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Constellation Program/Ares I–X Flight Test Mission Management Office/USS IPT
National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field, OH 44135

ARES I–X UPPER STAGE SIMULATOR (USS)

FLIGHT TEST VEHICLE WELDING REQUIREMENTS

CHECK THE MASTER LIST—VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE
Distributed by AIX USS CMO on 5/20/08
For John Pokatello for reference

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Constellation Program/Ares I–X Flight Test
Upper Stage Simulator (USS) IPT
Aerospace Welding Requirements

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1.0 INTRODUCTION

1.1 Purpose

These welding requirements were developed through a consolidation of applicable NASA standards and specifications and of commercial industry codes to fabricate, inspect, and nondestructively examine carbon steel developmental Flight Test Vehicle hardware to high-quality standards in a cost-effective manner. This "hybrid" approach to the selection of applicable standards and codes has been developed to reflect best practices for the welding and nondestructive evaluation (NDE) of ≥1/8-in.-thick welded steel structures.

1.2 Scope

The aerospace welding requirements contained in this document shall be used in the design, fabrication, and inspection of the Ares I–X hardware.

1.3 Safety Policy

It is the policy of all Ares I–X Upper Stage Simulator (USS) personnel to manage and conduct operations in such a manner as to eliminate or minimize all potential hazards and to avoid accidents involving injury to personnel, damage to property, or loss of research operating time and effectiveness. Ares I–X operations, design, fabrication, and assembly will follow all applicable Federal, state, and local laws; NASA safety, health, and environmental standards and policies; and the best practices of all recognized professional organizations.

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2.0 DOCUMENTS

2.1 Applicable Documents

2.1.1 Applicable NASA Welding Specifications and Standards

Document number	Document name
NASA–STD–5006	General Fusion Welding Requirements for Aerospace Materials Used In Flight Hardware

2.1.2 Applicable Glenn Research Center Documents

Document number	Document name
GRC-P4.7	Corrective and Preventive Action

2.2 Reference Documents

2.2.1 Reference Commercial Industry Codes and Standards

Document number	Document name
AWS A5.18	Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding
AWS A5.20	Specification for Carbon Steel Electrodes for Flux-Cored Arc Welding
AWS B2.1	Specification for Welding Procedure and Performance Qualification
AWS D1.1	Structural Welding Code—Steel (Sections 1, 2, 3, 5, 6, & 7 apply, incl. Annexes A to J & Q.)
AWS D17.1	Specification for Fusion Welding for Aerospace Applications(Sections 1, 2, 3, and 8.1(1) apply).
AWS QC1	Standard for AWS Certification of Welding Inspectors
NAS 410	Nondestructive Testing Personnel Qualification and Certification

2.2.2 Reference NASA Documents

Document number	Document name
GRC-ARES-I-X-PLAN-005	Configuration and Data Management Plan (CDMP)
JSC–PRC–0005	Process Specification for the Manual Arc Welding of Carbon Steel and Nickel Alloy Hardware
MSFC–SPEC–560	The Fusion Welding of Steels, Corrosion and Heat Resisting Alloys

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3.0 REQUIREMENTS

3.1 Welding Requirements for Flight Hardware Components and Materials

The welding requirements contained herein, are a reconciled compilation of applicable commercial aerospace and steel fabrication and design Codes, and NASA Flight and non-Flight specifications and standards. This "Hybrid" Code approach implements specific sections from each of the applicable Codes to address the key AWS Code sections pertaining to the, "General Requirements, Design of Welded Connections, Qualification of Welding Procedures, Qualification of Welders Performance and Inspection" as follows:

- AWS D17.1, "Specification for Fusion Welding for Aerospace Applications" (Requirements in Sections 1, 2, 3, and 8.1(1) apply.)
- AWS D1.1, "Structural Welding Code—Steel" (Requirements in Sections 1, 2, 3, 5, 6, and 7 apply, including Annexes A to J and Q.)
- AWS B2.1, "Specification for Welding Procedure and Performance Qualification" (All requirements apply in lieu of those in Sections 4 of AWS D17.1 and AWS D1.1)

The applicable NASA specifications and standards referenced herein complement this "Hybrid" Code approach with specific NASA and aerospace industry welding requirements related to Flight and non-Flight Hardware addressing the key areas of, "aerospace weld joint classification, in-process weld repairs, weld repairs and their documentation, welding inspector certifications, dimensional requirements and welder performance joint qualification testing".

3.1.1 Structural Components to Be Welded

Flight structural components shall be designed, at a minimum, in accordance with the requirements of "Structural Welding Code—Steel," AWS D1.1, for cyclically loaded non-tubular connections.

3.1.2 Welding Materials and Materials of Construction

The materials of construction shall be well-characterized, robust standard materials listed in "Structural Welding Code—Steel," AWS D1.1, and "Specification for Fusion Welding for Aerospace Applications," AWS D17.1, and shall be joined with filler metals specified to meet the requirements noted in Appendix C (Weld Filler Metal Requirements).

