AWS A5.16/A5.16M:2007
An American National Standard

Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods

American Welding Society

Approved American National Standard

ANSI

AWS A5.16/A5.16M:2007
An American National Standard

Approved by the
American National Standards Institute
August 17, 2007

Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods

5th Edition

Supersedes AWS A5.16/A5.16M:2004

Prepared by the
American Welding Society (AWS) A5 Committee on Filler Metals and Allied Materials

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

AWS A5.16/A5.16M:2007 is a revision of the titanium welding electrode document last revised in 2004. The compositions specified for each classification represent the state of the art. The specification contains testing procedures, standard sizes and forms, and identification and marking practices.

This specification makes use of both U.S. Customary Units and the International System of Units (SI). Since these are not equivalent, each system must be used independently of the other.

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Foreword

This foreword is not part of AWS A5.16/A5.16M:2007, *Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods*, but is included for informational purposes only.

This document is the second of the A5.16 specifications which makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other, without combining values in any way. In selecting rational metric units, AWS A1.1, *Metric Practice Guide for the Welding Industry*, and International Standard ISO 544, *Welding consumables — Technical delivery conditions for welding filler materials — Type of product, dimensions, tolerances, and markings,* are used where suitable. Tables and figures make use of both U.S. Customary and SI Units, which, with the application of the specified tolerances, provides for interchangeability of products in both the U.S. Customary and SI Units.

The current document is the fourth revision of the initial joint ASTM/AWS document issued in 1961. The evolution took place as follows: The first specification for titanium electrodes and welding rods was developed more than 40 years ago by a joint committee of the American Welding Society and the American Society for Testing and Materials. The 1970 revision was the first version of this specification to be published entirely by AWS. Three years later, it was recognized by the American National Standards Institute.

The following new electrode classifications were added: ERTi-19, ERTi-20, ERTi-21, ERTi-36, and ERTi-38. The current ERTi-9 composition requirements conform to the previous requirements of ERTi-9ELI. A new requirement (subclause 15.1) was added requiring positive identification on each cut length rod.

All new requirements within this document are italicized.

Document Development

AWS A5.16-61T ASTM B382-61T	*Tentative Specification for Titanium Alloy Bare Welding Rods and Electrodes*
AWS A5.16-70 ANSI W3.16-1973	*Specification for Titanium and Titanium Alloy Bare Welding Rods and Electrodes*
ANSI/AWS A5.16-90	*Specification for Titanium and Titanium Alloy Bare Welding Rods and Electrodes*
ANSI/AWS A5.16-90R	*Specification for Titanium and Titanium Alloy Welding Rods and Electrodes*, reaffirmed in 1997
AWS A5.16/A5.16M:2004	*Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods*

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, AWS A5 Committee on Filler Metals and Allied Materials, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

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Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods

1. Scope

1.1 This specification prescribes requirements for the classification of titanium and titanium-alloy electrodes and rods for gas tungsten arc, gas metal arc, and plasma arc welding.

1.2 Safety and health issues and concerns are beyond the scope of this standard and are therefore not fully addressed herein. Some safety and health information can be found in the informative annex clauses A5 and A10. Safety and health information is available from other sources, including, but not limited to, ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, and applicable federal and state regulations.

1.3 This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way when referring to filler metal properties. The specification with the designation A5.16 uses U.S. Customary Units. The specification A5.16M uses SI Units. The latter are shown within brackets [ ] or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for sizing of electrodes or packaging or both under A5.16 or A5.16M specifications.

2. Normative References

The standards listed below contain provisions, which, through reference in this text, constitute mandatory provisions of this AWS standard. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

2.1 American National Standards Institute (ANSI) standard:[1]

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

2.2 American Welding Society (AWS) standard:[2]

AWS A5.01, *Filler Metal Procurement Guidelines*

2.3 American Society for Testing and Materials (ASTM) standard:[3]

ASTM E 29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

2.4 International Organization for Standardization (ISO) standard:[4]

ISO 544, *Welding consumables — Technical delivery conditions for welding filler metals — Type of product, dimensions, tolerances, and markings*

3. Classification

3.1 The welding materials covered by this A5.16/A5.16M specification are classified using a system that is independent of U.S. Customary Units and the International System of Units (SI). Classification is according to chemical composition as specified in Table 1.

3.2 Materials labeled under one classification shall not be listed under any other classification of the specification except where reported chemical composition meets the narrow range of overlap between corresponding grades. An electrode or rod may be classified under both

[1] This ANSI standard is published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

[2] AWS standards are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

[3] ASTM standards are published by the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

[4] ISO standards are published by International Organization of Standardization, 1 rue de Varembé, Case postale 56, CH-1211 Geneva 20, Switzerland.

