Designation: E2669 – 16ε1

Standard Digital Reference Images for Titanium Castings[1]

This standard is issued under the fixed designation E2669; 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.

ε[1] NOTE—The designation for Volume I of the Reference Radiographs was corrected editorially in October 2016.

1. Scope*

1.1 The digital reference images provided in the adjuncts to this standard illustrate various types and degrees of discontinuities occurring in titanium castings.[2] Use of this standard for the specification or grading of castings requires procurement of the appropriate 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 titanium 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 The digital reference images consist of twenty-five digital files each illustrating eight grades of increasing severity. The Volume I files illustrate seven common discontinuity types representing casting sections up to 1 in. (25.4 mm). The Volume II files illustrate five discontinuity types representing casting sections over 1 in. (25.4 mm) to 2 in. (50.8 mm) in thickness.

1.3 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 digital reference images are available from ASTM International Headquarters. Order number RRE2669 and RRE266902. Each of the digital reference images contain an image of a step density scale and two duplex-wire gauges. Refer to Practice E2002 for wire pair details. Originally, only Volume I images were available and some sets may identify these only as RRE2669 without a volume designation. They remain valid for use as Volume I images.

1.4 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.

1.5 These digital reference images are not intended to illustrate the types or degrees of discontinuities when performing film radiography. If performing film radiography of titanium castings, refer to Reference Radiographs E1320.

1.6 *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.*

1.7 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]

E1316 Terminology for Nondestructive Examinations

E1320 Reference Radiographs for Titanium Castings

E2002 Practice for Determining Total Image Unsharpness and Basic Spatial Resolution in Radiography and Radioscopy

2.2 *SMPTE Practice:*[4]

RP133

2.3 *ASTM Adjuncts:*

Digital Reference Images for Titanium Castings:

Volume I: Applicable for Thicknesses up to 1 in. (25.4 mm)[5]

Volume II: Applicable for Thicknesses over 1 in. (25.4 mm) to 2 in. (50.8 mm)[6]

[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 titanium castings, requiring close tolerances. 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.smpte.org/smpte_store/

[5] Available from ASTM International Headquarters. Order Adjunct No. RRE2669.

[6] Available from ASTM International Headquarters. Order Adjunct No. RRE266902.

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

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*—Gas in its various forms is usually caused by the reaction of molten titanium with the mold or residual material left in the mold. Gas tends to migrate to the upper portions of the casting. The formation of clustered or scattered gas holes results from the generation of larger amounts of gas than a single gas hole. Whether the larger amount of gas spreads out or is confined to a small area is dependent upon a number of factors including casting process, reaction area, solidification rate, wall thickness, and geometry.

3.2.6.1 *gas holes*—spherical voids formed through the release and subsequent entrapment of gas during solidification. A gas hole will appear as a dark round spot on the digital image.

3.2.6.2 *clustered gas holes*—a closely nested group of dark round voids concentrated within a self-defined boundary area.

3.2.6.3 *scattered gas holes*—multiple voids appearing as dark round spots on the digital image. They are randomly spread throughout a part or area of a part to a lesser concentration than clustered gas holes but with the potential to degrade the casting through their interaction which precludes their evaluation on an individual basis.

3.2.7 *shrinkage*—While at times the appearance of shrinkage in titanium may be radiographically similar to shrinkage in steel, the faster solidification rate of titanium has a dramatic effect on the conditions under which each shrinkage type will occur in titanium. Other factors which influence the formation of shrinkage are wall thickness and thickness transition gradients, gate size and orientation, mold design, casting configuration, metal/mold temperature, and pouring rate and method. All the types of shrinkage described in 3.2.7.1 through 3.2.7.3 have a degree of overlap. However, each is most likely to occur under a specific set of conditions primarily influenced by metal feed, section thickness and cooling rate.

3.2.7.1 *shrinkage cavity*—appears as a dark void with smooth sides taking an appearance very similar to a gas hole. A shrinkage cavity, particularly in thicker wall sections, is usually larger than a single gas hole would be. The cavity is formed during the cooling process due to a lack of feeding metal. The cavity compensates for the rapid solidification taking place at the surface of the casting, thereby forming the cavity in the center area of the wall. Shrinkage cavity has a definite tendency to occur near hot spots where walls are ½-in. (12.7-mm) thick or more.

