

AWS B1.11M/B1.11:2015
An American National Standard

Guide for the Visual Examination of Welds



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An American National Standard

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Guide for the Visual Examination of Welds

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Prepared by the
American Welding Society (AWS) B1 Committee on Methods of Inspection

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

This guide contains information to assist in the visual examination of welds. Included are sections on fundamentals, surface conditions, and equipment. Sketches and full-color photographs illustrate weld discontinuities commonly found in welds.



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Foreword

This foreword is not part of AWS B1.11M/B1.11:2015, *Guide for the Visual Examination of Welds*, but is included for informational purposes only.

Visual examination (VT), as used in this guide, is a nondestructive method whereby a weldment, the related base metal, and particular phases of welding may be evaluated in accordance with applicable requirements. All visual examination methods require the use of eyesight to evaluate the conditions which are present; hence, the term *visual examination*.

The use of gauges and other tools is supplemental to the main method, and these are treated only as adjuncts to visual examination of weldments.

The *Guide for the Visual Examination of Welds* has been prepared by the AWS B1 Committee on Methods of Inspection to serve as a simple tutorial source of basic information concerning visual examination of welds. It is not the intent of this document to present the *only* approved methods for conducting visual examination. Some typical standards are listed in this document. It is intended that the material presented be useful to engineers, designers, educators, inspectors, and other welding personnel who need knowledge about basic visual examination attributes, which would be essential, or desirable, for a particular process. Included in this guide are fundamental prerequisites for performing visual examination, steps in performing visual examination at various stages of welding, and also typical examples of visual examination, discontinuities and conditions, equipment supplements and aids, records, and other reference sources which may be helpful. Terminology used throughout this guide has been established in AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*.

This guide is intended as an instructive reference. The codes or specifications applicable to any particular weldment always take precedence over the generalized material contained herein, should any conflict arise between the two. The text has been written in general terms and does not include all the conditions applicable to a specific instance. Examples given are general and are used only for the purpose of illustration.

This material can be used as a training text for inspectors. Although the information generally relates to the arc welding processes, most of it applies to weldments fabricated by other fusion welding processes, for which these methods may be required.

For the examination of resistance welded assemblies, refer to AWS C1.1M/C1.1, *Recommended Practices for Resistance Welding*, AWS C1.3, *Recommended Practices for Resistance Welding Coated Low Carbon Steels*, and AWS D8.7, *Recommended Practices for Automotive Weld Quality—Resistance Spot Welding*, published by the American Welding Society.

For the examination of brazed assemblies, refer to the *Brazing Handbook*, also published by the American Welding Society.

For those who need more detailed information than this guide provides, bibliographies or complete books on the subjects covered in each chapter may be found in good technical libraries. The many specifications and codes that are listed, and have been used as illustrative examples, may also be consulted for more detailed information.

Basic information on other nondestructive examination methods is contained in AWS B1.10M/B1.10, *Guide for Nondestructive Examination of Welds*, and in the *Welding Inspection Handbook*.

All revisions to the 2000 edition are identified by a vertical line in the margin next to the text.

Comments and inquiries concerning this standard are welcome. They should be sent to the Secretary, AWS B1 Committee on Methods of Inspection, American Welding Society, 8669 NW 36 St, # 130 Miami, FL 33166.

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Guide for the Visual Examination of Welds

1. General

1.1 Application. Information contained in this guide applies to the visual examination of weldments. This document is intended for those individuals that examine welds before, during, or after the weld is completed. Welders, examiners, engineers, supervisors, etc., that routinely examine welds will benefit from the information contained in this guide.

The individual examining the welds should be familiar with the principles and methods of visual examination. The qualification and certification of individuals may be required by the applicable welding standard or as a legal requirement stipulated by municipal, state, or federal statute. Current or past certification in accordance with AWS QC1, *Standard for AWS Certification of Welding Inspectors*, may be acceptable where an alternate certification scheme is not required.

Welding should not be initiated before the visual acceptance criteria are clearly defined. Clearly defined visual acceptance criteria will enable the visual examination to be effective and ensure the weldment is completed in accordance with the approved contract documents.

