Designation: E2981 – 21

Standard Guide for Nondestructive Examination of Composite Overwraps in Filament Wound Pressure Vessels Used in Aerospace Applications[1]

This standard is issued under the fixed designation E2981; 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 guide discusses current and potential nondestructive testing (NDT) procedures for finding indications of discontinuities and accumulated damage in the composite overwrap of filament wound pressure vessels, also known as composite overwrapped pressure vessels (COPVs). In general, these vessels have metallic liner thicknesses less than 2.3 mm (0.090 in.), and fiber loadings in the composite overwrap greater than 60 % by weight. In COPVs, the composite overwrap thickness will be of the order of 2.0 mm (0.080 in.) for smaller vessels and up to 20 mm (0.80 in.) for larger ones.

1.2 This guide focuses on COPVs with nonload-sharing metallic liners used at ambient temperature, which most closely represents a Compressed Gas Association (CGA) Type III metal-lined composite tank. However, it also has relevance to *(1)* monolithic metallic pressure vessels (PVs) (CGA Type I), *(2)* metal-lined hoop-wrapped COPVs (CGA Type II), *(3)* plastic-lined composite pressure vessels (CPVs) with a nonload-sharing liner (CGA Type IV), and *(4)* an all-composite, linerless COPV (undefined Type). This guide also has relevance to COPVs used at cryogenic temperatures.

1.3 The vessels covered by this guide are used in aerospace applications; therefore, the inspection requirements for discontinuities and inspection points will in general be different and more stringent than for vessels used in non aerospace applications.

1.4 This guide applies to *(1)* low pressure COPVs used for storing aerospace media at maximum allowable working pressures (MAWPs) up to 3.5 MPa (500 psia) and volumes up to 2 L (70 ft^3), and *(2)* high pressure COPVs used for storing compressed gases at MAWPs up to 70 MPa (10 000 psia) and volumes down to 8 L (500 $in.^3$). Internal vacuum storage or exposure is not considered appropriate for any vessel size.

NOTE 1—Some vessels are evacuated during filling operations, requiring the tank to withstand external (atmospheric) pressure, while other vessels may either contain or be immersed in cryogenic fluids, or both, requiring the tanks to withstand any potentially deleterious effects of differential thermal contraction.

1.5 The composite overwraps under consideration include, but are not limited to, ones made from various polymer matrix resins (for example, epoxies, cyanate esters, polyurethanes, phenolic resins, polyimides (including bismaleimides), and polyamides) with continuous fiber reinforcement (for example, carbon, aramid, glass, or poly-(phenylenebenzobisoxazole) (PBO)). The metallic liners under consideration include, but are not limited to, aluminum alloys, titanium alloys, nickel-chromium alloys, and stainless steels.

1.6 This guide describes the application of established NDT methods; namely, Acoustic Emission (AE, Section 7), Eddy Current Testing (ET, Section 8), Laser Shearography (Section 9), Radiographic Testing (RT, Section 10), Infrared Thermography (IRT, Section 11), Ultrasonic Testing (UT, Section 12), and Visual Testing (VT, Section 13). These methods can be used by cognizant engineering organizations for detecting and evaluating flaws, defects, and accumulated damage in the composite overwrap of new and in-service COPVs.

NOTE 2—Although visual testing is discussed and required by current range standards, emphasis is placed on complementary NDT procedures that are sensitive to detecting flaws, defects, and damage that leave no visible indication on the COPV surface.

NOTE 3—In aerospace applications, a high priority is placed on light weight material, while in commercial applications, weight is typically sacrificed to obtain increased robustness. Accordingly, the need to detect damage below the visual damage threshold is more important in aerospace vessels.

NOTE 4—Currently, no determination of residual strength can be made by any NDT method.

1.7 All methods discussed in this guide (AE, ET, shearography, RT, IRT, UT, and VT) are performed on the composite overwrap after overwrapping and structural cure. For NDT procedures for detecting discontinuities in thin-walled metallic liners in filament wound pressure vessels, or in the bare metallic liner before overwrapping; namely, AE, ET, laser profilometry, leak testing (LT), penetrant testing (PT), and RT; consult Guide E2982.

[1] This guide is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.10 on Specialized NDT Methods.

Current edition approved Feb. 1, 2021. Published February 2021. Originally approved in 2015. Last previous edition approved in 2015 as E2981 – 15ε1. DOI: 10.1520/E2981-21.

1.8 In the case of COPVs which are impact damage sensitive and require implementation of a damage control plan, emphasis is placed on NDT methods that are sensitive to detecting damage in the composite overwrap caused by impacts at energy levels and which may or may not leave any visible indication on the COPV composite surface.