3.1.3 Fillet welds for Flight Hardware

Continuous fillet welds (Flight only) shall have a minimum of 10% penetration beyond the root of the joint (10% of the fillet size) for their entire specified length. Intermittent fillet welds shall have fusion to, but not necessarily beyond the root of the joint for their entire specified length.

3.2 Welding

3.2.1 Welding Process Guidelines

- All welding shall be performed by qualified welders who will, at a minimum, be working in accordance with the following documents:
  - Welding Procedure Specification (WPS). (Current WPS's for use on Ares I–X are included in Appendix B.)
  - Released drawings (weld joint details, weld symbols, notes, etc.)

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- Surfaces to be welded shall be prepared to clean metal that is visibly free of oxide.
- Joint cleanliness and quality shall be maintained from pass-to-pass under the following guidelines:
  - All starts and stops shall be ground.
  - Complete removal of flux (slag) shall be maintained after each pass.
  - Grinding between passes, other than starts and stops, shall be kept to a minimum; however, it may be used as deemed necessary.
  - Any occurrence of undesirable features such as, but not limited to, underfill, undercut, overfill, visible slag, or craters shall be re-dressed by grinding prior to depositing a subsequent pass.

    Note: If the removal of such features requires a stringer-pass to refill the removed metal, it will be considered to be an in-process weld correction and shall be subject to the requirements of Section 3.4.2 (Number of In-Process Weld Corrections) of this document.

  - Grind all errant arc strikes.

    Note: After grinding the surrounding base material shall be examined visually by a Certified Welding Inspector (CWI), and tested by NDE magnetic particle testing (MT) by a certified inspector, utilizing approved procedures.

3.2.2 Welding Processes

Welding shall be performed utilizing "Structural Welding Code—Steel," AWS D1.1, Code-approved welding processes. Ares I–X shall use the following Code-approved welding processes:

- Flux-Cored Arc Welding (FCAW)
- Gas Tungsten Arc Welding (GTAW)
- Stud Welding
  Note: Stud Welding shall be in compliance with AWS D1.1 Section 7 (Stud Welding).

Additional code-approved welding processes may be utilized with engineering approval.

3.2.3 Welding Procedure Specifications

Welding shall be performed utilizing qualified welding procedure specifications (WPSs).

- "Structural Welding Code—Steel," AWS D1.1, Code "pre-qualified" welding procedures and joint configurations can be used where applicable, along with code-approved pre-qualified welding processes.
- Unique welding procedures shall be qualified in accordance with "Specification for Welding Procedure and Performance," AWS B2.1, utilizing code-approved welding processes.

3.2.4 Welder Performance Qualifications

Welds shall be made by welders qualified in accordance with "Specification for Welding Procedure and Performance," AWS B2.1.

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3.2.4.1 Welder Performance Qualification Mock-up Tests

Prior to performing welding on any production flight hardware at NASA Glenn Research Center (GRC) for the Ares I-X project, welders shall fabricate a weldment that is representative of the joint in production, henceforth referred to as a "Mock-up".

Mock-ups shall be performed for the following production weld joint configurations:

- Flange to Flange (F-F)
- Skin to Skin (S-S)
- Skin to Flange (S-F)

Note: If two or more of the weld joint configurations noted above are performed with the identical WPS, One mock-up test shall be acceptable, as long as that mock-up test is considered by the Welding Engineer to be the most stringent.

These Mock-ups are in addition to the welder qualifications stated in Section 3.2.4 herein. The Mock-up inspections and acceptance criteria shall be the same as those specified for production welds.

3.2.5 Weld Classifications

Welds shall be classified by engineering with respect to their safety, criticality, and consequences of failure and shall be consistent with the aerospace weld class designations—A, B, or C—defined in "Specification for Fusion Welding for Aerospace Applications," AWS D17.1; NASA–STD–5006; and NASA–SPEC–5004. Weld joint classes versus welding standards, codes, and specifications are included in Table 3.1.

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Aerospace weld joint classes	GRC Welding Manual Joint Classes[a] (flight and nonflight)	NASA–STD–5006 (flight)	NASA–SPEC–5004 (nonflight)	AWS D17.1 (flight)	AWS D1.1[b] (non-flight)	JSC–PRC–0005[c] (flight and nonflight)	MSFC–SPEC–560[d] (flight and nonflight)	Factor of safety, UTS[e] (JSC–PRC–0005)	Loading, percent of class A (MSFC–SPEC–560)
A	**A** Critical[f]	**A** Critical and structural[g]	**A** Critical and structural	**A** Critical	---	**A** Critical and structural	**I** (flight), **III** (non-flight)	<2.0	100
B	**B** Semi-critical[h]	**B** Noncritical[i] and structural	**B** Noncritical and structural	**B** Semi-critical	---	**B** Noncritical and structural	[j]**II** (flight), **IV** (non-flight)	≥2.0 and <3.5	80
C	**C1** Noncritical	**C** Noncritical, non-structural,[k] and contained	---	**C** Noncritical	---	**C** Noncritical and minor structural	---	≥3.5 and <5.0	---
	C2[l] Noncritical	---	**C** Noncritical and nonstructural	---	---	**D** Noncritical and nonstructural	**V**	≥5.0	---

[a]Extent of nondestructive testing:

- Class A welds require visual (visual testing, VT), surface (magnetic particle testing, MT, internal (ultrasonic testing (UT) and radiographic testing (RT)) examination.
- Class B welds require visual (VT) and surface (MT) examination.
- Class C1 welds require visual (VT) examination.
- Class C2 welds require only inspection to verify their type, nominal size, length, location, and that they were left in a condition exhibiting good workmanship practices. An AWS CWI is not required for class C2 welds.

