

# X-Ray Image Interpretation Guide for Aviation Aluminum Alloy Castings

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**Abstract:** The purpose of this paper is to introduce the basic steps of X-ray image interpretation of aviation castings, so as to provide a learning guidance for beginners and reduce the exploration time. Among them, the introduction of specifications, the requirements for image quality, and the application of reference radiographs are just a sorting out the key points. If there is a need for practical application, we should conduct a deeper exploration and understanding of each specification, not just cite this article.

**Key words:** Aviation aluminum casting, radiographic test, standard reference radiographs, X-ray indication interpretation.

## 1. Introduction

Casting is susceptible to many variables in the process, resulting in various types of discontinuities. Therefore, X-ray inspection is the most reliable method for comprehensive inspection of the internal and external conditions of castings. For castings used in aircraft, safety is the top priority. Therefore, there are strict standards for inspectors, equipment, procedures and even image quality requirements.

For beginners, the interpretation of X-ray images is usually like a blind man feeling for an elephant. They do not know where to start. This article aims to sort out the basic requirements of X-ray inspection aviation quality assurance, so that beginners can roughly understand the examination outline and rules, and then master the essentials and requirements of image interpretation.

## 2. Common Specifications of Aviation Aluminum Alloy Castings

### 2.1 Orders, Contracts and Drawings

If there is no specific requirement in the order or contract delivered by the customer, the parts or

components will be produced according to the drawing requirements. The non-destructive inspection requirements in the drawing usually include inspection specifications and acceptance criteria so that inspectors can follow them. Some customers may not put the information in the drawing, but specify it in other documents, but in any case, these two pieces of information are essential when inspecting aircraft parts. Therefore, it is also important to be familiar with the customer's document editing structure and linking habits.

### 2.2 Inspection Specification

The fundamental purpose of the inspection specification is to clarify how to produce consistent and satisfactory X-ray images. Therefore, regardless of whether the image carrier is a traditional radiograph or a digital image, the main function of the inspection specification is to verify the performance of the X-ray testing system. The so-called testing system can be roughly divided into four elements: operation procedures, equipment, materials, and personnel. The inspection specification not only requires that the four elements meet the requirements separately, but also the overall operation results of the four elements must meet the requirements. System performance should be conducted and recorded in accordance with the items,

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methods and frequencies specified in the specification, so that inspectors can monitor and evaluate the system performance. And the verification records need to be provided to internal and external auditors for review.

In addition, the inspection specifications also provide feasible irradiation technology and image quality requirements. Common industrial specifications are shown in Table 1. Customers may have additional requirements for image quality, so they often customize inspection specifications and use them in conjunction with industrial specifications.

**2.3 Acceptance Criteria**

The acceptance criteria provide the interpreter with guidance to decide whether to accept or reject the discontinuity found in the test. Acceptance criteria may be issued in the form of specifications or charts. In addition to defining the type of discontinuities, they also determine the acceptable level of discontinuities based on the size, area, density, or quantity of discontinuities. The acceptance criteria and acceptance levels are usually specified in the drawing. According to the drawings, different parts may have different acceptance levels; according to the designated area of the drawings, the same part may also have different

acceptance levels.

AMS2175 is usually used as the acceptance criteria for aviation castings. According to the inspection method, AMS2175 is applied to visual inspection (VT), liquid penetration inspection (PT), magnetic particle inspection (MT), and radiographic inspection (RT). Depending on the material, it is applied to steel, aluminum, magnesium, titanium, and copper alloys.

As far as RT is concerned, AMS2175 is usually used with standard reference radiographs (such as ASTM E155 or E2422) for the interpreter to evaluate and decide whether to accept the discontinuity indication. Customers often customize acceptance criteria for their parts, but they still must use standard reference radiographs to interpret indications.

**2.4 Standard Reference Radiographs for Inspection of Casting**

ASTM standard reference radiographs are often used to interpret casting discontinuities. The severity of discontinuity is evaluated by comparing discontinuity indication with a standard radiograph. The common standard reference radiographs for casting discontinuities are shown in Table 2.

**Table 1 Common industrial specifications for radiographic testing.**

Image capture method	Specification
Film system	ASTM E1742 standard practice for radiographic examination.
CR system (computed radiography)	ASTM E2445 standard practice for qualification and long-term stability of computed radiology systems. ASTM E2033 standard practice for radiographic examination using computed radiography (photostimulable luminescence method).
DR system (digital detector arrays)	ASTM E2737 standard practice for digital detector array performance evaluation and long-term stability. ASTM E2698 standard practice for radiological examination using digital detector arrays.

