



Standard Reference Radiographs for Titanium Castings¹

This standard is issued under the fixed designation E1320; 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 U.S. Department of Defense.

1. Scope

1.1 The reference radiographs provided in the adjunct to this standard are reproductions of original radiographs and are supplied as a means for establishing some of the categories and severity levels of discontinuities in titanium castings that may be revealed by radiographic examination. Use of this standard for the specification or grading of castings requires procurement of the adjunct reference radiographs which illustrate the discontinuity types and severity levels. They should be used in accordance with contractual specifications.

NOTE 1—The original radiographs produced for Volume I were taken with X-rays in the range of 110 KV to 220 KV. The original radiographs produced for Volume II were taken with X-rays in the range of 200 K to 340 KV.

1.2 These film reference radiographs are not intended to illustrate the types and degrees of discontinuities found in titanium castings when performing digital radiography. If performing digital radiography of titanium castings, refer to Digital Reference Image Standard E2669.

1.3 These reference radiographs consist of two volumes. Volume I, described in Table 1, is applicable to a wall thickness of up to 1 in. (0 to 25.4 mm). Volume II, described in Table 2, is applicable to a wall thickness of over 1 in. to 2 in. (25.4 mm to 50.8 mm). The standard may be used, where there is no other applicable standard, for other thicknesses for which agreement has been reached between purchaser and manufacturer.

NOTE 2—The reference radiographs are not impacted by this revision. There have been no revisions to the adjunct reference radiographs since original issue. The adjunct reference radiographs of any issue remain valid and may be used to this standard.

1.4 The plates produced to serve for use in this standard were purposely cast to exhibit the desired discontinuity. The plates were cast using different processes as shown in Table 1 and Table 2. Hot isostatic pressing was not used on any of the plates.

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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1.5 From time to time, there may be minor changes to the process for manufacturing of the reference radiograph adjunct materials. These changes could include changes in the films or processing chemicals used, changes in the dies or printing for the cardboard mats, etc.; however, in all cases, these changes are reviewed by the Illustration Monitoring Subcommittee and all reference radiographs are reviewed against a fixed prototype image to ensure that there are no changes to the acceptance level represented by the reference radiographs. Therefore, the adjunct reference radiographs remain valid for use with this standard regardless of the date of production or the revision level of the text standard.

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

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.*

2. Referenced Documents

2.1 *ASTM Standards*:²

E94 Guide for Radiographic Examination

E1316 Terminology for Nondestructive Examinations

E2669 Digital Reference Images for Titanium Castings

2.2 *ASTM Adjuncts*:

Reference Radiographs for the Inspection of Titanium Castings

Volume I, applicable up to 1 in. (25.4 mm)^{3,4}

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 ASTM International Headquarters. Order Reference Radiograph No. RRE132001.

⁴ Volumes I and II are available from ASTM International Headquarters as a set. Order Reference Radiographs RRE1320CS.

TABLE 1 VOLUME I—0 to 1 in.

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 holes	Centrifugal precision	Ti 6AL 4V	1/4	up to 3/8
Clustered holes	Centrifugal precision	Ti 6AL 4V	1/2	over 3/8 to 5/8
Clustered holes	Centrifugal precision	Ti 6AL 4V	3/4	over 5/8 to 1
Scattered gas holes	Top pour lost wax	Ti 6AL 4V	1/4	up to 3/8
Scattered gas holes	Top pour lost wax	Ti 6AL 4V	1/2	over 3/8 to 5/8
Scattered gas holes	Top pour lost wax	Ti 6AL 4V	3/4	over 5/8 to 1
Shrinkage cavity	Centrifugal ram graphite	Ti 6AL 4V	1/2	over 1/4 to 5/8
Shrinkage cavity	Centrifugal ram graphite	Ti 6AL 4V	3/4	over 5/8 to 1
Scattered shrinkage cavity	Top pour lost wax	Ti 6AL 4V	1/4	up to 3/8
Scattered shrinkage cavity	Top pour lost wax	Ti 6AL 4V	1/2	over 3/8 to 5/8
Scattered shrinkage cavity	Top pour lost wax	Ti 6AL 4V	3/4	over 5/8 to 1
Centerline shrinkage	Centrifugal ram graphite	Ti 6AL 4V	1/4	up to 3/8
Centerline shrinkage	Centrifugal ram graphite	Ti 6AL 4V	1/2	over 3/8 to 5/8
Centerline shrinkage	Centrifugal ram graphite	Ti 6AL 4V	3/4	over 5/8 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

NOTE 1—1 in. = 25.4 mm.

TABLE 2 VOLUME II—Over 1 in. to 2 in.

Discontinuity	Casting Process	Alloy	Plate Thickness, in.	Applicable Casting Thickness, in.
Gas hole	Centrifugal ram graphite	Ti 6AL 4V	1/4	over 1 to 2
Clustered gas holes	Centrifugal ram graphite	Ti 6AL 4V	1/4 to 1 3/4	over 1 to 2
Scattered gas holes	Centrifugal ram graphite	Ti 6AL 4V	1/4	over 1 to 1 1/2
Scattered gas holes	Centrifugal ram graphite	Ti 6AL 4V	1 3/4	over 1 1/2 to 2
Shrinkage cavity	Centrifugal ram graphite	Ti 6AL 4V	1/4	over 1 to 1 1/2
Shrinkage cavity	Centrifugal ram graphite	Ti 6AL 4V	1 3/4	over 1 1/2 to 2
Centerline shrinkage	Centrifugal ram graphite	Ti 6AL 4V	1/4	over 1 to 1 1/2
Centerline shrinkage	Centrifugal ram graphite	Ti 6AL 4V	1 3/4	over 1 1/2 to 2

NOTE 1—1 in. = 25.4 mm.

