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GENERAL WELDING REQUIREMENTS FOR AEROSPACE MATERIALS

MEASUREMENT SYSTEM IDENTIFICATION: METRIC/INCH-POUND

DOCUMENT HISTORY LOG

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FOREWORD

This Standard is published by the National Aeronautics and Space Administration (NASA) to provide uniform engineering and technical requirements for processes, procedures, practices, and methods that have been endorsed as standard for NASA programs and projects, including requirements for selection, application, and design criteria of an item.

This Standard is approved for use by NASA Headquarters and all NASA Centers, including Component Facilities and Technical and Service Support Centers.

This Standard establishes general directions and describes the type of information that NASA expects for welded structures. This Standard does not provide the detailed process and quality assurance requirements for weldments on flight hardware. Instead, it is intended as a higher level document which states minimum requirements for welded hardware.

"Requests for information, corrections, or additions to this Standard should be submitted via "Feedback" at http://standards.nasa.gov."

Original Signed By: ***2015-07-31***

Ralph R. Roe, Jr.
NASA Chief Engineer

Approval Date

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1. SCOPE

1.1 Purpose

The purpose of this Standard, as defined in NASA Procedural Requirement (NPR) 7120.10, Technical Standards for NASA Programs and Projects, is to establish the processing and quality assurance requirements for manual, automatic, machine, and semiautomatic welding for spaceflight applications and special test equipment used for testing flight hardware with the exception of ground-based pressure systems, which are subjected to NASA-STD-8719.17, NASA Requirements for Ground-Based Pressure Vessels and Pressurized Systems (PVS).

1.2 Applicability

This Standard is applicable to all welding processes used for joining metallic materials. This includes, but is not limited to arc welding (AW), solid state welding (SSW), resistance welding (RW), and high energy density welding (HEDW). This Standard covers all metallic materials used in the manufacture of hardware for spaceflight applications and special test equipment used for testing flight within NASA.

This Standard is approved for use by NASA Headquarters and NASA Centers, including Component Facilities and Technical and Service Support Centers, and may be cited in contract, program, and other Agency documents as a technical requirement. This Standard may also apply to the Jet Propulsion Laboratory or to other contractors, grant recipients, or parties to agreements only to the extent specified or referenced in their contracts, grants, or agreements.

Requirements are numbered and indicated by the word "shall." Explanatory or guidance text is indicated in italics beginning in section 4.

1.3 Tailoring

Tailoring of this Standard for application to a specific program or project shall be formally documented as part of program or project requirements and approved by the responsible Technical Authority in accordance with NPR 7120.5, NASA Space Flight Program and Project Management Requirements. The requirements in this document may be tailored by submitting a detailed weld process specification or stating applicable industry standards that meet the intent of this Standard.

2. APPLICABLE DOCUMENTS

2.1 General

The documents listed in this section contain provisions that constitute requirements of this Standard as cited in the text.

2.1.1 The latest issuances of cited documents shall apply unless specific versions are designated.

2.1.2 Non-use of specific versions as designated shall be approved by the responsible Technical Authority.

The applicable documents are accessible at https://standards.nasa.gov or may be obtained directly from the Standards Developing Organizations or other document distributors.

2.2 Government Documents

NASA

NPR 1441.1	NASA Records Management Program Requirements
NPR 7120.5	NASA Space Flight Program Management Requirements
NPR 7120.10	Technical Standards for NASA Programs and Projects

2.3 Non-Government Documents

Aerospace Industries Association (AIA)/National Aerospace Standard (NAS)

AIA/NAS 410	NAS Certification and Qualification of Nondestructive Test Personnel

American Welding Society (AWS)

AWS QC1	Standard for AWS Certification of Welding Inspectors

2.4 Order of Precedence

2.4.1 This Standard establishes requirements for all welding processes used for joining spaceflight metallic materials but does not supersede nor waive established Agency requirements found in other documentation.

2.4.2 Conflicts between this Standard and other requirements documents shall be resolved by the responsible Technical Authority.

3. ACRONYMS AND DEFINITIONS

3.1 Acronyms and Abbreviations

AIA	Aerospace Industries Association
AMS	Aerospace Material Specification
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing Materials
AW	arc welding
AWS	American Welding Society
FSW	friction stir welding
HEDW	high energy density welding
JSC	Johnson Space Center
MIL	military
MPR	Marshall Procedural Requirements
MRB	Material Review Board
MSFC	Marshall Space Flight Center
NAS	National Aerospace Standard
NASA	National Aeronautics and Space Administration
NDE	nondestructive evaluation
NPR	NASA Procedural Requirements
PVS	pressure vessels and pressurized systems
PQR	Procedure Qualification Record
QA	Quality Assurance
QC1	Standard for AWS Certification of Welding Inspectors
RW	resistance welding
S&MA	Safety and Mission Assurance
SAE	Society of Automotive Engineers
SSW	solid state welding
STD	standard
WPS	Welding Procedure Specification

3.2 Definitions

Automatic Welding: A welding operation performed without adjustment of the controls by a welding operator.

Certified: With respect to a welder, means a welder or inspector who has passed qualification tests based on requirements established in this Standard. With respect to a

procedure or process specification, a term describing a weld procedure or process that has passed qualification tests based on requirements established in this Standard.

Concave Root Surface: A weld root with penetration not extending beyond the thickness of the parent metal. *Note: Periodically referred to as "suckback."*

Conventional Friction Stir Welding (FSW): FSW in which the load is reacted by an anvil.

Critical Flaw Size: The analytically determined flaw size that produces a critical stress intensity factor of concern for a specified number of life cycles which will likely produce a catastrophic mission failure.

Defect: A discontinuity or discontinuities that by nature, or accumulated effect, render a part or product unable to meet minimum standards or specifications; designates rejectability.

