



Designation: E 2478 – 06a

Standard Practice for Determining Damage-Based Design Stress for Fiberglass Reinforced Plastic (FRP) Materials Using Acoustic Emission¹

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1. Scope

1.1 This practice details procedures for establishing the direct stress and shear stress damage-based design values for use in the damage-based design criterion for materials to be used in FRP vessels and other composite structures. The practice uses data derived from acoustic emission examination of four-point beam bending tests and in-plane shear tests (see [ASME Section X, Article RT-8](#)).

1.2 The onset of lamina damage is indicated by the presence of significant acoustic emission during the reload portion of load/reload cycles. “Significant emission” is defined with historic index.

1.3 *Units*—The values stated in inch-pound units are to be regarded as standard. The values given in brackets are mathematical conversions to SI units which are provided for information only and are not considered standard.

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

- [D 790](#) Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
- [D 4255/D 4255M](#) Test Method for In-Plane Shear Properties of Polymer Matrix Composite Materials by the Rail Shear Method
- [D 3846](#) Test Method for In-Plane Shear Strength of Reinforced Plastics

¹ This practice is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.04 on Acoustic Emission Method.

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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.

- [E 543](#) Specification for Agencies Performing Nondestructive Testing
- [E 976](#) Guide for Determining the Reproducibility of Acoustic Emission Sensor Response
- [E 1316](#) Terminology for Nondestructive Examinations
- [E 2374](#) Guide for Acoustic Emission System Performance Verification

2.2 ASME Documents:³

- [ASME Section X, Article RT-8](#) Test Method for Determining Damage-Based Design Criterion
- [ASME Section V, Article 11](#) Acoustic Emission Examination of Fiber-Reinforced Plastic Vessels

2.3 Other Standards:

- [ANSI/ASNT-CP-189](#) Qualification and Certification of Nondestructive Testing Personnel⁴
- [SNT-TC-1A](#) Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing⁴
- [NAS-410](#) Certification and Qualification of Nondestructive Test Personnel⁵

3. Terminology

3.1 Definitions of terms related to conventional acoustic emission are in Terminology [E 1316](#), Section B.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *historic index*—a measure of the change in MARSE (or other AE feature parameter such as AE Signal Strength or AE Energy) throughout an examination.

3.2.2 *measured area of the rectified signal envelope (MARSE)*—a measure of the area under the envelope of the rectified linear voltage time signal from the sensor. (see [ASME Section V, Article 11](#))

3.2.3 *significant emission*—a level of emission that corresponds to the first time during reloading that the historic index attains a value of 1.4.

³ Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Three Park Ave., New York, NY 10016-5990.

⁴ Available from American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlingate Ln., Columbus, OH 43228-0518.

⁵ Available from Aerospace Industries Association of America, Inc. (AIA), 1250 Eye St., NW, Washington, DC 20005.

3.2.4 *knee in the curve*—a dramatic change in the slope of the cumulative AE versus time curve.

4. Summary of Practice

4.1 This practice uses acoustic emission instrumentation and examination techniques during load/reloading of materials being examined, to determine the onset of significant acoustic emission. The onset of significant emission is related to the damage-based design stress by the Felicity ratio.^{6,7}

5. Significance and Use

5.1 The damage-based design approach will permit an additional method of design for FRP materials. This is a very useful technique to determine the performance of different types of resins and composition of FRP materials in order to develop a damage tolerant and reliable design. This AE-based method is not unique, other damage-sensitive evaluation methods can also be used.

5.2 This practice involves the use of acoustic emission instrumentation and examination techniques as a means of damage detection to support a destructive test, in order to derive the damage-based design stress.

5.3 This practice is not intended as a predictor of long-term performance of FRP materials (such as those used in vessels). For this reason, many codes and standards require cyclic proof testing of prototypes (for example, vessels) which are not a part of this practice.

5.4 Other design methods exist and are still permitted.

6. Basis of Application

6.1 The following items are subject to contractual agreement between the parties using or referencing this practice:

6.1.1 *Personnel Qualification*—If specified in the contractual agreement, personnel performing examinations to this practice shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard such as **ANSI/ASNT-CP-189**, **SNT-TC-1A**, **NAS-410**, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

6.1.2 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice **E 543**. The applicable revision of Practice **E 543** shall be specified in the contractual agreement.

6.1.3 *Procedure and Techniques*—The procedures and techniques to be utilized shall be as specified in the contractual agreement.

6.1.4 *Timing of Examination*—The timing of examination shall be in accordance with **12.4** unless otherwise specified.