**Table 2 Common standard reference radiographs/images.**

Casting material	Standard reference radiographs	Standard digital reference images
Aluminum	ASTM E155 Volume I	ASTM E2422
Magnesium	ASTM E155 Volume I, II	ASTM E2869
Investment steel for aerospace applications	ASTM E192	ASTM E2660
Steel up to 2 in.	ASTM E446	ASTM E2868
Aluminum and magnesium die castings	ASTM E505	ASTM E2973
Titanium	ASTM E1320	ASTM E2669

The entity standard radiographs are used for traditional radiographs, while the digital standard images are used for computed radiography (CR) or digital radiography (DR). Except for the different image carriers, the types, patterns, and severity levels of the discontinuity indications of the two standard images are identical.

### 2.5 Qualification Requirements for NDT Personnel

All personnel engaged in non-destructive testing of aircraft and aerial components must be certified by NAS 410 or EN 4179. This is the general specification for international aviation, without exception. NAS 410 belongs to the American specification, and EN 4179 belongs to the European specification. However, the requirements of these two specifications are not different. Therefore, non-destructive testing personnel should meet one of the specifications.

## 3. X-Ray Image Quality Requirements of Aviation Aluminum Alloy Castings

The X-ray image quality of castings is mainly based on the hole type image quality indicator (IQI). At least the sensitivity, contrast, and optical density should meet the requirements of the drawing and inspection specification. The materials and specifications of hole type IQI shall meet the requirements of ASTM E1025 or ASTM E1742, and the manufacturer's certificate, serial number, and dimension report should be provided.

### 3.1 Sensitivity

The requirements for image sensitivity are usually indicated in the drawing. If the order or drawing does not specify the sensitivity requirement, the default value is 2-2T [1-3]. This requirement usually applies to analog (radiograph) images and digital (CR, DR) images, and the required hole image should be clearly visible.

### 3.2 Contrast

The contrast of radiograph should be determined by

measuring the difference in optical density of the film through the IQI and the adjacent material. The optical density difference should meet the requirements of ASTM E1742 (Fig. 2). The contrast requirement varies with the thickness of the casting. The contrast of the image can not be changed on the radiograph, so the operation of verifying the contrast of the image is more direct and simpler.

Specifications have comprehensive requirements for the long-term stability monitoring of the contrast sensitivity of CR or DR testing system. Because the contrast of digital images can be adjusted, specifications do not require the image contrast as the radiograph but authorize RT Level 3 to determine the image contrast and write in the testing procedure. When RT Level 2 interprets the image, the contrast of the image should be adjusted according to the approved procedure before the interpretation can begin; during the interpreting process, the interpreter can only adjust the image brightness (window level), but not the contrast (window width).

### 3.3 Optical Density

According to the requirements of ASTM E1742, the optical density (radiograph density) should be between 1.5 and 4.0. However, most customers have their own preferences. Sometimes, the customer's optical density requirements are not stated in the drawing or specifications but are stated in the order or contract. Therefore, this point should be confirmed by detailed investigations before developing the test procedure.

There is no term "optical density" in digital images, only the concept of pixel value (PV) is similar. The PV is related to the exposure parameters and the thickness of X-ray penetrating the object. The CR system requires 10-90% [4] of the bit depth for pixel values. There are no direct requirements for the PV of DR images in the specification, but DR images have many properties, such as contrast to noise ratio (CNR), signal to noise ratio (SNR), etc. whose calculations

are related to the PV, and specifications specify these properties requirement, so it is also an indirect requirement of PV.

#### 4. Application of ASTM E155 and AMS2175

##### 4.1 ASTM E155 Standard Radiographs of Aluminum and Magnesium Alloy Castings

ASTM E155 is the standard reference radiographs used to inspect aluminum and magnesium castings. Volume I is applicable to aluminum and magnesium alloy castings, and Volume II is applicable to magnesium alloy castings. However, if the acceptance criteria have special requirements, aluminum alloy castings may also be specified to use Volume II radiographs. This situation may also occur in other alloy castings.

