National Aeronautics and
Space Administration

**METRIC/
INCH-POUND**

**NASA-SPEC-5004A
AUGUST 25, 2003**

WELDING OF AEROSPACE GROUND SUPPORT EQUIPMENT AND RELATED NONCONVENTIONAL FACILITIES

NASA TECHNICAL SPECIFICATION

APPROVED FOR PUBLIC RELEASE – DISTRIBUTION UNLIMITED

DOCUMENT HISTORY LOG, NASA-STD-5004A

Status (Baseline/ Revision/ Canceled)	Document Revision	Effective Date	Description
Baseline		2-2-1999	Baseline Release
Revision	A	8-25-2003	Revised as indicated below
			Revision consist of updates to office codes, update information concerning viewing and downloading NASA Standards, updating Applicable Documents, and minor editorial changes.

This Page Left Blank Intentionally

FOREWORD

This specification is approved for use by NASA Headquarters and all NASA Centers and is intended to provide a common framework for consistent practices across NASA programs.

This specification was developed to establish uniform engineering practices and methods and to ensure the inclusion of essential criteria in the welding of ground support equipment (GSE) used by or for NASA. The specification was prepared by the intercenter committee on materials and processes and approved by the Engineering Management Council (EMC). This specification is applicable to GSE that supports space vehicle or payload programs or projects and to critical nonconventional facilities, where applicable.

This specification establishes preferred practices for the welding of GSE used by or for NASA programs and projects. This specification is recommended for the design of nonflight hardware used to support the operations of receiving, transportation, handling, assembly, inspection, test, checkout, service, and launch of space vehicles and payloads at NASA launch, landing, or retrieval sites. These criteria and practices may be used for items used at the manufacturing, development, and test sites upstream of the launch, landing, or retrieval sites.

This specification may be cited in contracts and program documents as a technical requirement or as a reference for guidance. Determining the suitability of this specification and its provisions is the responsibility of program/project management and the performing organization. Individual provisions of this specification may be tailored (i.e., modified or deleted) by contract or program specifications to meet specific program/project needs and constraints.

Requests for information, corrections, or additions to this specification should be directed to the Spaceport Engineering and Technology Directorate, Mail Code: YA, John F. Kennedy Space Center, Florida 32899, using the form attached at the end of this specification. Requests for general information concerning NASA Technical Standards should be sent to the NASA Technical Standards Program Office, ED41, MSFC, AL, 35812 (telephone 256-544-2448). This and other NASA standards may be viewed and downloaded, free-of-charge from our NASA Standards Home Page: http://standards.nasa.gov/.

Original signed by:

Theron M. Bradley, Jr.
NASA Chief Engineer

This Page Left Blank Intentionally

TABLE OF CONTENTS

PARAGRAPH		PAGE
	DOCUMENT HISTORY LOG	i
	FOREWORD	iii
	TABLE OF CONTENTS	v
	LIST OF TABLES AND APPENDICES	viii
1.	SCOPE	1
1.1	Scope	1
1.2	Purpose	1
1.3	Applicability	1
2.	APPLICABLE DOCUMENTS	2
2.1	General	2
2.2	Government documents	2
2.3	Non-Government publications	3
2.4	Order of precedence	4
3.	DEFINITIONS AND ACRONYMS	5
3.1	General	5
3.1.1	Nonconventional facilities (including equipment)	5
3.1.2	Acronyms and abbreviations used in this specification	5
4.	DESIGN REQUIREMENTS	6
4.1	General	6
4.2	Weld classifications	6
4.2.1	Structural welding	6
4.2.1.1	Structural welding design	6
4.2.1.2	Structural welding inspection	6
4.2.2	Crane and other material handling equipment	7
4.2.2.1	Crane and other material handling equipment weld design	7
4.2.2.2	Crane and other material handling equipment weld inspection	7
4.2.3	Piping and tubing design and inspection	7
4.2.3.1	Normal fluid service	7
4.2.3.2	Severe cyclic conditions	7
4.2.3.3	Category M fluid service	7
4.2.3.4	High-pressure fluid service	7
4.2.3.5	Category D fluid service	8
4.3	Classification of weld reinspection	8
4.4	Materials	8
4.4.1	Base metals	8
4.4.1.1	Structural welding	8
4.4.1.2	Crane and other material handling equipment welding	8
4.4.1.3	Piping and tubing welding	8

TABLE OF CONTENTS (CONT'D)

PARAGRAPH		PAGE
4.4.2	Filler metals	8
4.4.2.1	Structural welding	8
4.4.2.2	Crane and other material handling equipment welding	8
4.4.2.3	Piping and tubing welding	12
4.4.2.4	Dissimilar metal welding	12
4.4.3	Consumable inserts	12
4.4.4	Backing rings	12
4.5	Heating requirements	12
4.5.1	Preheating	12
4.5.1.1	Carbon steel and low alloy steel	12
4.5.1.2	Stainless steel and nickel alloys	12
4.5.1.3	Aluminum alloys	12
4.5.2	Postweld heating	13
4.5.2.1	Carbon steel and low alloy steel	13
4.5.2.2	Stainless steel and nickel alloys	13
4.5.2.3	Aluminum alloys	13
4.6	Data required in design and fabrication documentation	13
5.	FABRICATION REQUIREMENTS	14
5.1	General	14
5.2	Calibration	14
5.3	Materials	14
5.3.1	Material certification	14
5.3.2	Filler metals	14
5.3.3	Consumable inserts	14
5.3.4	Backing rings	14
5.3.5	Tungsten electrodes	14
5.3.6	Shielding gases	14
5.3.7	Purging gases	14
5.3.8	Antispatter compounds	14
5.4	Welding procedure and welder/welding operator performance qualifications	15
5.4.1	Welding procedure qualification	15
5.4.2	Welder/welding operator performance qualification	15
5.5	Preweld operations	16
5.5.1	Cleaning requirements	16
5.5.2	Cleaning technique	16
5.6	Production welding	16
5.6.1	Preheating and interpass heating	16
5.6.1.1	Carbon steel and low alloy steel	16
5.6.1.2	Stainless steel and nickel alloys	16
5.6.1.3	Aluminum alloys	16

TABLE OF CONTENTS (CONT'D)

PARAGRAPH		PAGE
5.6.2	Use of purging gas	17
5.6.3	Tack welds	17
5.6.4	Weld bead initiation and termination	17
5.6.5	Back gouging	17
5.6.6	Identification of welds	17
5.6.7	Postweld heating	17
5.6.7.1	Carbon steel and low alloy steel	17
5.6.7.2	Stainless steel and nickel alloys	17
5.6.7.3	Aluminum alloys	18
5.6.8	Postweld cleaning	18
5.7	Welding repairs	18
5.7.1	Defect removal	18
5.7.2	Repair procedure	18
5.7.3	Repair records	18
6.	INSPECTION AND TESTING REQUIREMENTS	18
6.1	Inspection and testing	18
6.1.1	Responsibility for inspection and testing	18
6.1.2	Inspection and testing techniques	18
6.1.3	Visual inspection acceptance criteria	18
6.1.4	NDT acceptance criteria	18
6.1.5	Additional inspection and testing	19
6.2	Certified welding inspector	19
6.3	Qualification of NDT personnel	19
6.4	Preweld and welding inspection	19
6.5	Postweld inspection	19
6.5.1	Visual inspection	19
6.5.1.1	Structural welds	20
6.5.1.2	Crane and other material handling equipment welds	20
6.5.1.3	Piping and tubing welds	20
6.5.2	Nondestructive testing	20
6.5.2.1	Structural welds	20
6.5.2.1.1	Class A inspection	20
6.5.2.1.2	Class B inspection	20
6.5.2.1.3	Class C inspection	20
6.5.2.2	Crane and other material handling equipment welds	20
6.5.2.2.1	Primary welds (Class A)	20
6.5.2.2.2	Secondary welds (Class B)	20
6.5.2.2.3	Secondary welds (Class C)	21
6.5.2.3	Piping and tubing welds	21
6.5.2.3.1	Normal fluid service	21

