Selection of a cleaning agent should consider removal efficiency for both the type and condition of contaminants typically encountered at the facility.

6.1.2 Among typical contaminants, hydrocarbons are the prime candidates for the test protocol. When dealing with other contaminants, the user should attempt to classify the type of contamination expected on the equipment to be cleaned.

6.1.3 As a preliminary test, mineral oil or a mixture of common cutting oils may be used as a contaminant. It may be carried in a suitable volatile solvent as a means to introduce it into a system. In addition, vacuum pump oil, or a compressor oil are suggested as contaminants for the evaluation program. In a more refined test at later stages, fluorinated oils/greases, dye penetrants, or a mixture of as many contaminants as necessary may be prepared in a suitable solvent. Eventually, actual contaminants encountered on an engineering component or system for oxygen-enriched service should be evaluated for removal efficiency.

6.2 *Test Methods:*

6.2.1 A suggested starting level of contamination is 1000 mg/m^2. This is a hydrocarbon level that is consistent with contamination levels associated with final cleaning and it is twice the acceptable level specified for oxygen service in CGA pamphlet G-4.1. Heavily contaminated surfaces with levels in excess of 1000 mg/m^2 must be precleaned using more aggressive cleaning agents with mechanical scrubbing (Practice G93). Precleaning is not a cleaning step with which this guide is concerned.

6.2.2 Contaminants may be applied to the specimens by any of the means specified in Practice G121.

6.2.3 The cleaning effectiveness of a cleaning agent may be evaluated using the test method outlined in Test Method G122.

6.2.4 A test basis should be established for each contaminated sample by using an acceptable solvent as a control cleaning agent.

7. Material Compatibility Tests

7.1 If a cleaning agent's ability to remove the selected contamination is deemed promising, additional testing (see Sections 8.2.2 and 8.3) should be performed to evaluate its compatibility with the oxygen-enriched systems.

7.2 *Metallic Materials:*

7.2.1 Significant corrosion damage may occur during cleaning operations. Corrosion rates may be affected by temperature, contaminants, degree of aeration, concentration and presence of residual stress (see Note 2). To avoid this, assessments should be made of the corrosion severity of cleaning environments for the engineering materials of interest. Weight gain-loss measurements can be performed as per Practice F483 or G31. Where applicable, Test Method G5 can be applied (see Note 3).

7.2.2 The electrochemical technique of potentiodynamic polarization resistance (Practice G59) can be used to determine the corrosion rate of conductive cleaning agents on metal substrates. The corrosion rate (in mils per year, mpy) should be determined using the solution parameters which would be used in actual cleaning practices. The cleaning solution may be tested: (1) as is; (2) aerated; or (3) de-aerated. It is recommended, however, that the corrosion test be performed under as-is conditions in order to simulate the actual cleaning process. The pH and conductivity of the cleaning agent should be measured both before and after the corrosion test. If these values change, the test is considered invalid. A separate experiment should be performed.

7.2.3 Corrosion rates of less than 32.5 micrometre per year (0.0025 in. per year) are usually desirable. However, to avoid setting up unduly conservative criteria that may eliminate potential cleaning agents, estimation of corrosion rate can be made based upon realistic, total accumulated contact time of the cleaner with a component or system throughout its service life. The rate of corrosion should be determined based upon the maximum allowable dimensional variations of the component or system.

NOTE 2—The presence of residual stresses may promote stress corrosion cracking in susceptible materials. Information in the technical literature on corrosion rates and stress corrosion cracking may be used in evaluating corrosion susceptibility. Further testing, as outlined later in this guide, may be necessary.

NOTE 3—In order to reflect the actual material property, samples for corrosion tests should not be wet ground with 600-grit SiC papers to expose fresh surface. The surface roughness of test samples should be either in compliance with that recommended in Practice G121, or, if possible, commensurate with that of the actual engineering components.

7.3 *Nonmetallic Materials:*

7.3.1 When exposed to the cleaning agent under actual use conditions of temperature, time, concentration etc., some nonmetallics are susceptible to degradation and may experience physical, mechanical, and chemical changes. Physical and mechanical changes can be reversible or irreversible, while chemical changes are generally irreversible. Depending on the material-solvent pair, these changes can be characterized by swelling, distortion, weight gain or loss, cracking, crazing, blistering, embrittlement, decomposition temperature shift, or leaching of additives and low-molecular-weight species (e.g. unreacted monomer, catalyst residues). To evaluate the compatibility of cleaning agents with nonmetallic materials, refer to Test Methods D471, D543, and D1460. These test methods may not include a pass/fail criterion for each material property. Therefore, an engineering evaluation that considers whether any identified material property changes are acceptable in the application should be performed. Some of these material property changes can influence the oxygen compatibility of the nonmetallic material. If the influence of a material property change on oxygen compatibility is uncertain, the oxygen compatibility testing discussed in Guide G63 should be performed on the nonmetallic material (pre- and post-exposure to the cleaning solution and process) to support this evaluation.