ASTM E155 is divided into a complete set with entity plates (as Fig. 1) or text only. If the inspection requires interpretation, the full set of ASTM E155 should be purchased. If there is a subsequent revision of the specification, only the text needs to be updated. If CR or DR is used for casting inspection, ASTM E2422 digital reference image shall be used for aluminum alloy and ASTM E2869 digital reference image shall be used for magnesium alloy.

The operation method of the digital reference image is slightly different from entity reference radiographs, so there are differences in the text of both specifications. However, as far as the essentials of identification and evaluation indications are concerned, the skills of interpretation can be applied interactively.

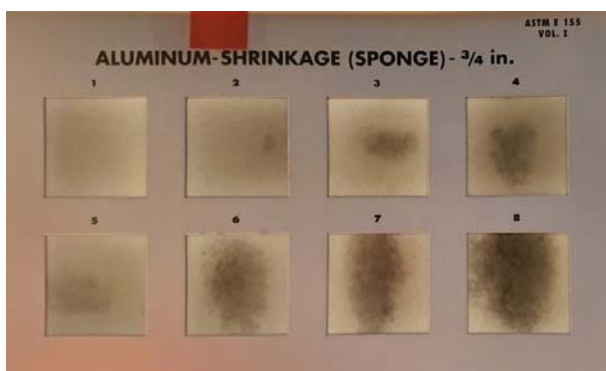


Fig. 1 ASTM E155 standard reference radiographs.

##### 4.1.1 ASTM E155 Discontinuity Type

In Volume I, there are seven types of discontinuities for aluminum alloy castings and five types for magnesium alloy castings. In addition to the shrinkage cavity of aluminum alloy castings, each discontinuity has a reference radiograph applicable to the thickness of castings less than 1/2 in. or more. The radiographs of the 1/4 in. (6.35 mm) castings are intended to be used in the thickness range up to and including 1/2 in. (12.7 mm). The radiographs of the 3/4 in. (19.1 mm) castings are intended to be used in the thickness range of over 1/2 in. up to and including 2 in. (51 mm). Each plate is held in a cardboard frame and each plate illustrates 8 grades of severity for the discontinuity. Frame 1 is the lowest severity level, and Frame 8 is the highest severity level.

There are four types of discontinuities in Volume II for magnesium alloy castings, which are suitable for all casting thicknesses. In addition to the Eutectic segregation (discrete discontinuities), there are discontinuity images with different severity levels 1-8 in each reference radiograph.

##### 4.1.2 The Operation Method of ASTM E155

When an indication of discontinuity is found on a film, it is necessary to first determine what kind of discontinuity it is, and then select a reference radiograph of appropriate thickness. We can measure the optical density of IQI and the adjacent area of the indication by a densitometer to estimate the inspecting thickness. Then select the appropriate (thickness) reference radiograph and compare the severity of indication with standard image to evaluate the grade of indication, and then decide whether to accept or reject the indication according to the acceptance criteria. At the same time, annotate the judgment result on the indication and reader sheet (recording sheet) respectively, and finally sign your name and interpretation date.

The standard image frame size of each grade in the reference radiograph is about 2 by 2 in. This size will also be used as the reference area for evaluating the

severity of the indication in the acceptance criteria. If the distribution, density, or quantity of indications exceeds the reference area, the interpreter should appropriately increase the severity level of indications. If there are two or more types of discontinuities present in the reference area, the acceptance criteria may reject these indications mandatorily, even if each type of indication meets the acceptance level.

#### 4.2 AMS2175 Acceptance Criteria for Radiographic

Continued from Section 2.3 of this paper, if AMS2175 is used as the casting acceptance criteria, the drawing will also provide information on the Class and Grade of castings.

- **Class**—Classifies the castings into 1, 2, 3 and 4 categories to indicate the damage to lives or aircraft when the casting failure. Class 1 indicates the most serious impact and Class 4 indicates the least serious impact. “Class” also has the function of defining sampling methods for sampling inspection. If the customer agrees with the sampling inspection, the sampling inspection can be carried out according to AMS2175 Tables 1 and 2.

- **Grade**—The casting is divided into four grades: A, B, C, and D to indicate the quality levels of the castings. Grade A is the highest quality grade of casting, or area of a casting, with minimum allowable discontinuities and very difficult to produce except in local areas. Grade D is the lowest quality grade of a casting, or area of a casting, that is easily produced and is used primarily for low stress or noncritical areas adjacent to the higher graded areas. If the grade of casting is not specified in the drawing or other contractual document, Grade C shall apply [5].