Dross: A mass of solid impurities floating on a molten metal or dispersed in the metal.

Essential Variables: Weld process parameters that influence directly the weld process and resulting weld properties in such a manner that changes to them require requalification of the weld procedure. *Note: Examples are heat input, travel speed, torch setup, and pin tool configuration.*

Fail Safe: A condition in which, after failure of a single individual structural member, the remaining structure can withstand the redistributed loads with an ultimate factor of safety of 1.0 on limit load. *Note: The failure is contained or constrained so that the failed part does not affect other flight elements or personnel.*

Heat-Affected Zone: The portion of the base metal whose microstructure or mechanical properties have been altered by the heat of welding, brazing, soldering, or thermal cutting.

Heat Input: Quantity of energy introduced per unit length of weld from a traveling heat source, expressed in joules per millimeter or joules per inch. *Note: Computed as the ratio of the total input power of the heat source in watts to the travel velocity in millimeters per second or inches per minute.*

Heat Sensitive Alloys: Alloys that require mechanical working, precipitation strengthening, or other metallurgical mechanisms to regain their rated strength due to exposure to the heat input from the welding process.

Improper Fusion: A condition when the weld metal that replaces base metal is insufficient.

Incomplete Fusion: A weld discontinuity in which fusion did not occur between weld metal and parent material or adjoining weld beads.

Incomplete Joint Penetration: The condition of a weld failing to extend through the full thickness of the joint.

In-Process Correction: Action taken by a welder to complete a process before submittal to inspection.

Lack of Fill: A weld face surface not extending to the surface of the parent metal.

Machine Welding: Welding with equipment that performs the welding operation under the constant observation and control of a welding operator.

Manual Welding: A welding operation performed and controlled completely by hand.

Material Review Board (MRB): A cross-functional group that reviews production or purchased items on hold because of nonconformance or usability concerns. The MRB is to determine the disposition, which may include rework, scrap, or return to the vendor.

Material Thickness: The minimum material thickness of a joint member per drawing tolerance. *Note: The thinner of the joint members with different thicknesses is designated "t."*

Mismatch: The linear misalignment of components resulting from improper fit-up or distortion during welding. *Note: Mismatch is calculated as the difference in the alignment of specified features (usually either center lines or surfaces) of the two parts having been welded and should not be confused with the difference in center lines as a result of welding two different thickness components.*

Nonstructural Weld: A non-load-bearing weld.

Peaking: The angular distortion of the components resulting from welding. *Note: Peaking is calculated as the angle resulting from the intersection of tangents taken from the surface of the two components being welded.*

Procedure Qualification Record (PQR): A document providing the actual welding variables used to produce an acceptable test weld and the results of tests conducted on the weld for the purpose of demonstrating process and procedural capability and repeatability. *Note: Demonstration of capability qualifies the welding procedure.*

Qualified Inspector: A certified individual with the responsibility and ability to judge the quality of the welded specimens in relation to some form of written specification.

Repair: A procedure that makes a nonconforming item acceptable for use. *Note: The purpose of the repair is to reduce the effect of the nonconformance. Repair is distinguished from rework in that the characteristics after repair still do not completely conform to the applicable drawings, specifications, or contract requirements. Nonstandard repair procedures are authorized by MRB action for use on a one-time basis only. All repairs require MRB approval before implementation.*

Rework: A procedure applied to a nonconforming item that completely eliminates the nonconformance and results in a characteristic that conforms completely to the drawings, specifications, or contract requirements. *Note: Not all rework activities require MRB approval before implementation.*

Semiautomatic Welding: Welding with equipment that controls only the filler metal feed. *Note: The weld progression is manually controlled.*

Special Test Equipment: Any non-flight, non-GSE, or non-facility structure, hardware, piping systems, pressure vessels, or equipment intended to be used for testing or simulation, or associated with the manufacturing, process development, and preparation of Marshall Space Flight Center (MSFC) facilities for testing or simulation. *Note: Designs include, but are not limited to, test stands, test beds, load reaction and application structures, load line components, hot fire testing of engines and engine components, fluid flow and pressure tests, high pressure and/or cryogenic storage and/or run systems, solid propellant tests, flight hardware mockups and simulators, hardware support stands and dollies, personnel access stands, lifting and handling hardware, and tooling used to facilitate the fabrication and/or assembly of flight/non-flight hardware, such as master drill templates or alignment/clamping fixtures used during machining and welding processes.*

Undercut: A groove melted into the base metal adjacent to the weld toe or weld root and left unfilled by weld metal.

Welding Procedure Specification (WPS): A document providing in detail the required variables for a specific application to ensure repeatability by properly trained welders and welding operators.

Welding Process Specification: A document that prescribes, in a complete, precise, verifiable manner, the requirements, design, behavior, or characteristics of a system or system component.

Weld Zone: The weld metal fusion zone plus the heat-affected zone.

4. REQUIREMENTS

4.1 Specification of this Standard on Contracts

When this Standard is specified on contract documents, a detailed weld process specification, as defined in NPR 7120.10, which meets the intent of this Standard shall be submitted. *Industry, government, and company specifications can be used for welding flight hardware if they contain the information required by this Standard. The contractor has the responsibility to submit the detailed weld process specification.*

4.2 Joint Classes

Welding performed using this Standard shall be classified in accordance with the service of the joints as follows in the next sections.

4.2.1 Class A

Critical applications. Welds where a single failure would cause loss of system, loss of major components, loss of control, and loss of crew.

4.2.1.1 Class A welds shall require visual, dimensional, surface, and volumetric inspections, and additional inspection when required by engineering drawing.

