Designation: E 390 – 01

Standard Reference Radiographs for Steel Fusion Welds[1]

This standard is issued under the fixed designation E 390; 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.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This standard provides reference radiographs for steel fusion welds that contain typical discontinuities with varying severity levels in different thicknesses of material.

1.2 There are three volumes of reference radiographs based on seven nominal weld thicknesses as follows:

Vol I—Set of 16 plates (8½ by 11 in.) covering base material up to and including ¼ in. (6.4 mm) in thickness.

Vol II—Set of 29 plates (8½ by 11 in.) covering base material over ¼ to and including 3 in. (6.4 to 76 mm) in thickness.

Vol III—Set of 32 plates (8½ by 11 in.) covering base material over 3 to including 8 in. (76 to 203 mm) in thickness.

1.3 The values stated in inch-pound units are to be regarded as the 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:*

E 94 Guide for Radiographic Examination[2]

E 1316 Terminology for Nondestructive Examinations[2]

2.2 *ASTM Adjuncts:*[3]

Reference Radiographs for Steel Fusion Welds:

Volume I, Thickness Up to and Including ¼ in. (6.4 mm)[4]

Volume II, Thickness Over ¼ to 3 in. (6.4 to 76 mm), incl[5]

Volume III, Thickness Over 3 to 8 in. (76 to 203 mm), incl[6]

3. Terminology

3.1 *Definitions*—For definitions of terms used in this document, see Terminology E 1316, Section D.

4. Significance and Use

4.1 These reference radiographs may be used as a means for establishing the types and severity levels of discontinuities that are revealed by radiographic examination of steel fusion welds.

4.2 Each volume contains illustrations of representative graded and ungraded discontinuities applicable to seven thickness ranges, as shown in Table 1. Table 2 lists the discontinuity types and severities illustrated for each thickness of base material. Each of the graded discontinuity types has five severity levels, 1 through 5 in order of increasing severity. The ungraded discontinuities are included for informational purposes.

4.3 These reference radiographs may be used in contractual specifications, for which agreement has been reached between purchaser and supplier, to establish acceptance limits of the types and severity levels of discontinuities revealed by radiographic examination.

4.4 The use of this document is not intended to be restricted to the specific energy levels given in Table 3 or to the thickness limits given in Table 1. This document may be used, where there is no other applicable document, for other energy levels or thicknesses, or both, for which it is found to be applicable and for which agreement has been reached between purchaser and manufacturer.

5. Preparation of Reference Radiographs

5.1 The illustration in Vol I and the first two thicknesses of Vol II are radiographic while those in the thick section of Vol II (2 in.) and Vol III are photographic reproductions.

5.2 The radiographs were made to a quality level of at least 2-2T penetrameter sensitivity.

5.3 Table 3 lists the technique used in producing the original radiographs. The data are included for information and are not to be construed as the recommended technique.

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[1] These reference radiographs are under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and are the direct responsibility of Subcommittee E07.02 on Reference Radiographs.

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[2] *Annual Book of ASTM Standards*, Vol 03.03.

[3] Available from ASTM Headquarters.

[4] Order RRE039001.

[5] Order RRE039002.

[6] Order RRE039003.

TABLE 1 Applicable Thickness Ranges

Illustration Thickness, in. (mm)	Base Material Thickness Range, in. (min)[A]
Vol I	
0.030 (0.8)	to and including 0.050 (3.3)
0.080 (2.0)	over 0.050 (1.3) to and including ⅛ (3.2)
3⁄16 (4.8)	over ⅛ (3.2) to and including ¼ (6.4)
Vol II	
⅜ (9.5)	over ¼ (6.4) to and including ½ (13)
¾ (19)	over ½ (13) to and including 1½ (48)
2 (51)	over 1½ (48) to and including 3 (76)
Vol III	
5 (127)	over 3.0 (75) to and including 8 (203)

[A] In the special cases of joining two members of unequal thickness, the standard applicable to the thinner member shall be used.