1.9 This guide does not specify accept-reject criteria (4.9) to be used in procurement or used as a means for approving filament wound pressure vessels for service. Any acceptance criteria specified are given solely for purposes of refinement and further elaboration of the procedures described in this guide. Project or original equipment manufacturer (OEM) specific accept/reject criteria should be used when available and take precedence over any acceptance criteria contained in this document. If no accept/reject criteria are available, any NDT method discussed in this guide that identifies broken fibers should require disposition by the cognizant engineering organization.

1.10 This guide references both established ASTM methods that have a foundation of experience and that yield a numerical result, and newer procedures that have yet to be validated and are better categorized as qualitative guidelines and practices. The latter are included to promote research and later elaboration in this guide as methods of the former type.

1.11 To ensure proper use of the referenced standard documents, there are recognized NDT specialists that are certified according to industry and company NDT specifications. It is recommended that an NDT specialist be a part of any composite component design, quality assurance, in-service maintenance, or damage examination.

1.12 *Units*—The values stated in SI units are to be regarded as standard. The English units given in parentheses are provided for information only.

1.13 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use. Some specific hazards statements are given in Section 7 on Hazards.*

1.14 *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]

D3878 Terminology for Composite Materials

D5687 Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation

E114 Practice for Ultrasonic Pulse-Echo Straight-Beam Contact Testing

E164 Practice for Contact Ultrasonic Testing of Weldments

E317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Instruments and Systems without the Use of Electronic Measurement Instruments

E543 Specification for Agencies Performing Nondestructive Testing

E569 Practice for Acoustic Emission Monitoring of Structures During Controlled Stimulation

E650/E650M Guide for Mounting Piezoelectric Acoustic Emission Sensors

E750 Practice for Characterizing Acoustic Emission Instrumentation

E976 Guide for Determining the Reproducibility of Acoustic Emission Sensor Response

E1001 Practice for Detection and Evaluation of Discontinuities by the Immersed Pulse-Echo Ultrasonic Method Using Longitudinal Waves

E1065/E1065M Practice for Evaluating Characteristics of Ultrasonic Search Units

E1067 Practice for Acoustic Emission Examination of Fiberglass Reinforced Plastic Resin (FRP) Tanks/Vessels

E1106 Test Method for Primary Calibration of Acoustic Emission Sensors

E1118 Practice for Acoustic Emission Examination of Reinforced Thermosetting Resin Pipe (RTRP)

E1316 Terminology for Nondestructive Examinations

E1416 Practice for Radioscopic Examination of Weldments

E1742/E1742M Practice for Radiographic Examination

E1781/E1781M Practice for Secondary Calibration of Acoustic Emission Sensors

E1815 Test Method for Classification of Film Systems for Industrial Radiography

E2104 Practice for Radiographic Examination of Advanced Aero and Turbine Materials and Components

E2191 Practice for Examination of Gas-Filled Filament-Wound Composite Pressure Vessels Using Acoustic Emission

E2033 Practice for Radiographic Examination Using Computed Radiography (Photostimulable Luminescence Method)

E2338 Practice for Characterization of Coatings Using Conformable Eddy Current Sensors without Coating Reference Standards

E2375 Practice for Ultrasonic Testing of Wrought Products

E2533 Guide for Nondestructive Testing of Polymer Matrix Composites Used in Aerospace Applications

E2580 Practice for Ultrasonic Testing of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications

E2581 Practice for Shearography of Polymer Matrix Composites and Sandwich Core Materials in Aerospace Applications

E2582 Practice for Infrared Flash Thermography of Composite Panels and Repair Patches Used in Aerospace Applications

[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.

E2661/E2661M Practice for Acoustic Emission Examination of Plate-like and Flat Panel Composite Structures Used in Aerospace Applications
E2662 Practice for Radiographic Examination of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications
E2698 Practice for Radiographic Examination Using Digital Detector Arrays
E2884 Guide for Eddy Current Testing of Electrically Conducting Materials Using Conformable Sensor Arrays
E2982 Guide for Nondestructive Testing of Thin-Walled Metallic Liners in Filament-Wound Pressure Vessels Used in Aerospace Applications

2.2 *AIA Standard:*[3]
NAS 410 NAS Certification and Qualification of Nondestructive Test Personnel

2.3 *ANSI/AIAA Standards:*[4]
ANSI/AIAA S-080 Space Systems—Metallic Pressure Vessels, Pressurized Structures, and Pressure Components
ANSI/AIAA S-081 Space Systems—Composite Overwrapped Pressure Vessels (COPVs)
ANSI NGV2-2007 American National Standard for Natural Gas Vehicle Containers

