SAE Aerospace
An SAE International Group

AEROSPACE MATERIAL SPECIFICATION

SAE AMS2694 | REV. C

Issued 1980-04
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Superseding AMS2694B

(R) In-Process Welding of Castings

RATIONALE

AMS2694C results from a Five Year Review and update of this specification. The provisions of AWS D17.1 made reference to in AMS2694B are supplemented by new technical requirements of AMS2694C. Changes are extensive and not marked.

1. SCOPE

1.1 Purpose

This specification defines the requirements for in-process correction of foundry discontinuities by manual welding of castings.

1.2 Application

This specification provides a means for purchasers to specify in-process manual welding procedures and manual welder qualification methods for correction of foundry discontinuities in castings. This specification does not apply to correction of casting discontinuities detected during machining or subsequent operations, modification of a sound casting for engineering purposes (3.3.3.a), or fabrication performed on or with castings.

1.3 Safety - Hazardous Materials

While the materials, methods, applications, and processes described or referenced in this specification may involve the use of hazardous materials, this specification does not address the hazards which may be involved in such use. It is the sole responsibility of the user to ensure familiarity with the safe and proper use of any hazardous materials and to take necessary precautionary measures to ensure the health and safety of all personnel involved.

2. APPLICABLE DOCUMENTS

The issue of the following documents in effect on the date of the purchase order forms a part of this specification to the extent specified herein. The supplier may work to a subsequent revision of a document unless a specific document issue is specified. When the referenced document has been cancelled and no superseding document has been specified, the last published issue of that document shall apply.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

AMS2175 Castings, Classification and Inspection of

TO PLACE A DOCUMENT ORDER: Tel: 877-606-7323 (inside USA and Canada)
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
SAE WEB ADDRESS: http://www.sae.org

SAE values your input. To provide feedback on this Technical Report, please visit
http://www.sae.org/technical/standards/AMS2694C

2.2 U.S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, https://assist.daps.dla.mil/quicksearch/.

MIL-A-18455 Argon, Technical

BB-H-1168 Helium, Technical

BB-0-925 Oxygen, Technical

A-A-59503 Nitrogen, Technical

BB-H-886 Hydrogen, Technical

BB-C-101 Carbon Dioxide, Technical

2.3 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM A 488/A 488M Steel Castings, Welding, Qualifications of Procedures and Personnel

ASTM E 1417 Standard Practice for Liquid Penetrant Testing

ASTM E 1444 Standard Practice for Magnetic Particle Testing

ASTM E 1742 Standard Practice for Radiographic Examination

2.4 AWS Specifications

Available from American Welding Society, 550 NW LeJeune Road, Miami, FL 33126, Tel: 1-800-443-9353, www.aws.org.

AWS A5.12/A5.12M Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for ArcWelding and Cutting

AWS D17.1 Specification for Fusion Welding for Aerospace Applications

2.5 Compressed Gas Association

Available from Compressed Gas Association, 14501 George Carter Way, Suite 103, Chantilly, VA 20151, Tel: 703-788-2700, www.cganet.com.

CGA-4.3 Commodity Specification for Oxygen

CGA-5.3 Commodity Specification for Hydrogen

CGA-6.2 Commodity Specification for Carbon Dioxide

CGA-9.1 Commodity Specification for Helium

CGA-10.1 Commodity Specification for Nitrogen

CGA-11.1 Commodity Specification for Argon

2.6 ISO Publications

Available from International Organization for Standardization, 1, rue de Varembe, Case postale 56, CH-1211 Geneva 20, Switzerland, Tel: +41-22-749-01-11, www.iso.org.

ISO 24394 Welding for aerospace application- Qualification test for welders and welding operators - Fusion welding of metallic components.

3. TECHNICAL REQUIREMENTS

3.1 When performed, castings shall be welded in any as-cast or heat treated condition appropriate to the alloy that will allow the welded casting to meet the material specification and other applicable purchaser requirements (See 3.5.8 and 8.8). All welding shall be manual welding.