Note: Based on consequences of failure, all fracture-critical welds are, by definition, Class A joint. If the quality of the Class A joint cannot be verified as required by this Standard, e.g., inaccessible volume or root surfaces, then alternative rationale for acceptance is to be presented to the responsible NASA Fracture Control Board for approval as required by NASA-STD 5019, Fracture Control Requirements for Spaceflight Hardware.

4.2.2 Class B

Semicritical applications. Welds where a failure would reduce overall efficiency of the system, preclude the intended function or use of the equipment, but loss of the system or endangering personnel would not be experienced.

4.2.2.1 Class B welds shall require visual, dimensional, and surface inspections, and additional inspection when required by engineering drawing.

4.2.2.2 Class B welds shall be subjected to volumetric inspection if required by engineering design and specified by drawing or special instruction.

4.2.2.3 Weld requiring fail-safe capability shall be classified as a Class B joint.

4.2.3 Class C

Noncritical applications. Welds where a failure would not affect the efficiency of the system or endanger personnel.

4.2.3.1 Class C welds shall require visual and dimensional inspections, and, additional inspection when required by engineering drawing.

4.2.3.2 Class C joints shall require weld integrity verification based on function of the joint (e.g., seal welds require leak testing commensurate with the leak rate requirement).

4.3 Equipment

4.3.1 Welding Equipment

a. Automatic, semiautomatic, manual, and machine welding shall be accomplished using equipment containing calibrated dials, meters, or recorders that quantitatively indicate process parameters.

b. All joining equipment (including manual) shall be capable of producing joints that meet the requirements specified herein.

4.3.1.1 Acceptance Testing

a. New, repaired, relocated, or modified welding machines and equipment for automatic and machine welding shall be acceptance-tested prior to processing of flight hardware.

b. Machines and equipment shall meet the requirements of the applicable purchase specification, design specification, or modification order.

c. Power supplies and supporting components (electrical or mechanical or both) shall be capable of operating reliably within the range of parameters and duty cycle to be used for joining production parts.

4.3.1.2 Calibration

a. Measuring instruments, meters, gages, or direct reading electrical control circuits to be used for automatic, semiautomatic, and machine joining operations shall be initially calibrated and periodically recalibrated to maintain adequate performance.

b. Maintenance performed on measuring instruments, meters, gages, or direct reading electrical control circuits to be used for automatic, semiautomatic, and machine performance joining operations shall require recalibration to maintain adequate performance.

c. Measuring instruments, meters, gages, or direct reading electrical control circuits to be used for automatic, semiautomatic, and machine joining operations shall be initially calibrated

and periodically recalibrated to maintain adequate performance or when any maintenance is performed that may have changed calibration.

4.3.1.3 Maintenance and Records

a. Welding machines shall be provided with adequate periodic maintenance service so that acceptable welds can be produced using qualified welding procedure specifications.

b. A current record of each maintenance repair or functional check shall be maintained for each welding machine.

4.3.2 Tooling and Fixtures

a. Tooling and fixtures used in the joining operation shall be constructed of nonmagnetic materials that do not affect the welding arc or beam, or that are not detrimental to the weld quality.

b. Tooling and fixtures shall not be a source of contamination of the joint.

c. Magnetic materials, when used, shall be degaussed prior to welding.

d. Degaussing, when necessary, shall be controlled by the WPS for the successful completion of the weld.

e. Tooling and fixtures required to ensure compliance with dimensional requirements of section 4.8.3 shall be identified on the WPS.

4.4 Materials

4.4.1 Base Metals

a. Unless otherwise specified or approved by the procuring agency, base metal alloy shall conform to applicable government and/or industry specifications for each alloy group.

b. The base metal, material condition, and appropriate specification shall be recorded in the WPS.

c. Weld start and runoff tabs, when used, shall be of the same alloy as the material being joined and be welded with the same filler metal specified on the drawing or WPS. *Backing material may be used when verified by procedure qualification.*

4.4.2 Filler Metals

a. Unless otherwise specified or approved by the procuring agency, fillermetal alloy shall conform to applicable government and/or industry specifications for each alloy group.

b. Specifications used to procure filler metals shall include provisions to mitigate the possibility of two different filler wires being errantly mixed together on a single spool or in a filler rod container.

c. Weld filler metals and the appropriate specifications shall be recorded in the WPS.

4.4.3 Shielding Gas

a. Welding-grade gases conforming to the applicable industry or military specifications shall be used for gas shielding.

b. The shield gas type, specification, and flow rate shall be recorded in the WPS.

4.4.4 Tungsten Electrodes

a. Tungsten electrodes shall conform to the applicable industry or military specifications.

b. The electrode diameter, electrode tip shape, alloy composition, and specification shall be recorded as a part of the WPS.

4.4.5 Friction Stir Welding Pin Tools

4.4.5.1 Pin and shoulder service life shall be demonstrated to meet the intended use.

4.4.5.2 Pins and shoulders shall be limited to the demonstrated life.

4.4.5.3 Pin tool design, materials, and service life shall be recorded in the WPS.

a. Pins and shoulders that have reached the specified service life shall be marked and removed from service to preclude an accidental future use in the FSW production process.

b. If used for more than one weld joint, pins and shoulders shall be cleaned and inspected before reuse on production hardware.

4.5 Weld Procedure and Performance Qualification

4.5.1 Welder Performance Qualification

a. Operators of automatic, semiautomatic, machine, or manual welding equipment shall be certified for the applicable process.

b. Suppliers shall define the weld certification process in their detailed weld process specification.

4.5.2 Welding Procedure Specification

a. Prior to first production of parts, or when changes are made to essential variables of the WPS, qualification joints shall be made to establish a satisfactory WPS for each different configuration of A, B, and C classes of welds. *Figure 1, Welding Procedure Specification Example, contains an example of a WPS (for reference only).*

b. Variables considered essential shall be so identified in the WPS.