TABLE OF CONTENTS (CONT'D)

PARAGRAPH		PAGE
6.5.2.3.2	Severe cyclic conditions	21
6.5.2.3.3	Category M fluid service	21
6.5.2.3.4	High-pressure fluid service	21
6.5.2.3.5	Category D fluid service	21
6.5.2.3.6	In-process examination for automatic gas tungsten arc welding (GTAW)	21
6.5.2.4	Alternate NDT methods	22
6.5.2.5	Etching for PT	22
6.5.3	Inspection records	22
7.	NOTES	23
7.1	Intended use	23

LIST OF TABLES

TABLE		PAGE
I.	Applicable Welding Codes	6
II.	Allowable Stainless Steel Base Metal and Filler Metal Combinations	9
III.	Allowable Nickel Alloy Base Metal and Filler Metal Combinations	10
IV.	Filler Metal Requirements for Aluminum Piping and Tubing	11
V.	Modified Invar 36 Filler Metal Composition	12
VI.	Recommended Filler Metals for Selected Dissimilar Metal Combinations	13
VII.	Shielding and Purging Gases	15

APPENDICES

APPENDIX		PAGE
A	Recommended ANSI/AWS Publications	25

WELDING OF AEROSPACE GROUND SUPPORT EQUIPMENT AND RELATED NONCONVENTIONAL FACILITIES

1. SCOPE

1.1 Scope. This specification establishes the minimum requirements for the design, fabrication (including the qualification of welders, welding operators, and welding procedures), and inspection of manual, semiautomatic, and automatic welds in aerospace ground support equipment (GSE) and related nonconventional facilities used by or for the National Aeronautics and Space Administration (NASA) with the exclusion of pressure vessels.

1.2 Purpose. This specification was developed to establish uniform practices for the design, fabrication, and inspection (including nondestructive testing [NDT] techniques and acceptance criteria) of welds in GSE and related nonconventional facilities used by or for NASA and provides a means to incorporate into these uniform practices the “lessons learned” from extensive agency wide GSE welding engineering experiences. This specification accomplishes these goals by combining the requirements of consensus industrial welding codes with supplementary requirements as necessary. Some examples are: provisions for verification of procedure and performance qualifications; imposing requirements for NDT; imposing requirements for inspection personnel qualifications, additional welding technique requirements, and requirements for material certifications.

1.3 Applicability. This specification recommends engineering practices for NASA programs and projects. It may be cited in contracts and program documents as a technical requirement or as a reference for guidance. It may be cited on engineering drawings. Determining the suitability of this specification and its provisions is the responsibility of program/project management and the performing organization. Individual provisions of this specification may be tailored (i.e., modified or deleted) by contract or program specifications to meet specific program/project needs and constraints.

This specification applies to the design, fabrication, inspection, and maintenance of aerospace GSE and related nonconventional facilities with the exclusion of pressure vessels used to support the operations of transporting, receiving, handling, assembly, inspection, test, checkout, service, and launch of space vehicles and payloads. The current revision of this specification shall be applicable to the design, fabrication, inspection, and maintenance of all GSE and related nonconventional facilities. The revision of this specification that was current at the time direction was issued to design, construct, manufacture, or procure the GSE or facility shall be applicable for the useful life of the hardware. Modifications and repair of existing hardware may be done so the modified/repaired hardware complies with the revision that is current at the time directions are issued to modify/repair the hardware.

Section 4, Design Requirements, of this specification contains requirements for the design engineer. Section 5, Fabrication Requirements, and Section 6, Inspection and Testing Requirements, of this specification contain requirements for the contractor performing qualification welding, production welding, and weld inspection and testing.

2. APPLICABLE DOCUMENTS

2.1 General. The applicable documents cited in this specification are listed in this section only for reference. The specified technical requirements listed in the body of this document must be met whether or not the source document is listed in this section.

2.2 Government documents. The following Government documents form a part of this document to the extent specified herein. Unless otherwise specified, the issuances in effect on date of invitation for bids or request for proposals shall apply.

FEDERAL

BB-C-101	Carbon Dioxide (CO_2): Technical and U.S.P.
BB-O-925	Oxygen, Technical, Gas and Liquid

MILITARY

MIL-A-18455	Argon, Technical
MIL-I-23413	Inserts, Welding, Filler Material, Coiled and Solid Rings
MIL-PRF-27407	Propellant Pressurizing Agent, Helium

(Copies of the above documents are available from the Standardized Documents Order Desk, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098, Attn: NPODS.)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)

NASA-STD-6001	Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments That Support Combustion

(Copies of the above document is available for viewing and/or downloading from the NASA Technical Standards Website: standards.nasa.gov.

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specified procurement functions should be obtained from the procuring activity or as directed by the Contracting Officer.)

2.3 Non-Government publications. The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issuances in effect on the date of invitation for bids or request for proposals shall apply.

AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)

ASME B31	Code for Pressure Piping
ASME B31.3	Process Piping

(Copies of the above documents are available from the American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017.)

AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)/AMERICAN SOCIETY FOR NONDESTRUCTIVE TESTING (ASNT)

ASNT-TC-1A	Recommended Practice, Personal Qualification and Certification in Nondestructive Testing

(Copies of the above document are available from the American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, OH 43228-0518.)

AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)/AMERICAN WELDING SOCIETY (AWS)

ANSI/AWS A3.0	Standard Welding Terms and Definitions; Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting and Thermal Spraying
ANSI/AWS A5.4	Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding
ANSI/AWS A5.9	Specification for Bare Stainless Steel Welding Electrodes and Rods
ANSI/AWS A5.10	Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods
ANSI/AWS A5.11	Specification for Nickel and Nickel Alloy Welding Electrodes for Shielded Metal Arc Welding
ANSI/AWS A5.12	Specification for Tungsten and Tungsten Alloy Electrodes for Arc Welding and Cutting
ANSI/AWS A5.14	Nickel and Nickel Alloy Bare Welding Electrodes and Rods

ANSI/AWS A5.22	Specification for Stainless Steel Electrodes for Flux Cored Arc Welding and Stainless Steel Flux Cored Rods for Gas Tungsten Arc Welding
ANSI/AWS A5.30	Specification for Consumable Inserts
ANSI/AWS D1.1	Structural Welding Code - Steel
ANSI/AWS D1.2	Structural Welding Code - Aluminum
ANSI/AWS D1.3	Structural Welding Code - Sheet Steel
ANSI/AWS D10.4	Welding Austenitic Chromium - Nickel Stainless Steel Piping and Tubing
ANSI/AWS D10.7	Recommended Practices for Gas Shielded Arc Welding of Aluminum and Aluminum Alloy Pipe
ANSI/AWS D10.8	Welding of Chromium-Molybdenum Steel Piping and Tubing
ANSI/AWS D10.10	Local Heating of Welds in Piping and Tubing
ANSI/AWS D10.11	Recommended Practices for Root Pass Welding of Pipe Without Backing
ANSI/AWS D10.12	Recommended Practices and Procedures for Welding Low Carbon Steel Pipe
ANSI/AWS D14.1	Welding of Industrial and Mill Cranes and Other Material Handling Equipment
ANSI/AWS QC1	Standard for AWS Certification of Welding Inspectors

(Copies of the above documents are available from the American Welding Society, 2-5 Metropolitan Court, Gaithersburg, MD 20878.)

