



AEROSPACE MATERIAL SPECIFICATION

AMS2681™**REV. B**

Issued 1982-10
Revised 2000-03
Reaffirmed 2022-01

Superseding AMS2681A

Welding, Electron-Beam

RATIONALE

AMS2681B has been reaffirmed to comply with the SAE five year review policy.

1. SCOPE:

1.1 Purpose:

This specification defines the procedures and requirements for joining metals and alloys using the electron-beam (EB) welding process.

1.2 Application:

These procedures are used typically for electron-beam welding of aerospace components in soft to hard vacuum atmospheres, but usage is not limited to such applications. EB welding for fatigue critical applications should be performed in accordance with AMS 2680.

2. APPLICABLE DOCUMENTS:

The issue of the following documents in effect on the date of the purchase order form 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 canceled and no superseding document has been specified, the last published issue of that document shall apply.

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AMS 2630	Ultrasonic Inspection, Product over 0.5 inch (12.7 mm) Thick
AMS 2631	Ultrasonic Inspection, Titanium and Titanium Alloy Bar and Billet
AMS 2632	Ultrasonic Inspection of Thin Materials, 0.50 inch (12.7 mm) and Thinner in Cross-Sectional Thickness
AMS 2680	Electron Beam Welding, For Fatigue Critical Applications
ARP1317	Electron Beam Welding
ARP1333	Nondestructive Testing of Electron Beam Welded Joints in Titanium-Base Alloys

SAE Executive Standards Committee Rules provide that: "This report is published by SAE to advance the state of technical and engineering sciences. The use of this report is entirely voluntary, and its applicability and suitability for any particular use, including any patent infringement arising therefrom, is the sole responsibility of the user."

SAE reviews each technical report at least every five years at which time it may be revised, reaffirmed, stabilized, or cancelled. SAE invites your written comments and suggestions.

Copyright © 2022 SAE International

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of SAE.

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
http://www.sae.org

SAE WEB ADDRESS:

For more information on this standard, visit
<https://www.sae.org/standards/content/AMS2681B/>

2.2 ASTM Publications:

Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM E 1417 Liquid Penetrant Examination
ASTM E 1444 Magnetic Particle Examination
ASTM E 1742 Radiographic Examination

2.3 U.S. Government Publications:

Available from DODSSP, Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-STD-1595 Qualification of Aircraft, Missile, and Aerospace Fusion Welders

2.4 AIA Publications:

Available from National Standards Association, Inc., 1250 Eye Street, Washington, D.C. 20014.

NAS 976 Electron Beam Welding Machine

3. TECHNICAL REQUIREMENTS:

3.1 Materials:

3.1.1 Parent Materials: Shall be as specified on the applicable part drawing. (See ARP1317 for guidelines.)

3.1.2 Filler Materials: When required, filler metal shall be as specified on the part drawing.

3.1.3 Cleaning Materials: Cleaning materials, chemical solvents, and etching solutions shall be as specified on the part drawing or in the certified welding schedule.

3.2 Equipment:

3.2.1 Electron-Beam Welding Equipment: Shall be capable of producing welds meeting the requirements of 3.6 and 3.7. Equipment conforming to NAS 976 shall be acceptable.

3.2.2 Jigs and Fixtures: All holding fixtures shall be capable of maintaining the desired configuration and tolerances during welding, providing back-up as required, and allowing required work space between the work piece and the electron gun. Back-up material used to deflect or absorb residual electron-beam energy shall be of the same alloy as the part being welded except that alternate back-up materials may be used when approved by procedure certification as in 3.4.2. Tooling within 6 inches (152 mm) of the weld joint shall be made from nonmagnetic materials or be degaussed to acceptable limits (See 3.2.3).

- 3.2.3 Degaussing: Ferromagnetic materials and tooling shall, prior to welding, be demagnetized to a level established by procedure certification (3.4.2) which prevents electron-beam deflections while welding the joint.