3.2 Welding shall be performed only in those areas and to the extent shown on the casting drawing, purchaser specifications, or as otherwise agreed upon by purchaser and supplier (See 8.2.1).

3.3 Correction by Welding

3.3.1 Casting nonconformances may be corrected by welding.

3.3.1.1 Examples of nonconformances allowed to be corrected by welding include cracks, handling damage, miscuts, laps, hot tears, cold shuts, cold shots, shrinkage, porosity, gas holes, inclusions, oxides, dross, and other nonmetallic material.

3.3.2 Mis-machined target points may be corrected by adding weld filler to the target point surface(s) and (re)machining. (See 3.3.3.d)

3.3.3 Unless authorized by purchaser, welding shall not be used to:

a. Correct dimensional discrepancies that are a product of the pattern or core tooling, or to modify a sound casting for engineering purposes except as noted in 3.3.1,

b. Correct casting discontinuities detected during machining or subsequent operations,

c. Fabricate or assemble castings or portions of castings,

d. Weld on target points after final heat treatment and dimensional inspection,

e. Weld broken features back onto the casting.

3.3.4 When authorized by purchaser, patches, sections, or plates of cast and wrought materials may be used to correct the conditions described in 3.3.1.

3.4 Materials and Equipment

3.4.1 Gases for welding, shielding, backing, and chambers shall be in conformance with Table 1.

TABLE 1 SHIELDING GASSES

Gas	Specification	Alternate Specification
Argon	CGA G-11.1, QVL C or better	MIL-A-18455
Helium	CGA G-9.1, QVL L or better	BB-H-1168
Oxygen	CGA G-4.3, , QVL C or better	BB-0-925, Type I or II
Nitrogen	CGA G-10.1, QVL L or better	A-A-59503, Type I or II, Class 1, Grade B
Hydrogen	CGA G-5.3, QVL B or better	BB-H-886, Type I or II
Carbon Dioxide	CGA G-6.2, QVL G or better	BB-C-101, Grade B
Gas Mixtures	Gas purity shall conform to the type and/or grade specified above. The composition shall be in accordance with the welding procedure, or as specified by the purchaser.	Gas purity shall conform to the type and/or grade specified above. The composition shall be in accordance with the welding procedure, or as specified by the purchaser.

3.4.2 Unless otherwise specified (See 8.2.2) or authorized by purchaser, welding filler metal type shall be the same nominal composition as the casting composition and, when specified, shall be procured to the applicable filler metal specification (See 8.2.3 and 8.3).

3.4.2.1 Filler metal type shall be identified and traceable to the applicable filler metal specification. If the identification and traceability is lost, the filler metal shall not be used. Traceability shall be maintained in accordance with 3.5.7.3.

3.4.2.2 Filler metal shall be stored in a clean and dry environment. Heating of the storage cabinet used for coated electrodes may be employed as necessary to prevent moisture accumulation. Filler metal types shall not be mixed during storage or use.

3.4.3 Equipment shall be maintained as required to facilitate meeting specified requirements.

3.4.4 Tungsten electrodes shall be in accordance with AWS A5.12/A5.12M.

3.5 Welding Procedure

3.5.1 Welding shall be accomplished in accordance with written work instructions. These instructions shall include, but are not limited to welding process, alloy type and preweld heat treatment condition, preweld conditioning, welding filler metal, preheat and/or post-heat temperature as applicable, control of rewelding, and subsequent processing including post-weld thermal treatment. Supplemental instructions for each purchaser or casting part number shall be established as required to control purchaser or casting specific items such as cleaning, inspection, weld zone locations and allowances, thermal treatments, and special qualification procedures.

3.5.2 Preparation, Welding and Finishing

3.5.2.1 Casting nonconformances to be corrected shall be prepared in accordance with 3.5.2.2 by a method that does not damage the base metal. The prepared area shall be smoothly contoured prior to welding.

