



Standard Digital Reference Images for Investment Steel Castings for Aerospace Applications¹

This standard is issued under the fixed designation E2660; 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 digital reference images provided in the adjunct to this standard illustrate various types and degrees of discontinuities occurring in thin-wall steel investment castings.² Use of this standard for the specification or grading of castings requires procurement of the adjunct digital reference images which illustrate the discontinuity types and severity levels. They are intended to provide the following:

1.1.1 A guide enabling recognition of thin-wall steel casting discontinuities and their differentiation both as to type and degree through digital radiographic examination.

1.1.2 Example digital radiographic illustrations of discontinuities and a nomenclature for reference in acceptance standards, specifications and drawings.

1.2 Two illustration categories are covered as follows:

1.2.1 *Graded*—Six common discontinuity types each illustrated in eight degrees of progressively increasing severity.

1.2.2 *Ungraded*—Twelve single illustrations of additional discontinuity types and of patterns and imperfections not generally regarded as discontinuities.

1.3 The reference radiographs were developed for casting sections up to 1 in. (25.4 mm) in thickness.

1.4 All areas of this standard may be open to agreement between the cognizant engineering organization and the supplier, or specific direction from the cognizant engineering organization. These items should be addressed in the purchase order or the contract.

NOTE 1—The set of digital reference images consists of 16 digital files, software to load the desired format and specific instructions on the loading process. The 16 reference images illustrate eight grades of severity in six common discontinuity types and twelve ungraded discontinuities and contain an image of a step wedge and two duplex-wire gauges. Available from ASTM International Headquarters. Order number RRE2660. Refer

to Practice E2002 for wire pair details.

1.5 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.6 These digital reference images are not intended to illustrate the types or degrees of discontinuities when performing film radiography. If performing film radiography of thin-wall investment castings, refer to Reference Radiographs E192.

1.7 *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.*

1.8 Only licensed copies of the software and images shall be utilized for production inspection. A copy of the ASTM/User license agreement shall be kept on file for audit purposes.

2. Referenced Documents

2.1 ASTM Standards:³

E94 Guide for Radiographic Examination

E192 Reference Radiographs of Investment Steel Castings for Aerospace Applications

E1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology

E1316 Terminology for Nondestructive Examinations

E1320 Reference Radiographs for Titanium Castings

E2002 Practice for Determining Total Image Unsharpness in Radiology

E2597 Practice for Manufacturing Characterization of Digital Detector Arrays

2.2 SMPTE Practice:⁴

RP133 SMPTE Recommended Practice Specifications for Medical Diagnostic Imaging test Pattern for Television Monitors and Hard-Copy Recording Cameras

¹ This standard is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.02 on Reference Radiological Images.

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² The digital reference images are considered to be applicable to all thin-wall steel castings, requiring close tolerances. They may also be used for nickel-base and cobalt-base cast alloys. Castings for which these images are applicable generally include those made by the lost wax, frozen mercury, ceramicast or shell mold processes.

³ 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.

⁴ Available from Society of Motion Picture and Television Engineers, 3 Barker Avenue, White Plains, NY 10601; or www.smpete.org/smpete_store/

*A Summary of Changes section appears at the end of this standard.

2.3 ASTM Adjuncts:

Digital Reference Images of Investment Steel Castings for Aerospace Applications⁵

3. Terminology

3.1 *Definitions*—Definitions of terms used in this standard may be found in Terminology E1316.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 The terms relating to discontinuities used in these digital reference images are described based upon radiographic appearance when viewed in the negative polarity such that the images appear in the same sense as they would when viewed on X-ray film. If images are viewed in the positive polarity, the terms lighter and darker will need to be reversed.

3.2.2 *aliasing*—artifacts that appear in an image when the spatial frequency of the input is higher than the output is capable of reproducing. This will often appear as jagged or stepped sections in a line or as moiré patterns.

3.2.3 *contrast normalization*—the adjustment of contrast between the production image and the reference image that makes the change in digital driving level versus change in thickness equal for both images.

3.2.4 *DDL*—digital driving level also known as monitor pixel value.

3.2.5 *system resolution*—the detector-measured resolution divided by the geometric magnification.

3.2.6 Gas

3.2.6.1 *gas holes*—round or elongated, smooth edged dark spots, occurring individually, in clusters, or distributed randomly throughout the casting.

3.2.7 Shrinkage

3.2.7.1 *shrinkage cavity*—an area with distinct jagged boundaries.