3.3 Preparation:

Joint and surface preparation, prior to welding, shall be as follows and shall be included as part of the approved procedure certification:

- 3.3.1 Joint Preparation: Joints shall be prepared to conform to requirements specified on the part drawing.
- 3.3.2 Edge Preparation: Edges shall be machined square and parallel to ensure proper fit-up. Joints shall have no rounded-off edges, but shall be deburred after machining. (See ARP1333 for guidelines.)
- 3.3.3 Pre-Weld Fit-Up: Gap shall not exceed the limits shown in Table 1, unless otherwise specified on the certified weld schedule:

TABLE 1 - Gap Limits

Thickness	Gap, max
Up to 0.009 inch (0.23 mm), incl	5% of joint thickness
Over 0.009 to 0.061 inch (0.23 to 1.55 mm), incl	10% of joint thickness
Over 0.061 to 1.49 inch (1.55 to 37.8 mm), incl	Not to exceed 0.010 inch (0.25 mm)
Over 1.49 inch (37.8 mm)	Not to exceed 0.005 inch (0.13 mm)

- 3.3.4 Weld Start and Run-Off Tabs: Tabs, when used, shall be of the same alloy as the detail parts being welded and shall be cleaned in the same manner as the parts. Tabs shall be integral with the part, either being machined in, or welded to, the part pieces prior to assembly.
- 3.3.5 Surface Preparation: Prior to welding surfaces of parts shall be prepared using a suitable cleaning agent and method, consistent with the alloys being welded. If solvents are used on titanium alloys, they must be nonhalogenated. Welding should commence within 40 hours after surface preparation, unless otherwise permitted or restricted by purchaser.
- 3.3.5.1 After surface preparation, parts shall be handled in the joint area with clean, lint-free gloves and shall be covered or otherwise protected to prevent contamination.

- 3.3.6 Accessory Equipment Preparation: Jigs, fixtures, and measuring devices shall be free of scale, grease, protective coatings, oxides, dust, oil, and other foreign materials detrimental to the welding process.
- 3.4 Procedure:
- 3.4.1 Electron beam weld operators shall be certified. Unless other methods are specified by purchaser, operators certified in accordance with MIL-STD-1595 shall be acceptable.
- 3.4.1.1 Personnel performing welding in accordance with this specification shall be qualified under the cognizance and supervision of the designated welding activity and approved by the cognizant quality control activity. Qualified personnel shall be assigned a stamp with a number or symbol that shall be used to identify all weldments made by such personnel.
- 3.4.1.2 An operator undergoing qualification testing may weld a certification plate in accordance with 3.4.2 according to a pre-established schedule as part of the test.
- 3.4.2 Procedure Certification: Prior to production, a separate weld schedule shall be established for each joint and alloy or alloy combination to be welded. The schedule shall be prepared for each alloy, penetration, weld joint configuration, and for each cosmetic pass configuration, if required, showing all applicable items listed in Table 3.
- 3.4.2.1 Tacking/Locking Passes: A tack weld or locking pass may be used to restrict relative motion in the weld assembly prior to the first full penetration pass. Weld schedule certification of a tack weld or locking pass is not required provided all of the tack welds are consumed by the penetration pass.
- 3.4.2.1.1 A tacking pass, other than a full-penetration pass and made with a power density setting substantially reduced from the certified settings, may be used over any portion of the weld joint up to and including the full length of the weld.
- 3.4.2.1.2 A full-penetration tacking pass using certified parameters may be utilized but shall not exceed 10% of the weld joint length. This locking pass shall terminate in the starting or stopping tabs, when applicable.
- 3.4.2.2 Cosmetic Pass: Cosmetic passes for bead appearance improvement may be applied at any time after completion of the initial full-penetration pass. Cosmetic passes, if used, shall be certified in accordance with 3.4.2.
- 3.4.3 Procedure Recertification: Recertification of weld schedules shall be required for failed test welds and when any change is made to the following parameters:
- 3.4.3.1 When a change is made in parent metal composition or a change in thickness in excess of $\pm 10\%$ (not applicable to cosmetic-pass-weld configuration).