4.5.2.1 Classes A and B Joints

a. Classes A and B joints shall be qualified with joints that simulate the production part with respect to section thickness, alloy, heat-treat condition, joint preparation, pre-weld cleaning, fit-up, position, and post-weld operations.

b. The joints shall be processed in either the actual production fixture or in a test fixture simulating the production fixture using the production welding equipment.

c. Base metal for qualification joining tests shall be identified by lot or heat number, type, and condition and maintain identification through all evaluation processes.

d. The qualification weld shall be subjected to metallurgical evaluation and the same post-weld inspections and processes as the production parts, including reinforcement removal, mechanical deformation, stress relief, and thermal treatments associated with artificial aging or any operation affecting mechanical properties.

Weld Panel ID	Program Code	Material Type	Material Heat Lot Number	Material Manufacturer	Material Thickness	Material Ser. Num.	Welding Process (dc-,dc+,vpps)

Operator	Electrode Type	Welding Torch	Welding Torch Shield Cup	Torch Orientation (Lead, Lag)	Welding Position (Vertical)	Back Purge Gas Type	Plasma Gas Type	Shield Gas Type	Trailing Shield Gas Type

Building Number	Power Supply	Weld Fixture	Weld Station	Back Purge Type	Filler Wire Type	Filler Wire Heat Lot Number	Filler Wire Manufacturer	Trailing Shield Type

Electrode Configuration	Joint Configuration

Weld Passes	Welding Current	Welding Voltage	Shield Gas Flow (SCFH)	Plasma Gas Flow Rate	Plasma Gas Pressure	Filler Wire Size Dia.	Filler Wire Rate (IPM)	Travel Rate (IPM)	Interpass Temperature	Orifice Size
Tack Pass										
First Pass										
2nd Pass										
3rd Pass										
4th Pass										
5th Pass										
6th Pass										
7th Pass										
8th Pass										

Weld Passes	Electrode Size	Electrode Set Back	Back Purge Gas Flow	Back Purge Gas Pressure	Trailing Shield Gas Flow	Straight Polarity Time (ms)	Reverse Polarity Time (ms)	Added Reverse Current	Arc Oscillation Dwell	Arc Oscillation Frequency	Arc Oscillation Position	Arc Oscillation Amplitude
Tack Pass												
First Pass												
2nd Pass												
3rd Pass												
4th Pass												
5th Pass												
6th Pass												
7th Pass												
8th Pass												

Comments:

Figure 1—Welding Procedure Specification Example

4.5.2.2 Joining Parameters

a. As a minimum, all essential joining variables (such as voltage, current, rate of travel, position, and filler-wire feed rate) shall be recorded during qualification welding.

b. Manual weld parameters and operating parameter ranges shall be established during the WPS qualification.

c. The WPS shall document all pre-welding operations, setup conditions, welding equipment, and any pertinent information about the welding system used which affects the joining operation.

4.5.2.3 Parameter Tolerances

a. For automatic, semiautomatic, and machine joining, parameter tolerances may be used and shall be listed in the qualified WPS.

b. Test samples representing the minimum and maximum heat input shall be processed to verify acceptable welds and the results documented in the PQR.

4.5.3 Welding Procedure Specification Qualification

All test and inspection results used to verify the weld integrity shall be recorded on the PQR.

4.5.4 Records

4.5.4.1 Records of test specimens that meet the acceptance requirements of this process specification shall be signed and dated by a Quality Assurance (QA) representative as an accurate record of the welding and testing of the procedure test weldment.

4.5.4.2 The WPS and PQR shall be prepared and retained as long-term temporary records in accordance with NPR 1441.1, NASA Records Retention Schedules, with the current WPS being maintained at the welding station.

4.5.4.3 All WPSs and PQRs shall be maintained and made available for review by the responsible NASA Engineering Authority before production of hardware covered under this Standard.

4.6 Pre-Weld Operations

4.6.1 Joint Design

Acceptable joint designs are butt, lap, corner, tee, and edge. All joints shall be documented on a WPS, design drawing, or other suitable document.

4.6.2 Pre-Weld Cleaning

a. Pre-weld cleaning of filler materials and surfaces to be welded in order to remove contaminants that are detrimental to weld quality shall be accomplished in an environment that will not degrade the quality of the weld.

b. Cleanliness shall be maintained during welding.

c. Pre-weld and interpass cleaning requirements shall be included in the WPS.

4.7 Production Welding

4.7.1 Equipment Operational Check

a. A welding equipment operational readiness check shall be made immediately prior to a production weld to verify the equipment is operating properly.

b. The equipment operational readiness check criteria shall be provided to the procuring agency.

4.7.2 Temperature Control

a. Pre-heat, interpass, and post-heat temperatures shall be controlled so as not to degrade the properties of the material being welded.

b. The parameters of pre-heat, interpass, and post-heat temperatures shall be recorded in an applicable WPS.

4.7.3 Tack Welding

a. Tack welding is allowable and shall either be removed or become a part of the finished weld (i.e., tack welds are to be completely consumed by the final weldment).

b. Tack welds that become part of the finished weld shall be performed by certified welders in accordance with certified procedures meeting the requirements of this Standard.

c. After the weldment is completed, the tack areas shall be evaluated to the requirements of the finished weld.

d. Tack welding requirements shall be included in the WPS.