3.2.7.2 *shrinkage, sponge*—an area, lacy in texture, with a very diffuse outline.

3.2.7.3 *shrinkage, dendritic*—a distribution of very fine lines or small elongated cavities that may vary in darkness and are usually unconnected.

3.2.7.4 *shrinkage, filamentary*—usually a continuous structure of connected lines or branches of variable length, width and darkness, or occasionally, a network.

3.2.8 *foreign material less dense*—irregularly shaped indications darker than the adjacent material, but lighter than gas holes of similar magnitude.

3.2.9 *foreign material more dense*—irregularly shaped indications lighter than the adjacent material.

3.2.10 Discrete Discontinuities

3.2.10.1 *hot tears*—ragged dark lines of variable width and numerous branches. They have no definite lines of continuity and may exist in groups. They may originate internally or at the surface.

3.2.10.2 *cold cracks*—straight or jagged lines usually continuous throughout their length. Cold cracks generally appear singly. They start at the surface.

3.2.10.3 *cold shut*—a distinct dark line or band of variable length and definite smooth outline.

3.2.10.4 *misruns*—prominent dark areas of variable dimensions with a definite smooth outline.

3.2.10.5 *core shift*—a variation in wall thickness.

3.2.11 *defective mold*—is illustrated by such common defects as mold crack, mold ridge, rattle, scab, and fin. These conditions appear as areas or lines of different darkness than the adjacent material. Illustrations of the defect include:

3.2.11.1 *mold buckle, positive*—a lightened irregularly shaped area lightest near the center and gradually increasing in darkness away from the center.

3.2.11.2 *mold buckle, negative*—a darkened irregularly shaped area darkest near the center and gradually getting lighter away from the center.

4. Significance and Use⁶

4.1 These digital reference images are intended for reference only, but are designed such that acceptance standards, which may be developed for particular requirements, can be specified in terms of these digital reference images. The illustrations are digital images of castings that were produced under conditions designed to develop the discontinuities.

4.1.1 Graded Discontinuities:

4.1.1.1 Gas holes, sponge shrinkage, dendritic shrinkage, less dense foreign material

(1) The images of the 1/8-in (3.2-mm) castings are intended to be used in the thickness range up to and including 1/4-in (6.3-mm). The images of the 3/8-in (9.5-mm) castings are intended to be used in the thickness range of over 1/4-in (6.4-mm), up to and including 1/2-in (12.7-mm). The images of the 3/4-in (19.1-mm) castings are intended to be used in the thickness range of over 1/2-in (12.7-mm), up to and including 1-in (25.4-mm).

4.1.1.2 Cavity Shrinkage, Filamentary Shrinkage:

(1) The images of the 3/4-in (19.1-mm) castings are intended to be used in the thickness range up to and including 1-in (25.4-mm).

4.1.2 Ungraded Discontinuities:

4.1.2.1 The images of the 3/8-in (9.5-mm) castings are intended to be used in the thickness range up to and including 1-in (25.4-mm).

4.2 *Image Deterioration*—Many conditions can affect the appearance and functionality of digital reference images. For example, electrical interference, hardware incompatibilities, and corrupted files and drivers may affect their appearance. The Practice E2002 line pair gauges located in each digital reference image can be used as an aid to detect image deterioration by comparing the measured resolution using the gauges to the resolution stated on the digital reference image. Do not use the digital reference images if their appearance has been adversely affected such that the interpretation and use of the images could be influenced.

⁵ Available from ASTM International Headquarters. Order Adjunct No. RRE2660.

⁶ A study was performed that compared film to digital modalities for the classification of aluminum casting discontinuities. Results of this study are available from ASTM as RR:E07-1004. A subsequent study was performed that compared film to digital modalities for the classification of titanium and steel casting discontinuities. Results of this study are available from ASTM as RR:E07-1006.

4.3 Agreement should be reached between cognizant engineering organization and the supplier that the system used by the supplier is capable of detecting and classifying the required discontinuities.

5. Basis of Application

5.1 The digital reference images may be applied as acceptance standards tailored to the end use of the product. Application of these digital reference images as acceptance standards should be based on the intended use of the product and the following considerations (see [Note 2](#)).

5.1.1 An area of like size to that of the digital reference image shall be the unit areas by which the production digital image is evaluated, and any such area shall meet the requirements as defined for acceptability.