SOCIETY OF AUTOMOTIVE ENGINEERS (SAE)

SAE-AMS-H-6088	Heat Treatment of Aluminum Alloys

(Copies of the above document are available from the Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096-0001.)

2.4 Order of precedence. Where this document is adopted or imposed by contract on a program or project, the technical requirements of this document take precedence, in the case of conflict, over the technical requirements cited in other referenced documents.

3. DEFINITIONS AND ACRONYMS

3.1 General. The welding terms used in this specification shall be interpreted in accordance with the definitions of ANSI/AWS A3.0. For the purpose of this specification, the following definition shall also apply.

3.1.1 Nonconventional facilities (including equipment). Nonconventional facilities (including equipment) are program-oriented or experimental in nature and include wind tunnels, test stands, launch complexes, operational or research facilities, towers, and similar special-purpose facilities whose structures are characterized by unusual or inadequately defined loading conditions, a lack of established design precedent, or frequent modifications to support changes in the operational requirements.

3.1.2 Acronyms and abbreviations used in this specification

AA	Aluminum Association
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASNT	American Society for Nondestructive Testing
AWS	American Welding Society
BPVC	Boiler and Pressure Vessel Codes
$^{\circ}C$	degree Celsius
CO_2	carbon dioxide
CWI	certified welding inspector
e.g.	for example
EMC	Engineering Management Council
etc.	et cetera
$^{\circ}F$	degree Fahrenheit
GSE	ground support equipment
GTAW	gas tungsten arc welding
i.e.	that is
MIL	military
mm	millimeter
MT	magnetic particle testing
NASA	National Aeronautics and Space Administration
NDT	nondestructive testing
PQR	procedure qualification record
PT	penetrant testing
rpm	revolutions per minute
RT	radiographic testing
SPEC	specification
STD	standard
UNS	Unified Numbering System
WPQ	welder/welding operator performance qualification
WPS	welding procedure specification

4. DESIGN REQUIREMENTS

4.1 General. All welding design shall be in accordance with the applicable welding codes listed in Table I and the additional requirements specified herein.

TABLE I. Applicable Welding Codes

Welding Activity	Applicable Code
Structural welding of carbon steel, low alloy steel, stainless steel, and nickel alloys	ANSI/AWS D1.1
Structural welding of aluminum and aluminum alloys	ANSI/AWS D1.2
Structural welding of sheet steel	ANSI/AWS D1.3
Welding of cranes and other material handling equipment	ANSI/AWS D14.1
Welding of pressurized piping and tubing	ASME B31

4.2 Weld classifications. The classifications defined in the following paragraphs shall be used by the design engineer to establish design (e.g., allowable stresses, NDT acceptance criteria) and inspection (i.e., methods and extent of NDT) requirements for all welds. Note that for structural welding and welding of cranes (the categories covered by ANSI/AWS D1.1, D1.2, and D14.1), the design and inspection classifications are separate; however, for welding of piping and tubing in accordance with ASME B31.3, the design and inspection classifications are combined into one classification label. No additional classification requirements are levied on sheet steel welds (covered by ANSI/AWS D1.3).

4.2.1 Structural welding

4.2.1.1 Structural welding design. The design engineer shall identify structural welds as either tubular, statically loaded nontubular, or cyclically loaded nontubular connections, in accordance with ANSI/AWS D1.1 or D1.2, as applicable.

4.2.1.2 Structural welding inspection. The design engineer shall use the following classifications to establish levels of inspection for structural weldments:

a. Class A inspection. Applicable to those welds where failure would be catastrophic in effect and/or welds that are highly loaded and characterized as a single point of failure with no redundancy for the redistribution of stress into another member. These welds shall meet the highest strength and quality requirements specified. Groove welds designated Class A shall be complete joint penetration welds, unless otherwise specified. In addition to a visual inspection performed by a Certified Welding Inspector (CWI), Class A welds are typically subjected to both internal and surface inspections (e.g., radiographic testing [RT] and penetrant testing [PT)], respectively) (see 6.5.2); therefore, the ability to successfully perform RT on the weld should be considered during design.

b. Class B inspection. Applicable to those welds where failure would reduce the overall efficiency of the system, but loss of system, hazard to personnel, or significant cost or loss in schedule would not be experienced. In addition to a visual inspection performed by a CWI, Class B welds are typically subjected to a surface inspection(e.g., PT or magnetic particle testing [MT]) (see 6.5.2).

c. Class C inspection. Applicable to those welds where failure would not affect the efficiency of the system or create a hazard to personnel. Class C welds typically receive only a visual inspection; a CWI is not required to perform this inspection (see 6.5.2).

4.2.2 Crane and other material handling equipment

4.2.2.1 Crane and other material handling equipment weld design. The design engineer shall classify all welds as either primary or secondary, in accordance with ANSI/AWS D14.1.

4.2.2.2 Crane and other material handling equipment weld inspection. The design engineer shall use the following classifications to establish levels of inspection for crane and other material handling equipment welds:

a. Class A inspection. All primary welds shall be classified as Class A. This classification is analogous to the Class A classification described in 4.2.1.2 a.

b. Class B inspection. Secondary welds may be classified as Class B (the other option is Class C [see 4.2.2.2 c]). This classification is analogous to the Class B classification described in 4.2.1.2 b.

c. Class C inspection. Secondary welds may be classified as Class C (the other option is Class B [(see 4.2.2.2 b]). This classification is analogous to the Class C classification described in 4.2.1.2 c.

4.2.3 Piping and tubing design and inspection. For piping and tubing welds in accordance with ASME B31.3 only, the design engineer shall use the classifications indicated in the following paragraphs to establish the design and inspection requirements for piping and tubing welds.

4.2.3.1 Normal fluid service. This design and inspection classification is defined in ASME B31.3. In addition to a visual inspection performed by a CWI, normal fluid service welds are typically subjected to 10-percent random RT (see 6.5.2.3).

4.2.3.2 Severe cyclic conditions. This design and inspection classification is defined in ASME B31.3 or determined by the design engineer. In addition to a visual inspection performed by a CWI, welds classified for severe cyclic service are typically subjected to 100-percent RT and either 100-percent PT or 100-percent MT (see 6.5.2.3).

4.2.3.3 Category M fluid service. This design and inspection classification is defined in ASME B31.3; all welds in hypergol systems shall be classified for category M fluid service. In addition to a visual inspection performed by a CWI, category M fluid service welds are typically subjected to 100-percent RT and either 100-percent PT or 100-percent MT (see 6.5.2.3).

4.2.3.4 High-pressure fluid service. This design and inspection classification is defined in ASME B31.3. In addition to a visual inspection performed by a CWI, high-pressure fluid service welds are typically subjected to 100-percent RT and either 100-percent PT or 100-percent MT (see 6.5.2.3).

4.2.3.5 Category D fluid service. This design and inspection classification is defined in ASME B31.3. Category D fluid service welds typically receive a visual inspection (a CWI is not required) and either 100-percent PT or 100-percent MT (see 6.5.2.3).

4.3 Classification of weld reinspection. With the exception of reinspection of welds during the repair of fabrication defects (see 5.7.1), this specification does not cover the reinspection requirements (e.g., annual reinspections) of welds such as those required by operational or maintenance documents. This specification does not cover the identification of welds requiring such reinspections, often referred to as "critical welds." Identification of welds requiring such reinspection and the method of reinspection should be specified in the design and fabrication documentation.