7.3.2 Weight loss, shrinkage, cracking, crazing, blistering, or embrittlement are evidence that the cleaning agent is reacting with or leaching materials from the nonmetal and is therefore incompatible.

7.3.3 Swelling and weight gain may indicate that the nonmetal is absorbing some of the cleaning agent during exposure. Some slight swelling and weight gain may be acceptable if the cleaning agent does not adversely affect oxygen compatibility or component function. The drying method and length of drying time used in the test should be representative of the expected user cleaning process.

NOTE 4—Return to original dimensions after drying is indicative of a totally reversible solvent absorption/desorption process with no effect on properties or oxygen compatibility.

Warning—Prolonged exposure to solvents can result in time-dependent absorption and desorption processes, and lead to erroneous conclusions based on weight and dimensions alone.

7.3.4 Cleaning agents that are effective at removing hydrocarbon, halocarbon, perhalogenated, or silicone contaminants will be incompatible with some nonmetals with analogous hydrocarbon, halocarbon, etc., content. This may require that the incompatible soft goods be removed from a component prior to cleaning and cleaned by another method. This may also require changing seal materials in the cleaning equipment when changing to a new cleaning agent.

8. Oxygen Compatibility

8.1 *Approach:*

8.1.1 Historically, chlorinated solvents that are minimally reactive with oxygen have been used to clean oxygen-enriched systems. Production of ozone-depleting chlorofluorocarbon (CFC)-based and hydrochlorofluorocarbon (HCFC)-based solvents has now been banned by international treaties. Other solvents, such as trichloroethylene, have been found to be highly toxic or carcinogenic and are heavily regulated or banned. As a result, the oxygen service industry has shifted to the use of aqueous-based cleaners, flammable solvents, or newer generation cleaning solvents that may be less effective unless blended with a flammable chlorinated solvent. Any of these approaches may be acceptable when used with the proper safety precautions.

8.1.2 Determination of the suitability of a cleaning agent for use with oxygen-enriched systems and the need for specific safety precautions are based on an oxygen compatibility assessment of the cleaning agent. The oxygen compatibility assessment should consider the potential for the cleaning agent to remain undetected within a system or to produce a residue, the ignitability of the cleaning agent or its residue, or both, and the potential for damage, should such an ignition occur. The approach described in Guide G63 for assessing the oxygen compatibility of nonmetals may be applied to the assessment of cleaning agents. Oxygen compatibility data for the new material should be compared with oxygen compatibility for cleaning agents and other nonmetals that have been successfully used in the past to evaluate the suitability of the new material for use with oxygen-enriched systems.

8.2 *Residue Analysis:*

8.2.1 Highly purified or reagent-grade cleaning solvents such as the CFCs and HCFCs usually have a fast evaporation rate and do not leave measurable quantities of non-volatile residues after complete evaporation. On the other hand, higher boiling point cleaning agents, especially water-based detergents, exhibit a much slower evaporation rate. They may leave a significant amount of residue after complete drying of the surfaces. If residues are not reduced to acceptable levels, they are susceptible to ignition or combustion, or both, during oxygen-enriched service, which may lead to a fire. As a result, a water or solvent rinse, after final cleaning by aqueous cleaning agents is an essential step in the aqueous cleaning process.

8.2.2 A quantitative determination of the cleaning agent's rinsability can be made by assessing the amount of residue remaining after complete drying. This assessment can be accomplished by weight measurement using the procedures described in 8.2.2.1, 8.2.2.2 and 8.2.2.3. When the amount of residue is low and cannot be accurately determined by weight measurement, the residue may be extracted by flushing, rinsing, or immersing in a low-residue solvent, such as Type II reagent water (Specification D1193). The rinsing solvent can be examined by analytical methods such as UV spectroscopy, total organic carbon analysis, ion chromatography, high performance liquid chromatography, etc.

8.2.2.1 A fixed quantity of the cleaning solution is prepared in the concentration to be used in actual cleaning operations, weighed, and placed in beakers. The solution is completely dried and the remaining residue is weighed to determine the weight percent residue. See Note 5.