[b]AWS D1.1 can be considered for flight welds if modified to reconcile differences with AWS D17.

[c]NASA Johnson Space Center.

[d]NASA Marshall Space Flight Center.

[e]UTS—ultimate tensile strength.

[f]Critical—Would result in a loss of life, mission, or spacecraft if failure occurred; no redundant load path for stress redistribution.

[g]Structural—Significant load-bearing capacity required to maintain the efficiency of a system or prevent hazard to personnel if failure occurred.

[h]Semi-critical—Considered fail-safe with a redundant load path for stress redistribution if failure occurred.

[i]Noncritical—Considered fail-safe with a redundant load path for stress redistribution if failure occurred.

[j]Internal inspection requirements of MSFC–SPEC–560 apply.

[k]Nonstructural—Minor load-bearing capacity that would not affect the efficiency of the system or create a hazard to personnel if failure occurred.

[l]Category applies to nonflight welds only.

Table 3.1—Weld joint classes versus welding standards, codes, and specifications.

3.3 Weld Joint Fit-Up Requirements and Temporary Attachments

Weld joints may be fitted, aligned, and retained in position to meet the weld joint configuration fit-up tolerances specified by the use of bars, jacks, clamps, tack welds, other means, or temporary attachments prior to and during welding.

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3.3.1 Compatibility of Temporary Attachment

- Bars, clamps, temporary attachments, and other items welded to the base metal shall be compatible with the base metal. They shall have the same AWS steel specification "group number" or "material number" given in "Structural Welding Code—Steel," AWS D1.1, and "Specification for Welding Procedure and Performance," AWS B2.1, respectively, except that a lower group or material number may be used with a higher group or material number but not vice versa.
- Such temporary attachment materials need only a Certificate of Conformance to the steel specification indicated to verify compatibility.

3.3.1 Required Welder Qualifications for Fit-Up and Temporary Attachments

Temporary attachments that are welded to components to provide stability during rigging or lifting shall utilize either "Structural Welding Code—Steel," AWS D1.1, prequalified WPSs or "Specification for Welding Procedure and Performance," AWS B2.1, qualified WPSs and shall be made by qualified welders.

3.3.2 Removal of Temporary Attachments

When no longer required, the temporary attachment shall be removed by grinding or other mechanical means without causing damage to the base metal. The temporary attachment removal area shall be ground to blend uniformly with the surrounding base material and shall be examined visually and by NDE by magnetic particle testing (MT) by certified inspection and NDE personnel utilizing approved procedures.

3.3.3 Final Surface Requirements - After Removal of Temporary Attachments

The surface shall be visibly free of cracks, undercut, arc strikes, and any other surface defects. Any defects more than 1/32 in. in depth that cannot be completely removed shall be documented on a corrective and preventative action report (CPAR) to be evaluated by engineering per GRC-P4.7 "Corrective and Preventive Action".

3.4 In-Process Weld Corrections

An "In-Process Weld Correction", as used in this document, is defined as "a need to deposit an additional weld pass in order to correct a partially welded joint that has been re-ground to correct or eliminate a potential flaw that has been detected by the welder, a CWI, a NDE inspector, or the Welding Supervisor.

3.4.1 In-Process Weld Inspection

"In-Process Inspection", as used in this document, is defined as "an inspection that is performed by the welder, a CWI, a NDE inspector or the Welding Supervisor, and are preformed to aid in the prevention of carrying a potential "flaw" through the weld process and there-by create a rejection during final inspection. The flaw is to have been detected by a means other than that of the final required inspection."

3.4.2 Number of In-Process Weld Corrections

The number of In-Process weld corrections shall be limited by the Weld Class as defined in Table 3.1, and shall apply as noted below.

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- Class A welds shall be corrected only once per linear heat affected area.
- Class B welds may be corrected up to two times per linear heat affected area.
- Class C welds may be corrected in-process as many times as necessary.

Note: A linear heat affected area is defined as: "the total weld length of a previous weld correction plus four (4) inches to each end of that weld correction.

3.4.3 In-Process Weld Correction Process

In-process weld defects shall be removed by approved means to sound metal and verified with the inspection method by which they were originally found. The unacceptable portions of the weld shall be either locally repaired or entirely replaced and re-welded by qualified welders utilizing a qualified WPS.