4.7.4 Welding Techniques

4.7.4.1 Classes A and B Joints

a. The technique of welding the initial passes from both sides where the weld roots overlap beneath the exposed surfaces (reference figure 2 (A), Welding Techniques) shall be permitted only if the root of the first pass is removed to sound metal prior to placement of the first weld pass from the second side.

b. Joints which have prepared grooves from one or both sides (reference figure 2 (B) and (C)) and/or multi-pass welds shall have a weld land that is completely penetrated on the initial

pass. *Partial penetration welds from one side are permissible provided the opposite side is machined into the penetration root prior to completing the weld.*

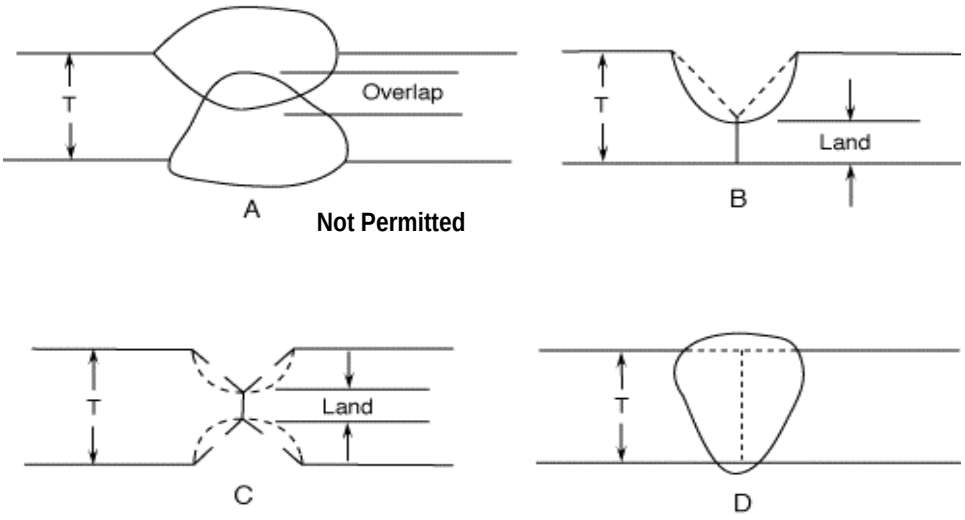


Figure 2—Welding Techniques

c. Adequate nondestructive evaluation(NDE) procedures shall be employed to ensure that the weld root has been exposed by machining.

d. All penetration weld passes shall have no visual evidence of improper fusion or presence of dross.

e. Square groove welds shall be completely penetrated from one side (reference figure 2 (D)).

4.7.4.2 Class C Joints

a. The technique of welding and joint geometry shall be as stated on the engineering drawing and the WPS.

b. Any deviation regarding weld technique and joint geometry shall be approved by the procuring agent prior to use.

c. Partial penetration groove welds shall be used only for Class C joints.

4.7.5 Welding Procedure

Production welding shall be accomplished according to a qualified WPS. *A specific WPS for each weld is required for production welding Classes A, B, and C.*

4.7.6 Procedure Departure

a. Departure from the qualified WPS during production welding shall require withholding the part for MRB disposition.

b. The cause for departure shall be determined.

c. Corrective action shall be taken prior to further production welding.

4.8 Post-Weld Operations

4.8.1 Inspection

Each completed weldment, including the base metal, shall be inspected to ensure compliance with the requirements of sections 4.8.2, 4.8.3, and 4.10, and as dictated by the class of weld for a minimum of 12.5 mm (0.5 in) on either side of the weld interface.

4.8.2 General Visual/Surface Requirements

a. Weld deposits, buildup, and root reinforcement shall comply with the criteria outlined in the accompanying detailed weld process specification that is submitted in support of this Standard.

b. The edge of the weld deposit shall blend into the base metal without unfused overlaps or undercut.

c. Weld face and root sides shall be free of surface cracks, crater cracks, and other defects open to the surface.

d. Weld deposits shall be free of open voids or unfused overlapping folds or other lack of fusion.

e. Undercutting, concavity, lack of fill, or root concavity shall be unacceptable in any weld where it occurs as a sharp notch or where the depth reduces the material thickness below the minimum thickness specified on the applicable drawing.

4.8.3 Dimensional Requirements

4.8.3.1 Mismatch

If not specifically addressed in drawing tolerances or by specified welding standards, allowable post-weld mismatch shall be governed by overall drawing tolerances. *An example of weld joint mismatch is shown in figure 3, Mismatch and Peaking.*

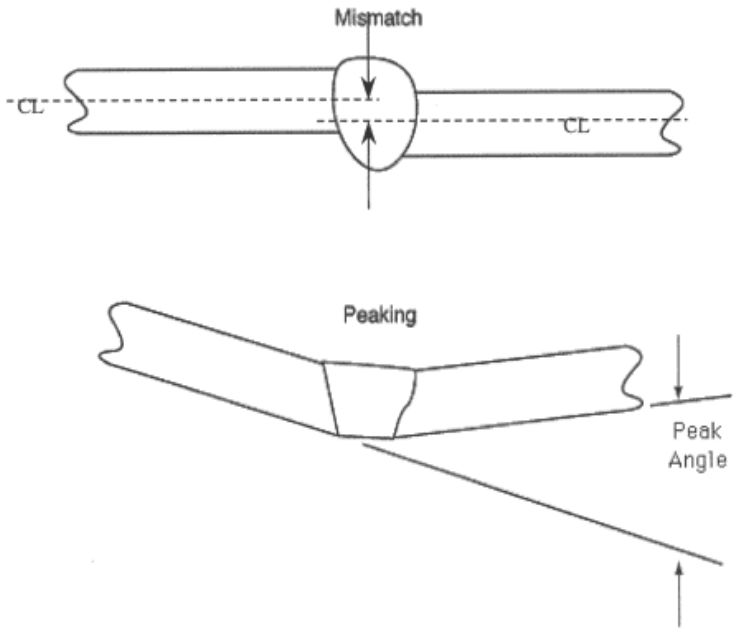


Figure 3—Mismatch and Peaking

4.8.3.2 Peaking

a. If not specifically addressed in drawing tolerances or by specified welding standards, allowable post-weld peaking of the welded joint and adjacent base metal shall be governed by overall drawing tolerances.

b. A standard template or other device having specified reference points shall be used for determination of peaking. *Weld peaking is shown in figure 3.*

4.8.3.3 Combination Mismatch and Peaking

The combined effect of mismatch and peaking on the efficiency of the weld joint is so related that one can be increased if the other is decreased. This condition can be tolerated if it can be shown by engineering analysis that positive margins of safety exist.