8.2.2.2 A fixed quantity of the cleaning solution is prepared in the concentration to be used in actual cleaning operations, and placed in a beaker of known mass. The solution is emptied, leaving the walls of the beaker wetted with the solution. The beaker is then allowed to dry and the weight of the residue is determined. See Note 5.

8.2.2.3 A test, similar to 8.2.2.2, is performed with the exception that the recommended number of water or solvent rinses are performed before the amount of residue is determined.

8.2.2.4 Similar procedures (8.2.2.2 and 8.2.2.3 can be used with metal panels chosen to represent typical materials used in the system or components to be cleaned. The use of metal panels with known surface area allows a comparison of cleaning agent residue (i.e. mg/m^2) to acceptable cleaning levels, which are typically expressed as mg/m^2.

NOTE 5—A sufficient quantity of solution ranging from 100 to 1000 mL may be required in order to yield satisfactory statistical confidence.

8.2.3 Excessive concentration of the aqueous cleaning agent or low temperatures during cleaning, rinsing, or drying will increase the propensity of the cleaning agent to leave a residue. Rinsing and drying times can also influence the concentration of the residue. Rinsability and residue tests should mimic the concentration, temperatures, and rinsing and drying times to be used in production. In production, these cleaning parameters should be carefully monitored and controlled.

8.3 *Oxygen Compatibility Test for Cleaning Agent Residues:*

8.3.1 When there is a risk that residue from the cleaning solution may remain in the system undetected, such as in blind holes or crevices, cleaning agents that leave only non-reactive amounts of residues are preferred.

8.3.2 The following methods may be used to evaluate the oxygen compatibility of the cleaning agent residues: an oxygen impact test per Test Method D2512 or Guide G86, an oxygen index test per Test Method D2863, a heat of combustion test per Test Method D4809, an autoignition temperature (AIT) test per Test Method G72, and a pneumatic impact test per Test Method G74.

8.3.3 Samples of residues for testing can be developed by performing the procedures in 8.2.2.1, 8.2.2.2, 8.2.2.3, or combinations thereof.

8.3.4 For cleaning agents that are supplied as a powder or liquid concentrate to be diluted in water for use, testing of the powder or dried concentrate my be necessary to yield sufficient residue mass for testing the reactivity of the residue.

8.3.5 At minimum, the AIT test should be performed on the cleaning agent and the cleaning agent residue obtained from procedure 8.2.2.1 (if the cleaning agent is to be diluted in an aqueous solution, then this dilution may need to be avoided to generate sufficient residue mass for testing per Test Method G72). This AIT testing will provide a relative indication of ignitability as compared with the ignitability of hydrocarbon oils, which have been used historically to establish acceptable cleaning levels as indicated in Practice G93. If the cleaning agent's AITs are comparable to or higher than the AIT of hydrocarbon oils, then cleaning levels in Practice G93 would apply. If the autoignition temperature of the cleaning agent or residue is lower than the autoignition temperature of hydocarbon oils, then additional testing according to Test Method G74 should be considered to determine if the cleaning agent or residue is ignitable by pneumatic impact and whether cleaning levels need to be more conservative.

8.4 *Oxygen Compatibility Tests for Solvents:*

8.4.1 When solvent cleaning is required, solvents that are minimally reactive with oxygen are preferred for cleaning oxygen-enriched systems. A flammable solvent absorbed into a soft good, entrapped within a crevice, or un-evaporated after a field cleaning operation may create a fire hazard. Solvents that are nonflammable in air should be tested in the neat form to determine reactivity at elevated oxygen concentration.

NOTE 6—The "neat" solvent is not diluted, concentrated by evaporation, or mixed with other constituents that are not normally a part of the solvent as procured. The solvent may be filtered for particulate or purified to lower the NVR content to meet user specifications to ensure that contaminants do not affect the test results. Filtration and purification should be noted in the test report.

NOTE 7—Some solvents require stabilizers or other additives. These additives may be present in concentrations sufficient to alter the reactivity of the solvent in oxygen. Solvent manufacturers and blenders may change these additives, many of which are considered proprietary, without notifying the customer. For solvents that require additives, these additives should be controlled by specification or lot-to-lot oxygen compatibility testing should be performed.