4.4 Materials

4.4.1 Base metals. Unless otherwise specified or approved by the procuring agency, the base metals to be welded in accordance with this specification are as indicated in the following paragraphs.

4.4.1.1 Structural welding. Carbon steel and low alloy steels shall be in accordance with ANSI/AWS D1.1; aluminum alloys shall be in accordance with ANSI/AWS D1.2; sheet steel shall be in accordance with ANSI/AWS D1.3; stainless steels shall be in accordance with Table II, and nickel alloys shall be in accordance with Table III.

4.4.1.2 Crane and other material handling equipment welding. All materials to be welded shall be in accordance with ANSI/AWS D14.1.

4.4.1.3 Piping and tubing welding. All materials to be welded shall be in accordance with ASME B31 and Table IV.

4.4.2 Filler metals. Unless otherwise specified or approved by the procuring agency, all filler metals shall be as follows.

4.4.2.1 Structural welding. Filler metal selection for carbon steel and low alloy steel shall be in accordance with ANSI/AWS D1.1; filler metal selection for aluminum alloys shall be in accordance with ANSI/AWS D1.2; filler metal selection for sheet steel shall be in accordance with ANSI/AWS D1.3; filler metal selection for stainless steels shall be in accordance with Table II.; and filler metal selection for nickel alloys shall be in accordance with Table III.

4.4.2.2 Crane and other material handling equipment welding. Filler metal selection shall be in accordance with ANSI/AWS D14.1.

TABLE II. Allowable Stainless Steel Base Metal and Filler Metal Combinations(1)

Base Metal Alloy Designation	304L (S30403)	316L (S31603)	321 (S32100) 347(S34700)	Nitronic 33(2) (S24000)	Nitronic 40(2) (S21900 and S21904)
304L (S30403)	E308L ER308L E308LT-X E347 ER347 E347T-X				
316L (S31603)	E308L ER308L E308LT-X E347 ER347 E347T-X	E316L ER316L			
321 (S32100) 347 (S34700)	E308L ER308L E308LT-X E347 ER347 E347T-X	E347 ER347 E347T-X	E347 ER347 E347T-X ER321		
Nitronic 33(2) (S24000)	E308L ER308L E308LT-X	E308L ER308L E308LT-X	E347 ER347 E347T-X E308L ER308L E308LT-X	E209 ER209 E240 ER240 E308L ER308L E308LT-X	
Nitronic 40(2) (S21900 and S21904)	E308L ER308L E308LT-X EniCrMo-3 ERNiCrMo-3	E308L ER308L E308LT-X ENiCrMo-3 ERNiCrMo-3	E347 ER347 E347T-X E308L ER308L E308LT-X ENiCrMo-3 ERNiCrMo-3	E209 ER209 E308L ER308L E308LT-X	E209 ER209 E219 ER219 E308L ER308L E308LT-X ENiCrMo-3 ERNiCrMo-3

NOTES:

(1) The left column and top row list the base metals. The remaining columns and rows list the filler metals to be used when matched to a combination of base metals. The base metals are listed by either their American Iron and Steel Institute classification or their trade name with their Unified Numbering System (UNS) designation in parentheses. The filler metals are listed by their AWS classifications in accordance with either ANSI/AWS A5.4, A5.9, or A5.22.

(2) Welding Nitronic stainless steel with 308L filler metal will result in a joint with an ultimate tensile strength significantly less than that of a weld made with matching (Nitronic) filler metal. Where weldments greater than 6.35 millimeters (mm) (0.25 inch) are to be used in cryogenic applications, the use of 308L (if the lower strength is acceptable) or a nickel-based filler metal is recommended.

TABLE III. Allowable Nickel Alloy Base Metal and Filler Metal Combinations(1)

Base Metal(2)	Filler Metal(2)
Invar 36	Modified Invar 36(3)
Hastelloy C-22 (N06022)	ENiCrMo-10 ERNiCrMo-10
Inconel 600 (N06600)	ERNiCr-3 ERNiCrFe-5
Inconel 718 (N07718)	ERNiFeCr-2
Monel K-500 (N05500) or Monel 400 (N04400)	ENiCu-7 ERNiCu-7
Haynes 625 (N06625)	ENiCrMo-3 ERNiCrMo-3

NOTES:

(1) For recommended filler metals for other nickel alloys, refer to ANSI/AWS A5.11 Section A7, and ANSI/AWS A5.14, Section A7.

(2) The base metals are listed by their trade names with their UNS designations in parentheses. The filler metals are listed by their AWS classifications in accordance with either ANSI/AWS A5.11 or A5.14.

(3) The chemical composition of Modified Invar 36 shall be in accordance with Table V.

TABLE IV. Filler Metal Requirements for Aluminum Piping and Tubing

Base metal alloy designation	356.0 443.0	6061 6063 6101 6351	5454	514.0 5154 5254[a]	5086	5083	5052 5652[a]	3004	1100 3003 Alc 3003	1060 1350
1060, 1350	ER 4043[f]	ER 4043[b,f]	ER 5654[b]	ER 5654[b]	ER 5356[b]	ER 5356[b]	ER 5654[b]	ER 5654[b]	ER 1100[c]	ER 1100[c]
1100, 3003, Alc 3003	ER 4043[f]	ER 4043[b,f]	ER 5654[b]	ER 5654[b]	ER 5356[b]	ER 5356[b]	ER 5654[b]	ER 5654[b]	ER 1100[c]	
3004	ER 4043[f]	ER 5654[b,c]	ER 5654[b]	ER 5654[b]	ER 5356[b]	ER 5356[b]	ER 5654[b]	ER 5654[b]		
5052, 5652[a]	ER 4043[f]	ER 5654[b,c]	ER 5654[b]	ER 5654[b]	ER 5356[b]	ER 5356[b]	ER 5554[a,b]			
5083	ER 5356[b,c]	ER 5356[b]	ER 5356[b]	ER 5356[b]	ER 5356[e]	ER 5183[e]				
5086	ER 5356[b,c]	ER 5356[b]	ER 5356[b]	ER 5356[b]	ER 5356[e]					
514.0, 5154, 5254b	ER 4043[b,f]	ER 5654[b]	ER 5654[b]	ER 5654[a,b]						
5454	ER 4043[b,f]	ER 5654[b]	ER 5554[b]							
6061, 6063, 6101, 6351	ER 4043[b,f]	ER 4043[b]								
356.0, 443.0	ER 4043[d,f]									

Notes:

1. Recommendations in this table apply to the gas shielded arc welding processes. For oxyacetylene gas welding, only ER1100, ER4043, and ER4047 filler metals are ordinarily used.
2. Filler metals are listed in AWS Specification A5.10.
3 Filler metals ER5356, ER5183, ER5556, and ER5654 are not recommended for sustained elevated temperature service (over 65 degrees Celsius [°C] 150 degrees Fahrenheit [°F]). ER5554 is suitable for elevated temperature service.
4. Local corrosion attack may occur in the weld region in certain electrolytes, due to solution potential variations. These variations can result from compositional differences between the filler and base metals or from heat-related metallurgical effects.

[a] Base metal alloys 5254 and 5652 are used for hydrogen peroxide service. ER5654 filler metal is used for welding both alloys for service below 65 °C (150 °F).

[b] ER5183, ER5356, ER5556, and ER5654 may be used. In some cases they provide (1) improved color match after an anodizing treatment, (2) higher weld ductility, and (3) higher weld strength. ER5554 is suitable for elevated temperature service.

[c] ER4043 or ER4047 may be used.