Table 1
Chemical Composition Requirements for Titanium and Titanium-Alloy Electrodes and Rods

AWS Classification	UNS Number[e]	Weight Percent[a, b, c, d] C	O	N	H	Fe	Al	V	Pd	Ru	Ni	Other Elements	Amount
ERTi-1	R50100	0.03	0.03–0.10	0.012	0.005	0.08	—	—	—	—	—		
ERTi-2	R50120	0.03	0.08–0.16	0.015	0.008	0.12	—	—	—	—	—		
ERTi-3	R50125	0.03	0.13–0.20	0.02	0.008	0.16	—	—	—	—	—		
ERTi-4	R50130	0.03	0.18–0.32	0.025	0.008	0.25	—	—	—	—	—		
ERTi-5	R56402	0.05	0.12–0.20	0.03	0.015	0.22	5.5–6.75	3.5–4.5	—	—	—		
ERTi-7	R52401	0.03	0.08–0.16	0.015	0.008	0.12	—	—	0.12–0.25	—	—		
ERTi-9[f]	*R56321*	*0.03*	*0.06–0.12*	*0.012*	*0.005*	*0.20*	*2.5–3.5*	*2.0–3.0*	—	—	—		
ERTi-11	R52251	0.03	0.03–0.10	0.012	0.005	0.08	—	—	0.12–0.25	—	—		
ERTi-12	R53401	0.03	0.08–0.16	0.015	0.008	0.15	—	—	—	—	0.6–0.9	Mo	0.2–0.4
ERTi-13	R53423	0.03	0.03–0.10	0.012	0.005	0.08	—	—	—	0.04–0.06	0.4–0.6		
ERTi-14	R53424	0.03	0.08–0.16	0.015	0.008	0.12	—	—	—	0.04–0.06	0.4–0.6		
ERTi-15A	R53416	0.03	0.13–0.20	0.02	0.008	0.16	—	—	—	0.04–0.06	0.4–0.6		
ERTi-16	R52403	0.03	0.08–0.16	0.015	0.008	0.12	—	—	0.04–0.08	—	—		
ERTi-17	R52253	0.03	0.03–0.10	0.012	0.005	0.08	—	—	0.04–0.08	—	—		
ERTi-18	R56326	0.03	0.06–0.12	0.012	0.005	0.20	2.5–3.5	2.0–3.0	0.04–0.08	—	—		
ERTi-19	*R58641*	*0.03*	*0.06–0.10*	*0.015*	*0.015*	*0.20*	*3.0–4.0*	*7.5–8.5*	—	—	—	*Mo* *Cr* *Zr*	*3.5–4.5* *5.5–6.5* *3.5–4.5*
ERTi-20	*R58646*	*0.03*	*0.06–0.10*	*0.015*	*0.015*	*0.20*	*3.0–4.0*	*7.5–8.5*	*0.04–0.08*	—	—	*Mo* *Cr* *Zr*	*3.5–4.5* *5.5–6.5* *3.5–4.5*
ERTi-21	*R58211*	*0.03*	*0.10–0.15*	*0.012*	*0.005*	*0.20–0.40*	*2.5–3.5*	—	—	—	—	*Mo* *Nb* *Si*	*14.0–16.0* *2.2–3.2* *0.15–0.25*

(Continued)

Table 1 (Continued)
Chemical Composition Requirements for Titanium and Titanium-Alloy Electrodes and Rods

AWS Classification	UNS Number[e]	Weight Percent[a, b, c, d]											
		C	O	N	H	Fe	Al	V	Pd	Ru	Ni	Other Elements	Amount
ERTi-23	R56408	0.03	0.03–0.11	0.012	0.005	0.20	5.5–6.5	3.5–4.5	—	—	—		
ERTi-24	R56415	0.05	0.12–0.20	0.03	0.015	0.22	5.5–6.75	3.5–4.5	0.04–0.08	—	—		
ERTi-25	R56413	0.05	0.12–0.20	0.03	0.015	0.22	5.5–6.75	3.5–4.5	0.04–0.08	—	0.3–0.8		
ERTi-26	R52405	0.03	0.08–0.16	0.015	0.008	0.12	—	—	—	0.08–0.14	—		
ERTi-27	R52255	0.03	0.03–0.10	0.012	0.005	0.08	—	—	—	0.08–0.14	—		
ERTi-28	R56324	0.03	0.06–0.12	0.012	0.005	0.20	2.5–3.5	2.0–3.0	—	0.08–0.14	—		
ERTi-29	R56414	0.03	0.03–0.11	0.012	0.005	0.20	5.5–6.5	3.5–4.5	—	0.08–0.14	—		
ERTi-30	R53531	0.03	0.08–0.16	0.015	0.008	0.12	—	—	0.04–0.08	—	—	Co	0.20–0.80
ERTi-31	R53533	0.03	0.13–0.20	0.02	0.008	0.16	—	—	0.04–0.08	—	—	Co	0.20–0.80
ERTi-32	R55112	0.03	0.05–0.10	0.012	0.008	0.20	4.5–5.5	0.6–1.4	—	—	—	Mo Si Zr Sn	0.6–1.2 0.06–0.14 0.6–1.4 0.6–1.4
ERTi-33	R53443	0.03	0.08–0.16	0.015	0.008	0.12	—	—	0.01–0.02	0.02–0.04	0.35–0.55	Cr	0.1–0.2
ERTi-34	R53444	0.03	0.13–0.20	0.02	0.008	0.16	—	—	0.01–0.02	0.02–0.04	0.35–0.55	Cr	0.1–0.2
ERTi-36	*R58451*	*0.03*	*0.06–0.12*	*0.02*	*0.0035*	*0.03*	—	—	—	—	—	*Nb*	*42.0–47.0*
ERTi-38	*R54251*	*0.05*	*0.20–0.27*	*0.02*	*0.010*	*1.2–1.8*	*3.5–4.5*	*2.0–3.0*	—	—	—		