4.8.3.4 Weld Reinforcement Removal

a. *Weld bead reinforcement may be removed to eliminate defects occurring in the outer zones of the reinforcement unless otherwise specified on the engineering drawing.* Weld bead reinforcement removal shall not thin the weld or parent metal below drawing dimensional requirements.

b. When flush contour is required by the welding symbol, weld reinforcement shall not exceed 0.4 mm (0.015 in).

c. Metal removal shall be such that the reworked area blends smoothly (e.g., 3.175 mm (0.125 in) radius) with adjacent material without abrupt sectional changes.

d. Surface grinding of base metal is permitted provided wall thickness is verified in compliance with dimensional requirements after grinding.

e. Weldments that are machined ground or otherwise mechanically worked causing disruption or smearing of the material surface shall be etched to remove the masking material before penetrant application.

4.8.3.5.1 Fillet Welds

a. Fillet weld fusion of the root shall have a minimum of 10 percent penetration of base metal thickness of the thinnest member of the root of the joint as determined by evaluation of transverse sections taken from the qualification welds.

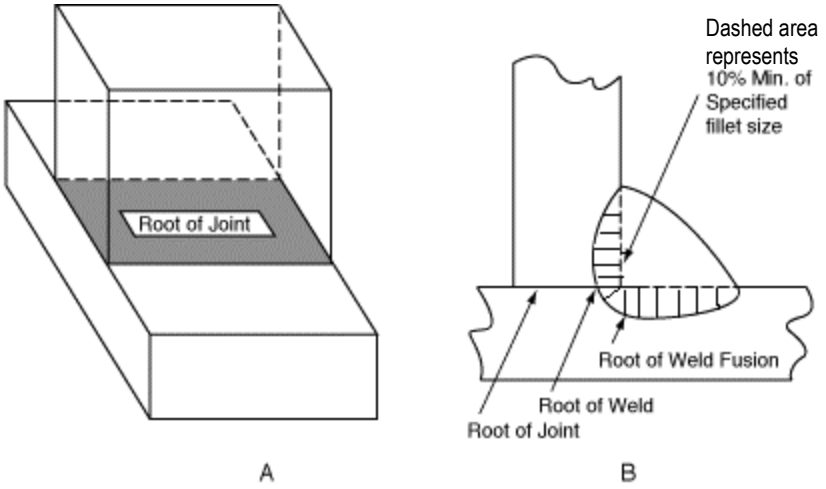
(1) The minimum penetration shall be verified by destructive test/metallography.

(2) Weld parameters used to successfully and repeatedly complete the fillet welds shall be entered into the WPS and used for actual welding.

b. Fillet weld fusion of the root (reference figure 4, Fillet Welds) shall be determined by evaluation of transverse sections taken from the qualification welds.

c. Intermittent fillet welds shall have fusion of the root throughout the specified length. *Unless otherwise specified on the engineering drawing, the fillet may be extended by 6.35 mm (0.25 in) at each end without penetration in the extension.*

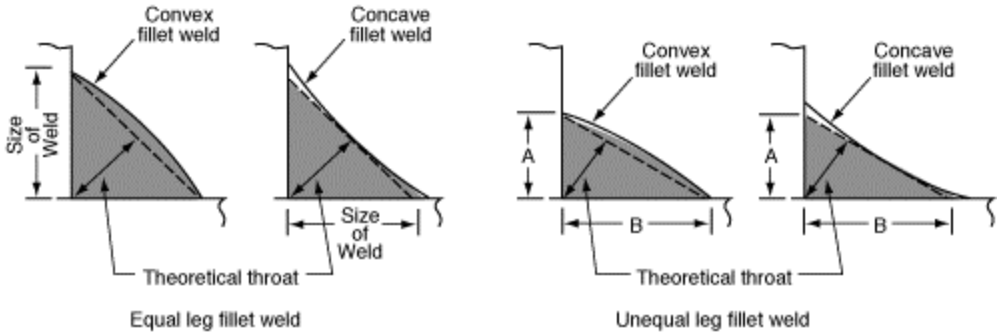
d. The minimum acceptable fillet size shall be that specified by the engineering drawing.



Notes: Root of Joint – That portion of a joint where members are closest to each other.

Root of Weld – The point, as shown in cross section, at which the weld intersects the base metal surfaces.

The root of the weld shall penetrate to the extent that the actual throat dimension exceeds the theoretical throat dimension, in addition, each member shall be penetrated a minimum of 10% of the specified fillet size at the root of the weld. Each leg length shall show fusion along the surface of each common member.



For equal-leg fillet welds, the fillet size is equal to the leg length of the largest inscribed right isosceles triangle.

For unequal-leg fillet welds, the leg lengths of the largest right triangle which can be inscribed within the fillet weld cross section. Size of weld is A and B.

Figure 4—Fillet Welds

e. Unless otherwise specified on the engineering drawing, the maximum acceptable fillet size shall be the size specified plus 50 percent or 4.8 mm (0.188 in), whichever is less, as permitted in section 4.11.

f. The minimum acceptable actual throat shall equal or exceed the theoretical throat (reference figure 4).