8.4.2 The following test methods may be used to evaluate the oxygen compatibility of a neat solvent:

8.4.2.1 An oxygen impact test per Test Method D2512 or G86 using a liquid sample cup. Filling and freezing of the sample cups must be performed carefully to prevent excessive evaporation of the solvent. For comparison of solvents that show reactions at the maximum drop height, the test should be repeated at lower drop heights to determine the threshold of reactivity for each solvent. Solvents that react even at low drop heights should be considered flammable and controlled accordingly (see subsection 8.5). Both ambient pressure and elevated pressure tests may be useful for comparison of solvent candidates.

8.4.2.2 An autogenous ignition temperature test per Test Method G72. When testing volatile liquids, the sample size may need to be increased and the liquid may need to be pre-chilled to ensure that sufficient fuel is present after purging to support a valid test.

8.4.2.3 A heat of combustion test per Test Method D4809.

NOTE 8—Some non-flammable hydrofluroether (HFE) and hydrofluorocarbon (HFC) solvents with poor solvency for hydrocarbon oils and greases are blended with trans-1,2 dichloroethylene (tDCE) to boost cleaning power while suppressing the flammability of the tDCE. These blends may be marketed as non-flammable azeotropes or near-azeotropes that maintain stable relative concentrations during use. The potential for these multi-component solvents to separate or vary in relative concentration at high pressures or low temperatures generally has not been characterized; therefore they should be used with caution when complete removal cannot be ensured.

8.5 *Use of Flammable Cleaning Solutions*

8.5.1 In some cases, use of a flammable solvent such as isopropyl alcohol, ethyl acetate, or cyclohexane may be justified for cleaning. When a flammable solvent is used with an oxygen-enriched system component, extreme care must be taken to ensure that the component is thoroughly dried and all solvent is removed. Processes should be developed and verified to ensure that the flammable solvent can be reliably removed from the oxygen-enriched system.

8.5.2 Drying to remove residual solvent may be performed by blowing with warm, dry nitrogen or purified air, by bake-out, or by vacuum drying. For controlled hand wiping operations where minimal solvent is used, simple evaporation over a period of time may suffice.

8.5.3 A hydrocarbon detector, calibrated to detect the solvent, may be used to ensure effective and complete removal of residual solvent from an oxygen-enriched system or component. When using a hydrocarbon detector, it may be necessary to purge the internal volume of the component with an inert gas, or place the component in a test chamber that is then purged, and then use the hydrocarbon detector after a 24 h "lockup" period to allow time for entrapped solvent to diffuse from seals or entrapment areas for adequate detection.

9. Keywords

9.1 chlorofluorocarbon; cleaning; compatibility; contaminant; detergent; non-volatile residue; oxygen-enriched environment; oxygen system; ozone depletion; rinsing; solvent

REFERENCES

The following are additional sources of information:

(1) "Alternatives to Chlorofluorocarbon Fluids in the Cleaning of Oxygen and Aerospace Systems and Components," *ASTM STP 1181*, Eds. C. J. Bryan and K. Gebert-Thompson, 1993.

(2) Antin, Neil. "NAVSEA Report on Aqueous Oxygen Cleaning Products and Processes," March 1994. Naval Sea Systems Command, 2531 Jefferson Davis Hwy, Arlington, VA 22242–5160.

(3) ASM Handbook, Volume 5, *Surface Engineering*, ASM International, 1994, ISBN: 978-0-87170-384-2

(4) F331 Standard Test Method for Nonvolatile Residue of Halogenated Solvent Extract from Aerospace Components (Using Rotary Flash Evaporator)

(5) G88 Standard Guide for Designing Systems for Oxygen Service

(6) ICGA G-4.1, "Cleaning Equipment for Oxygen Service." Compressed Gas Association, Inc., 14501 George Carter Way, Suite 103, Chantilly, VA, 20151-2923, USA.

(7) MIL-STD-1330 Precision Cleaning and Testing of Shipboard Oxygen, Helium, Helium-Oxygen, Nitrogen, and Hydrogen Systems.

(8) MSFC-SPEC-164 Cleanliness of Components for Use in Oxygen, Fuel, and Pneumatic Systems, Specification for.

(9) STANAG 1449 (Edition 1) Diving Systems – Oxygen Cleaning Procedures and Standards, NATO Standardization Agency, 25 October 2006.

(10) Walter, A. E. and J. W. Parker, "Solvent-Based Cleaning: A Viable Alternative for Precision Cleaning," *Precision Cleaning*, pp. 26–34, February, 1994

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org). Permission rights to photocopy the standard may also be secured from the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, Tel: (978) 646-2600; http://www.copyright.com/