6.1.5 *Extent of Examination*—The extent of examination shall be in accordance with Sections **9** and **10** unless otherwise specified.

6.1.6 *Reporting Criteria*—Reporting criteria for the examination results shall be in accordance with **15.1** unless otherwise specified.

7. Apparatus

NOTE 1—Refer to **Fig. 1** for AE system block diagram showing key components of the AE system. It is recommended to use two AE sensors to monitor the specimen, evaluated on a per channel basis.

7.1 AE Sensors

7.1.1 AE sensors shall be resonant in a 100 to 300 kHz frequency band.

7.1.2 Sensors shall have a peak sensitivity greater than -77 dB (referred to 1 volt per microbar, determined by face-to-face ultrasonic examination) within the frequency range 100 to 300 kHz. Sensitivity within the 100 to 300 kHz range shall not vary more than 3 dB within the temperature range of intended use.

7.1.3 Sensors shall be shielded against electromagnetic interference through proper design practice or differential (anti-coincidence) element design, or both.

7.1.4 Sensors shall have omni-directional response, with variations not exceeding 2 dB from the peak response.

7.2 Couplant

7.2.1 Commercially available couplants for ultrasonic flaw detection may be used. Silicone-based high-vacuum grease has been found to be particularly suitable. Adhesives may also be used.

7.2.2 Couplant selection should be made to minimize changes in coupling sensitivity during a complete examination. Consideration should be given to the time duration of the examination and maintaining consistency of coupling throughout the examination.

7.3 Sensor-Preamplifier Cable

7.3.1 The cable connecting the sensor to the preamplifier shall not attenuate the sensor peak voltage in the 100 to 300 kHz frequency range more than 3 dB (6 ft [1.8 m] is a typical length). Integral preamplifier sensors meet this requirement. They have inherently short, internal, signal cables.

7.3.2 The sensor-preamplifier cable shall be shielded against electromagnetic interference. Standard low-noise coaxial cable is generally adequate.

7.4 Preamplifier

7.4.1 The preamplifier shall have a noise level no greater than five microvolts rms (referred to a shorted input) within the 100 to 300 kHz frequency range.

7.4.2 Preamplifier gain shall vary no more than ± 1 dB within the 100 to 300 kHz frequency band and temperature range of use.

7.4.3 Preamplifiers shall be shielded from electromagnetic interference.

7.4.4 Preamplifiers of differential design shall have a minimum of 40 dB common-mode rejection.

7.4.5 Preamplifiers shall include a bandpass filter with a minimum bandwidth of 100 kHz to 300 kHz. Note that the crystal resonant characteristics provide additional filtering as does the bandpass filter in the signal conditioner.

⁶ Ramirez, G., Ziehl, P., Fowler, T., 2004, "Nondestructive Evaluation of FRP Design Criteria with Primary Consideration to Fatigue Loading", *ASME Journal of Pressure Vessel Technology*, Vol. 126, pp. 1–13.

⁷ Ziehl, P. and Fowler, T., 2003, "Fiber Reinforced Polymer Vessel Design with a Damage Approach", *Journal of Composite Structures*, Vol. 61, Issue 4, pp. 395–411.