4.8.4 Weldment Straightening

a. *Welds and adjacent base metal which have been deformed by the welding operation may be straightened.* Prior to implementation, however, verification by NDE, destructive testing, and metallurgical evaluation that the process used for straightening does not degrade the weld or surrounding material below the specified design requirements shall be performed.

b. Following weldment straightening, the weld and adjacent base metal shall be inspected in accordance with section 4.8.1.

c. Weldments in which defects caused by weldment straightening are revealed shall not be acceptable.

4.8.5 Post-Weld Heat Treat Requirements

a. Weldments that are subject to heat treatment operations shall be subsequently inspected to the surface quality requirements of the engineering drawing.

b. Any required post-weld heat treatment processing shall be specified in the WPS.

4.9 Weld Joint Strength Requirements

4.9.1 Butt Joints

a. If not otherwise specified in the design requirements, weld strength shall meet or exceed that of the parent material.

b. Qualified WPSs shall be established to demonstrate the weld meets the strength required by design.

4.9.2 Fillet Welds

a. Unless otherwise directed by the procuring agency, fillet weld shear strength shall meet or exceed 60 percent of the minimum ultimate tensile requirements of the weld.

b. For fillet weld joints involving materials of different thicknesses having different ultimate tensile strength values, the minimum requirement for the shear joint shall be 60 percent of the lower of the minimum ultimate tensile requirements.

4.10 Weldment Quality Requirements

a. Weldment quality requirements shall be established to ensure the weld meets design requirements for strength and integrity.

b. The compliance of the weld with quality requirements shall be verified by mechanical testing.

4.11 Repair Welding

4.11.1 Allowable Repair Welding

a. Additional welding operations shall be permitted to correct any unacceptable condition established per section 4.10, provided the repair welding parameters and procedures are specified in a qualified repair WPS, and the repair is contained within the original weld zone.

b. Complete records of the repair welding operation, including identification of the repaired weldment, type of defect, and location of the repair weld, shall be retained in permanent records. *Examples of typical weld defects requiring repair are listed below.*

(1) Undercut.
(2) Lack of fill.
(3) Concave root surface.
(4) Incomplete joint penetration.
(5) Crack and crack-like defects.
(6) Oxides and porosity.
(7) Lack of fusion.

4.11.1.1 No more than two weld repair attempts shall be made without approval of the MRB.

4.11.2 Repair Welding Requiring Disposition

At a minimum, the following conditions require MRB disposition by the procuring agency:

a. When more than two weld repair attempts have been performed at any one location.

b. When the incorrect filler metal has been used.

c. When a weldment has been post-weld heat treated to increase its strength and cannot be returned to the original drawing requirements with additional heat treatments following reweld.

d. When finish machining has been completed prior to rewelding.

e. When the repair extends outside the original weld zone.

f. All FSW repairs.

g. All friction plug repairs.

4.11.3 Repair Welding Reinspection

Reinspection of all repair weld areas shall be performed using the same methods/requirements as the original weld.

4.12 Quality Assurance

a. *The supplier is responsible for the performance of all inspection requirements as specified herein.* Except as otherwise specified, the supplier shall use inspection facilities and services approved by the procuring agency shall be used by the supplier.

b. Inspection and test records shall be kept complete and, upon request, made available to the procuring agency or its designated representative. *The procuring agency or its designated representative reserves the right to perform any or all of the inspections set forth in the specification to ensure that the end item conforms to the prescribed requirements.*

c. NDE procedures to be employed in inspection for weldment internal and surface quality requirements shall be qualified/validated as being capable of detecting the weldment quality criteria prescribed prior to inspection of the first production weld.

d. The documented proof of capability shall be retained as a permanent record.

e. Personnel performing visual weld inspections shall be certified in accordance with AWS QC1, Standard for AWS Certification of Welding Inspectors, or an equivalent standard as determined by the Quality Authority.

f. Personnel performing NDE weld inspections shall be certified in accordance with NAS 410, NASA Certification and Qualification of Nondestructive Test Personnel, or an equivalent standard as determined by the Quality Authority.

4.12.1 Pre-Weld and Weld Inspection

a. Documentation relative to the production weld shall be reviewed for conformance to section 4.

b. Each production weld shall be certified that it was made within the range of operating parameters established in the WPS. *The contractor has the responsibility for certification.*

c. Any deviations from operating parameters established in WPS shall be noted and referred to the procuring agency for disposition.

4.12.2 Post-Weld Inspection

4.12.2.1 Visual Inspection

a. Each completed weldment, including the base metal, shall be inspected to ensure compliance with the requirements of sections 4.8.2, 4.8.3, 4.10, and as dictated by the class of weld for a minimum of 12.5 mm (0.5 in) on either side of the weld interface.

b. The weld shall be in the as-welded condition for the initial inspection, with surface smut and loose oxide removed using a technique that does not smear metal or change the quality of the weld.

c. Titanium weld deposit and heat-affected zone shall adhere to the color requirements of the accompanying detailed weld process specification identified in section 1.2.

4.12.2.2 Dimensional Inspection

Dimensional inspection shall be performed on weldments to ensure compliance with the requirements of the design drawing for all weld classes.

4.12.2.3 Internal Quality Inspection

a. NDE shall be performed to ensure compliance with the internal quality requirements of the design drawing established per section 4.10 for Class A, B and C welds as noted in figure 5, Minimum Inspection Requirements.

b. NDE procedures and techniques shall be qualified. *When a critical flaw size is specified, qualification includes verification of detectability of the critical size either by demonstration or by reference to the "standard" NDE methods and procedures identified in NASA-STD-5009, Nondestructive Evaluation Requirements for Fracture Critical Metallic Components. When reliability of inspection and critical flaw detection so dictate, redundant and/or complementing inspection techniques and procedures shall be employed.*

Method of Inspection	Weld Class		
	A	B	C
Visual	X	X	X
Dimensional	X	X	X
Surface	X	X	O
Volumetric	X	see note	O
Additional Inspection When Required by Drawing	X	X	X

Note: Class B welds shall be subjected to volumetric inspection if required by engineering design and specified by drawing or special instruction.