[d] Filler metal with the same analysis as the base metal can be used.

[e] ER5183, ER5356, or ER5556 may be used.

[f] ER4047 may be used.

TABLE V. Modified Invar 36 Filler Metal Composition

Element	Percent
Nickel	35.0 to 36.5
Manganese	2.6 to 3.4
Titanium	0.7 to 1.3
Carbon	0.04 (maximum)
Silicon	0.30 (maximum)
Sulfur	0.008 (maximum)
Phosphorus	0.012 (maximum)
Iron	Remainder

4.4.2.3 Piping and tubing welding. Filler metal selection shall be in accordance with ASME B31and as indicated in Table II for stainless steel, Table III for nickel alloys, and Table IV for aluminum alloys.

4.4.2.4 Dissimilar metal welding. Recommended filler metals for the welding of selected dissimilar metal combinations are listed in Table VI.

4.4.3 Consumable inserts. Consumable inserts shall be in accordance with ANSI/AWS A5.30 or MIL-I-23413. Consumable inserts shall be of the same nominal composition as the filler metal to be used.

4.4.4 Backing rings. With the exception of welds designated for ASME B31.3, Category D fluid service, backing rings shall not be used.

4.5 Heating requirements

4.5.1 Preheating

4.5.1.1 Carbon steel and low alloy steel. Preheating and interpass heating requirements shall be in accordance with the appropriate code listed in Table I.

4.5.1.2 Stainless steel and nickel alloys. These materials shall not be preheated.

4.5.1.3 Aluminum alloys. Preheating is not usually allowed for aluminum alloys. Preheating should only be considered if the base metal thickness is large and/or the ambient temperature is very low. If the design engineer allows preheating, the specific requirements shall be included in the design and fabrication documentation (see 5.6.1.3 for detailed requirements on preheating allowables).

TABLE VI. Recommended Filler Metals for Selected Dissimilar Metal Combinations
(Reprinted from ANSI/AWS D10.7 with permission from the American Welding Society)

Base Metal	Carbon Steel and Low Alloy Steel	Austenitic (300-series) Stainless Steel	Invar 36	Hastelloy C-22	Inconel (600/718)	Monel K-500	Monel 400
Austenitic (300 series) Stainless Steel	ENiCrFe-2 ENiCrFe-3 ERNiCr-3 E312 ER312 E312T-X						
Invar 36		ERNiCr-3					
Hastelloy C-22	ENiCrMo-10 ERNiCrMo-10 ERNiCrMo-9	ENiCrMo-10 ERNiCrMo-10					
Inconel (600/718)	ENiCrFe-2 ENiCrFe-3 ERNiCr-3	ENiCrFe-2 ENiCrFe-3 ERNiCr-3					
Monel K-500	ENiCu-7 ERNi-1	ENiCrFe-2 ENiCrFe-3 ERNiCr-3			ENiCrFe-2 ENiCrFe-3 ERNiCr-3	ERNiCr-7 ERNiCr-7	ERNiCr-7 ERNiCr-7
Monel 400	ENiCu-7 ERNiCu-7	ENiCu-7 ERNiCu-7				ENiCu-7 ERNiCu-7	

Note: The left column and top row list the base metals. The remaining columns and rows list the filler metals to be used when matched to a combination of base metals. The base metals are listed by either general classification or trade name; the filler metals are listed by their AWS classifications in accordance with ANSI/AWS A5.4, A5.9, A5.11, A5.14, or A5.22.

4.5.2 Postweld heating

4.5.2.1 Carbon steel and low alloy steel. Stress-relief heat treatment requirements shall be in accordance with the appropriate code listed in Table I.

4.5.2.2 Stainless steel and nickel alloys. Stress-relief heat treatment of these materials is not permitted. If a postweld heat treatment of a precipitation-hardening stainless steel and/or nickel alloy is desired by the design engineer, these requirements shall be included in the design and fabrication documentation.

4.5.2.3 Aluminum alloys. Stress-relief heat treatment of aluminum alloys is not permitted. If artificial aging of heat-treatable aluminum alloys is desired by the design engineer, such heat treatment shall be in accordance with SAE-AMS-H-6088; these requirements shall be included in the design and fabrication documentation.

4.6 Data required in design and fabrication documentation. The following information shall be provided in both the design and fabrication documentation:

a. Title and number of this specification
b. Design and inspection classifications of welds (see 4.2)
c. Base metal specification
d. Filler metal specification (optional; if none is specified, the contractor will select in accordance with 4.4.2)
e. Additional preheating and postheating instructions, if required (see 4.5.1 and 4.5.2)

5. FABRICATION REQUIREMENTS

5.1 General. All welding shall be in accordance with the applicable welding codes listed in Table I and the additional requirements specified herein. The necessary equipment, materials, qualified welders, welding operators, and procedures shall be provided by the contractor to meet the requirements of this specification. The contractor shall ensure adequate protection is provided for equipment and adjacent surfaces during welding operations. Damages resulting from failure to provide protection shall be repaired to the satisfaction of the procuring agency at no additional cost to the Government.

5.2 Calibration. Measuring instruments, meters, gages, or direct reading electrical control circuits to be utilized for automatic and semiautomatic welding operations shall be calibrated.

5.3 Materials. All welding materials shall be stored and handled so that no damage or degradation will result during storage and handling. Filler metals and inserts shall be handled and stored to prevent moisture contact, condensation, and/or absorption. Filler metals and inserts that show signs of damage shall not be used. Storage methods for steel and low-alloy steel-covered, low-hydrogen shielded metal arc welding electrodes shall be in accordance with section 5.3 of ANSI/AWS D1.1.

5.3.1 Material certification. Prior to the start of production welding, the contractor shall ensure that all materials to be used (e.g., base metals, filler metals, etc.) conform to the appropriate specifications. A record (i.e., written documentation) of material certifications (e.g., results of any chemical analyses or mechanical testing, manufacturer's or heat treater's records, etc.) shall be maintained by the contractor and made available to the procuring agency.

5.3.2 Filler metals. Refer to 4.4.2, 4.4.2.1, 4.4.2.2, 4.4.2.3, and 4.4.2.4.

5.3.3 Consumable inserts. Refer to 4.4.3.

5.3.4 Backing rings. With the exception of welds designated for ASME B31.3, Category D fluid service, backing rings shall not be used.

5.3.5 Tungsten electrodes. Tungsten electrodes shall be in accordance with ANSI/AWS A5.12.

5.3.6 Shielding gases. Shielding gases shall be in accordance with Table VII.

5.3.7 Purging gases. Purging gases shall be either argon, helium, or an argon-helium mixture as shown in Table VII.

5.3.8 Antispatter compounds. Antispatter compounds shall not be used.

TABLE VII. Shielding and Purging Gases

Gas	Description and Percentage	Specification
Argon	Gas	MIL-A-18455
Carbon dioxide	Grade B	BB-C-101
Helium	Type I, grade A	MIL-PRF-27407
Oxygen	Type I	BB-O-925
Argon-oxygen mixture	Argon plus 1 to 5 percent oxygen	MIL-A-18455 (for argon) BB-O-925, type I (for oxygen)
Argon-carbon dioxide mixture	Argon plus 20 to 50 percent carbon dioxide	MIL-A-18455 (for argon) BB-O-925, type I (for oxygen)
Argon-helium mixture	Any combination	MIL-A-18455 (for argon) MIL-PRF-27407, type I, grade A (for helium)

5.4 Welding procedure and welder/welding operator performance qualifications

5.4.1 Welding procedure qualification. Prior to the start of production welding, the contractor shall prepare a welding procedure specification (WPS) for each weld to be made. Each WPS shall be prepared and qualified in accordance with the appropriate code listed in Table I. A WPS is always required, even if the procedure is considered to be prequalified in accordance with ANSI/AWS D1.1 or D14.1, as applicable. The WPS and any resulting procedure qualification records (PQR's) shall record all required information on forms similar to or identical with those described in the appropriate code listed in Table I. Copies of the WPS shall be available for reference by the welders, welding operators, and the procuring agency. The procuring agency reserves the right to require that all WPS's and PQR's be submitted for approval prior to the start of any production welding. The procuring agency shall be notified prior to any procedure qualification welding and/or testing with sufficient time to allow witnessing. The procuring agency reserves the right to witness all procedure qualification welding and/or testing.