- 3.4.3.2 When a change is made in joint design (not applicable to cosmetic-passweld configuration), but not necessarily after changes in length of joint.
- 3.4.3.3 When the welding position (relationship between the gun angle and the work angle) is changed.
- 3.4.3.4 When a change is made in any one of the machine settings (items 1, 10, 12, 15 through 21 and 25 of Table 3).
 - 3.4.3.4.1 The use of the beam-deflection switch, item 20 of Table 3, need not be considered when used for the purpose of scanning or beam alignment.

3.4.3.5 When a machine other than the machine used for weld procedure certification tests is used.

3.4.4 Production Welding: Production parts shall be welded in accordance with the parameters established in the certified weld schedule of 3.4.2.

3.4.4.1 Welding Environment: Electron-beam welding shall be performed in a vacuum at a partial pressure not exceeding 1×10^{-3} Torr (0.133 Pa). Venting the chamber after welding shall not occur less than two minutes after completion of welding, unless otherwise established in the procedure certification.

3.4.5 Marking and Identification: Each weld shall be traceable to the date of welding and identifiable to the welding operator, and shall be recorded, unless waived by purchaser.

3.4.6 Rework: A rework shall be a full or partial electron-beam penetration weld accomplished subsequent to the full-penetration weld. Rework of imperfections, such as cosmetic passes for correction of underfill, as well as full-penetration passes for correction of a missed joint, and other defects may be accomplished by electron-beam welding in accordance with a certified welding schedule. Restarting of the electron beam after an arc-out shall not be classified as a rework but the reason, location, and method shall be recorded.

3.5 Post Treatment:

3.5.1 Finishing: Post weld machining of face or root surfaces, or both, shall be as described on the applicable part drawing and/or the certified weld schedule. Postweld blending shall not decrease material thickness by more than 10% of joint thickness, or more than 5% of the maximum depth of penetration for partial penetration welds.

3.5.2 Heat Treatment: Weldments requiring heat treatment shall be processed in accordance with part drawing requirements.

3.6 Properties:

Specimens taken from test plates, actual parts, or simulated parts produced for procedure certification as in 3.4.2 shall conform to the following requirements:

3.6.1 Metallurgical Examination for Soundness, and Bead Shape:

3.6.1.1 Macro-sections of the weld shall conform to the minimum requirements of the part drawing for weld size, location, length, and configuration. Sections shall be taken transverse and parallel to the weld direction and shall be examined at 10X magnification.

3.6.1.2 Certification test welds shall meet all requirements of the part drawing and 3.7.

3.7 Quality:

All electron-beam welds shall be subjected to visual inspection at 10X magnification and, when specified, to radiographic inspection in accordance with ASTM E 1742 or MIL-STD-453, to ultrasonic inspection in accordance with AMS 2630 or AMS 2632 or, for titanium and titanium alloys, AMS 2631, to fluorescent penetrant inspection in accordance with ASTM E 1417, to magnetic particle inspection in accordance with ASTM E 1444, or to any combination thereof, and shall conform to the following requirements:

3.7.1 Color: The weld bead and adjacent parent metal shall have a color similar to that of the unwelded parent metal. Discoloration due to vapor deposition occurring during welding is acceptable. Areas that exhibit loose spatter shall be mechanically cleaned to remove loose particles. Cosmetic passes shall not be used to change color.

3.7.1.1 In the case of titanium alloys, this color shall be a bright silver or light straw-colored in appearance; blue-gray or gray discoloration or the presence of loose scale is not acceptable.

3.7.2 Penetration: Joints shall show evidence of complete penetration on fillet welds, tee welds, and butt welds. Penetration for tube welds shall be as specified on the part drawing. In all other cases, weld root reinforcement shall not exceed 1T or 0.070 inch (1.78 mm), whichever is less, except as otherwise specified by the certified weld procedure. Weld reinforcement shall blend evenly into the adjacent base metal with no sharp notches.

3.7.3 Incomplete Fusion: Incomplete fusion or missed joints are not acceptable. Fillet welds shall show complete fusion at the root of the joint.

