Designation: E 1496 – 05

Standard Test Method for Neutron Radiographic Dimensional Measurements[1]

This standard is issued under the fixed designation E 1496; 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 provides a technique for extracting quantitative dimensional information on an object from its neutron radiograph. The technique is based on the identification of changes in film density caused by material changes where a corresponding discontinuity in film density exists. This test method is designed to be used with neutron radiographs made with a well-collimated beam. The film densities in the vicinity of the edge must be in the linear portion of the density versus exposure curve. The accuracy of this test method may be affected adversely in installations with high-angular-divergence neutron beams or with large object-to-film distances.

1.2 *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]

E 94 Guide for Radiographic Examination

E 543 Practice for Agencies Performing Nondestructive Testing

E 748 Practices for Thermal Neutron Radiography of Materials

E 803 Method for Determining the L/D Ratio of Neutron Radiography Beams

E 1316 Terminology for Nondestructive Testing

2.2 *Other Documents:*

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification[3]

ANSI/ASNT CP-189 ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel[3]

NAS-410 Nondestructive Testing Personnel Qualification and Certification[4]

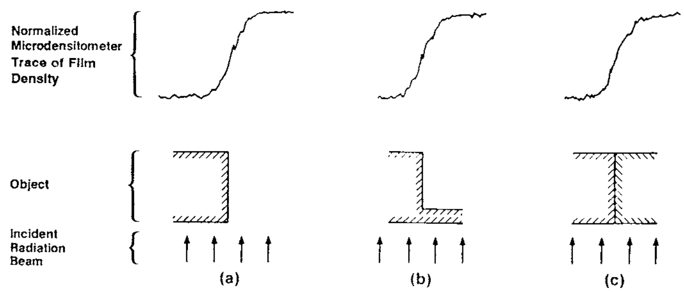

FIG. 1 Typical Microdensitometer Film Density Traces Associated with Three Rectangular Material Discontinuities: (a) Edge of Object, (b) Thickness Variation, and (c) Dissimilar Material Boundary

3. Terminology

3.1 *Definitions*—Definitions of the many terms relative to radiography (for example, X, gamma, and neutron radiography) can be found in Terminology E 1316.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *extremum*—the point on the linear response portion of the curve of smoothed density versus location at which the slope is a maximum.

3.2.2 *extremum slope criterion*—the criterion that specifies the edge of a discontinuity or an object, located at the spatial position corresponding to the extremum as determined from examination of a radiograph.

3.2.3 *linear response*—a radiographic response where the film density across an edge within an object is contained in the linear part of the density versus exposure curve.

3.2.4 *traveling-stage microdensitometer*—a densitometer with a small aperture (typically between 10 to 25 μm by 200 to 300 μm) that has the capability of scanning a radiograph in a continuous or stepped manner and generating either a digital or an analog mapping of the film density of the radiograph as a function of position.

[1] This test method is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.05 on Radiology (Neutron) 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.

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

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

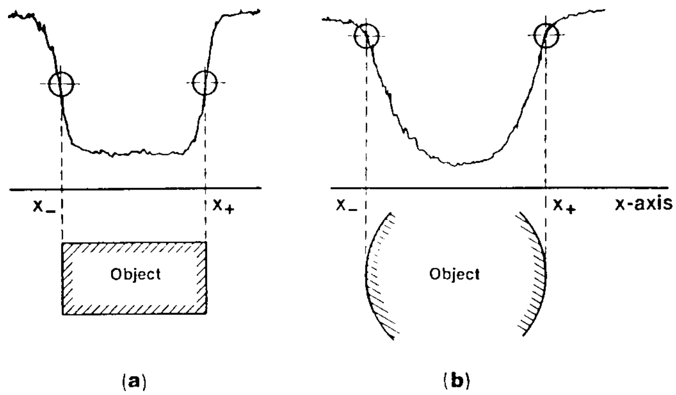

FIG. 2 Typical Microdensitometer Traces of Film Density for (a) Rectangular Objects and (b) Cylindrical Objects; Note Placements of Edges x_+ and x_- on the Traces