- Excessive weld metal shall be removed by approved means in the cases of overlap, excessive convexity, and excessive reinforcement.
- Weld surfaces shall be mechanically cleaned and prepared to accommodate the deposition of additional weld metal for undersized welds, undercut welds, and welds with excessive concavity or crater size.
- Excessive amounts of weld porosity or slag inclusions and any amount of incomplete fusion shall be removed by approved means, and the area shall be re-welded.
- When cracks and /or linear defects are revealed, there extent shall be ascertained with MT, or other equally positive means. Subsequently, the defect and sound metal 2 in. beyond each end of the defect shall be removed, and the area shall be re-welded.
- If the in-process correction is not satisfactory, the weld correction technique shall be referred to the Material Review Board (MRB) for review and disposition before proceeding.

3.5 Final Weld Inspection

"Final Weld Inspection", as used in this document, is defined as "an inspection that is performed after all welding, on the weld length to be inspected, is deemed, by the Welding Supervisor, or a designated CWI, to be complete.

Surfaces to be inspected shall be free of paint, rust, oil, grease weld spatter or any other surface contamination that would interfere with a proper inspection.

3.5.1 Inspection Type Determined by Weld Class

The minimum level of inspection for each weld shall be in accordance with that specified for its weld class. The weld class shall be assigned by Engineering and shall be noted on the weldment drawing. Weld joint classes versus required inspections are included in Table 3.2.

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Aerospace weld joint classes	GRC Welding Manual Joint Classes (flight and nonflight)	Internal examination	Surface examination	Visual examination	Workmanship verification	Layer-by-layer surface examination in lieu of internal examination
A	**A** Critical[a]	UT/RT	MT	VT	---	Contact engineering for approval
B	**B** Semi-critical[b]	---	MT	VT	---	**---**
C	**C1** Noncritical	---	---	VT	---	**---**
	C2[c] Noncritical[d]	---	---	---	(e)	**---**

[a]Critical—Would result in a loss of life, mission, or spacecraft if failure occurred; no redundant load path for stress redistribution.

[b]Semi-critical—Considered fail-safe with a redundant load path for stress redistribution if failure occurred.

[c]Class C2 applies to nonflight welds only.

[d]Noncritical—Considered fail-safe with a redundant load path for stress redistribution if failure occurred.

[e]Class C2 welds require inspection only to verify their type, nominal size, length, location, and that they were left in a condition exhibiting good workmanship practices. The shop welding lead may perform this inspection. An AWS Certified Welding Inspector (CWI) is not required for class C2 welds.

Table 3.2—Weld joint classes versus required inspections.

3.5.2 Acceptance Criteria

The acceptance criteria for flight hardware visual weld inspection and nondestructive testing shall be in accordance with that stated in "Structural Welding Code—Steel," AWS D1.1, for cyclically loaded non-tubular connections.

3.5.3 Qualifications of Inspectors

- NDE personnel shall be qualified to inspect flight hardware in accordance with "Nondestructive Testing Personnel Qualification and Certification," NAS 410.
- Visual weld inspection shall be performed by CWI's (Certified Welding Inspector) in conformance with the provisions of "Standard for AWS Certification of Welding Inspectors," AWS QC1.
- In-process informational weld inspections shall take place as specified by engineering, the Welding Engineer or the welder, and shall be performed by certified inspection and/or NDE personnel. Inspection of each groove weld layer with a surface weld inspection method and/or inspection of a groove weld root layer and hot pass layer with an internal weld inspection method are typical examples of in-process informational weld inspections.

3.6 Weld Repair

A "Weld Repair", as used in this document, is defined as "a repair that is deemed necessary to correct a flaw that has been detected during "Final Weld Inspection". Weld defects revealed during final inspection shall be documented on a corrective and preventative action report (CPAR) to be evaluated by engineering in accordance with the project configuration and data management plan. All weld repairs are to be performed to an approved and signed "Weld Repair Procedure"

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3.6.1 Documentation of Weld Repairs

The weld repair shall be subject to the inspection methods and acceptance criteria for the original weld. The defective areas shall be documented in the CPAR and, shall also be identified in the appropriate GRC-ARES-I-X-RPT-XXX Weldment Inspection Record.

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APPENDIX A—ACRONYMS

CPAR	corrective and preventative action report
CWI	Certified Welding Inspector
FCAW	Flux-Cored Arc Welding
F-F	Flange to Flange
GRC	NASA Glenn Research Center
GTAW	Gas Tungsten Arc Welding
JSC	NASA Johnson Space Center.
MRB	Material Review Board
MSFC	NASA Marshall Space Flight Center
MT	magnetic particle testing
NDE	nondestructive evaluation
RT	radiographic testing
S-F	Skin to Flange
S-S	Skin to Skin
USS	Upper Stage Simulator
UT	ultrasonic testing
UTS	ultimate tensile strength
VT	visual testing
WPS	Welding Procedure Specification

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APPENDIX B—WELDING PROCEDURES SPECIFICATIONS (WPS)

All weld procedure specifications are under Ares I–X USS Configuration Management Office (CMO). To obtain a copy of a WPS listed below see Ares I–X USS CMO.