3.5.2.1.1 For autogenous welding of 3.5.2.2.1, it is not necessary to remove the defect.

3.5.2.2 The area shall be examined prior to welding to ensure that the nonconformance has been removed or reduced to the extent required. The method(s) of in-process examination shall be any suitable combination of visual and/or nondestructive inspections used to determine final acceptance of the weld. Cracks, laps, hot tears, cold shuts, cold shots, and other linear discontinuities shall be removed completely, unless otherwise authorized by purchaser. Other discontinuities such as shrinkage, porosity, gas holes, inclusions, dross, and other nonmetallic material shall be removed to the extent necessary to produce a sound weld acceptable to 3.6 (See 8.7).

3.5.2.2.1 When authorized by purchaser, surface-contained gas holes, pits, HIP sinks, porosity, cold shuts, and cold shots may be reworked using autogenous welding. Filler material may be added for dimensional compliance.

3.5.2.2.2 The weld area, heat affected zone, weld filler metal, and fixturing if required shall be free from slag, surface oxides, scale, oils, grease, dirt, and other contaminants. Chemical methods or mechanical methods shall be used, as appropriate, to remove contamination before welding. Chlorinated solvents or methyl alcohol shall not be used to clean titanium or titanium alloys. Stainless steel wire brushes or carbon steel wire brushes may be used on carbon or low alloy steels. Only stainless steel wire brushes shall be used on all other materials being welded. Once an individual wire brush is used on a certain material group (i.e., titanium, aluminum, nickel-base alloys, etc.), it shall be suitably identified and used only on that material group.

3.5.3 Castings may be preheated or preweld-stress-relieved in accordance with the weld procedure as required to provide good weld quality.

3.5.4 Welding shall be accomplished by manual gas-tungsten-arc welding (GTAW), unless use of another manual process such as plasma arc welding (PAW), gas metal arc welding (GMAW), or shielded metal arc welding (SMAW) is authorized by purchaser.

3.5.4.1 The weld and heat affected zone shall be protected from oxidation during welding using a shielding gas (See 3.4.1). When welding titanium and titanium alloys, backup shielding gas shall be used and metal deposited behind the weld pool shall be shielded.

3.5.5 Welding shall be performed by welders qualified in accordance with 3.8.

3.5.6 Welded areas shall be blended to conform to drawing requirements. Root weld reinforcement, penetration, and drop-through in inaccessible areas shall be blended in accordance with purchaser requirements. Unless otherwise specified by purchaser, the perimeter of the weld shall be blended flush with the parent metal. See 8.5 and 8.6.

3.5.7 Identification

3.5.7.1 Welded areas shall remain traceable to their location on the castings until inspection is completed. (See 3.6).

3.5.7.2 When specified, welded castings shall be marked with a symbol of the type, method, and in the place specified by the purchaser.

3.5.7.3 Traceability of welder personnel and lot number of filler material shall be maintained by the supplier through shop traveler, weld map, or other record suitable to satisfy purchaser requirements, and as necessary to demonstrate continuing welder proficiency or qualification status.

3.5.8 Heat Treatment

After all welding is complete, castings shall be heat treated to the condition required for shipment, as specified by the casting drawing and the applicable casting material specification.

3.5.8.1 When austenitizing, annealing, normalizing, or solution treating are not specified by the casting drawing, specification, or purchase order, post-weld stress-relief heat treatment shall be performed, as appropriate to the alloy, unless otherwise specified by purchaser.

3.5.8.2 Post-weld stress-relief is allowed prior to required heat treatment, as appropriate to the alloy.

3.6 Inspection of Welded Castings

3.6.1 Welded areas shall be inspected after completion of all blending, using the same inspection procedures and acceptance standards required of the casting. The inspection of the welded areas may be performed at the same time as final visual, fluorescent penetrant, and/or magnetic particle, and radiographic acceptance inspection of the casting to the drawing requirements, if conducted after all required heat treatments including any stress relief. Final radiographic inspection may be performed before the required heat treatment when authorized by purchaser, but shall be performed after completion of all welding and blending. Linear indications are not permitted unless authorized by purchaser.

3.6.2 Personnel performing in-process and final visual inspections shall be trained and qualified in accordance with the supplier's documented procedure. Approval of the procedure by the cognizant engineering organization is not required. Welders may perform in-process visual inspection. Certification of visual weld inspectors to AWS QC1 is not required.