##### 4.2.1 AMS2175 Table 5—General Notes for Acceptance Criteria of Radiographic Testing of Various Alloy Castings

In AMS2175, Tables 1 and 2 are the sampling Tables for sampling inspection; Table 3 is the acceptance criteria for gate, riser, and parting line; Table 4 is the acceptance criteria for magnetic particle

and liquid penetration inspection; Tables 5-14 are the acceptance criteria for radiographic inspection of various alloy castings.

Table 5 is the general requirements of radiographic testing. When interpreting any alloy casting, in addition to being familiar with the quoted Table and its notes, the notes in Table 5 are also the key points to be considered. If the interpreter is not familiar with the notes in Table 5 or careless interpretation, it may lead to misjudgment.

##### 4.2.2 AMS2175 Table 6—Maximum Permissible Radiographic Severity Levels for Discontinuities in Aluminum Castings in Accordance with ASTM E155 and ASTM E2422

AMS2175 Table 6 is the acceptance criteria for radiographic testing of aluminum alloy castings. The left column is discontinuous type, the upper right columns are Grade A-D, the 1/4 and 3/4 columns are reference plates of ASTM E155 thickness range. The number displayed in the middle field corresponding to the Discontinuity and the Grade is the acceptable level. After comparing the indication with the ASTM E155 reference image, then determine the indication grade. Decide whether to accept or reject the indication according to the specified casting grade.

Table 6 has its special notes, when using this table for interpretation, its instructions and requirements should not be ignored.

#### 4.3 The Steps and Principles of X-Ray Image Interpretation

When interpreting X-ray images of castings, Level 2 is often confused, unable to distinguish indications, or difficult to make the decision. It requires a period of practice and experience accumulation, and often exchanges experience with seniors to grow effectively. When a Level 2 candidate begins to learn X-ray image interpretation, it is recommended that you take the following steps to face each indication.

**Interpretation:** To determine whether the indication is relevant or non-relevant. If it is relevant [6], what

type of discontinuity is it?

**Evaluation:** Measure the dimensions, numbers, area, or distribution of indications and evaluate their severity level.

**Judgment:** Decide whether to accept or reject the indication according to the acceptance criteria.

According to some specification definitions, the process of “Evaluation” may be included the act of “Judgment”, which does not matter. Here is just provided a concise step for beginners.

When judging indications, there are only two choices of “accept” or “reject”, and the acceptance criteria never provide a third choice to the interpreter. For many reasons, it may be difficult for the interpreter to distinguish or evaluate the instructions, or the interpreter can only make a judgment after performing the necessary mechanical processing or verification. This situation often occurs in practice, but it can not be called the third choice. If the interpreter does not accept the indication at the time, it shall be deemed that he/she has rejected the indication, and the first round of the judgment has concluded. As for the judgment made on the subsequent processes or verification of the instruction, it should be regarded as the second round of judgment, that is, re-inspection. This concept should be clarified carefully, especially in NADCAP (National Aerospace and Defense Contractors Accreditation Program) or customer audits. When the auditor witnesses the interpretation operation, after the interpreter completed the inspection of the specimen, the interpreter must clearly inform the auditor that the interpretation has been completed, and the judgment result must be explained at the same time. If the interpreter provides an ambiguous answer to the auditor, such audit findings are often difficult to reply and are adopted.

The interpreter should decide whether to accept or reject the indication based on the acceptance criteria. External pressures such as production needs and economic considerations should not affect his/her decision [7]. Senior interpreters should not rely too

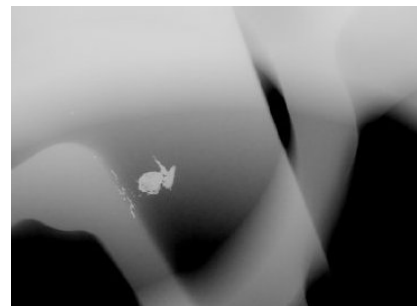
much on experience to interpret indications. Changes in process and environment or changes in equipment and personnel may cause unexpected indications, which may be relevant or non-relevant.