NOTE: WPS's for stainless steels and nickel alloys to be welded in accordance with ANSI/AWS D1.1 are never considered to be prequalified and must always be qualified by testing.

5.4.2 Welder/welding operator performance qualification. Prior to the start of production welding, each welder and welding operator shall be qualified in accordance with the appropriate code listed in Table I. The resulting welder/welding operator performance qualification (WPQ) test records shall record all required information on forms similar to or identical with those described in the appropriate code listed in Table I. Copies of the WPQ's shall be made available to the procuring agency. The procuring agency reserves the right to require that all WPQ's be submitted for approval prior to the start of any production welding. The procuring agency shall be notified prior to any performance qualification welding and/or testing with sufficient time to allow witnessing. The procuring agency reserves the right to witness all performance qualification welding and/or testing.

5.5 Preweld operations

5.5.1 Cleaning requirements. For the purposes of cleaning, the term "joint" shall be defined as the base metal surfaces to be welded, the adjacent base metal surfaces for a minimum of 50 mm (2 inches) on each side of those to be welded, any consumable inserts or backing, and all fixtures used in the vicinity of the weld. The joint shall be thoroughly cleaned prior to welding and kept clean during welding (e.g., by interpass cleaning in multipass welds). The joint and all filler metal shall be free of scale, slag, oil, grease, paint, low-melting temperature metals (e.g., lead, tin, cadmium), pencil or ink marks, oxides, and other contaminants. A cleaned joint shall not be touched by bare hands. Cleaning requirements shall be incorporated into the WPS (see 5.4.1).

5.5.2 Cleaning technique. All cleaning shall be performed before assembling the joints. Oils and greases shall be removed by solvent cleaning; contaminated solvents shall not be used. When wire brushing is performed, only clean, austenitic stainless steel wire brushes that have not been used on any other materials shall be used (e.g., a brush used to clean carbon steel shall not be used to clean stainless steel). When cleaning aluminum, solvent cleaning shall be followed by mechanical scraping; surfaces that are not welded within 4 hours shall be recleaned.

5.6 Production welding

5.6.1 Preheating and interpass heating. Temperatures shall be measured by suitable temperature-indicating methods that are accurate within plus or minus 14 $^{\circ}$C (25 $^{\circ}$F). Heating and maintaining the proper temperature may be accomplished by any suitable method capable of providing a reasonably uniform temperature throughout the part. For field applications, it is preferred that induction coils or resistance heating braided "blankets" be used. When preheating is required, the joint shall be preheated prior to any welding, including tack welding.

5.6.1.1 Carbon steel and low alloy steel. Unless otherwise indicated in the design and fabrication documentation, preheating and interpass heating requirements shall be in accordance with the appropriate code listed in Table I.

5.6.1.2 Stainless steel and nickel alloys. These materials shall not be preheated. The interpass temperature shall not exceed 93 $^{\circ}$C (200 $^{\circ}$F) at a maximum distance of 13 mm (0.5 inch) in all directions from the point of welding.

5.6.1.3 Aluminum alloys. Unless otherwise indicated in the design and fabrication documentation, preheating is not allowed for aluminum alloys. Preheating should only be considered if the base metal thickness is large and/or the ambient temperature is very low. If preheating is allowed by the design and fabrication documentation, the preheat temperature shall not exceed 93 $^{\circ}$C (200 $^{\circ}$F) at a maximum distance of 13 mm (0.5 inch) in all directions from the point of welding for Aluminum Association (AA) 5000-series aluminum alloys, and the holding time at this temperature shall not exceed 15 minutes. The maximum interpass temperature for AA 5000-series aluminum alloys shall not exceed 149 $^{\circ}$C (300 $^{\circ}$F) at a maximum distance of 13 mm (0.5 inch) in all directions from the point of welding. The maximum preheat and interpass temperatures for all other aluminum alloys shall be 177 $^{\circ}$C (350 $^{\circ}$F) at a maximum distance of 13 mm (0.5 inch) in all directions from the point of welding. Holding times at these temperatures should be minimized.

5.6.2 Use of purging gas. Inert gas purging is required for all joints when consumable inserts are used. Inert gas purging is required for stainless steel, aluminum alloy, and nickel alloy joints with or without the use of consumable inserts. Inert gas purges shall be maintained for the root pass and subsequent passes until a minimum of 5 mm (0.2 inch) of weld metal has been deposited.

5.6.3 Tack welds. Tack welds shall be used as required and shall be made by a qualified welder or welding operator (see 5.4.2). Tack welds shall be spaced symmetrically around or along the joint whenever possible. Chipping or grinding shall be done to fair both ends of the tack weld in with the base metal. Tack welds that contain cracks or visible porosity shall not be fused with the root pass weld and shall be removed in accordance with 5.7.1.

5.6.4 Weld bead initiation and termination. Extension bars and runoff plates on which the welding arc can be started or extinguished shall be used whenever practicable. The initiation and termination points of each weld bead shall be chipped or ground as necessary to remove any visible defects in the weld metal before depositing any subsequent weld beads. The ground areas shall fair in with the adjacent base metal. No additional filler metal shall be added to a root pass when using a consumable insert. Weld beads shall not terminate in inside corners or notches or in other critical areas such as changes in welding direction or sudden changes in section thickness.

5.6.5 Back gouging. All groove welded joints to be welded from both sides and require 100 percent penetration shall be back gouged to sound metal prior to the welding of the second side. Whenever possible, two or three passes shall be deposited on the first side prior to the gouging of the back side. Back gouging to sound metal may be done by chisel, grinder, or arc gouging. Gouged areas shall be smoothed to fair in with adjacent metal.

5.6.6 Identification of welds. Appropriate records shall be maintained that identify the welds made by each qualified welder and welding operator. These records shall be made available to the procuring agency. The actual weldments shall not be marked.

5.6.7 Postweld heating. Temperatures shall be measured by suitable temperature-indicating methods that are accurate within plus or minus 14 $^{\circ}$C (25 $^{\circ}$F). Heating and maintaining the proper temperature may be accomplished by any suitable method capable of providing a reasonably uniform temperature throughout the part. For field applications, it is preferred that induction coils or resistance heating braided "blankets" be used. If the entire weldment cannot be stress-relieved, then the minimum area to be heated to the required stress-relieving temperature shall be the same as the minimum area that would be required to be heated to preheating temperature.

5.6.7.1 Carbon steel and low alloy steel. Unless otherwise indicated in the design and fabrication documentation, stress-relief heat treatment requirements shall be in accordance with the appropriate code listed in Table I.

5.6.7.2 Stainless steel and nickel alloys. Stress-relief heat treatment of these materials is not permitted. Postweld heat treatment of precipitation-hardening stainless steels and/or nickel alloys shall be as indicated in the design and fabrication documentation.