3.2.7.2 *scattered shrinkage*—appears on a digital image as dark fine lacy or filamentary voids of varying densities. These voids are usually uniformly spread throughout the area of the casting where shrinkage is occurring and are relatively shallow.

3.2.7.3 *shrinkage, centerline*—characterized by a more discrete dark indication than scattered shrinkage. The indication has definite borders consisting of a lacy network of varying density or a network of interconnected elongated voids. Centerline shrinkage is located primarily in the center of the material cross section with a tendency to orient toward gates or risers.

3.2.8 *foreign material, less dense*—appear as dark indications in a variety of shapes and sizes on a digital image. Inclusions may be found in groups or appear singularly. Less dense inclusions can be caused by contaminants in the molten titanium, residual materials left on the surface of the mold, or broken pieces of the mold becoming entrapped during solidification.

3.2.9 *foreign material, more dense*—appear as light indications in a variety of shapes and sizes on a digital image. More dense inclusions can be caused by contaminants introduced in the same manner as less dense inclusions, or tungsten introduced during weld repairs.

4. Significance and Use[7]

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 *Applicability of Thickness Designations:*

4.1.1.1 The discontinuity types, illustrated thickness and applicable thickness range are summarized in Table 1 for the Volume I images and in Table 2 for the Volume II images.

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

[7] 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.

TABLE 1 Volume I Digital Reference Images for Titanium Castings up to 1 in. [25.4 mm]

Discontinuity	Casting Process	Alloy	Plate Thickness, in.	Applicable Casting Thickness, in.
Gas hole	Centrifugal ram graphite	Ti 6AL 4V	N/A	Up to 1
Clustered gas holes	Centrifugal precision	Ti 6AL 4V	¼	Up to ⅜
Clustered gas holes	Centrifugal precision	Ti 6AL 4V	½	Over ⅜ to ⅝
Clustered gas holes	Centrifugal precision	Ti 6AL 4V	¾	Over ⅝ to 1
Scattered gas holes	Top pour lost wax	Ti 6AL 4V	¼	Up to ⅜
Scattered gas holes	Top pour lost wax	Ti 6AL 4V	½	Over ⅜ to ⅝
Scattered gas holes	Top pour lost wax	Ti 6AL 4V	¾	Over ⅝ to 1
Shrinkage cavity	Centrifugal ram graphite	Ti 6AL 4V	½	Over ¼ to ⅝
Shrinkage cavity	Centrifugal ram graphite	Ti 6AL 4V	¾	Over ⅝ to 1
Scattered shrinkage cavity	Top pour lost wax	Ti 6AL 4V	¼	Up to ⅜
Scattered shrinkage cavity	Top pour lost wax	Ti 6AL 4V	½	Over ⅜ to ⅝
Scattered shrinkage cavity	Top pour lost wax	Ti 6AL 4V	¾	Over ⅝ to 1
Centerline shrinkage	Centrifugal ram graphite	Ti 6AL 4V	¼	Up to ⅜
Centerline shrinkage	Centrifugal ram graphite	Ti 6AL 4V	½	Over ⅜ to ⅝
Centerline shrinkage	Centrifugal ram graphite	Ti 6AL 4V	¾	Over ⅝ to 1
Less dense inclusions	Varied	Ti 6AL 4V	N/A	Up to 1
More dense inclusions	Varied	Ti 6AL 4V	N/A	Up to 1

TABLE 2 Volume II Digital Reference Images for Titanium Castings over 1 in. (25.4 mm) to 2 in. (50.8 mm)

Discontinuity	Casting Process	Alloy	Plate Thickness, in.	Applicable Casting Thickness, in.
Gas hole	Centrifugal ram graphite	Ti 6AL 4V	1 ¼	Over 1 to 2
Clustered gas holes	Centrifugal ram graphite	Ti 6AL 4V	1¼ to 1 ¾	Over 1 to 2
Scattered gas holes	Centrifugal ram graphite	Ti 6AL 4V	1 ¼	Over 1 to 1 0½
Scattered gas holes	Centrifugal ram graphite	Ti 6AL 4V	1 ¾	Over ½ to 2
Shrinkage cavity	Centrifugal ram graphite	Ti 6AL 4V	1 ¼	Over 1 to 1 ½
Shrinkage cavity	Centrifugal ram graphite	Ti 6AL 4V	1 ¾	Over 1 ½ to 2
Centerline shrinkage	Centrifugal ram graphite	Ti 6AL 4V	1 ¼	Over 1 to 1 ½
Centerline shrinkage	Centrifugal ram graphite	Ti 6AL 4V	1 ¾	Over 1 ½ to 2

digital reference images if their appearance has been adversely affected such that the interpretation and use of the images could be influenced.