#### 4.4 Common X-Ray Indication of Aluminum Alloy Castings

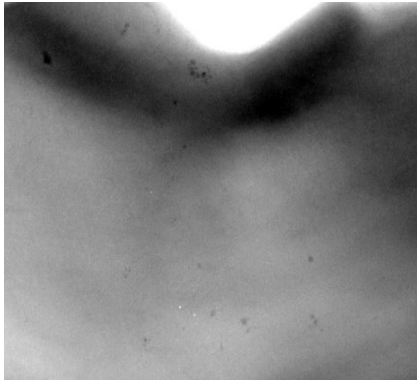
Figs. 2-8 showed the common X-ray indications of aluminum alloy castings. Some indications can be interpreted using ASTM E155 reference radiographs (or images), while some indications are difficult to find the corresponding reference radiographs. However, the types of flaws or defects in castings are numerous, so only typical discontinuities are listed in the reference radiographs. Therefore, the interpreter should try his/her best to verify the questionable indication, take the indication (radiograph) to verify it with the surface of the suspicious part, irradiate the discontinuity with different exposure parameters or angles, or gradually remove the discontinuity and observe the changes of the indication, so as to enhance the understanding of the indications. Discussion of casting schemes with process engineers is helpful to understand the cause of defect generation. It is also



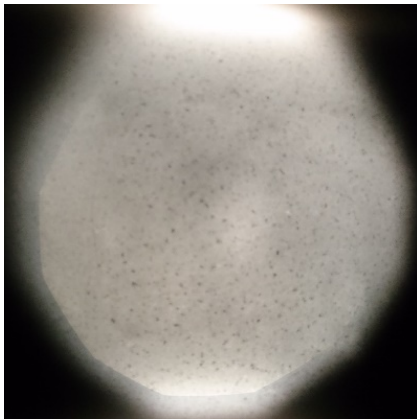
**Fig. 2 Gas holes plate 2.**



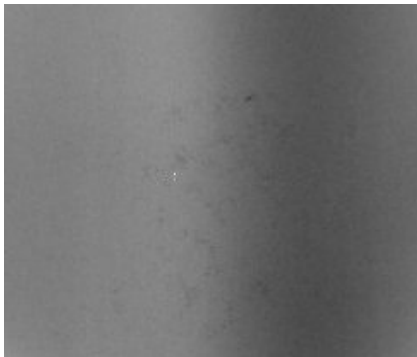
**Fig. 3 Foreign material, more dense plate 5.**



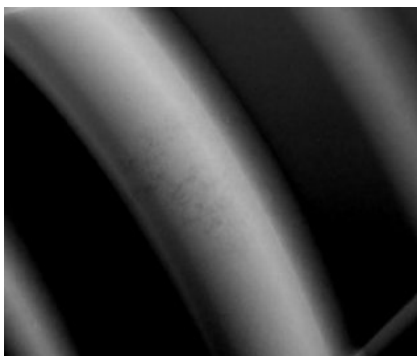
**Fig. 4** Foreign material, less dense plate 3.



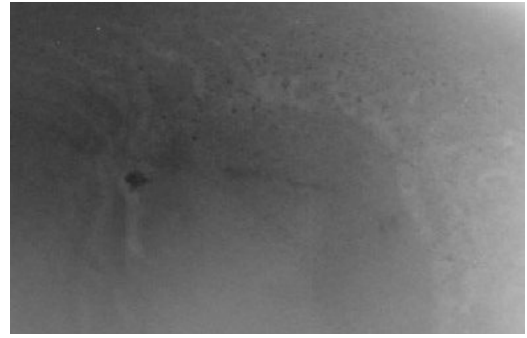
**Fig. 5** Gas porosity, round plate 3.



**Fig. 6** Shrinkage sponge plate 3.



**Fig. 7** Shrinkage cavity plate 6.



**Fig. 8** Segregation mixed with shrinkage cavity.

helpful to judge indications and accumulate experience and confidence by communicating with other interpreters.

## 5. Conclusions

For aircraft castings, interpreting X-ray image is the most basic ability of Level 2. Proficient interpretation skills depend on extensive inspection and manufacturing knowledge and a correct understanding of specifications. If we often discuss and share our interpreting experience with experienced people, we can also enhance the confidence of interpretation and accelerate our self-growth.

The institute meets the requirements of customers; we often deal with various situations encountered in practice and specifications, which is helpful to the combination of testing technology and specifications. These growth processes can help us not be afraid to face the doubts and challenges of our customers' NDT professionals, and then we can build mutual trust with customers and cultivate friendship between teaching and learning.

## References

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