3.6.3 If inspection methods are not specified by purchaser, then one or more of the following methods acceptable to purchaser shall be used as applicable: fluorescent penetrant inspection in accordance with ASTM E 1417, magnetic particle inspection in accordance with ASTM E 1444, and/or radiographic inspection in accordance with ASTM E 1742.

3.6.4 When specified (8.2.2), radiographic images or weld maps shall be identified with the welded region for each casting welded and shipped with the castings, or, retained in accordance with the purchaser's requirements. See 4.6.1.

3.7 Control of Rewelding

3.7.1 In-process correction of weld-related nonconformances is permitted prior to post-weld heat treatment. Each nonconformance shall be prepared, welded, blended and inspected in accordance with the work instructions. See 3.5 and 3.6.

3.7.2 Any welded area which contains nonconformances after postweld heat treatment and inspection shall be re-prepared, rewelded, reblended, and reinspected in accordance with the work instructions and all requirements of 3.5 and 3.6, including post-weld thermal treatment in accordance with 3.5.8. Additional process limitations, if required, shall be as specified by purchaser.

3.8 Welder Qualification

3.8.1 Welders shall meet the physical requirements of AWS D17.1. When color recognition is required (for example, for color coded or flagged wire, or for evaluation of titanium for oxygen contamination), then the ability to discern the differences between the required colors shall be demonstrated and documented in the welder qualification record.

3.8.2 Welders shall be qualified by welding cast specimens to the requirements of this AMS and the essential variables of 3.8.5. Cast specimen weld areas shall be prepared by machining or shall be cast net and prepared in accordance with 3.5.2. Specimen configuration shall be as shown in Figure 1, or as shown in the TP6 test piece of ISO 24394, or another configuration representative of the casting features to be welded.

3.8.2.1 Alternatively, qualification by the groove weld performance and procedure qualification requirements of AWS D17.1 or ASTM A 488 is permitted, except that ASTM A 488 qualification must be achieved for each welding process (GTAW, SMAW, PAW, or GMAW).

3.8.2.2 Alternatively, qualification for the repair of castings to ISO 24394 is permitted, including any "X" designation special qualification test appropriate to the welding of castings.

3.8.3 Alternatives to 3.8.2

When specified by the purchaser, supplier's welder(s) shall be qualified by welding and subsequent mechanical testing of welds in plates (such as those in Figure 1, or equivalent) to procedures and standards agreed upon between purchaser and supplier. The supplier may use an alternative qualification procedure when authorized by purchaser.

3.8.4 At least one test weld shall be required for each combination of welding conditions. Test welds shall be accomplished in accordance with a written weld test procedure governing each of the material groups of Table 2 for which qualification is attempted. The weld test procedure shall include the essential variables used to accomplish base metal group qualification of Table 2. Unless otherwise specified by purchaser, qualification is not required for the weld test procedure.

3.8.5 Each individual qualification shall be separate and distinct from any other based upon the following variables:

3.8.5.1 Welding process - GTAW, SMAW, PAW, or GMAW. For GTAW, AC, and DC polarity to be qualified separately. For GMAW, changes in transfer modes to be qualified separately.

3.8.5.2 Base Metal Grouping of Table 2.

3.8.5.3 Backing

Test piece welded with backing or heat sinks qualifies only for in-process welding with backing or heat sinks. Test piece welded without backing or heat sinks qualifies for in-process welding with or without backing or heat sinks.

3.8.5.4 Position

The test piece shall be welded in the same position(s) as the castings to be welded. A single test piece may be rotated during qualification to simulate all of the necessary positions (i.e., flat, horizontal, vertical).

3.8.5.5 Thickness

A test weld thickness (depth) of t shall qualify welds with a thickness range of 0.67t to 4t, except when the test weld thickness is equal to or greater than 1 inch (25 mm) the qualification range is 0.67t to unlimited. Two test welds shall qualify welds with all intermediate thicknesses.