[a] Titanium constitutes the remainder of the composition.
[b] Single values are maximum.
[c] Analysis of Fe and the interstitial elements C, O, H, and N shall be conducted on samples of filler metal taken after the filler metal has been reduced to its final diameter and all processing operations have been completed. Analysis of the other elements may be conducted on these same samples or it may have been conducted on samples taken from the ingot or the rod stock from which the filler metal is made. In case of dispute, samples from the finished filler metal shall be the referee method.
[d] Any element intentionally added (O, Fe, N, and C) must be measured and reported. Residual elements, total, shall not exceed 0.20%, with no single element exceeding 0.05%, except for yttrium, which shall not exceed 0.005%. Residual elements need not be reported unless specifically required by the purchaser. A residual element is any element present in the metal in small quantities that is inherent in the sponge or scrap additions, but not intentionally added. In titanium these elements include, among others, aluminum, vanadium, tin, chromium, molybdenum, niobium, zirconium, hafnium, bismuth, ruthenium, palladium, yttrium, copper, silicon, and cobalt.
[e] SAE HS-1086/ASTM DS-56, *Metals & Alloys in the Unified Numbering System*.
[f] ERTi-9 now conforms to the lower interstitial levels of the previous classification ERTi-9ELI (AWS A5.16/A5.16M:2004).

A5.16 and A5.16M providing it meets the requirements of both specifications.

3.3 The filler metals classified under this specification are intended for gas tungsten arc, gas metal arc, and plasma arc welding processes, but that is not to prohibit their use with any other process for which they are found suitable.

4. Acceptance

Acceptance[5] of the electrode shall be in accordance with the provisions of AWS A5.01.

5. Certification

By affixing the AWS specification and classification designations to the packaging, or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification.[6]

6. Rounding-Off Procedure

For the purpose of determining conformance with this specification, an observed or calculated value shall be rounded to the "nearest unit" in the last right-hand place of figures used in expressing the limiting value in accordance with the rounding-off method given in ASTM E 29.

7. Summary of Tests

Chemical analysis of the filler metal or the rod stock from which the filler metal is made is the only test required for classification of a product under this specification.

8. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Material for retest may be taken from the original sample or from a new sample. Retest need be only for those specific elements that failed to meet the test requirement. If the results of one or both retests fail to meet the requirement, the materials under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that, during preparation or after completion of any test, it is clearly determined that specified or proper procedures were not followed in preparing the test specimens or in conducting the test, the test shall be considered invalid, without regard to whether the test was actually completed, or whether test results met, or failed to meet, the requirement. That test shall be repeated, following proper prescribed procedures. In this case, the requirement for doubling the number of test specimens does not apply.

9. Chemical Analysis

9.1 A sample of the filler metal, or the stock from which it is made, shall be prepared for chemical analysis, except as provided for in Table 1, table footnote c.

9.2 The sample shall be analyzed by accepted analytical methods.

9.3 The results of the analysis shall meet the requirements of Table 1 for the classification of filler metal under test.

10. Method of Manufacture

The welding electrodes and rods classified according to this specification may be manufactured by any method that will produce material that meets the requirements of this specification.

11. Standard Sizes and Lengths

11.1 Standard sizes and lengths for electrodes and rods in the different package forms (straight lengths, coils with support, coils without support, and spools) are shown in Table 2.

12. Finish and Uniformity

12.1 All electrodes and rods shall have a smooth finish that is free from slivers, depressions, scratches, scale, seams, laps, and foreign matter that would adversely affect the welding characteristics, the operation of the welding equipment, or the properties of the weld metal.

12.2 Each continuous length of filler metal shall be from a single heat or lot of material, and welds, when present, shall have been made so as not to interfere with the uniform, uninterrupted feeding of the filler metal on automatic and semiautomatic equipment.

[5] See A3 (in Annex A) for further information concerning acceptance, testing of the material shipped, and A5.01.
[6] See A4 (in Annex A) for further information concerning certification and the testing called for to meet this requirement.

Table 2
Standard Sizes and Length[a]

Standard Package Forms	Diameter in	Diameter decimal in[b]	Diameter mm	Tolerances in	Tolerances mm
Straight Lengths[c] Coils without Support Coils with Support	1/16	0.062	1.6	±0.002	+0.01, –0.04
		0.079	2.0	±0.002	+0.01, –0.04
	3/32	0.094	2.4	±0.002	+0.01, –0.04
		0.098	2.5	±0.002	+0.01, –0.04
	1/8	0.125	3.2	±0.002	+0.01, –0.07
	5/32	0.156	4.0	±0.002	+0.01, –0.07
	3/16	0.188	4.8[d]	±0.002	+0.01, –0.07
		0.197	5.0	±0.002	+0.01, –0.07
Spools		0.020	0.5[d]	+0.001, –0.002	+0.01, –0.03
		0.030	0.8	+0.001, –0.002	+0.01, –0.03
		0.035	0.9	+0.001, –0.002	+0.01, –0.04
		0.039	1.0	+0.001, –0.002	+0.01, –0.04
		0.045	—	+0.001, –0.002	—
		0.047	1.2	+0.001, –0.002	+0.01, –0.04
	1/16	0.062	1.6	±0.002	+0.01, –0.04

[a] Dimensions, tolerances, and package forms (for round filler metal) other than those shown shall be as agreed by purchaser and supplier.
[b] Decimal inch are exact conversions with appropriate rounding.
[c] Length shall be 36 in ± 1/4 in [915 mm ± 6 mm].
[d] Not shown as standard metric size in ISO 544.