1.2 Scope. This guide essentially provides an introduction to visual examination of welding. These examinations fall into three categories based on the time they are performed, as follows: (1) prior to welding, (2) during welding, and (3) after welding. An extensive treatment is provided on weld surface conditions, including reference to frequently used terminologies associated with *preferred* and *non-preferred* conditions. Visual examination may be performed by different people or organizations. Personnel performing welding examination include welders, welding supervisors, the contractor's welding examiner, the purchaser's examiner, or the regulatory examiner. For the purpose of simplicity, these individuals are referred to as visual examiners in the remainder of this standard in that they perform visual examination. Fabrication documents, contract specifications, and regulatory agencies may specify who performs final examinations.

Also provided is a review of visual examination equipment routinely used, such as gauges and lighting equipment. Formal documentation of visual examination results is also discussed. Finally, the guide suggests additional reading or references, that may provide more detailed requirements for specific visual examination applications.

AWS A3.0M/A3.0 uses nondestructive examination (NDE) as the standard terminology for these examination methods. In other standards, literature, and industry usage, other expressions are commonly used. Among these are: nondestructive inspection (NDI) and nondestructive testing (NDT). It must be emphasized that all of these expressions are commonly used and may be considered equivalent.

1.2.1 Unit of Measurement. This standard makes use of both the International System of Units (SI) and U.S Customary Units. The latter are shown within brackets ([]) or in appropriate columns in tables and figures. The measurements may not be exact equivalents; therefore, each system must be used independently.

1.3 Safety and Health. Safety and health issues and concerns are beyond the scope of this standard and therefore are not addressed herein. Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

U.S. Department of Labor Regulations:

CFR-29, Part 1910.107, *Spray Finishing using Flammable and Combustible Liquids*

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous, and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The standards listed below contain provisions which, through reference in this text, constitute mandatory provisions of this AWS standard. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

AWS Documents:¹

AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*

3. Qualification of Examination Personnel

3.1 General. Individuals assigned the task of performing formal visual examinations should be qualified. The three elements of qualification may include education, training, and experience. Since visual examination requires the ability to see small discontinuities or imperfections, good visual acuity is also desirable.

3.2 Visual Acuity. The individual should have sufficient visual acuity to perform an adequate examination. Consideration should be given to sufficient near and far vision with natural or corrected vision. A documented periodic visual acuity examination is a requirement of many codes and specifications, and is generally considered good practice.

3.3 Equipment. Visual examination may require the use of special tools or equipment. The tools or equipment depend upon the application and the degree of accuracy required. Some tools may need to be calibrated prior to use. Although this guide presents an outline of visual examination aids, there are many different concepts and other variations of equipment. As a general rule, those tools should be used that: (1) comply with the project requirements, (2) are adequate for the intended accuracy, and (3) satisfy the need of the examination.

3.4 Experience and Training. The visual examiner should have sufficient knowledge and skill to perform the examination successfully and meaningfully. Knowledge and skill can be imparted or obtained through the educational and training processes. Either method can be performed in a classroom or on the job. The variety of methods and processes of imparting or obtaining knowledge and skill are many, but the art of good judgment does not always come easily or readily. Sufficient time should be allowed for individuals to properly grasp key points pertaining to the following: (1) joint preparation, (2) welding preheat, (3) interpass temperature, (4) weldment distortion, (5) welding consumables, (6) base materials, and (7) workmanship standards.

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3.5 Procedures. Development of standard or specialized procedures covering examination methodology and acceptance criteria produces consistent and accurate results. Such procedures are normally prepared by the employer and typically consist of detailed instructions that interrelate the various fabrication processes, the customer's detailed requirements, and examination criteria. Items such as *who* performs an examination, *when* to perform an examination, *how* to perform an examination, and *where* to perform an examination are typically included in the procedure. As a minimum the standard procedures should include the following: workmanship standards, check lists, and examination equipment requirements.

When written procedures are not available, examiners may be asked to work directly with relevant codes and specifications.

3.6 Certification Programs. To provide assurance that visual examiners are qualified it may be desirable to have visual examination personnel formally certified. Contract documents, fabrication standards, or regulatory agencies may require special qualifications for visual examiners. Several standards developers offer certification programs for visual examiners such as AWS QC1, *Standard for Certification of Welding Inspectors*.