3.8.6 When specified by purchaser, weld procedure schedules (WPS) and procedure qualification requirements (PQR) shall be established using the purchaser's requirements, e.g., the criteria of ASTM A 488.

3.8.7 Test welds shall be inspected by radiographic and fluorescent penetrant examination to the Grade A acceptance criteria of AMS2175. Inspection may be performed to Grades B or C, as applicable, if the welder's qualification is restricted to welds in those Grade areas of castings. Test welds shall be sectioned and evaluated metallographically for complete fusion and freedom from linear defects. Unless otherwise specified by purchaser, mechanical testing of test welds is not required.

3.8.8 In event of failure, the weld test shall be repeated.

3.8.9 Welder qualification shall not transfer between suppliers or between sites of multisite suppliers unless all process variables of 3.8.5 are the same.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

The supplier of castings shall supply all samples for supplier's tests and shall be responsible for performance of all required tests. Purchaser reserves the right to sample and to perform any confirmatory testing deemed necessary to ensure that the castings conform to the requirements of this specification.

4.2 Classification of Tests

4.2.1 Acceptance Tests

Tests to determine conformance to the inspection requirements (3.6) for welded castings are acceptance tests.

4.2.2 Periodic Tests

Welder qualification requirements of 3.8 are periodic tests and shall be performed at the frequency required by AWS D17.1, unless specified otherwise by purchaser. Alternatively, a system acceptable to purchaser documenting continuing welder proficiency may be used.

4.2.3 Preproduction Tests

4.2.3.1 Welder qualification requirements of 3.8 are preproduction tests and shall be performed prior to in-process welding of production castings.

4.2.3.2 Preproduction welding and testing of each casting part number is not required unless specified by the purchaser. When required by the purchaser, an evaluation of the welding procedure shall be performed using the purchaser's criteria.

4.3 Sampling shall not be less than the following:

4.3.1 Acceptance Tests

Welded castings shall be inspected in accordance with 3.6 and purchaser requirements.

4.3.2 Periodic and Preproduction Tests

Samples shall be tested in accordance with 3.8, except periodic requalification testing is not required when proficiency testing is allowed.

4.4 Approval

4.4.1 When specified by purchaser, the supplier's welder qualification procedure and/or the supplier's procedure for welding of products shall be approved by purchaser.

4.5 Reports

Unless otherwise specified by purchaser, certifications for shipments containing welded castings shall contain the following notation (or equivalent):

"In-process welding has been performed in accordance with AMS2694. In-process records and inspection results are on file at this facility and are available to purchaser upon request."

4.6 Records

Records of welding procedures and welder qualifications and requalifications, including welder proficiency when applicable, shall be maintained on file by the supplier in accordance with purchaser's retention requirements.

4.6.1 Certificates of conformance, inspection results, radiographic images, and weld maps, if required, shall be maintained on file at supplier, or submitted to the purchaser, in accordance with purchaser's requirements.

4.6.2 Welder qualification results shall document the welder, date of test, welding process, alloy, condition, position, backing, thickness, casting tested if applicable, test results, and alloy group for which the welder qualifies based on this test, and if corrected vision is required (See 3.8.1).

4.7 Resampling and Retesting

4.7.1 If results of any acceptance inspection of welded castings fail to meet specified requirements, the castings may be rewelded in accordance with 3.7.

4.7.2 If results of any periodic qualification test fail to meet specified test requirements, the welder shall be disqualified except as specified in 4.7.2.1. If failure to maintain continuing proficiency standards required by the supplier and acceptable to the purchaser occurs, the welder shall be disqualified. If there is a specific reason to question the ability of the welder to meet the requirements for qualification, the welder shall be disqualified. No additional production castings may be welded by a disqualified welder until new qualification requirements are satisfied.

4.7.2.1 The welder shall not be disqualified if mechanical property or other requirements are not met when failure occurs in parent metal outside of the weld or heat affected zone, or if metallurgical investigation establishes that nonconforming mechanical test results are not a result of the welder's technique.

5. PREPARATION FOR DELIVERY

Not applicable.