13. Standard Package Forms

13.1 Standard package forms are straight lengths, coils with support, coils without support, and spools. Standard package dimensions and weights for each form are given in Table 3. Package forms, sizes, and weights other than these shall be as agreed upon between the purchaser and supplier.

13.2 The liners in coils with support shall be designed and constructed to prevent distortion of the coil during normal handling and use, and shall be clean and dry in order to maintain the cleanliness of the filler metal.

13.3 Spools (Figure 1) shall be designed and constructed to prevent distortion of the filler metal during normal handling and use and shall be clean and dry enough in order to maintain the cleanliness of the filler metal.

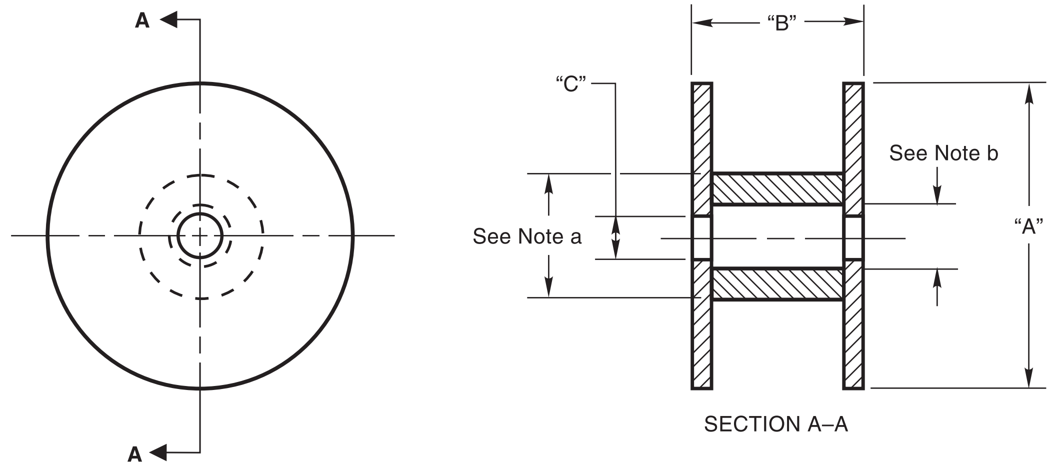
14. Winding Requirements

14.1 Filler metal in coils and on spools shall be wound so that kinks, waves, sharp bends, overlapping, or wedging are not encountered, leaving the filler metal free to unwind without restriction. The outside end of the electrode (the end with which welding is to begin) shall be

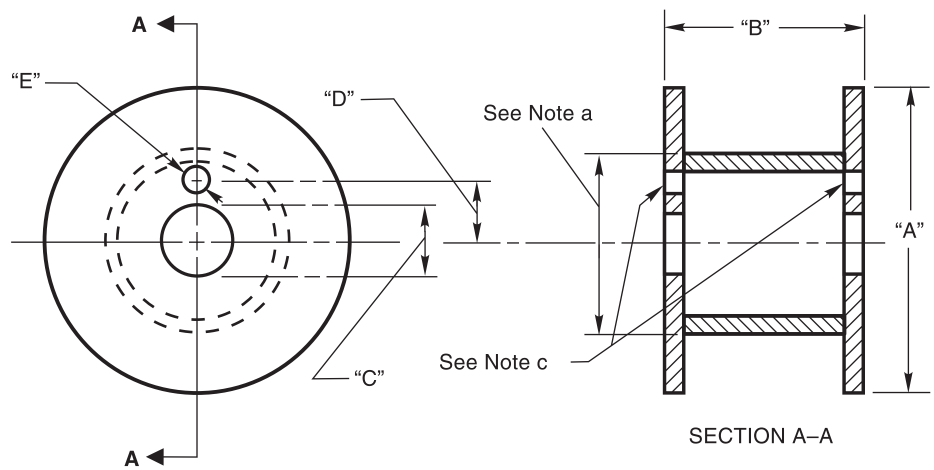
Table 3
Standard Packages, Dimensions, and Weights

Package Form			Nominal Net Weight lb	Nominal Net Weight kg
Straight Lengths			5	2.5
			10	5
			25	10
			50	25
Coils without Support			25	10
Coils with Support			50	25
Spools	in	mm		
	4	100	1	0.5
	8	200	5	2.5
	12	300	10–26	5–12
	—	340	30	15

Notes:
1. Filler metal diameters for all forms and lengths are given in Table 2.
2. No more than one classification or size shall be included in each package.
3. Dimensions of coils shall be as agreed by purchaser and supplier.
4. Dimensions of standard spools are shown in Figure 1.