3.7.4 Cracks: Cracks are not acceptable.

3.7.5 Voids and Pores: Voids and pores open to the surface are not acceptable unless they are subsequently to be removed by machining or blending.

3.7.6 Underfill and Concave Root Surfaces: The cumulative depths of underfill of face and root surfaces shall not exceed the post-weld machining allowances specified on the part drawing. The allowable underfill for each surface not machined after welding shall be 10% of the joint thickness or as specified on the drawing.

3.7.7 Undercut and Root Notches: Where permissible, shall not exceed engineering drawing tolerances. When not specifically noted, undercut or root notches shall not exceed 10% of material thickness total and shall be blended to have not less than 0.06 inch (1.5 mm) root radius.

3.7.8 Overlaps: Protrusion of weld metal beyond the toe, face, or root of the weld is not acceptable.

3.7.9 Mismatch: Shall not exceed the limits shown in Table 2.

TABLE 2 - Mismatch

Thickness	Maximum Mismatch
Up to 0.250 inch (6.35 mm), incl	10% of joint thickness or 0.010 inch (0.25 mm), whichever is less
Over 0.250 inch (6.35 mm)	10% of joint thickness or 0.030 inch (0.76 mm), whichever is less

3.7.10 Internal Discontinuity Limits:

3.7.10.1 Maximum Pore Diameter: The following limits apply to aluminum, titanium, iron, nickel, and cobalt alloys for various applications:

3.7.10.1.1 0.25 Inch (6.4 mm) and Under in Nominal Parent Metal Thickness: Shall not exceed 0.33T or 0.060 inch (1.52 mm), whichever is less.

3.7.10.1.2 Over 0.25 Inch (6.4 mm) in Nominal Parent Metal Thickness: Shall not exceed 0.33T or 0.125 inch (3.18 mm), whichever is less.

3.7.10.2 Other Discontinuities: Maximum number of pores, total defect area, and defect spacing shall be as specified by purchaser. (See ARP1317 for guidelines.)

4. QUALITY ASSURANCE PROVISIONS:

4.1 Responsibility for Inspection:

The welding processor 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 welded parts conform to the requirements of this specification.

4.2 Classification of Tests:

4.2.1 Acceptance Tests: Quality (3.7) is an acceptance test and shall be performed on each weld.

4.2.2 Preproduction Tests: All technical requirements including procedure certification tests are preproduction tests and shall be performed prior to or on the initial shipment of a welded part to a purchaser, when a change in material and/or processing requires reapproval as in 4.4.2 and when purchaser deems confirmatory testing to be required.

4.3 Sampling and Testing:

Shall be in accordance with the following; a lot shall be all parts of the same alloy(s) of one configuration processed at one time in sequence and presented for processor's inspection at one time:

4.3.1 For Acceptance Tests: All production weldments.

4.3.2 For Procedure Certification: Not less than three welds for procedure certification (3.4.2) representative of each joint in the part or assembly. When test welds are made on actual hardware, one part may be welded for procedure certification (3.4.2).

4.4 Approval:

4.4.1 The purchaser shall approve the vendor's facilities, inspection methods, and process controls before production parts are supplied.

4.4.2 When required by purchaser, sample welded parts and the welding procedure shall be approved by purchaser before parts for production use are supplied. If necessary to make any significant change in procedures or methods of inspection, the welding processor shall submit for reapproval details of the proposed changes and, when requested sample welded joints or assemblies. A significant change is one which, in the judgement of the cognizant engineering organization, could affect the properties or performance of the parts.

4.5 Reports:

The processor of welded parts shall furnish with each shipment a report showing the results of tests on each lot to determine conformance to the acceptance test requirements and stating that the parts have been processed in accordance with the certified welding procedure by certified welding operators. This report shall include the purchase order number, AMS 2681B, part or assembly number, and quantity.

5. PREPARATION FOR DELIVERY:

5.1 Identification:

Welded parts shall be identified as specified on the part drawing or as agreed upon by purchaser and vendor.

5.2 Protective Treatment:

When required, welded parts shall be given a suitable protective treatment as specified in the process schedule or on the part drawing.