5.6.7.3 Aluminum alloys. Unless otherwise indicated in the design and fabrication documentation, postweld heating of aluminum alloys is not permitted. When artificial aging of heat-treatable aluminum alloys is specified in the design and fabrication documentation, such heat treatment shall be in accordance with SAE-AMS-H-6088.

5.6.8 Postweld cleaning. All welded assemblies shall be cleaned free of oxide, flux, scale, slag, or other foreign matter prior to the postweld inspections (see 6.5).

5.7 Welding repairs.

5.7.1 Defect removal. Weld and/or base metal containing defects (see Section 6 for inspection and acceptance criteria requirements) shall be removed to sound metal. The use of mechanical means (e.g., grinding, chipping, or machining) to remove defective weld and/or base metal is preferred. After the removal of any metal containing defects, and prior to rewelding, the joint shall be reinspected to ensure that the defects have been completely removed, using the same NDT method and acceptance criteria used to originally detect the defect.

5.7.2 Repair procedure. The repair welding procedure shall be the same as the original qualified welding procedure, recognizing that the cavity to be repaired may differ in contour and dimensions from the original joint. The completed repair weld shall be subjected to the same NDT requirements and acceptance criteria as the original weld.

5.7.3 Repair records. The contractor shall prepare and maintain records of all weld repairs and shall make these records immediately available to the procuring agency. No more than two attempts shall be made to repair a weld defect; deviation from this requirement shall be requested in writing to the procuring agency.

6. INSPECTION AND TESTING REQUIREMENTS

6.1 Inspection and testing

6.1.1 Responsibility for inspection and testing. The contractor is responsible for the performance of all inspections, tests, and quality control requirements as specified herein. The contractor may utilize his own or any other testing laboratory acceptable to and approved by the procuring agency for the performance of all required destructive and nondestructive testing.

6.1.2 Inspection and testing techniques. All completed welds and the adjacent base metal up to a minimum of 12.5 mm (0.5 inch) from both sides of the edge of the deposited weld metal shall be visually inspected and subjected to NDT in accordance with 6.5. Welds that do not satisfy the acceptance criteria of 6.1.3 and 6.1.4 shall be repaired in accordance with 5.7.

6.1.3 Visual inspection acceptance criteria. The acceptance criteria for the visual inspection of completed welds shall be in accordance with the appropriate code listed in Table I, as otherwise specified herein, and in accordance with the specified weld classification.

6.1.4 NDT acceptance criteria. The acceptance criteria for NDT shall be in accordance with the appropriate code listed in Table I for the appropriate NDT technique and weld classification.

6.1.5 Additional inspection and testing. The procuring agency reserves the right to require additional NDT. This NDT may consist of the same NDT methods originally required, different methods, or a combination of both previously used and new methods. The procuring agency reserves the right to require that coupons be cut from base and/or weld metal for destructive testing. If the applicable acceptance criteria for any additional NDT is not satisfied, or if the coupons subjected to destructive testing do not meet the applicable requirements for strength and soundness, the contractor shall be liable for the cost of the investigation and repair of these defective areas. When coupons are removed from any part of a weldment, the members shall be repaired in accordance with 5.7.

6.2 Certified welding inspector. When a CWI is required for the final visual inspection of completed welds (see 6.5.1), this individual shall be certified as an AWS CWI in accordance with the provisions of ANSI/AWS QC1. Evidence of this certification shall be made available to the procuring agency.

The CWI will be provided with all WPS's, PQR's, and WPQ's and will verify through this supplied documentation that the WPS was qualified and that the welders/welding operators were qualified (see 5.4). If all visual inspection acceptance criteria are satisfied, but the requirements of 5.4 are not satisfied, the affected weld will not be labeled as having failed visual inspection; however, the CWI shall inform the procuring agency that the requirements of 5.4 were not satisfied.

NOTE: This requirement does not mean that the CWI must witness all qualification testing or that the CWI must inspect the WPS's, PQR's, and WPQ's prior to welding. The procuring agency reserves the right to witness all qualification welding/testing and to review the WPS's, PQR's, and WPQ's prior to the start of welding (see 5.4).

6.3 Qualification of NDT personnel. All personnel performing NDT or interpreting NDT results shall be certified in accordance with ASNT-TC-1A or other NDT standards that are satisfactory to the procuring agency. When the engineering drawing specifies the use of an examination method not presently incorporated in ASNT-TC-1A, the contractor shall be responsible for developing and submitting to the procuring agency the training program, written practice, examination, and practical demonstrations equivalent to the requirements of ASNT-TC-1A or other standards.

6.4 Preweld and welding inspection. All preweld and welding inspection requirements (e.g., inspections to verify base metal preparations, proper joint assembly, joint cleanliness, etc.) shall be in accordance with the appropriate code listed in Table I.

6.5 Postweld inspection

6.5.1 Visual inspection. The contractor shall provide the inspector with the engineering drawings and WPS's showing the size, length, type, and location of all welds. The inspector shall verify that the size, length, type, and location of all welds conform to the requirements of the engineering drawings and this specification and that no unspecified welds have been added.

6.5.1.1 Structural welds. All completed welds shall be subjected to a 100 percent visual inspection in accordance with ANSI/AWS D1.1, D1.2, or D1.3, as applicable. Visual inspections of Class A and Class B welds shall be performed by a CWI (see 6.2).

6.5.1.2 Crane and other material handling equipment welds. All completed welds shall be subjected to a 100 percent visual inspection in accordance with ANSI/AWS D14.1. Visual inspections of welds classified as Class A and Class B shall be performed by a CWI (see 6.2).

6.5.1.3 Piping and tubing welds. All completed welds shall be subjected to a 100 percent visual inspection in accordance with ASME B31, with the following additional requirements for welds made in accordance with ASME B31.3: all weld profiles shall be in accordance with section 3.6 of ANSI/AWS D1.1, with the exception that the acceptance criteria for undercutting and reinforcement shall be in accordance with ASME B31.3. With the exception of welds designated for Category D fluid service, these visual inspections shall be performed by a CWI (see 6.2).

6.5.2 Nondestructive testing

6.5.2.1 Structural welds. In addition to the required visual inspection (see 6.5.1), all structural welds shall be subjected to NDT in accordance with the following paragraphs.

6.5.2.1.1 Class A inspection. All Class A inspections shall require 100 percent RT and either 100 percent MT or 100 percent PT in accordance with ANSI/AWS D1.1, D1.2, or D1.3, as applicable.

6.5.2.1.2 Class B inspection. All Class B inspections shall require either 100 percent MT or 100 percent PT in accordance with ANSI/AWS D1.1, D1.2, or D1.3, as applicable. When multipass welds are subjected to a Class B inspection, the root pass, final pass, and each 13-mm (0.5-inch) interval of thickness shall be so inspected. In addition to the normal interpass cleaning requirements for multipass welds, all liquid penetrant materials and/or metal particles shall be removed after each such inspection.

6.5.2.1.3 Class C inspection. All Class C inspections require only the visual inspection described in 6.5.1.

6.5.2.2 Crane and other material handling equipment welds. In addition to the required visual inspection (see 6.5.1), all crane and material handling equipment welds shall be subjected to NDT in accordance with the following paragraphs.

6.5.2.2.1 Primary welds (Class A). All Class A inspections shall require 100-percent RT and either 100-percent MT or 100 percent PT in accordance with ANSI/AWS D14.1.

6.5.2.2.2 Secondary welds (Class B). All Class B inspections shall require either 100 percent MT or 100 percent PT in accordance with ANSI/AWS D14.1. When multipass welds are subjected to a Class B inspection, the root pass, final pass, and each 13-mm (0.5-inch) interval of thickness shall be so inspected. In addition to the normal interpass cleaning requirements for multipass welds, all liquid penetrant materials and/or metal particles shall be removed after each such inspection.