DIMENSIONS OF STANDARD 4 in [100 mm] SPOOL



DIMENSIONS OF STANDARD 8 in AND 12 in [200 mm AND 300 mm] SPOOLS

		4 in [100 mm]		8 in [200 mm]		12 in [300 mm]	
		in	mm	in	mm	in	mm
A	Diameter, max. (Note d)	4.0	102	8.0	203	12	305
B	Width Tolerance	1.75 ±0.03	46 +0, –2	2.16 ±0.03	56 +0, –3	4.0 ±0.06	103 +0, –3
C	Diameter Tolerance	0.63 +0.01, –0	16 +1, –0	2.03 +0.06, –0	50.5 +2.5, –0	2.03 +0.06, –0	50.5 +2.5, –0
D	Distance between axes Tolerance	— —	— —	1.75 ±0.02	44.5 ±0.5	1.75 ±0.02	44.5 ±0.5
E	Diameter (Note c) Tolerance	— —	— —	0.44 +0, –0.06	10 +1, –0	0.44 +0, –0.06	10 +1, –0

[a] Outside diameter of barrel shall be such as to permit feeding of the filler metals.
[b] Inside diameter of the barrel shall be such that swelling of the barrel or misalignment of the barrel and flanges will not result in the inside diameter of the barrel being less than the inside diameter of the flanges.
[c] Holes are provided on each flange, but they need not be aligned. No driving holes required for 4 in [100 mm] spools.
[d] Metric dimensions and tolerances conform to ISO 544 except that "A" specifies ± tolerances on the nominal diameter, rather than a plus tolerance only, which is shown here as a maximum.

Figure 1—Dimensions of Standard 4 in, 8 in, and 12 in [100 mm, 200 mm, and 300 mm] Diameter Spools

identified so it can be readily located and shall be fastened to avoid unwinding. The winding shall be level winding.

14.2 The cast and helix of filler metal in coils and on spools shall be such that the filler metal will feed in an uninterrupted manner in automatic and semiautomatic equipment.

14.2.1 The cast and helix of filler metal on 4 in [100 mm] spools shall be such that a specimen long enough to produce a single loop, when cut from the spool and laid unrestrained on a flat surface, will:

(1) Form a circle not less than 2-1/2 in [65 mm] nor more than 9 in [230 mm] in diameter, and

(2) Rise above the flat surface no more than 1/2 in [13 mm] at any location.

14.2.2 The cast and helix of filler metal on 8 in [200 mm] spools shall be such that a specimen long enough to produce a single loop, when cut from the spool and laid unrestrained on a flat surface, will:

(1) Form a circle not less than 10 in [250 mm] nor more than 20 in [510 mm] in diameter, and

(2) Rise above the flat surface no more than 3/4 in [19 mm] at any location.

14.2.3 The cast and helix of filler metal on 12 in [300 mm] spools shall be such that a specimen long enough to produce a single loop, when cut from the spool and laid unrestrained on a flat surface, will:

(1) Form a circle not less than 15 in [380 mm] nor more than 30 in [760 mm] in diameter, and

(2) Rise above the flat surface no more than 1 in [25 mm] at any location.

15. Filler Metal Identification

15.1 *Each bare straight length filler rod shall be durably marked with identification traceable to the unique product type of the manufacturer or supplier. Suitable methods of identification could include stamping, coining, embossing, imprinting, flag-tagging, or color coding. (If color coding is used, the choice of color shall be as agreed between supplier and purchaser and the color shall be identified on the packaging.) When the AWS classification is used, the "ER" may be omitted; for example, "Ti-12" for classification ERTi-12. Additional identification shall be as agreed upon between supplier and purchaser.*

15.2 The product information and the precautionary information required in Clause 17 for marking each package shall appear also on each coil and spool.

15.3 Coils without support shall have a tag containing this information securely attached to the filler metal at the inside end of the coil.

15.4 Coils with support shall have the information securely affixed in a prominent location on the support.

15.5 Spools shall have the information securely affixed in a prominent location on the outside of at least one flange of the spool.

16. Packaging

Electrodes and rods shall be suitably packaged to ensure against damage during shipment and storage under normal conditions.

17. Marking of Packages

17.1 The following product information (as a minimum) shall be legibly marked so as to be visible from the outside of each unit package:

(1) AWS specification and AWS classification designation (year of issue may be excluded);

(2) Supplier's name and trade designation;

(3) Size and net weight; and

(4) Lot, control, or heat number.

17.2 The appropriate precautionary information[7] as given in ANSI Z49.1, latest edition, (as a minimum) shall be prominently displayed in legible print on all packages of welding material, including individual unit packages enclosed within a larger package.

[7] Typical examples of "warning labels" are shown in figures in ANSI Z49.1, for some common or specific consumables used with certain processes.

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Annex A

Guide to AWS Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods

This annex is not part of AWS A5.16/5.16M:2007, *Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods*, but is included for informational purposes only.

A1. Introduction

The purpose of this guide is to correlate the filler metal classifications with their intended applications so the specification can be used effectively. Appropriate base metal specifications are referred to whenever that can be done and when it would be helpful. Such references are intended only as examples rather than complete listings of the materials for which each filler metal is suitable.