2.4 *ASME Standards:*[5]
ASME Boiler and Pressure Vessel Code, Section V, Nondestructive Examination, Article 11, Acoustic Emission Examination of Fiber-Reinforced Plastic Vessels
ASME Boiler and Pressure Vessel Code, Section X, Mandatory Appendix 8, Class III Vessels With Liners for Gaseous Hydrogen in Stationary Service, Subsection 8-600 EXAMINATION, 8-600.2.7 Acoustic Emission Examination

2.5 *ASNT Standards:*[6]
ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel
SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification

2.6 *BSI Document:*[7]
EN 4179 Aerospace Series — Qualification and Approval of Personnel for Non-Destructive Testing

2.7 *CGA Standards:*[8]
CGA Pamphlet C-6.2 Standard for Visual Inspection and Requalification of Fiber Reinforced High Pressure Cylinders
CGA Pamphlet C-6.4 Methods for Visual Inspection of AGA NGV2 Containers

2.8 *Federal Standards:*[9]
21 CFR 1040.10 Laser Products
21 CFR 1040.11 Specific Purpose Laser Products

2.9 *ISO Document:*[10]
ISO 9712 Non-destructive Testing—Qualification and Certification of NDT Personnel

2.10 *LIA Document:*[11]
ANSI Z136.1-2000 Safe Use of Lasers

2.11 *MIL Documents:*[12]
MIL-HDBK-17 Composite Materials Handbook, Guidelines for Characterization of Structural Materials
MIL-HDBK-6870 Inspection Program Requirements, Nondestructive for Aircraft and Missile Materials and Parts
MIL-HDBK-340 Test Requirements for Launch, Upper-Stage, and Space Vehicles, Vol. I: Baselines
MIL-HDBK-787 Nondestructive Testing Methods of Composite Materials—Ultrasonics
MIL-HDBK-1823 Nondestructive Evaluation System Reliability Assessment

2.12 *NASA Documents:*[13]
KNPR 8715.3 (Kennedy NASA Procedural Requirements) Chapter 13: NASA KSC Requirements for Ground-Based Vessels and Pressurized Systems (PV/S), Rev. G.
NASA/TM-2012-21737 Elements of Nondestructive Examination for the Visual Inspection of Composite Structures
NASA-STD-(I)-5019 Fracture Control Requirements for Spaceflight Hardware
MSFC-RQMT-3479 Fracture Control Requirements for Composite and Bonded Vehicle and Payload Structures

2.13 *Air Force Documents:*[12]
AFSPCMAN 91-710 v3 Range Safety User Requirements Manual Volume 3 - Launch Vehicles, Payloads, and Ground Support Systems Requirements
AFSPCMAN 91-710 v6 Range Safety User Requirements Manual Volume 6 - Ground and Launch Personnel, Equipment, Systems, and Material Operations Safety Requirements

2.14 *ECSS Document:*[14]
ECSS-E-30-01A Space Engineering Fracture Control

3. Terminology

3.1 *Abbreviations*—The following abbreviations are adopted in this guide: acoustic emission (AE), eddy current testing (ET), radiographic testing (RT), ultrasonic testing (UT), and visual testing (VT).

[3] Available from Aerospace Industries Association (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209-3928, http://www.aia-aerospace.org.
[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.
[5] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Two Park Ave., New York, NY 10016-5990, http://www.asme.org.
[6] Available from American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlingate Ln., Columbus, OH 43228-0518, http://www.asnt.org.
[7] Available from British Standards Institution (BSI), 389 Chiswick High Rd., London W4 4AL, U.K., http://www.bsigroup.com.
[8] Available from Compressed Gas Association (CGA), 14501 George Carter Way, Suite 103, Chantilly, VA 20151, http://www.cganet.com.
[9] Available from U.S. Food and Drug Administration (FDA), 10903 New Hampshire Ave., Silver Spring, MD 20993, http://www.fda.gov.
[10] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, http://www.iso.org.
[11] Available from the Laser Institute of America, 13501 Ingenuity Drive, Suite 128, Orlando, FL 32826.
[12] Available from Standardization Documents Order Desk, Bldg 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.
[13] Available from National Aeronautics and Space Administration, Technical Standards Program, 300 E. Street SW, Suite 5R30, Washington, D. C. 20546. https://standards. nasa.gov/documents/nasa.
[14] Available from ESA Publications Division, ESTEC, P.O. Box 299, 2200 AG Noordwijk, The Netherlands.