5.1.2 Any combination or subset of these digital reference images may be used as is relevant to the particular application. Different grades or acceptance limits may be specified for each discontinuity type. Furthermore, different grades may be specified for different regions, or zones of a component.

5.1.3 Special considerations may be required where more than one discontinuity type is present in the same area. Any modifications to the acceptance criteria required on the basis of multiple discontinuity types must be specified.

5.1.4 Production digital images containing porosity, gas, or inclusions may be rated by the overall condition with regard to size, number, and distribution. These factors should be considered in balance.

5.1.5 As a minimum, the acceptance criteria should contain information addressing: zoning of the part (if applicable), the acceptance severity level for each discontinuity type, and the specified area to which the digital reference images are to be applied.

5.1.6 Where the reference images provide only an ungraded illustration of a discontinuity, an acceptance level may be specified by referencing a maximum discontinuity size, or a percentage of the discontinuity size illustrated.

NOTE 2—Caution should be exercised in specifying the acceptance criteria to be met in a casting. Casting design coupled with foundry practice should be considered. It is advisable to consult with the manufacturer/foundry before establishing the acceptance criteria to ensure the desired quality level can be achieved.

6. Procedure for Evaluation

6.1 Select the appropriate Digital Reference Image.

6.2 Apply contrast adjustments to the reference image by either method described in [9.5](#).

6.3 Evaluation shall be performed against the adjusted reference image.

7. Description

7.1 The digital reference images listed in [Table 1](#) illustrate each type of graded discontinuity in eight grades. Although eight grades of each discontinuity are shown, a numerically smaller graded set of discontinuities based on these digital

TABLE 1 Digital Reference Images for Investment Steel Castings for Aerospace Applications

Illustrations	Illustration Plate Thickness, in. (mm)	Applicable Casting Thickness, in. (mm)
Graded:		
Gas holes	1/8 (3.2)	1/4 (6.4) and under
Gas holes	3/8 (9.5)	Over 1/4 to 1/2 (6.4 to 12.7), incl
Gas holes	3/4 (19.1)	Over 1/2 to 1 (12.7 to 25.4), incl
Shrinkage cavity	3/4 (19.1)	All thicknesses
Shrinkage, sponge	1/8 (3.2)	1/4 (6.4) and under
Shrinkage, sponge	3/8 (9.5)	Over 1/4 to 1/2 (6.4 to 12.7), incl
Shrinkage, sponge	3/4 (19.1)	Over 1/2 to 1 (12.7 to 25.4), incl
Shrinkage, dendritic	1/8 (3.2)	1/4 (6.4) and under
Shrinkage, dendritic	3/8 (9.5)	Over 1/4 to 1/2 (6.4 to 12.7), incl
Shrinkage, dendritic	3/4 (19.1)	Over 1/2 to 1 (12.7 to 25.4), incl
Shrinkage, filamentary	3/4 (19.1)	All thicknesses
Foreign material, less dense	1/8 (3.2)	1/4 (6.4) and under
Foreign material, less dense	3/8 (9.5)	Over 1/4 to 1/2 (6.4 to 12.7), incl
Foreign material, less dense	3/4 (19.1)	Over 1/2 to 1 (12.7 to 25.4), incl
Ungraded:		
Discrete Discontinuities:		
Foreign material, more dense	3/8 (9.5)	
Hot tear	3/8 (9.5)	
Cold crack	3/8 (9.5)	
Cold shut	3/8 (9.5)	
Misrun	3/8 (9.5)	
Core shift	3/8 (9.5)	
Defective Mold:		
Mold buckle, positive	3/8 (9.5)	
Mold buckle, negative	3/8 (9.5)	
Mold ridge	3/8 (9.5)	
Excess metal in cracked core	3/8 (9.5)	
Diffraction pattern:		
Columnar	3/8 (9.5)	
Mottled	3/8 (9.5)	

reference images could be used for acceptance standards.⁷ The ungraded illustrations have been included to establish the appearance of the digital image indications they represent in thin-wall investment castings.

7.2 The alloys used to reproduce the various discontinuities are listed in [Table 2](#).

7.3 The step wedges shown in the digital reference images are made of 8630 steel with the step thicknesses listed in [Table 3](#).

8. Digital Image Installation Procedure

8.1 Follow the instructions provided with the digital reference images to load the reference image software.

8.2 The software files will be saved to a default location during installation unless instructed otherwise during the loading process.