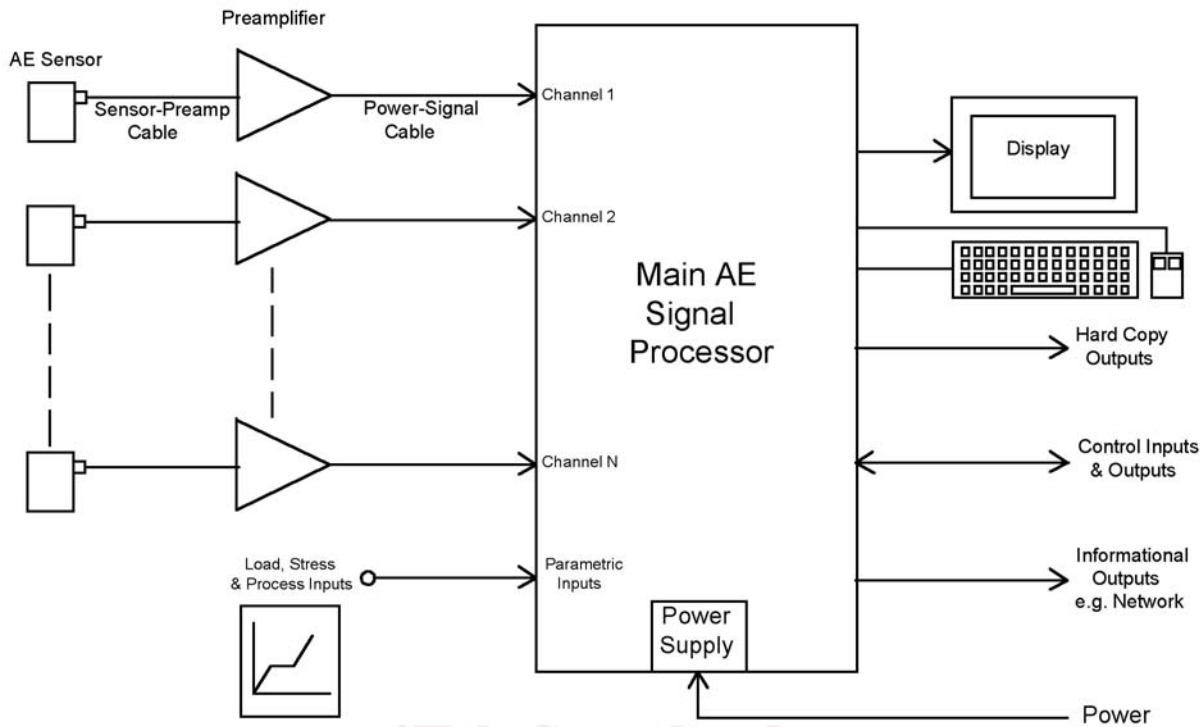


FIG. 1 AE System Block Diagram

7.4.6 It is preferred that the preamplifier be mounted inside the sensor housing.

7.5 Power-Signal Cable

7.5.1 The cable and connectors that provide power to preamplifiers, and that conduct amplified signals to the main processor, shall be shielded against electromagnetic interference. Signal loss shall be less than 3 dB over the length of the cable. (When standard coaxial cable is used, 1000 ft is the maximum recommended cable length to avoid excessive signal attenuation).

7.6 Power Supply

7.6.1 A stable, grounded, power supply that meets the signal processor manufacturer’s specification shall be used.

7.7 Main Signal Processor

7.7.1 The main processor shall have circuitry through which sensor data will be processed. It shall be capable of processing hits, hit arrival time, duration, counts, peak amplitude, and MARSE (or similar AE feature parameters such as Signal Strength or Energy) on each channel.

7.7.2 Electronic circuitry shall be stable within ± 1 dB in the temperature range 40 to 100°F [4 to 38°C].

7.7.3 Threshold shall be accurate within ± 1 dB.

7.7.4 MARSE shall be measured on a per channel basis and shall have a resolution of 1 % of the value obtained from a one millisecond duration, 150 kHz sine burst having an amplitude 25 dB above the data analysis threshold. Usable dynamic range shall be a minimum of 40 dB.

NOTE 2—Instead of MARSE, other AE feature parameters such as “Signal Strength” or “Energy” may be used.

7.7.5 Amplitude shall be measured in decibels referenced to 0 dB as 1 microvolt at the preamplifier input. Usable system

dynamic range shall be a minimum of 60 dB with 1 dB resolution over the frequency band of 100 to 300 kHz, and the temperature range of 40 to 100°F [4 to 38°C]. Not more than ± 1 dB variation in peak detection accuracy shall be allowed over the stated temperature range.

7.7.6 Hit duration (AE signal duration) shall be accurate to ± 5 μ s and is measured from the first threshold crossing to the last threshold crossing of the AE signal.

7.7.7 Hit arrival time shall be recorded globally for each channel accurate to within one millisecond, minimum.

7.7.8 The system deadtime of each channel of the system shall be no greater than 200 μ s.

7.7.9 The hit definition time shall be 400 μ s.

7.7.10 The examination threshold shall be set at 40 dB (depending on background noise of the system setup when subjected to a constant load of 10 % or less of the estimated failure load). Threshold should remain constant during the entire examination.

8. Calibration and Verification

8.1 Annual calibration and verification of AE sensors, preamplifiers (if applicable), signal processor, and AE electronic waveform generator (or simulator) should be performed. Equipment should be adjusted so that it conforms to equipment manufacturer’s specifications. Instruments used for calibrations must have current accuracy certification that is traceable to the National Institute for Standards and Technology (NIST).

8.2 Routine electronic evaluations must be performed any time there is concern about signal processor performance. An AE electronic waveform generator or simulator, should be used in making evaluations. Each signal processor channel must