AWS TF.1-1.3.1 Flange to Flange Double V Groove (GTAW root – FCAW)

Skin to Skin Double V Groove (GTAW root – FCAW)

AWS F.1-1.5.1 Flange to Skin Double Bevel Groove (FCAW)

AWS F.1-1.f.1 Fillet Weld (FCAW)

AWS T.1-1.2 V Groove (GTAW)

AWS F.1-1.6.1 Flare Bevel, Flare V (FCAW)

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AWS B2.1

WELDING PROCEDURE SPECIFICATION (WPS) Yes ☒
PREQUALIFIED _____ QUALIFIED BY TESTING _____
or PROCEDURE QUALIFICATION RECORDS (PQR) Yes ☐

Identification # AWS F.1-1.5.1
Revision 0 Date 8/7/07 By S. Angelone
Company Name NASA Glenn Research Center Authorized by J. Jackson Date 8/7/08
Welding Process(es) FCAW Type—Manual ☐ Semi-Automatic ☒
Supporting PQR No.(s) AWS F.1-1.3.1 Machine ☐ Automatic ☐

JOINT DESIGN USED
Type: Double-Bevel Groove (Corner Joint) and Fillets
Single ☐ Double Weld ☒
Backing: Yes ☒ No ☐
Backing Material: Weld Metal
Root Opening 1/8-3/16" Root Face Dimension 0-1/32"
Groove Angle: 45° Radius (J–U) N/A
Back Gouging: Yes ☒ No ☐ Method _____
CAC-A and/or Grinding

BASE METALS
Material Spec. M1 Group 2 to M1 Group 2
Type or Grade (A516 Grade 70 to A516 Grade 70)
Thickness: Groove 3/16-1 1/2 Fillet Unlimited
Diameter (Pipe) N/A

FILLER METALS
AWS Specification A5.20
AWS Classification E71T-1M (F-No.6)
Deposit Thickness (Maximum) - 1 1/2"

SHIELDING
Flux None Gas Argon(Ar)-CO_2
Composition 75%-25%
Electrode-Flux (Class) N/A Flow Rate 35-50 CFH
Gas Cup Size 1/2"-3/4"

PREHEAT
Preheat Temp., Min 50°F
Interpass Temp., Min 50°F Max 400°F

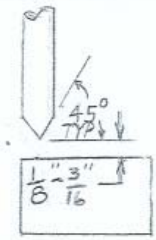
POSITION
Position of Groove: All Fillet: All
Vertical Progression: Up ☒ Down ☐

ELECTRICAL CHARACTERISTICS
Transfer Mode (GMAW) Short-Circuiting ☐ Globular ☐ Spray ☒
Current: AC ☐ DCEP ☒ DCEN ☐ Pulsed ☐
Other _____
Tungsten Electrode (GTAW)
Size: None
Type: N/A

TECHNIQUE
Stringer or Weave Bead: Stringer
Multi-pass or Single Pass (per side) Multi-pass
Number of Electrodes Single
Electrode Spacing Longitudinal None
Lateral N/A
Angle N/A
Contact Tube to Work Distance 5/8"-3/4"
Peening Not Allowed
Interpass Cleaning: Chip, brush, grind
*Maximum Bead Width - 1/2"

POSTWELD HEAT TREATMENT
Temp. None
Time N/A

WELDING PROCEDURE

Pass or Weld Layer(s)	Process	Filler Metals Class	Filler Metals Diam.	Current Type & Polarity	Current Amps or Wire Feed Speed	Volts	*MAX BEAD WIDTH ~~Travel Speed~~	Joint Details
All	FCAW	E71T-1M	0.045"	DCEP	280-380 (IPM) (170-275 AMPS)	24-27	1/2"	

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AWS B2.1

WELDING PROCEDURE SPECIFICATION (WPS) Yes ☒
PREQUALIFIED _____ QUALIFIED BY TESTING X
or PROCEDURE QUALIFICATION RECORDS (PQR) Yes ☐

Identification # AWS F.1-1.6.1
Revision 0 Date 8-22-07 By S. ANZALONE
Company Name NASA Glenn Research Center Authorized by J. Jackson Date 8-22-07
Welding Process(es) FCAW Type—Manual ☐ Semi-Automatic ☒
Supporting PQR No.(s) AWS TF.1-1.3.1 Machine ☐ Automatic ☐

JOINT DESIGN USED
Type: Flare-Bevel, Flare-V
Single ☒ Double Weld ☐
Backing: Yes ☐ No ☒
Backing Material:
Root Opening 0-1/8" Root Face Dimension N/A
Groove Angle: N/A Radius (J–U) N/A
Back Gouging: Yes ☐ No ☒ Method N/A

BASE METALS
Material Spec. M1 Groups 1&2 to M1 Groups 1&2
Type or Grade (A500, A106, A36)
Thickness: Groove 1½" max Fillet N/A
Diameter (Pipe) N/A

FILLER METALS
AWS Specification A5.20
AWS Classification E71T-1M

SHIELDING
Flux None Gas Argon – CO_2
Composition 75%-25%
Electrode-Flux (Class) N/A Flow Rate 35 - 45 CFH
Gas Cup Size ½"-¾"