4. Fundamentals of Visual Examination

4.1 General. Visual examination reveals surface discontinuities and is a valuable method for evaluating weld quality. It is a simple, accessible, low cost examination method, but it requires a trained examiner. Additionally, it can be an excellent process control tool to help avoid subsequent fabrication problems and improve workmanship.

Visual examination only identifies surface discontinuities. Consequently, any conscientious quality control program should include a sequence of examinations performed during all phases of fabrication. An examination plan should establish hold/witness points that allow for visual examination prior to subsequent operations.

A conscientious program of visual examination before and during welding may reduce costs by revealing surface defects early in the fabrication process.

4.2 Prior to Welding. Prior to welding, some typical action items requiring attention by the visual examiner should include the following:

- (1) Review drawings and specifications
- (2) Review material documentation
- (3) Review procedure and performance qualifications
- (4) Establish examination points if required
- (5) Establish documentation plan
- (6) Examine base material
- (7) Examine fitup and alignment of joints
- (8) Review storage of welding consumables

If the examiner pays particular attention to these preliminary items, many problems that might occur later can be prevented. It is important that the examiner review the governing documents to determine the job requirements. A system should be established to assure that accurate and complete records are produced. Users of this standard are encouraged to reference AWS D14.8M (ISO/TR 17844:2004 IDT), *Standard Methods for Avoidance of Cold Cracks*, as a means to prevent or correct conditions that contribute to weld cracking.

4.2.1 Review Drawings and Specifications. The examiner should either have copies of the drawings and specifications, or have access to them, and should review them periodically. Information to be gained, but not limited to, includes: weld details, material requirements, examination requirements, dimensions, and qualification requirements.

4.2.2 Review Material Documentation. The examiner should verify that the correct materials were ordered, received, and used during fabrication.

4.2.3 Review Procedure and Performance Qualifications. The examiner should review welding procedures and welder qualification records to assure the qualifications meet the requirements of the job specification.

4.2.4 Establish Examination Points. The examination plan should consider the sequence of construction and determine whether there is a need to establish examination points to ensure suitable access for examination is provided. A mandatory examination point permits work that may be concealed by subsequent work to be examined and accepted before additional manufacturing operations are resumed.

4.2.5 Establish Documentation Plan. The examiner should review the reporting requirements to establish what is to be reported and who will receive copies of the examination reports. It may also be beneficial to establish a means of marking the workpiece examined in order to identify defects and the need for repair. More serious quality problems such as cracking or excessively poor workmanship should be reported to the appropriate parties. The documentation will indicate the examination status.

4.2.6 Examine Base Materials. Prior to welding, the base materials should be examined for unacceptable discontinuities such as laminations, seams, laps, cracks, and other surface conditions that would prevent proper welding. The surfaces of cut edges, groove preparations, access holes, etc., should be evaluated using a surface roughness comparator such as the AWS C4.1 Surface Roughness Gauge as a guide.

4.2.7 Examine Fit-Up and Alignment of Joints. Joint fit-up and alignment are critical to the production of a sound weld. Items that may be considered prior to welding include:

- (1) Groove angle
- (2) Bevel depth
- (3) Root opening
- (4) Joint alignment and weld joint mismatch (see Figure 1)
- (5) Backing
- (6) Consumable insert
- (7) Joint cleanliness
- (8) Tack welds
- (9) Preheat