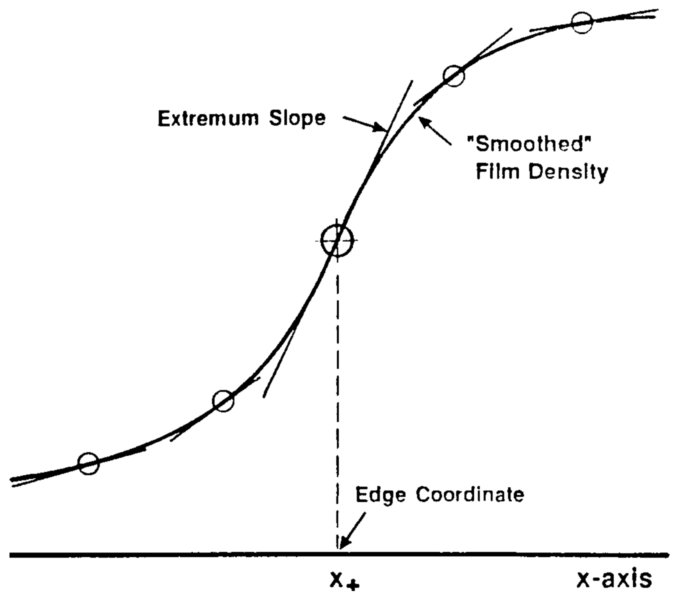

FIG. 3 Depiction of Various Slopes on a Smoothed Microdensitometer Trace; The Object Edge Coordinate, x_+, Corresponds to the Extremum Slope Point on the Trace

4. Summary of Test Method

4.1 All radiation used in radiography is attenuated in its passage through an object according to its thickness and magnitude of the material attenuation properties appropriate to the type and energy of radiation. Additionally, significant spatial spreading occurs due to the system imperfections, nonsymmetric radiation transport, and image formation process. Significant variations in the recorded radiation near edges and material discontinuities therefore occur and manifest themselves by film density variations in the radiograph, as illustrated in Fig. 1.

4.2 A graph of detector response (film density) versus location across an interface is similar in form for many different types of interface, provided that the detector responds linearly to increased exposure over the entire region of interest. Typical radiographic responses are shown in Fig. 2 (a) and (b).

4.3 Both theoretical and experimental studies in neutron radiography have established that under commonly encountered high-quality linear-response radiographic conditions, the edge of an object corresponds to that point on the smoothed experimentally obtained microdensitometer trace at which the slope is a maximum, as illustrated in Fig. 3. This point is called the extremum, and the relationship between the spatial position of the extremum and location of the edge is called the extremum slope criterion. These have been confirmed by careful experimentation (**1-3**).[5]

5. Significance and Use

5.1 Many requirements exist for accurate dimensional information in industrial quality control. Frequently, this information cannot be measured directly, may be very uncertain, or is expensive to obtain. If a radiograph of the object in question displays a sufficient film density variation near the edge of interest, however, dimensional radiography methods may be applied. This test method provides a technique for extracting quantitative dimensional information from the neutron radiograph of an object. Guide E 94 and Practices E 748 are helpful for understanding the principles involved in obtaining a high-quality neutron radiograph.

5.2 Dimensional radiography appears to be particularly relevant in determination of the following: (*1*) diameters of spent radioactive fuel, (*2*) gap sizes in contact-circuit mechanisms of shielded components, and (*3*) prescribed spacings between distinct materials.

5.3 While this test method addresses dimensional measurements using neutron radiography, the methods and techniques of dimensional radiography are also equally applicable to various types of radiography, such as x-ray, γ-ray, and neutron.

5.4 A fundamental assumption of this test method is that the user will have access to a system that permits the attainment of data describing the density response of the radiograph. Although a system may include any digitization equipment capable of providing the spatial resolutions recommended in 6.1.1, a typical system will include a high-resolution traveling-stage microdensitometer and a neutron radiograph of the object.

5.5 An object with accurately known dimensions must be available to calibrate the equipment used to measure the radiographic response, that is, the traveling-stage microdensitometer (or other digitization system capable of spatial resolution comparable to that of the detector).

6. Basis of Application

6.1 The following items are subject to contractual agreement between parties using or referencing this test method.

6.1.1 *Personnel Qualification*—If specified in the contractual agreement, personnel performing examinations in accordance with this test method 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

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

or standard used and its applicable revision shall be specified 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 *Procedures and Techniques*—The procedures and techniques to be utilized shall be as specified in the contractual agreement.

7. Apparatus

7.1 In addition to the instruments and facilities normally used in radiography (refer to Guide E 94 and Practices E 748), dimensional radiography relies critically on the use of a high-resolution traveling-stage (continuous or stepping) microdensitometer or digitization system. The purpose of the microdensitometer is to obtain a quantitative trace or digital sequence of the film density along a specified traverse of the radiograph. Two features are of particular importance:

7.1.1 The aperture for light passing through the film must be narrow enough to respond accurately to the macroscopic properties of the film density, but not so narrow as to introduce excessive microscopic film noise. An aperture width between 10 and 20 µm along the direction of the traverse, and between 200 and 300 µm in the perpendicular direction, is recommended for typical applications (**4**).