A2. Classification System

A2.1 The system for identifying the filler metal classifications in this specification follows the standard pattern used in other AWS filler metal specifications. The letter "E" at the beginning of each classification designation stands for electrode, and the letter "R" stands for welding rod. Since these filler metals are used as electrodes in gas metal arc welding, as rods in gas tungsten arc welding and (as applicable) in plasma arc welding, both letters are used.

A2.2 The chemical symbol "Ti" appears after "R" as a means of identifying the filler metals as unalloyed titanium or a titanium-base alloy. The numeral provides a means of identifying different variations in the composition.

A2.3 Specific alloys are identified by a number similar to the grade designation used in ASTM/ASME[8] specifications for corresponding base metals. See Table A.1 for cross reference with the earlier designations.

A2.4 Table A.1 provides a correlation of the classifications in this revision with those in earlier (1970, 1990, and 2004) revisions and with other specifications for titanium alloy filler metals. The Aerospace Material Specifications[9] (AMS) and ASTM/ASME Specifications listed are also widely used in industry as shown in Table A.1.

A2.5 Request for Filler Metal Classification

(1) When a filler metal cannot be classified according to some existing classification, the manufacturer may request that a classification be established for that filler metal. The manufacturer may do this by following the procedure given here.

(2) A request to establish a new filler metal classification must be a written request and it needs to provide sufficient detail to permit the A5 Committee on Filler Metals and Allied Materials or the Subcommittee to determine whether the new classification or the modification of an existing classification is more appropriate, and whether either is necessary to satisfy the need.

In particular, the request needs to include:

(a) All classification requirements as given for existing classifications, such as, chemical composition ranges.

(b) Information on *Description and Intended Use*, which parallels that for existing classifications, for that clause of Annex A.

[8] ASME Specifications are available in Boiler and Pressure Vessel Code, Section IIB, from American Society of Mechanical Engineers, 345 East 47th Street, New York, New York 10007.

[9] Aerospace Material Specifications are available from Society of Automotive Engineers, 40 Commonwealth Drive, Warrendale, PA 15096-0001.

Table A.1
Specification Cross Index—Including Discontinued Titanium Electrodes

Filler Metal								Base Metal
AWS Classification				UNS Numbers	Aerospace Materials Specification	ISO Classification[a]	Japan JIS Z3331[b]	ASTM/ ASME Grades
2007	2004	1990	1970					
ERTi-1	ERTi-1	ERTi-1	ERTi-1	R50100	4951	STi-0100	YTx 28	1
ERTi-2	ERTi-2	ERTi-2	ERTi-2	R50120	—	STi-0120	YTx-35	2
ERTi-3	ERTi-3	ERTi-3	ERTi-3	R50125	—	STi-0125	YTx 49	3
ERTi-4	ERTi-4	ERTi-4	ERTi-4	R50130	—	STi-0130	—	4
ERTi-5	ERTi-5	ERTi-5	ERTi-6Al-4V	R56402	4954	STi-6402[c]	YTAx 640	5
ERTi-7	ERTi-7	ERTi-7	ERTi-0.2Pd	R52401	—	STi-2401	YTx 49Pd	7
ERTi-9[e]	ERTi-9ELI[d]	ERTi-9ELI	ERTi-3A1-2.5V-1	R56321	—	STi-6321	—	N/A
ERTi-11	ERTi-11	—	—	R52251	—	STi-2251	Ytx 28 Pd, YTx35 Pd	11
ERTi-12	ERTi-12	ERTi-12	—	R53401	—	STi-3401	—	12
ERTi-13	ERTi-13	—	—	R53423	—	STi-3423	—	13
ERTi-14	ERTi-14	—	—	R53424	—	STi-3424	—	14
ERTi-15A	ERTi-15A	—	—	R53416	—	STi-3416	—	15
ERTl-16	ERTl-16	—	—	R52403	—	STi-2403	—	16
ERTi-17	ERTi-17	—	—	R52253	—	STi-2253	—	17
ERTi-18	ERTi-18	—	—	R56326	—	STi-6326	—	18
ERTi-19	—	—	—	R58641	—	STi-8641[c]	—	19
ERTi-20	—	—	—	R58646	—	STi-8646[c]	—	20
ERTi-21	—	—	—	R58211	—	STi-8211[c]	—	21
ERTi-23	ERTi-23	ERTi-5ELI	ERTi-6Al-4V-1	R56408	4956	STi-6408	YTAx 640E	23
ERTi-24	ERTi-24	—	—	R56415	—	STi-6415	—	24
ERTi-25	ERTi-25	—	—	R56413	—	STi-6413	—	25
ERTi-26	ERTi-26	—	—	R52405	—	STi-2405	—	26
ERTi-27	ERTi-27	—	—	R52255	—	STi-2255	—	27
ERTi-28	ERTi-28	—	—	R56324	—	STi-6324	—	28
ERTi-29	ERTi-29	—	—	R56414	—	STi-6414	—	29
ERTi-30	ERTi-30	—	—	R53531	—	STi-3531	—	30
ERTi-31	ERTi-31	—	—	R53533	—	STi-3533	—	31
ERTi-32	ERTi-32	—	—	R55112	—	STi-5112	—	32
ERTi-33	ERTi-33	—	—	R53443	—	STi-3443	—	33
ERTi-34	ERTi-34	—	—	R53444	—	STi-3444	—	34
ERTi-36	—	—	—	R58451	—	STi-4841[c]	—	36
ERTi-38	—	—	—	R54251	—	STi-5451[c]	—	38
—	Discontinued	ERTi-6	ERTi—5Al-2.5Sn	R54522	4953	STi-5631	YTAx 525	—
—	Discontinued	ERTi-6ELI	ERTi—5Al-2.5Sn-1	R54523	—	STi-5631	—	—
—	Discontinued	ERTi-9	ERTi-3Al-2.5V	R56320	—	STi-6320	YTAx 325	9
—	Discontinued	ERTi-15	ERTi-6Al-2Cb-1Ta-1Mo	R56210	—	STi-5621	—	—
—	Discontinued		ERTi-8Al-1Mo-1V	—	—	—	—	—
—	Discontinued		ERTi-13V-11Cr-3Al	—	—	—	—	—