8.3 The software will require the user to specify either a positive or negative image. Select the option to match the viewing format (positive or negative image) of the system's viewing software.

⁷ Each grade of a given discontinuity type is contained in an individual approximate 2 by 2 3/4-in. (51 by 70-mm) machined cast block. These blocks were inserted in steel keeper plates with radiographic characteristics similar to the cast blocks. The assembled plates were then radiographed and digitally reproduced to obtain the various gradations shown. The image content utilized in the reference images for each cast block is approximately 1.81 by 2.5-in. (46 by 63.5-mm).

TABLE 2 Actual Alloys Used to Reproduce Discontinuities

Illustration	Alloy
Gas holes, 1/8 in. (3.2 mm), 3/16 in. (9.5 mm), and 1/4 in. (19.1 mm)	4330
Foreign material less dense, 1/8 in. (3.2 mm), 3/16 in. (9.5 mm) and 1/4 in. (19.1 mm)	4330
Shrinkage cavity, 1/4 in. (19.1 mm)	4330
Shrinkage, sponge, 1/8 in. (3.2 mm)	AMS 5355A
Shrinkage, sponge, 3/16 in. (9.5 mm) and 1/4 in. (19.1 mm)	4330
Shrinkage, dendritic, 1/8 in. (3.2 mm), 3/16 in. (9.5 mm), and 1/4 in. (19.1 mm)	4330
Shrinkage, filamentary, 1/4 in. (19.1 mm)	4330
Foreign material more dense	4330
Cold shut	ACI HK
Hot tear	4330
Cold crack	4330
Misrun	4330
Core shift	4330
Mold buckle, positive	AMS 5382B
Mold buckle, negative	AMS 5360A
Mold ridge	AMS 5382B
Excess metal in cracked core	ACI CF-8M
Diffraction pattern, columnar	ACI HK
Diffraction pattern, mottled	ACI HK

8.4 The software load process will require the digital reference image resolution to be specified to the nearest 10-micron increment. Select the resolution that will most closely match the system resolution. System resolution is the detector resolution divided by the geometric magnification to be used during inspection.

8.5 Determine the detector resolution for digital detector arrays (DDA) as described in Practice E2597.

8.6 Compare the measured resolution to the theoretical resolution determined by pixel size. If the measured resolution differs by no more than 30 % from the theoretical resolution, use the theoretical resolution as the detector resolution.

8.7 If the measured resolution differs from the theoretical resolution by more than 30 %, adjust the process parameters and measure the resolution again. For computed radiography, a suggested parameter to change is the sampling resolution.

NOTE 3—The resolution conversion process is performed by the provided load software. This process is performed by grouping pixels into bins and calculating the average value of the pixels in the bin. This average value is then the pixel value for the pixels of the same size and location as the subject bins.

9. Viewer Software Requirements

9.1 Viewer software shall be capable of importing the digital reference images as either a 16-bit grayscale uncompressed TIFF format or in the DICOM format.

9.2 Viewer software shall be capable of importing and storing digital reference images at resolutions in 10-micron increments starting at 10 microns, and displaying these images without loss of data integrity or resolution.

9.3 Digital reference images shall be selectable by discontinuity type.

9.4 Production and digital reference images shall be viewed simultaneously on a single monitor or optionally, on several monitors that are matched to provide equal brightness for a given digital driving level.

9.5 The contrast of the reference image shall be adjusted to assure the displayed image reflects a suitable gray value change

commensurate with material thickness change. Contrast adjustment shall be performed in accordance with 9.5.1 or 9.5.2 as directed by the cognizant engineering organization.

9.5.1 *Manual Contrast Method*—The Radiographic Level III shall adjust the contrast of the reference image to provide an appropriate presentation of discontinuities. This may be done by comparison with the image in the equivalent film reference radiograph. Once established and secured, the window width of the reference image shall not be modified by the user.

9.5.2 *Contrast Normalization Method*—The user shall employ software tools approved by the cognizant engineering organization to establish a relationship between the reference and production image such that the change in gray scale versus change in material thickness will be similar in both images. Once established the normalized contrast relationship between the production and reference image shall not be modified further by the user.

9.6 Viewer software shall provide the capability to lock the zoom levels of the production and reference digital images, so that both images are simultaneously adjusted.