6. ACKNOWLEDGMENT

Not applicable.

7. REJECTIONS

Welded castings that do not conform to the requirements of this specification or modifications authorized by purchaser shall be subject to rejection.

8. NOTES

8.1 A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

8.2 Terms used in this AMS are clarified in ARP1917, AWS D17.1 and section 3. and defined as follows:

8.2.1 "Purchaser"

The cognizant engineering organization responsible for casting design.

8.2.2 "Specified"

Requires documented instruction from purchaser through casting drawing, purchase order, specification, or other engineering documentation.

8.2.3 “Nominal composition”

Includes equivalent, if not identical, controls and limits on composition. An example is, but not limited to, iron levels in 357 aluminum alloys.

8.2.4 “Autogenous Weld”

A fusion weld made without filler metal.

8.3 Nominal composition weld filler material may not be available or desirable in all situations for all alloys, castings or areas of castings. For example, IN 625 could be used as a weld filler material for some areas of IN713 castings, or 2319 could be used as a weld filler material for 201 or 206 aluminum alloy castings. Note that such substitutions must be specified or authorized by purchaser in accordance with 3.4.2.

8.4 This specification is intended to provide sufficient controls to perform in-process welding of castings without Material Review Board activity on each casting to be welded, provided permission to weld is authorized in purchaser drawings and/or specifications. The purchaser should determine a) if welding of castings needs to be an essential aspect of the planned production process (e.g., welding of hot isostatically pressed titanium alloy castings is commonly required), b) whether the weld and heat affected zone are capable of meeting the design parameters for the entire casting configuration or a portion thereof, and c) if any limits need be applied to the size, depth, number and spacing of individual welds. This information should be noted on casting drawings or by reference to supporting documents. When specified by purchaser, details of weld procedures, including rework allowances, for specific casting configurations should be documented by the casting supplier as an aspect of the process approval application for each casting part number. AWS D17.1 contains informative discussion on these topics.

8.4.1 With respect to any weld test,

a. the test is to evaluate the capability of the welder to make sound welds; not to ascertain if the alloy is weldable

b. the welder has no influence over the inherent base material properties

c. the welder has no influence over the post-weld heat treatments that may be required of the material spec

d. the welder has no influence over the laboratory practice used to excise and test the tensile specimens.

e. the "laboratory conditions" under which a qualification specimen is welded are not typical of the production environment.

8.5 Care must be taken in blending welds to ensure that casting thicknesses and profile tolerances are maintained.

8.6 Cast plate equivalency

The specific configuration of the test plate in Figure 1 was developed to accommodate tensile test bars and include typical, but not authoritative, shapes to be welded. If tensile testing is not necessary, test plates may be smaller. The shapes to be welded may be considered equivalent if representative of the shapes and sizes of production welds performed at the facility.

8.7 Mechanical Property Evaluation

Purchasers desiring to qualify welders and/or weld procedures by testing mechanical properties should consider specifying at minimum: post-weld heat treatment (if applicable), restrictions on the location of the fracture (if applicable), and minimum mechanical property requirements for the parent metal and for the weld, or the minimum ratio required. Note that minimum mechanical property values for test bars machined from cast plate may not be published for some of the alloys listed in Table 2.

8.8 Order information should include not less than the following:

Authorization to weld in accordance with AMS2694
Filler metal to be used, if other than nominal composition. See 3.4.2.
Limits on location, size, depth, number and spacing of welds, if any
Post weld heat treatment (thermal treatments required after welding), if other than 3.5.8
Weld maps (or equivalent), when required. See 3.6.3.
Inspection methods and frequency of examination if different from the base material requirements. See 3.6.
Finishing requirements if other than specified in this AMS
Additional requirements for part certification, if applicable (i.e., traceability of weld areas or welded items).
In addition, ordering documents need to state, as applicable: (a) if WPS and PQR of AWS D17.1, ASTM A 488/A 488M, or other purchaser standard are required, (b) if welder qualifications are contingent upon satisfying mechanical property requirements specified in the material specification, and/or (c) if supplier procedures are subject to purchaser review and approval.