7.1.2 It is required that the response of the microdensitometer be linear or that data exist to correct its nonlinearity. Such data can be obtained by scanning either a neutron radiograph of an object with a known and uniform composition or calibrated film step wedges (see Section 8).

8. Calibration of Microdensitometer

8.1 No specific calibration procedures are provided because the calibration of each traveling-stage microdensitometer depends on its type and model. However, several general procedural steps are common to the calibration of all of the microdensitometers used in this test method.

8.2 A calibration procedure must exist that transforms the dimension scale on the strip-chart record of the microdensitometer trace, or pixel dimensions and intervals for a digitized data set, to the true physical dimension of a test object. The procedure should permit periodic checking.

8.3 It is required that the density response of the microdensitometer be linear or that data exist to correct its nonlinearity.

8.3.1 Obtain a density trace from a neutron radiograph of an object that covers the range from 0 to 4.0 density units. Calibrated film step wedges are commercially available and can be used for this purpose.

8.3.2 Check the microdensitometer data for a linear response between the object density and reported density values.

8.3.3 If the density response is nonlinear, develop a correction curve, table, or equation based on the object and response data.

9. Procedure

9.1 Obtain a neutron radiograph of the object under examination.

9.2 The dimensions of interest are deduced from the coordinates of either individual edges of the object or edges of material discontinuities within the object. Hence, it is necessary to describe only the methodology of determining the maximum film density slope on a radiograph for an edge of interest, that is, the extremum.

9.2.1 Identify the region for the traverse of interest from a visual examination of the radiograph.

9.2.2 Obtain a high-quality continuous or digital microdensitometer trace along the traverse, ensuring that the traveling stage is set for a speed or pixel dimension that scales the film density variation in the vicinity of the edge adequately (refer to 7.1.1).

9.2.3 Determine the point on the smoothed microdensitometer trace at which the slope is maximum by either visual or computer-based means, and obtain the corresponding edge coordinate x_+ from this, as shown in Fig. 3.

9.2.3.1 Note that if visual methods do not permit a decisive determination of the extremum, algebraic-fitting and subsequent analytic techniques must be used. Studies of knife-edges have shown that edge location is insensitive to the functional form used in the smoothing technique (**5-7**).

9.2.3.2 It is critical to ensure that the film densities obtained experimentally in the vicinity of the edge are in the linear portion of the density versus exposure curve (see 4.2). This is particularly important for curved edges where, as suggested in Fig. 2 (b), the extremum slope coordinate corresponds to film density close to the maximum density on the radiograph. (The reason for this care is the potential interference with the edge-scattering distortion process (**8**).)

9.2.4 Repeat the steps given in 9.2.1-9.2.3 for the companion edge of interest to identify the edge coordinate x.

10. Calculation

10.1 The difference $(x_+ - x_-)$ corresponds to the separation of edges on the microdensitometer trace, referred to as the trace spacing.

10.2 Use the calibration curve, table, or equation developed in Section 8 to convert the trace spacing to the separation dimension of the edges.

11. Precision and Bias [6]

11.1 *Precision*—The precision of this test method has been determined at several laboratories.

11.1.1 Test results obtained in the same laboratory (repeatability conditions) yielded errors averaging under 25 µm.

11.1.2 Test results obtained in different laboratories (reproducibility conditions) yielded errors that were always below 100 µm and averaged 25 µm.

11.2 *Bias*—Systematic errors might arise if adequate care is not exercised in obtaining the extremum slope (see 9.2.3).

11.3 *General Considerations*—The above assumes a well-collimated neutron beam with an L/D ratio greater than 100, as determined using Method E 803, and divergence half-angle less than two degrees.

[6] Supporting data have been filed at ASTM headquarters and may be obtained by requesting RR:E07-1001.

11.3.1 For installations in which the beam is highly divergent, or the object-film distance is sufficiently large to create a penumbra shadowing affect, further complications appear that can affect the precision, or bias, or both.

11.3.2 Effects of the extended dimensions of the object and neutron radiographic facility can be taken into account if some details of the edge of the object are known. However, these corrections are not straightforward unless the geometry of the object is simple.

11.3.3 The precision and bias of any particular object should be determined by multiple test measurements of an object that are similar to the actual object in both geometry and composition. It should be anticipated that variations in both precision and bias will be greater than those stated in 11.1 since the measurement is sensitive to a number of parameters, including those depending on the object, detector, facility, and density-response measurement.

12. Keywords

12.1 dimensional measurement; neutron radiography; quantitative radiography

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(**8**) Wyman, D. R., and Harms, A. A., "The Radiographic Edge Scattering Distortion," *Journal of Nondestructive Testing*, Vol 4, No. 2, 1984, p. 75.