9.7 Viewer software shall be capable of displaying the raw data value at the current cursor position.

9.8 Viewer software shall be capable of displaying the DDL at the current cursor position.

9.9 Viewer software shall be capable of displaying the distance between two selected points.

9.10 Viewer software shall allow the adjustment of the contrast (window width) of the production image. Contrast adjustment of the production image may direct the contrast of the reference image through contrast normalization. Refer to 9.5.2 for contrast normalization requirements.

9.11 Viewer software shall allow the independent adjustment of the brightness (window level) of the production image and reference image.

9.12 Viewer software shall be capable of generating line profiles of the raw data values.

9.13 Viewer software shall allow the user to select an area of interest and calculate the average and standard deviation of the raw data of the area selected by the user.

9.14 Viewer software shall have ability for one-on-one pixel mapping, that is, each pixel of data shall be mapped individually to a monitor pixel at a zoom of one.

9.15 Viewer software may apply image processing parameters to the displayed production images. This includes, but is not limited to, image processing functions such as filters, smoothing functions, edge enhancement or the conversion of data through logarithmic or exponential transformation. Application of these non-linear functions or filters to the reference image shall only be made with the approval of the cognizant level 3. If the manual contrast normalization method is used (see 9.5.1), the production image shall be adjusted to facilitate the comparison with the reference image. The reference image may be lightened or darkened to facilitate this comparison. This shall not be interpreted to mean that the window level must be the same for the production and reference images due to the possible difference in thickness between the area of interest of the production part and the reference hardware.

TABLE 3 Thicknesses of Steps of Included Step Wedges

Step Number	1/8-in. (3.2-mm) Plates	3/8-in. (9.5-mm) Plates	3/4-in. (19.1-mm) Plates
1	0.090 in. (2.29 mm)	0.236 in. (5.99 mm)	0.547 in. (13.89 mm)
2	0.121 in. (3.07 mm)	0.299 in. (7.59 mm)	0.610 in. (15.49 mm)
3	0.153 in. (3.89 mm)	0.363 in. (9.22 mm)	0.672 in. (17.07 mm)
4	0.182 in. (4.62 mm)	0.424 in. (10.77 mm)	0.733 in. (18.62 mm)
5	0.214 in. (5.44 mm)	0.485 in. (12.32 mm)	0.795 in. (20.19 mm)
6	0.243 in. (6.17 mm)		0.858 in. (21.79 mm)
7			0.920 in. (23.37 mm)
8			0.981 in. (24.92 mm)

10. System Requirements

10.1 Minimum brightness as measured at the monitor screen at maximum digital driving level shall be at least 250 cd/m².

10.2 Minimum contrast as determined by the ratio of the monitor screen brightness at the maximum digital driving level compared to the monitor screen brightness at the minimum digital driving level shall be at least 250:1.

10.3 The monitor shall be capable of displaying linear patterns of alternating pixels at full contrast in both the horizontal and vertical directions without aliasing.

10.4 The monitor shall be capable of displaying linear patterns of alternating pixels at 100 % modulation.

10.5 The display shall be free of discernible geometric distortion.

10.6 The display shall be free of screen flicker, characterized by a high frequency fluctuation of high contrast image details.

10.7 The monitor shall be capable of displaying a 5 % DDL block against a 0 % DDL background and simultaneously displaying a 95 % DDL block against a 100 % DDL background in a manner clearly perceptible to the user.

NOTE 4—The SMPTE test pattern as defined in **RP133** may be used in the validation of system requirements.

11. Keywords

11.1 aerospace; digital reference image; discontinuities; investment castings; nickel; steel; X-ray

SUMMARY OF CHANGES

Committee E07 has identified the location of selected changes to this standard since the last issue (E2660 - 10) that may impact the use of this standard. (December 1, 2011)

- (1) Added to **Note 1** the order number for the adjunct materials.
- (2) Added discussion to **6.2** and **6.3** about the application of contrast adjustment of the reference radiographs.
- (3) Added some description to **9.5** of the process for conducting the contrast adjustment and added **9.5.1** and **9.5.2** describing contrast adjustment by means of manual adjustment or contrast normalization.
- (4) Updated the reference in **9.10** to the contrast normalization instructions to **9.5.2**.

- (5) Removed the requirement for line profiles of the DDL in **9.12**.
- (6) Removed the requirement for average and standard deviation of DDL in a ROI in **9.13**.
- (7) Changed **9.15** to clarify the contrast normalization process and that the level 3 must approve changes to the reference images.

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