Figure 5—Minimum Inspection Requirements

4.12.2.4 Surface Quality Inspection

a. NDE shall be performed to ensure compliance with the surface quality requirements of the design drawing for Class A and Class B welds.

b. NDE procedures shall be qualified. *When a critical flaw size is specified, qualification includes verification of detectability of the critical size either by demonstration or by reference to the "standard" NDE methods and procedures identified in NASA-STD-5009.*

c. When reliability of inspection and critical flaw detection so dictate, redundant and/or complementing inspection techniques and procedures shall be employed.

d. Machined, ground, or otherwise mechanically worked weldments that have been subject to smearing of the weld material surface shall be etched to remove the masking material prior to penetrant application.

4.12.2.5 Records

a. A continuous audit of weldment production quality shall be maintained.

b. Weldment production quality audit records shall include, but not be limited to, the location of repairs, type of defects repaired, procedures used, and inches of repair per total inches of weld.

c. Audit records of weldment production quality shall be made available to the procuring agency upon request.

APPENDIX A

GUIDANCE

A.1 Purpose

The purpose of this appendix is to provide guidance, which is made available in the reference documents listed below.

A.2 Reference Documents

A.2.1 Government Documents

Department of Defense

MIL-A-18455	Argon, Technical
MIL-PRF-27401	Propellant Pressurizing Agent, Nitrogen
MIL-PRF-27407	Propellant Pressurizing Agent, Helium
MIL-STD-1537	Test Method Standard for Electrical Conductivity Test for Verification of Heat Treatment of Aluminum Alloys, Eddy Current Method
MIL-STD-2154 (Cancelled)	Inspection, Ultrasonic, Wrought Metals, Process For
MIL-H-81200 (Cancelled)	Heat Treatment of Titanium and Titanium Alloys
MIL-HDBK-1823	Nondestructive Evaluation System Reliability Assessment
MIL-STD-2219A (Cancelled)	Fusion Welding For Aerospace Applications

Federal (authorized by the General Services Administration)

BB-C-101	Carbon Dioxide (CO_2): Technical and USP
BB-H-886	Hydrogen

BB-O-925 Cancelled	Oxygen, Technical, Gas and Liquid

National Aeronautics and Space Administration

NASA-STD-5001A	Structural Design and Test Factors of Safety for Spaceflight Hardware
NASA-STD-5009	Nondestructive Evaluation Requirements for Fracture Critical Metallic Components
NASA-STD-5019	Fracture Control Requirements for Spaceflight Hardware
NASA-STD- 6016	Standard Materials and Processes Requirements for Spacecraft
NASA-STD-8719.17	NASA Requirements for Ground-Based Pressure Vessels and Pressurized Systems (PVS)

Johnson Space Center (JSC)

PRC-0001	Process Specification for the Manual Arc Welding of Aluminum Alloy Hardware
PRD-0002 B	Process Specification for the Manual Arc Welding of Titanium Alloy Hardware
PRC-0005 F	Process Specification for the Manual Arc Welding of Carbon Steel and Nickel Alloy Hardware
PRC-0008C	Process Specification for the Qualification of Manual Arc Welders
PRC-0009 D	Process Specification for the Resistance Spot Welding of Battery and Electronic Assemblies
PRC-0010	Automatic and Machine Arc Welding of Steel and Nickel Alloy Hardware

Marshall Space Flight Center (MSFC)

MPR 8715.1	Marshall Safety, Health, and Environmental (SHE) Program
MSFC-SPEC-3679	Process Specification-Welding Aerospace Flight Hardware

A.2.2 Non-Government Documents

Aerospace Industries Association (AIA)/National Aerospace Standard (NAS)

AIA/NAS 976 (Inactive for New Design)	Electron-Beam Welding Machine—High Vacuum
AIA/NAS 1514	Radiographic Standard for Classification of Fusion Weld Discontinuities

American Society of Mechanical Engineers (ASME)

ASME B46.1	Surface Texture (Surface Roughness, Waviness, and Lay)

American Society for Testing Materials (ASTM)

ASTM E 8/E 8M	Standard Test Methods for Tension Testing of Metallic Materials

American Welding Society (AWS)

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
AWS A5.01M/A5.01	Welding Consumables—Procurement of Filler Metals and Fluxes
AWS A5.36/A5.36M:2012	Specification for Carbon and Low-Alloy Steel Flux Cored Electrodes for Flux Cored Arc Welding and Metal Cored Electrodes for Gas Metal Arc Welding
AWS B4.0	Standard Methods for Mechanical Testing of Welds
AWS C6.1	Recommended Practices for Friction Welding

AWS C7.4/C7.4 M	Process Specification and Operator Qualification for Laser Beam Welding
AWS D17.1/D17.1M:2010-AMD1	Specification for Fusion Welding for Aerospace Applications
AWS D17.2/D17.2 M	Specification for Resistance Welding for Aerospace Applications
AWS D17.3/D17.3M:2010	Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications
AWS G2.4/G2.4 M	Guide for the Fusion Welding of Titanium and Titanium Alloys

SAE International/American Material Specification (AMS)

SAE-AMS-2154	Inspection, Ultrasonic, Wrought Metals, Process For
SAE AMS 2680C-2001	Electron-Beam Welding for Fatigue Critical Applications (Reaffirmed 2010)
SAE AMS 2770J-2011	Heat Treatment of Wrought Aluminum Alloy Parts
SAE AMS-H-81200B	Heat Treatment of Titanium and Titanium Alloys
SAE AMS-W-6858A	Welding, Resistance: Spot and Seam