PREHEAT
Preheat Temp., Min 50°F
Interpass Temp., Min 50°F Max 400°F

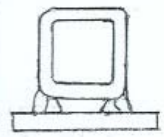
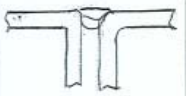
POSITION
Position of Groove: All Fillet: N/A
Vertical Progression: Up ☒ Down ☐

ELECTRICAL CHARACTERISTICS
Transfer Mode (GMAW) Short-Circuiting ☐ Globular ☐ Spray ☒
Current: AC ☐ DCEP ☒ DCEN ☐ Pulsed ☐
Other
Tungsten Electrode (GTAW)
Size: None
Type: N/A

TECHNIQUE
Stringer or Weave Bead: *Weave (V-only) *Stringer (F,H,OH)
Multi-pass or Single Pass (per side) Multi-pass
Number of Electrodes Single
Electrode Spacing Longitudinal None
Lateral N/A
Angle N/A
Contact Tube to Work Distance ½" - 5/8"
Peening Not Allowed
Interpass Cleaning: Power wire brush, brush, chip, grind
*Maximum bead width - ½"

POSTWELD HEAT TREATMENT
Temp. None
Time N/A

WELDING PROCEDURE *Maximum Bead width

Pass or Weld Layer(s)	Process	Filler Metals Class	Filler Metals Diam.	Current Type & Polarity	Current Amps or Wire Feed Speed	Volts	Travel Speed	Joint Details
Root	FCAW	E71T-1M	0.045	DCEP	170-200 AMPS (280-300 IPM)	23.5 to 25.5	½" MAX	
Fill	FCAW	E71T-1M	0.045	DCEP	Same as Above	Same as Above	Same as Above	

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ANNEX N

AWS D1.1/D1.1M:2006

WELDING PROCEDURE SPECIFICATION (WPS) Yes ☒
PREQUALIFIED _____ **QUALIFIED BY TESTING** Yes
or PROCEDURE QUALIFICATION RECORDS (PQR) Yes ☐

Identification # AWS F.1-1.f.1
Revision 0 Date 6-29-07 By S. ANZALONE
Company Name NASA Glenn Research Center Authorized by J. Jackson Date 7-2-07
Welding Process(es) FCAW Type—Manual ☐ Semi-Automatic ☒
Supporting PQR No.(s) AWS TF.1-1.3.1 Machine ☐ Automatic ☐

JOINT DESIGN USED
Type: Fillets
Single ☐ Double Weld ☐
Backing: Yes ☐ No ☐
Backing Material:
Root Opening 0-1/16" Root Face Dimension N/A
Groove Angle: N/A Radius (J–U) N/A
Back Gouging: Yes ☐ No ☒ Method N/A

POSITION
Position of Groove: N/A Fillet: All
Vertical Progression: Up ☒ Down ☐

ELECTRICAL CHARACTERISTICS
Transfer Mode (GMAW) Short-Circuiting ☐ Globular ☐ Spray ☒
Current: AC ☐ DCEP ☒ DCEN ☐ Pulsed ☐
Other
Tungsten Electrode (GTAW)
Size: None
Type: N/A

BASE METALS
Material Spec. M1 Group 2 to M1 Group 2
~~Type or Grade~~ (A516 Grade 70 to A516 Grade 70)
Thickness: Groove N/A Fillet All
Diameter (Pipe) N/A

TECHNIQUE
Stringer or Weave Bead: Stringers-(F,H,OH) *Weave -(V)
Multi-pass or Single Pass (per side) Multi-pass
Number of Electrodes Single
Electrode Spacing Longitudinal None
Lateral N/A
Angle N/A

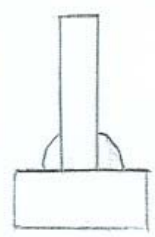
FILLER METALS
AWS Specification A5.20
AWS Classification E71T-1M

SHIELDING
Flux None Gas Argon - CO_2
Composition 75-25
Electrode-Flux (Class) N/A Flow Rate 35-45
Gas Cup Size 1/2-3/4
Contact Tube to Work Distance 1/2" - 5/8"
Peening Not Allowed
Interpass Cleaning: Power Wire Brush, Brush, Chip, Grind
*Maximum bead width - 1/2" Fillet

PREHEAT
Preheat Temp., Min 50°F
Interpass Temp., Min 50°F Max 400°F

POSTWELD HEAT TREATMENT
Temp. None
Time N/A

WELDING PROCEDURE

Pass or Weld Layer(s)	Process	Filler Metals Class	Filler Metals Diam.	Current Type & Polarity	Current Amps or Wire Feed Speed	Volts	Maximum bead width ~~Travel Speed~~	Joint Details
1	FCAW	E71T-1M	0.045"	DCEP	170-200A (280-300 IPM)	23.5 to 25.5	1/2" Fillet Max	

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ANNEX N

AWS B2.1

WELDING PROCEDURE SPECIFICATION (WPS) Yes ☒
PREQUALIFIED _____ QUALIFIED BY TESTING X
or PROCEDURE QUALIFICATION RECORDS (PQR) Yes ☐