[a] The International system for Ti filler metal specifications has been published as ISO 24034:2005, *Welding Consumables — Solid wires and rods for fusion welding of titanium and titanium alloys — Classification*. The four-digit numbers in most instances are truncated from the five-digit UNS R-series numbers.
[b] The "x" designates the filler metal form, B = rods, W = wire.
[c] These designation numbers have been proposed for addition to ISO 24034:2005.
[d] Renamed ERTi-9 in this edition.
[e] The 2007 ERTi-9 composition has been specifically designed for welding Grade 9. It replaces the lower interstitial levels of the previous ERTi-9ELI.

A request for a new classification without the above information will be considered incomplete. The Secretary will return the request to the requestor for further information.

(3) The request should be sent to the Secretary of the A5 Committee on Filler Metals and Allied Materials at AWS Headquarters. Upon receipt of the request, the Secretary will:

(a) Assign an identifying number to the request. This number shall include the date the request was received.

(b) Confirm receipt of the request and give the identification number to the person who made the request.

(c) Send a copy of the request to the Chair of the A5 Committee on Filler Metals and Allied Materials and the Chair of the particular Subcommittee involved.

(d) File the original request.

(e) Add the request to the log of outstanding requests.

(4) All necessary action on each request will be completed as soon as possible. If more than 12 months lapse, the Secretary shall inform the requestor of the status of the request, with copies to the Chairs of the Committee and of the Subcommittee. Requests still outstanding after 18 months shall be considered not to have been answered in a "timely manner" and the Secretary shall report these to the Chair of the A5 Committee on Filler Metals and Allied Materials, for action.

(5) The Secretary shall include a copy of the log of all requests pending and those completed during the preceding year with the agenda for each A5 Committee on Filler Metals and Allied Materials meeting. Any other publication of requests that have been completed will be at the option of the American Welding Society, as deemed appropriate.

A3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01, *Filler Metal Procurement Guidelines*, as the specification states. Any testing a purchaser requires of the supplier, for material shipped in accordance with this specification, needs to be clearly stated in the purchase order, according to the provisions of AWS A5.01. In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing the supplier normally conducts on material of that classification, as specified in Schedule F, Table 1, of AWS A5.01. Testing in accordance with any other Schedule in that Table shall be specifically required by the purchase order. In such cases, acceptance of the material shipped shall be in accordance with those requirements.

A4. Certification

The act of placing the AWS specification and classification designation on the packaging enclosing the product or the classification on the product itself, constitutes the supplier's (manufacturer's) certification that the product meets all of the requirements of the specification. The only testing requirement implicit in this *certification* is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped and that the material met the requirements of the specification. Representative material, in this case, is any production run of that classification using the same formulation. *Certification* is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been conducted. The basis for the *certification* required by the specification is the classification test of *representative material* cited above, and the Manufacturer's Quality Assurance Program in AWS A5.01.

A5. Ventilation During Welding

A5.1 Five major factors govern the quantity of fumes to which welders and welding operators are exposed during welding. They are:

(1) Dimensions of the space in which welding is done (with special regard to the height of the ceiling);

(2) Number of welders and welding operators working in that space;

(3) Rate of evolution of fumes, gases, or dust, according to the materials and processes used;

(4) The proximity of the welders or welding operators to the fumes as the fumes issue from the welding zone, and to the gases and dusts in the space in which they are working; and

(5) The ventilation provided to the space in which the welding is done.

A5.2 American National Standard Z49.1, *Safety in Welding, Cutting, and Allied Processes* (published by the American Welding Society), discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the Clause on Ventilation in that document. See also AWS F3.2, *Ventilation Guide for Weld Fume*, for more detailed descriptions of ventilation options.

A6. Welding Considerations

A6.1 Titanium and titanium alloys can be welded by gas tungsten arc, gas metal arc, plasma arc, and electron beam welding processes. Titanium is a reactive metal and is sensitive to embrittlement by oxygen, nitrogen, and hydrogen, at elevated temperatures. Consequently, the metal must be protected from atmospheric contamination. This can be provided by shielding the metal with welding grade inert gas as specified in AWS A5.32/A5.32M, *Specification for Welding Shielding Gases*, for classes SG-A or SG-He or by having mixtures of these single shielding gas classes surrounding the arc as molten or solidified hot weld metal. Welding can also be done remotely in a chamber or in a glove bag. These chambers can be purged of air and back filled with inert gas, or, if they are rigid gas tight walls, can be evacuated to at least 10^{-4} torr [0.013 Pa] to remove any air contaminants.