TABLE 2 Types of Discontinuities Illustrated for Each Thickness of Base Material

Discontinuity Type	Base Material Thickness and Grading, in. (mm)						
	0.030 (0.8)	0.080 (2.0)	3⁄16 (4.8)	⅜ (9.5)	¾ (19)	2 (51)	5 (127)
Scattered porosity							Grade 1–5
Fine scattered porosity	Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5	
Coarse scattered porosity	Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5	
Clustered porosity	Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5
Linear porosity (globular indications)[A]	ungraded	Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5
Slag inclusions		Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5
Tungsten inclusions	Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5	ungraded	
Incomplete penetration		ungraded	Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5
Lack of fusion	ungraded		Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5	Grade 1–5
Elongated or worm hole porosity	ungraded		ungraded	ungraded	ungraded	ungraded	
Burn through	ungraded		ungraded	ungraded	ungraded	ungraded	
Icicles (teardrops)	ungraded		ungraded	ungraded	ungraded	ungraded	
Longitudinal crack		ungraded	ungraded	ungraded	ungraded	ungraded	ungraded
Transverse crack	ungraded		ungraded	ungraded	ungraded	ungraded	ungraded
Crater crack	ungraded		ungraded	ungraded	ungraded	ungraded	
Undercut	ungraded		ungraded	ungraded	ungraded	ungraded	

[A] The severity of linear porosity (globular indications) should be judged by their length and clustering rather than by their optical density.

TABLE 3 Radiographic Technique[A]

Base Material Thickness, in. (mm)	kVp	mA	Timers	Source-to-Film Distance, in.	Screens in Cassettes	Film Type ASTM E 94[B]
Vol I						
0.030 (0.8)	90	10	180–210	48	none	1
0.080 (2.0)	120	10	150–210	48	none	1
3⁄16 (4.8)	150	10	180–270	48	0.005 in. Pb front 0.010 in. Pb back	1
Vol II						
⅜ (9.5)	175	10	175–200	48	0.005 in. Pb front 0.010 in. Pb back	[C]
¾ (19)	250	10	43–65	60	0.005 in. Pb front 0.010 in. Pb back	1
2 (51)	2000 or ^{60}Co[D]	1.5	45–53	108	0.005 in. Pb front 0.010 in. Pb back	1
Vol III						
5 (203)	2000 or ^{60}Co[D]	1.5	420–450	108		1

[A] All films were processed by automatic film processors.
[B] ASTM Guide E 94.
[C] Not defined in Guide E 94; manufacturers' description is—ultra fine grain, high contrast.
[D] These reference radiographs were made with ^{60}Co.

5.4 The radiographic exposure was controlled so as to produce an optical density of from 2.00 to 2.25 in a selected location on the weld bead. The reproductions used in Vol III were prepared to the same density requirements and they substantially retain the contrast and detail of the original radiographs.

6. Description of Discontinuities

6.1 *Porosity* occurs as voids caused by gas trapped in the weld metal deposit. The voids may occur as spherical, elongated, or "worm hole" shapes and in patterns that are random, clustered, or linear. On a radiograph the spherical voids have the appearance of a rounded dark area while the nonsperhical voids have an elongated dark area with a smooth outline.

6.2 *Tungsten Inclusions* are tungsten particles entrapped in the weld deposit. These inclusions are particles broken off or melted from the electrodes and may be caused by faulty equipment or poor manipulation. On the radiograph the tungsten inclusions are lighter than the surrounding areas and may be rounded or irregularly shaped.

6.3 *Incomplete Penetration* is a discontinuity that occurs at the root of welds designed for through penetration where full penetration has not been achieved. The discontinuity appears on a radiograph as a straight dark line that may be either continuous or intermittent. The indication may be thin and sharp, broad and diffuse or two parallel lines depending upon the specific geometry of the joint and the width of the discontinuity.

6.4 *Slag Inclusions* are particles of slag entrapped in the weld metal or along the fusion planes. The particles appear darker than the surrounding area and may be irregular in shape or elongated in the direction of the deposited weld bead.

6.5 *Lack of Fusion* is a discontinuity caused by molten weld metal which has failed to bond to the base metal or to a previously deposited weld bead. On the radiograph it appears as a dark indication usually elongated and varying in width.

6.5.1 Although all of the illustrations for lack of fusion show the discontinuity near the edge of a weld joint, this discontinuity may exist anywhere in the weld.