Identification # AWS T.1-1.2
Revision 0 Date 6-29-07 By S. ANZALONE
Company Name NASA Glenn Research Center Authorized by J. Jackson Date 7-2-07
Welding Process(es) GTAW Type—Manual ☒ Semi-Automatic ☐
Supporting PQR No.(s) AWS TF.1-1.3.1 Machine ☐ Automatic ☐

JOINT DESIGN USED
Type: V-Groove
Single ☒ Double Weld ☐
Backing: Yes ☐ No ☒
Backing Material:
Root Opening 0-1/8 Root Face Dimension 0-1/8"
Groove Angle: 60-70° Radius (J–U) N/A
Back Gouging: Yes ☐ No ☒ Method N/A

POSITION
Position of Groove: All Fillet: N/A
Vertical Progression: Up ☒ Down ☐

ELECTRICAL CHARACTERISTICS
Transfer Mode (GMAW) Short-Circuiting ☐ Globular ☐ Spray ☐
Current: AC ☐ DCEP ☐ DCEN ☒ Pulsed ☐
Other
Tungsten Electrode (GTAW)
Size: 3/32" - 1/8"
Type: EWTh-2

BASE METALS
Material Spec. M1 Group 2 to M1 Group 2
~~Type or Grade~~ A516 Grade 70 to A516 Grade 70
Thickness: Groove 1 1/2" Fillet N/A
Diameter (Pipe) All

TECHNIQUE
Stringer or Weave Bead: Stringer
Multi-pass or Single Pass (per side) Multi-pass
Number of Electrodes Single
Electrode Spacing Longitudinal None
Lateral N/A
Angle N/A

FILLER METALS
AWS Specification A5.18
AWS Classification ER70S-2
Weld Metal Thickness Deposited-1/2" max

SHIELDING
Flux None Gas Argon
Composition 100%
Electrode-Flux (Class) N/A Flow Rate 18-24
Gas Cup Size 5-10

Contact Tube to Work Distance N/A
Peening Not Allowed
Interpass Cleaning: Power Wire Brush, Brush, Grind

PREHEAT
Preheat Temp., Min 50°F
Interpass Temp., Min 50°F Max 400°F

POSTWELD HEAT TREATMENT
Temp. None
Time N/A

WELDING PROCEDURE

Pass or Weld Layer(s)	Process	Filler Metals		Current		Volts	Travel Speed	Joint Details
		Class	Diam.	Type & Polarity	Amps ~~or Wire Feed Speed~~			
Root	GTAW	ER70S-2	3/32-1/8	DCEN	180-240	20-24	N/A	
Balance	GTAW	"	"	"	"	"	"	

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AWS B2.1

WELDING PROCEDURE SPECIFICATION (WPS) Yes ☒
PREQUALIFIED — **QUALIFIED BY TESTING** X
or PROCEDURE QUALIFICATION RECORDS (PQR) Yes ☐

Identification # WPS # AWS TF.1-1.3.1
Revision 1 Date 8/10/07 By S. ANZALONE
Authorized by J. Jackson Date 8/10/07
Type—Manual ☒ (GTAW) Semi-Automatic ☒ (FCAW)
Machine ☐ Automatic ☐

Company Name NASA Glenn Research Center
Welding Process(es) GTAW / FCAW
Supporting PQR No.(s) AWS TF.1-1.3.1

JOINT DESIGN USED
Type: Double V-Groove Butt
Single ☐ Double Weld ☒
Backing: Yes ☐ No ☒
Backing Material:
Root Opening 3/32-1/8" Root Face Dimension 0.0"
Groove Angle: 90° max Radius (J–U) N/A
Back Gouging: Yes ☐ No ☒ Method N/A

POSITION
Position of Groove: All Fillet: N/A
Vertical Progression: Up ☒ Down ☐

ELECTRICAL CHARACTERISTICS
Transfer Mode (GMAW) (FCAW) Short-Circuiting ☐ Globular ☐ Spray ☐
Current: AC ☐ DCEP ☒ DCEN ☒ (GTAW) Pulsed ☐
Other
Tungsten Electrode (GTAW)
Size: 3/32" - 1/8"
Type: EWTh-2

BASE METALS
Material Spec. M1 Group 2 to M1 Group 2
~~Type or Grade~~ (A516 Grade 70 to A516 Grade 70)
Thickness: Groove 3/16"-1½" Fillet N/A
Diameter (Pipe) N/A

FILLER METALS

AWS Specification	A 5.18	A5.20
AWS Classification	ER70S-2	E71T-1M
Deposit Thickness (Maximum)	½"	1"

TECHNIQUE
Stringer or Weave Bead: Stringers*
Multi-pass or Single Pass (per side) Multipass
Number of Electrodes Single
Electrode Spacing Longitudinal N/A
Lateral N/A
Angle N/A

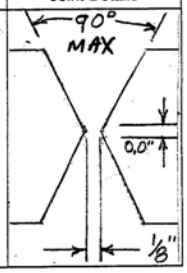
SHIELDING
Flux None
Gas Argon (Ar) | $ArCO_2$
Composition 100% | 75-25%
Electrode-Flux (Class) N/A
Flow Rate 18-24 | 35-45
Gas Cup Size 5-10 | ½-¾"