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 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.

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 and Table 2 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 reference images could be used for acceptance standards.

7.2 The step wedges shown in the Volume I digital reference images are made of Titanium 6 Al 4V with the step thicknesses listed in Table 3. The Volume II images utilize a stepped density scale rather than a radiograph of a physical step wedge.

TABLE 3 Thicknesses of Steps of Included Step Wedges in the Volume I Images

Step Number	¼ in. (6.3 mm) Plates	½ in. (12.7 mm) Plates	¾ in. (19.1 mm) Plates
1	0.188 in. (4.78 mm)	0.374 in. (9.50 mm)	0.626 in. (15.9 mm)
2	0.248 in. (6.30 mm)	0.436 in. (11.1 mm)	0.810 in. (20.6 mm)
3	0.312 in. (7.92 mm)	0.500 in. (12.7 mm)	0.932 in. (23.7 mm)
4	0.374 in. (9.50 mm)	0.626 in. (15.9 mm)	1.060 in. (26.9 mm)
5	0.436 in. (11.1 mm)	0.810 in. (20.6 mm)	
6	0.500 in. (12.7 mm)	0.932 in. (23.7 mm)	
7	0.626 in. (15.9 mm)	1.060 in. (26.9 mm)	

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.

8.4 The software load process will require the digital reference image resolution to be specified to the nearest 10-micron increment. Volume I images can be installed at resolutions from 10 microns to 400 microns. Volume II images can be installed at resolutions from 20 microns to 400 microns. 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 system spatial resolution (also referred to as SR b image or SR min) at the magnification to be used for production imaging using the duplex wire gauge as described in Practice E2002 .

8.6 Compare the measured system spatial resolution to the theoretical resolution determined by nominal pixel size divided by the geometric magnification. Where parts are placed directly on the detector, use the nominal pixel size as the theoretical resolution. If the measured system spatial resolution differs by no more than 30 % from the theoretical system resolution, use the theoretical system resolution as the system spatial 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 sample 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 DICONDE 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 (applicable to both Volume I and Volume II images) or 9.5.2 (applicable only to Volume 1 images) as directed by the cognizant engineering organization.

9.5.1 *Manual Contrast Method*—The contrast of the reference image shall be adjusted to provide an appropriate presentation of discontinuities. This may be accomplished, for example, by comparison with the image in the equivalent film reference radiograph. The step wedge image in Volume I or the stepped density scale in the Volume II images may be used to guide the establishment of the display contrast for the reference images. This may be accomplished by performing a histogram normalization on defined steps of the step wedge or the stepped density scale or by setting the display window width to a fixed value. The specific method to be used for establishing the display of the reference image, including the accept able range of the window width, shall be documented and approved by the Level 3. Once established and approved by the Level 3, 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.

10. System Requirements

10.1 Minimum brightness as measured at the monitor screen at maximum digital driving level shall be at least 250 cd/m^2.

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; titanium; X-ray

SUMMARY OF CHANGES

Committee E07 has identified the location of selected changes to this standard since the last issue (E2669 - 11) that may impact the use of this standard. (June 1, 2016)

(1) Added reference to second volume of reference images covering thicknesses over 1 in. to 2 in.
(2) Deleted text description of images and applicable thickness range in subsection 4.1.1 and referenced Table 1 and Table 2 for this information
(3) Added Table 2 showing thickness applicability for Volume II images.
(4) Clarified in section 7.2 that Volume II images have stepped density scale rather than physical step wedge.
(5) Clarified the method for determining system spatial resolution in section 8.
(6) Clarified the manual method of contrast normalization in subsection 9.5.1.