6.5.2.2.3 Secondary welds (Class C). All Class C inspections require only the visual inspection described in 6.5.1.

6.5.2.3 Piping and tubing welds. For piping and tubing welds in accordance with ASME B31.3 only, in addition to the required visual inspection (see 6.5.1), all welds shall be subjected to NDT in accordance with the following paragraphs.

6.5.2.3.1 Normal fluid service. All welds classified for normal fluid service shall be subjected to 10 percent random RT in accordance with ASME B31.3; if any of the tested welds are found to be unacceptable, an additional randomly selected 10 percent (minimum) of the production welds shall be tested. If any of the tested welds in the second sampling are found to be unacceptable, then a 100 percent inspection of the remaining production welds is required.

6.5.2.3.2 Severe cyclic conditions. All welds classified as subjected to severe cyclic conditions shall be subjected to 100 percent RT and either 100 percent PT or 100 percent MT in accordance with ASME B31.3.

6.5.2.3.3 Category M fluid service. All welds classified for Category M fluid service shall be subjected to 100 percent RT and either 100 percent PT or 100 percent MT in accordance with ASME B31.3.

6.5.2.3.4 High-pressure fluid service. All welds classified for high-pressure fluid service shall be subjected to 100 percent RT and either 100 percent PT or 100 percent MT in accordance with ASME B31.3.

6.5.2.3.5 Category D fluid service. All welds classified for Category D fluid service shall be subjected to either 100 percent MT or 100 percent PT in accordance with ASME B31.3.

6.5.2.3.6 In-process examination for automatic gas tungsten arc welding (GTAW). With the exception of welds designated for high pressure and category M fluid service in accordance with ASME B31.3, an in-process examination may be substituted for the required RT of piping and tubing welds made using a fully automatic GTAW process only. In addition to the in-process examination requirements defined in ASME B31.3, the following additional requirements shall be satisfied:

a. The in-process examination shall be applied to all welds.

b. The automatic GTAW process parameters shall be strictly monitored and recorded; if these parameters exceed plus or minus 10 percent of the qualified values established during the WPS qualification, the affected weld shall be subjected to RT. The process parameters to be monitored and recorded shall include the following:

(1) Arc current
(2) Pulse high (amperes)
(3) Pulse low (amperes)
(4) Pulse high (time)
(5) Pulse low (time)
(6) Start slope

(7) Finish slope
(8) Rotation delay
(9) Head speed (rpm)
(10) Shielding and backup gas flow rate
(11) Arc voltage
(12) Tungsten electrode (position, length, bevel, land, arc length)

c. Welds classified as subjected to severe cyclic conditions shall be 100 percent PT or 100 percent MT inspected in accordance with 6.5.2.3.2.

NOTE: All NDT materials (e.g., liquid penetrates, developers, ultrasonic couplants, etc.) that are to be applied to surfaces that will be exposed to oxygen (gaseous or liquid) or hypergols in service shall be compatible with that service fluid. Oxygen compatibility shall be determined by batch testing in accordance with NASA-STD-6001; compatibility with hypergols shall also be assessed by testing in accordance with NASA-STD-6001. Final approval for use of these materials must be obtained from the procuring agency's appropriate Center Materials Representative.

6.5.2.4 Alternate NDT methods. In cases where RT is designated for a fillet weld or for a weld that consists of or is part of multiple connections or corner or tee joints of varying thicknesses such that the joint configuration makes it impractical to obtain a satisfactory radiograph, a satisfactory alternate method of NDT shall be proposed by the contractor and approved by the procuring agency. If PT or MT is proposed to be used in lieu of RT, then the root pass, final pass, and each 13-mm (0.5-inch) interval of thickness shall be so inspected. In addition to the normal interpass cleaning requirements for multipass welds, all liquid penetrant materials and/or metal particles shall be removed after each such inspection. In cases where adequate post-inspection cleaning is difficult to achieve (e.g., inner lines of vacuum-jacketed systems; intermediate passes of multipass welds in aluminum), PT may be selectively omitted if approved by the procuring agency (e.g., a visual inspection, RT, and a proof test of an inner line in a vacuum-jacketed cryogenic system could be considered sufficient without PT). Also, a PT of just the final pass of a multipass aluminum weld could be considered sufficient. The necessity of selectively omitting PT, as well as the necessity and acceptability of any proposed alternate NDT methods, should be agreed upon by the level III individual (see 6.3) and the procuring agency.

6.5.2.5 Etching for PT. Weldments that are machined, ground, sanded, abraded, or otherwise mechanically worked to cause disruption or smearing of the metal surface shall be etched to remove the masking material prior to penetrant application.

6.5.3 Inspection records. The contractor shall prepare and maintain records of all visual inspections and NDT procedures and results. These records shall be made available to the procuring agency.

7. NOTES

(This section contains information of a general or explanatory nature which may be helpful but is not mandatory.)

7.1 Intended use. This specification is intended to be used for the welding of aerospace GSE and related nonconventional facilities. This specification provides supplementary requirements (e.g., provisions for verification of procedure and performance qualifications, imposing requirements for NDT, imposing requirements for inspection personnel qualifications, additional welding technique requirements, requirements for material certifications, etc.) to the referenced ANSI/AWS and ASME industrial codes.

This Page Left Blank Intentionally

APPENDIX A

RECOMMENDED ANSI/AWS PUBLICATIONS

It is recommended that the following ANSI/AWS publications be used when developing piping and tubing welding procedures in accordance with this specification:

ANSI/AWS D10.4	Welding Austenitic Chromium-Nickel Stainless Steel Piping and Tubing
ANSI/AWS D10.7	Recommended Practices for Gas Shielded Arc Welding of Aluminum and Aluminum Alloy Pipe
ANSI/AWS D10.8	Welding of Chromium-Molybdenum Steel Piping and Tubing
ANSI/AWS D10.10	Local Heating of Welds in Piping and Tubing
ANSI/AWS D10.11	Recommended Practices for Root Pass Welding of Pipe Without Backing
ANSI/AWS D10.12	Recommended Practices and Procedures for Welding Low Carbon Steel Pipe

This Page Left Blank Intentionally

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

INSTRUCTIONS

1. The preparing activity must complete blocks 1, 2, 3, and 8. In block 1, both the document number and revision letter should be given.
2. The submitter of this form must complete blocks 4, 5, 6, and 7.
3. The preparing activity must provide a reply within 30 days from receipt of the form.

NOTE: This form may not be used to request copies of documents, nor to request waivers or clarification of requirements on current contracts. Comments submitted on this form do not constitute or imply authorization to waive any portion of the referenced document or to amend contractual requirements.

I RECOMMEND A CHANGE:	1. DOCUMENT NUMBER NASA SPEC-5004A	2. DOCUMENT DATE August 25, 2003

3. DOCUMENT TITLE
Welding of Aerospace Ground Support Equipment and Related Nonconventional Facilities

4. NATURE OF CHANGE *(Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)*

5. REASON FOR RECOMMENDATION

6. SUBMITTER

a. NAME *(Last, First, Middle Initial)*	b. ORGANIZATION	
c. ADDRESS *(Include Zip Code)*	d. TELEPHONE *(Include Area Code)*	7. DATE SUBMITTED

8. PREPARING ACTIVITY

a. NAME	d. TELEPHONE *(Include Area Code)*
c. ADDRESS *(Include Zip Code)*	

KSC FORM 21-610NS (2/94) (C/G 2/94)