Contact Tube to Work Distance ½" - 5/8" (FCAW)
Peening None
Interpass Cleaning: Power Wire Brush, Brush, Chip, Grind
*Maximum Bead Width - ¼" (GTAW), ½" (FCAW)

PREHEAT
Preheat Temp., Min 50°F
Interpass Temp., Min 50°F Max 400°F

POSTWELD HEAT TREATMENT
Temp. None
Time N/A

WELDING PROCEDURE *Maximum

Pass or Weld Layer(s)	Process	Filler Metals Class	Filler Metals Diam.	Current Type & Polarity	Current Amps or Wire Feed Speed	Volts	Bead Width ~~Travel Speed~~	Joint Details
Root 1	GTAW	ER70S-2	3/32"-1/8"	DCEN	205-225 A	22-23	¼"	
Pass 2	GTAW	ER70S	3/32"-1/8"	DCEN	220-240 A	23-24	¼"	
Fill	FCAW	E71T-1M	0.045	DCEP	170-200 A (280-300 IPM)	23.5 to 25.5	½"	

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APPENDIX C – WELD FILLER METAL REQUIREMENTS

Requirements For Dual Certified E71T-1M / E71T-12M Flux Cored Arc Weld (FCAW) Filler Metal.

0.045 Inch Diameter

Welded with 75% Argon + 25% CO2

Supplier must provide a CMTR (Certified Material Test Report) for the specific lot of weld wire supplied to the above requirements. This CMTR must document welding parameters and test results complying with each of the following criteria.

Chemistry As Deposited:

C Max 0.12%
Mn Max 1.60%
Si Max 0.90%
S Max 0.03%
P Max 0.03%
Cr Max 0.20%
Ni Max 0.50%
Mo Max 0.30%
V Max 0.08%
Cu Max 0.35%

Radiographic:

One test sample prepared according to Figure 3 Page 9 with weld backup and weld reinforcement removed..

Radiographic quality level 2-2T in accordance with ASTM E 1032 reference AWS A5.20 Figure 8 Page 18 for descriptions of indications.

Tension Testing:

Ultimate Calculated Tensile: 85,000 PSI

Minimum Calculated Yield: 77, 000 PSI

Minimum Elongation: 22%

Impact Testing:

Five full size Charpy V-Notch impact specimens to meet the requirements of AWS B4.0. Lowest and highest test values to be disregarded. Two of the middle three test values to exceed the specified 110 ft lbf and the lowest of the middle three not to be less than 90 ft lbf. The average of the middle three to exceed 110 ft-lb at –20 Degrees F.

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For John Pokatello for reference

Fillet Weld:

Two fillet weld test assemblies per Figure 5 Page 11. One welded vertical up and the other welded in the overhead position. The entire face of the fillet welds to be examined visually for cracks, undercut, overlap, trapped slag, and surface porosity. After passing visual examination a one inch wide specimen is to be cut from each of the two fillet weld test assemblies and polished and macro etched on one side. Scribe lines per Figure 6 will be used to determine leg lengths and convexity. Table 7 will be referred to in determining if the maximum convexity or difference in weld leg lengths has been exceeded.

The remaining two sections of the test assembly shall be broken longitudinally through the fillet weld per Figure 7C. The fractured surfaces shall be free of cracks and reasonable free of porosity and trapped slag. Incomplete fusion shall be less than 20% of the total length of the weld.

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Requirements For ER70S-2

Gas Tungsten Arc Weld (GTAW) Filler Metal.

Welded with 100% Argon

1/8" (0.125") Diameter

Supplier must provide a CMTR (Certified Material Test Report) for the specific lot of weld wire supplied to the above requirements. This CMTR must document welding parameters and test results complying with each of the following criteria.

Chemistry Of Rod:

C Max 0.07%
Mn 0.90 to 1.40%
Si 0.40 to 0.70%
S Max 0.035%
P Max 0.025%
Cr Max 0.15%
Ni Max 0.15%
Mo Max 0.15%
V Max 0.03%
Cu Max 0.50%
Ti 0.05 to 0.15%
Zr 0.02 to 0.12%
Al 0.5 to 0.15%

Radiographic:

One test sample prepared according to Figure 1 Page 6 with weld backup and weld reinforcement removed.

Radiographic quality level 2-2T in accordance with ASTM E 1032 reference AWS A5.18 Figure 4 Page 10 for descriptions of indications.

Tension Testing:

Ultimate Calculated Tensile: 87,500 PSI
Minimum Calculated Yield: 74,000 PSI
Minimum Elongation: 30%

Impact Testing:

Five full size Charpy V-Notch impact specimens to meet the requirements of AWS B4.0. Lowest and highest test values to be disregarded. Two of the middle three test values to exceed the specified 150 ft lbf and the lowest of the middle three not to be less than 120 ft lbf. The average of the middle three to exceed 150 ft-lb at –20 Degrees F

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