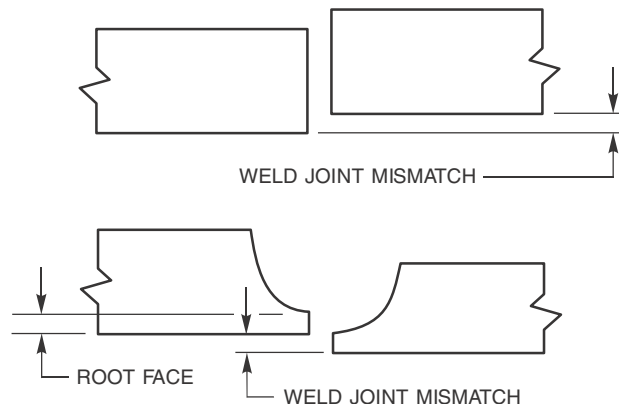


Figure 1—Weld Joint Mismatch

All of these factors could have a direct bearing on the resultant weld quality. If the fit-up is poor, it should be corrected before being tack welded. Extra care taken during the joint assembly can greatly improve the efficiency of the welding operation. Examination of the joint prior to welding can reveal irregularities that are within the limitation of the applicable standard, but may become areas of concern and require careful observation during subsequent operations. For example, if a T-joint exhibits the maximum root opening, the size of the required fillet weld may have to be increased by an amount equal to the measured root opening. Conditions such as an excessive root opening can be discovered only when a fit-up examination is performed before the joint is welded. The drawing or member should be marked indicating the problem so that the corrected weld size is verified during the final examination.

4.2.8 Review Storage of Welding Consumables. Welding consumables should be checked to ensure they are appropriate for the work and are as specified by the welding procedure specification. The procurement, storage, and handling of filler metals is crucial to producing welds that meet the mechanical properties and soundness requirements of the welding standard. Filler metals should be stored in a manner prescribed by the manufacturer and applicable welding standard.

Electrode manufacturers have established maximum atmospheric exposure limits for low-hydrogen electrodes. This is the maximum amount of time a low-hydrogen electrode can be out of heated storage before reconditioning is required. These limits have been incorporated into many welding codes. Exposure times start when the electrodes are removed from the electrode storage oven, portable storage oven, or their original, hermetically-sealed containers.

Filler metals should be checked during fabrication to ensure the welder is using the filler metal specified.

Filler metal control also includes the disposal of used or damaged filler metal in a manner that will ensure they are not used for production.

4.3 During Welding. During welding, some typical action items requiring attention by those responsible for weld quality should include the following:

- (1) Verify conformance to Welding Procedure Specification (WPS),
- (2) Verify preheat and interpass temperatures,
- (3) Examine root bead,
- (4) Examine weld layers, and
- (5) Examine second side prior to welding.

Any of these factors, if ignored, could result in discontinuities that could cause serious quality degradation.

4.3.1 Verify Conformance with Welding Procedure Specification. Monitor the welding operation to ensure compliance with the applicable WPS. The specific welding variables to be verified will depend on the welding process and the WPS. However, they would typically include factors such as the consumable classification, joint design, electrical characteristics, and welding techniques.

4.3.2 Verify Preheat and Interpass Temperatures. When the temperature of the material is below a specified temperature, supplemental preheat may be required by the applicable welding standard or WPS. The goal is to heat the base metal to or above the minimum temperature specified. Preheat should be verified before any welding is begun.

Not all metals require preheat, but when preheat is specified by the welding standard, the location of the temperature measurement is usually specified. In the absence of a welding standard, preheat may be measured at a distance equal to the thickness of the thicker member from the edge of the joint to be welded. Preheat requirements may specify that the preheat extend through the thickness of the members being welded. If that is the case, the preheat temperature should also be verified on both the root and the face sides of the joint.

Some applications impose a maximum interpass temperature to ensure welding does not continue if a specified maximum temperature is exceeded. A cooling period is observed if the temperature approaches or exceeds the maximum specified interpass temperature.

Interpass temperature should be checked immediately before a weld bead is initiated when making a multi-pass weld. The applicable welding standard may specify that the interpass temperature be measured adjacent to the location where the next weld pass is to be initiated.

There are several temperature measuring tools used to measure preheat and interpass temperatures. Temperature sensitive crayons, contact thermometers, pyrometers, thermocouples, infrared thermometers, etc., are typically used to monitor preheat and interpass temperatures.

4.3.3 Examine Weld Root Bead. The first weld deposited in a multiple pass weld, called the root bead, is susceptible to a number of weld discontinuities such as cracks, incomplete fusion, incomplete joint penetration, etc. A thorough visual examination of the root bead can detect many unacceptable conditions that should be corrected before depositing additional weld metal.

4.3.4 Examine Intermediate Weld Beads. Examine intermediate weld beads as work progresses to ensure the weld beads are free of unacceptable conditions or discontinuities such as cracks, undercut, incomplete fusion, slag or oxides, etc., which if left uncorrected can result in unacceptable welds.