6.6 A *Crack* is a rupture of solidified metal. Cracks associated with welding may be longitudinal, transverse, or radially oriented and may occur in the weld metal, base metal, or through both. Radially oriented cracks are called crater cracks because they generally originate in a weld bead crater. When the plane of the crack is perpendicular to the film, the radiographic image appears as either a jagged or a straight line. As the plane of the crack deviates from the direction of the radiation beam, the appearance of the crack becomes an increasingly broad and poorly defined line.

6.7 *Icicles* (*Teardrops*) are fused droplets of weld metal extending beyond the root of the weld. They appear as individual, rounded, lighter indications with an occasional small dark spot in the center of a drop. Icicles occur in seams welded from one side only.

6.8 A *Burn Through* is a melting of the metal from the root of the weld or through the backing strip. It appears on the radiograph as an individual darkened area of elongated or rounded contour which may be surrounded by a lighter ring. This discontinuity occurs in seams welded from one side only.

6.9 An *Undercut* is a longitudinal groove melted into the base metal adjacent to the toe of a weld and left unfilled with weld metal. It appears as a dark linear indication of indistinct outline adjacent to the edge of the weld. Undercut may be observed by visual examination. Another type of undercut may occur in backing strip joints where the backing strip is left in place. It is caused by a melting away of the base metal at the root. This type is generally termed root undercut. It appears on the radiograph as a relatively straight and narrow dark line and can be located on either or both sides of the root opening location.

7. Application of Reference Radiographs

7.1 The following procedures are recommended in arriving at acceptance standards in the application of such standards to film interpretation.

7.1.1 The graded reference radiographs may be used in whole or in part as applicable to particular requirements.

7.1.2 The length of the welding to which the selected standard applies shall be established. These designated lengths shall not contain any discontinuity whose severity exceeds that in the reference.

7.1.3 When the production radiograph is interpreted as showing equal or less severe discontinuities than the selected standard, the weld shall be judged radiographically acceptable. When the production radiograph is interpreted as showing greater severity than the selected standard, the weld shall be judged unacceptable and shall be repaired in accordance with contractual agreements.

7.1.4 If more than one type of discontinuity occurs in the same radiograph, the predominating type along shall govern acceptability unless the severity represented by the combination of discontinuity types is such as to make the overall condition unacceptable for the intended application.

7.1.5 When two or more discontinuity types are present in the same radiograph to an extent equal to the maximum acceptable for two of these types, the weld shall be judged unacceptable, with repair welding to be done according to contractual agreement.

7.1.6 Where the reference image consists of a collection of discontinuities, as in the case of porosity, for example, acceptability may be based on the aggregate size of the discontinuities present on both the reference radiograph and the object radiograph, the maximum defect size present, the spacing between discontinuities, or a combination of these or other criteria. These criteria must be determined based upon the particular application or part under consideration and must be specified by agreement between the purchaser and supplier.

7.1.7 When repair welding is permitted, the repair need only be to that extent which will bring the weld quality to within the acceptable reference.

7.2 *Film Deterioration*—Radiographic films are subject to wear and tear from handling and use. The extent to which the image deteriorates over time is a function of storage conditions, care in handling and amount of use. Reference radiograph films are no exception and may exhibit a loss in image quality over time. The radiographs should therefore be periodically examined for signs of wear and tear, including scratches, abrasions, stains, and so forth. Any reference radiographs which show signs of excessive wear and tear which could influence the interpretation and use of the radiographs should be replaced.

8. Keywords

8.1 discontinuities; fusion welds; gamma ray; reference radiographs; steel; X-ray

APPENDIX

(Nonmandatory Information)

X1. ADDITIONAL INSTRUCTIONS

X1.1 In selecting the reference radiographs, the attempt was made to obtain a progressively increasing severity of grades for each discontinuity type. It is not to be implied that the same grade number designation represents equivalent severity for all types of discontinuities. To arrive at acceptance standards, each type of discontinuity should be considered individually, and an appropriate grade (severity) designation applicable to the type should be assigned.

X1.2 Any film indication suspected to be a crack should be treated with concern and properly investigated with other applicable nondestructive testing techniques.

X1.3 The suggested optical density range in some ASTM documents is 1.5 to 3.5. In general, however, better interpretation will be obtained when the production radiographs are of approximately the same film density as the reference radiographs to which they are compared.