Volume II, applicable over 1 in. to 2 in. (25.4 mm to 50.8 mm)^{4,5}

3. Terminology

3.1 *Definitions*—For definitions of terms used in this standard, see Terminology E1316.

4. Significance and Use

4.1 These reference radiographs are designed so that acceptance standards, which may be developed for particular requirements, can be specified in terms of these radiographs. The radiographs are of castings that were produced under conditions designed to produce the discontinuities. The reference radiographs are intended to be used for casting thickness ranges in accordance with Table 1 and Table 2.

5. Description of Discontinuities

5.1 This section is provided to aid in the identification and classification of discontinuities. It briefly describes the radiographic appearance of those discontinuities in the reference radiograph adjuncts and indicates their probable cause in titanium. The radiographic appearance of different discontinuities can at times be very similar. Therefore, care should always

be taken during the process of identification. In extreme cases other methods of identification, either nondestructive or destructive, may need to be employed to obtain positive identification.

5.1.1 *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.

5.1.1.1 *Gas hole*—A spherical void formed through the release and subsequent entrapment of gas during solidification. A gas hole will appear as a dark round spot on the radiograph.

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

5.1.1.3 *Scattered gas holes*—Multiple voids appearing as dark round spots on the radiograph. 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.

5.1.2 *Shrinkage*—While at times the appearance of shrinkage in titanium may be radiographically similar to shrinkage in

⁵ Available from ASTM International Headquarters. Order Reference Radiograph No. RRE132002.

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 5.1.2.1 through 5.1.2.3 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.

5.1.2.1 *Scattered shrinkage*—Appears on a radiograph 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. Scattered shrinkage cavities are most common in wall thicknesses ranging from 1/8 in. to 3/4 in. (3.175 mm to 19.05 mm) being more prevalent in the thinner sections of the range. Scattered shrinkage cavities are caused by varying cooling rates in the same area of a casting that can result from differences in wall thickness or other factors.

5.1.2.2 *Centerline shrinkage*—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. It is more common in thickness over 1/4 in. (6.35 mm).

5.1.2.3 *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 1/2 in. (12.7 mm) thick or more.

5.1.3 *Less dense inclusions*—Appear as dark indications in a variety of shapes and sizes on a radiograph. 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.

5.1.4 *More dense inclusions*—Appear as light indications in a variety of shapes and sizes on a radiograph. More dense inclusions can be caused by contaminants introduced in the same manner as less dense inclusions, or tungsten introduced during weld repairs.

6. Method of Preparation

6.1 The original radiographs used to prepare the adjunct reference radiographs were produced on high contrast, fine grained film. The radiographs were made with a penetrometer sensitivity as determined by ASTM penetrameters (see Guide E94) of 2-2T. The reproductions of the original radiographs have been made with a desired density within the range of 2.0 to 2.25. They have retained substantially the contrast of the original radiographs.

6.2 In selecting the individual reference radiographs, the aim was to obtain a graduated series for each type of discontinuity. It is not intended that like numbered levels or classes on the different reference radiograph pages be considered to cause equal degradation in the ultimate performance, or serviceability, or both, of any particular casting.

6.2.1 The criteria used to select the individual radiographs representing each severity level were based on the size, shape, spacing, alignment, and radiographic density of the discontinuities present.

6.3 In some cases, plates other than the thickness indicated on the reference radiographs were utilized to complete individual severity levels.

6.4 For the discontinuity classifications of gas hole, less dense inclusions, and more dense inclusions, only one series of eight gradations is displayed for each. These gradations are intended to be used over the entire thickness range applicable to the volume. Therefore, careful consideration should be taken when specifying allowable severity levels for the thicker wall sizes.

6.5 *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.

7. Basis for Application

7.1 The reference radiographs may be applied as acceptance standards tailored to the end use of the product. Application of these reference radiographs as acceptance standards should be based on the intended use of the product and the following considerations:

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

7.1.2 Any combination or portion of these reference radiographs may be used as is relevant to the particular application. Different grades or acceptance limits may be specified for each discontinuity type. Further, different grades may be specified for various regions or zones of the component.

7.1.3 Special consideration may be required where more than one discontinuity type is present in the same area. Any modification of the acceptance criteria required on the basis of multiple discontinuity types must be specified.

7.1.4 Production radiographs containing shrinkage, gas, or inclusions may be rated by the overall condition with regard to size, number, and distribution. These factors should be considered in balance.

7.1.5 As a minimum, the acceptance criteria should contain information addressing: zoning of the part (if applicable),

acceptance severity level for each discontinuity type, and the specific area to which the reference radiographs are to be applied.

NOTE 3—Caution should be exercised in specifying the acceptance criteria to be met in the casting. Casting design coupled with foundry practice should be considered. It is advisable to consult with the manufacturer or foundry before establishing the acceptance criteria to ensure the desired quality level can be achieved.

8. Procedure for Evaluation

8.1 Compare the production radiographs of the casting submitted for evaluation with the reference radiographs applicable to designated wall thickness in accordance with the written acceptance criteria.

8.2 When the severity level of discontinuities per unit area in the production radiograph being evaluated is equal to or

better than the severity level in the specified reference radiograph, that part of the casting represented by the production radiograph shall be acceptable. If the production radiograph shows discontinuities per unit area of greater severity than the reference radiograph, that part of the casting shall not be accepted.

9. Application to Weld Repair Castings

9.1 When castings subject to this standard are repaired by welding, the purchaser may impose specific instructions addressing the use of these reference radiographs in the evaluation of the repaired sections.

10. Keywords

10.1 castings; discontinuities; reference radiographs; titanium; X-ray

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