4.3.5 Examine Second Side Prior to Welding. Critical joint root conditions may exist on the second side of a double welded joint. This area should be examined after removal of slag and other irregularities. This is to assure that all discontinuities have been removed and that the contour and cleanliness of the excavation are suitable for subsequent welding.

4.4 After Welding. Following welding, some typical action items requiring attention by the visual examiner should include the following:

- (1) Examine weld surface quality
- (2) Verify weld dimensions
- (3) Verify dimensional accuracy
- (4) Review subsequent requirements

4.4.1 Examine Weld Surface Quality. Visually examine weld surface to verify the weld profile meets the acceptance criteria specified by the contract documents. Workmanship standards may address such items as surface roughness, weld spatter, and arc strikes. Most codes and specifications describe the type and size of discontinuities that are acceptable. Many of these discontinuities can be found by visual examination of the completed weld. The following are typical discontinuities found at the surface of welds:

- (1) Porosity
- (2) Incomplete fusion
- (3) Incomplete joint penetration
- (4) Undercut
- (5) Underfill
- (6) Overlap
- (7) Cracks
- (8) Metallic and nonmetallic inclusions

- (9) Reinforcement
- (10) Weld bead profile
- (11) Root oxidation

4.4.2 Verify Weld Dimensions. All completed welds should be visually examined to verify the weld meets the drawing requirements for profile, size, length, and location. Fillet weld sizes can be determined by using one of several types of weld gauges to be discussed later. Groove welds should be filled to the full cross section of the joint, or as specified, and the weld reinforcement should not be excessive. Some conditions may require the use of special weld gauges to verify these dimensions.

4.4.3 Verify Dimensional Accuracy. Final examination of a fabricated weldment should verify that the dimensions are in accordance with the drawing.

4.4.4 Review Subsequent Requirements. Review the specification to determine if additional procedures are required. Such procedures may include postweld heat treatment, nondestructive testing, proof testing, or other operations.

5. Weld Surface Conditions

5.1 General. This clause is concerned only with discontinuities, which may or may not be classed as defects (rejectable) depending on requirements of individual specifications or codes. The intent is informational and instructional, and meant to assist in the identification of discontinuities. Discontinuities can occur at any location in the weld. Visual examination after welding is limited to the surface condition of the weld. Discovery of subsurface discontinuities requires the visual examination be supplemented by a volumetric nondestructive test method such as ultrasonic or radiographic examination.

A discontinuity is an interruption of the typical structure of a material, such as a lack of homogeneity in its mechanical, metallurgical, or physical characteristics. A discontinuity is not necessarily a defect. Discontinuities are rejectable only if they exceed specification requirements in terms of type, size, distribution, or location. A defect is a discontinuity or discontinuities that by nature or accumulated effect (for example, total crack length) render a part or product unable to meet minimum applicable acceptance standards or specifications. The term *defect* designates rejectability.

Weld and base-metal discontinuities of specific types are more common when certain welding processes and joint details are used. Attendant conditions, such as high restraint and limited access to portions of a weld joint, may lead to a higher than normal incidence of weld or base-metal discontinuities. For example, highly restrained weld joints are more prone to cracking.

Each general type of discontinuity is discussed in detail in this clause (see also Table 1 and Figures 2 through 7). Other documents may use different terminology for some of these discontinuities; however, whenever possible, the approved AWS terminology, as found in AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*, should be used to eliminate confusion. An example of additional terminology occurs in AWS D1.1/D1.1M, *Structural Welding Code—Steel*. There, *fusion-type discontinuity* is a general term which is used to describe a number of discontinuities, including: slag inclusions, incomplete fusion, incomplete joint penetration, and similar elongated discontinuities in fusion welds.

5.2 Porosity [see Table 1(1)].² Porosity is a cavity-type discontinuity formed by gas entrapment during solidification or in a thermal-spray deposit. The discontinuity formed is generally spherical and may be elongated. Two common causes of porosity are contamination and insufficient shielding during welding.

² The numbers in parenthesis in 5.2–5.13 refer to numbers in Table 1 and Figures 2–7.