During arc welding, the titanium should be shielded from the ambient air atmosphere until it has cooled below 800°F [430°C]. Adequate protection by auxiliary inert gas shielding can be provided when welding is being performed in ambient air atmosphere. Ventilation and exhaust at the arc must be carried out in such a manner that the protective inert gas shielding (arc shielding, trailing shielding, or root shielding) is not impaired.

A6.2 The titanium metal should be free of thick oxide and be chemically clean prior to welding, as contamination from oxide, water, grease, or dirt will also cause embrittlement.

A6.3 Titanium welding rods should be chemically clean and free of heavy oxide, absorbed moisture, grease, and dirt. If the hot end of the filler metal is removed from the gas shield prior to cooling and then reused, it contributes to weld contamination. The welding rod should be added by a technique that keeps the hot end within the torch gas blanket. If the rod tip becomes contaminated, the discolored end should be cut off before reusing.

A6.4 Titanium can be successfully fusion welded to zirconium, tantalum, niobium, and vanadium, although the weld metal will be stronger and less ductile than the parent metals. Titanium should not be fusion welded to other commonly welded metals such as copper, iron, nickel, and aluminum, as brittle titanium intermetallic alloys are formed which produce extremely brittle welds.

A6.5 In this specification, any individual residual elements shall not exceed 0.05%, of which the total shall not exceed a maximum of 0.20%. Residual elements can be present in trace amounts only and these elements cannot have been added intentionally. Yttrium, however, has been controlled to a maximum level of 0.005% because it acts as a strong grain refiner for titanium and titanium alloys. Yttrium added to titanium in higher levels could result in stringers and may reduce the fatigue strength in some product forms. Any element intentionally added shall be measured and reported.

A7. Description and Intended Use of Titanium and Titanium-Alloy Electrodes and Rods

Titanium exhibits excellent corrosion resistance in a wide variety of media, but most notably in natural solutions associated with chloride ion, whether in salt or brackish water cooling, desalinization, brine handling, bleaching, chlorine and chlorate chemical applications, or orthopedic implants. The addition of small amounts of palladium or ruthenium extends the range of corrosion resistance to moderately reducing conditions such as low concentration HCl and H_2SO_4 and in crevice situations where temperatures are above the limits where unalloyed and standard alloy grades perform satisfactorily. High strength to weight ratio in alloys allows for extensive use in aircraft and aerospace applications; from aircraft wing support forgings to the compressor blades on turbine engines. High strength applications also include a variety of weight critical military hardware, and in increasingly sophisticated industrial applications like downhole equipment for energy exploration or geothermal brine production. Recently, titanium has found its way into architectural uses for building sheathing, roofing, and even structural applications, as well as many consumer applications like bicycle frames, golf clubs, high performance sports equipment, eyeglass frames, automotive springs and mufflers, and even art forms.

There are many proprietary alloys and grades covered in specifications other than those published by ASTM; however, many of those alloys are not readily available. This listing is confined to filler metals intended for titanium and titanium alloy grades in common use that are recommended for ASTM base metal grades. See Table A.1 for specification cross reference.

A7.1 In general, each ERTi-XX filler metal grade is designed for welding the corresponding XX base metal grade. The range of oxygen in the ERTi-XX grade is specified to allow approximately 300 ppm increase during welding to then match the typical base metal composition. Iron, nitrogen, carbon, and hydrogen are specified to lower levels than corresponding base metal. Other alloy elements are specified to the same level in filler and base metal grades.

A7.2 Use of a filler metal of the same strength and composition except enhanced with palladium or ruthenium (e.g. substituting ERTi-7 for ERTi-2) could be considered where preferential weld metal corrosion is anticipated and will generally produce satisfactory results. If it is desired to weld other combinations of dissimilar grades, welds should be evaluated as to suitability for the purpose intended for both mechanical and corrosion properties. Caution should be exercised when considering welding alloys with unalloyed filler metals because differences in hydrogen solubility can lead to delayed cracking problems. In the absence of specific information, consultation with the material supplier is recommended. Additional information may be found in the titanium chapter of the AWS *Welding Handbook*, Volume 4, Eighth Edition. Filler metal classifications are listed in Table A.2.

A7.3 ERTi-1. Grade 1 is the lowest strength unalloyed (or Commercially Pure—CP) grade. Grade 1 is used in applications where ductility is paramount, such as explosive cladding, loose linings, expanded metal, and deep drawing applications. It is also used in electrolytic applications like coated anode substrates for production of chlorine and sodium chlorate.

A7.4 ERTi-2. Grade 2 is the "workhorse" of the industrial corrosion market and most common unalloyed (or Commercially Pure—CP) grade. Grade 2 is generally the most readily available in all product forms and has the lowest cost. It is used for process equipment like pressure vessels, columns, tanks, heat exchangers, shafts, blowers and fans, condenser tubing, valves, fittings, and pipe.

A7.5 ERTi-3. Grade 3 is a higher strength unalloyed (or Commercially Pure—CP) grade. Grade 3 is used for process equipment, tubing and pipe. Grade 3 is not as readily available as ERTi-2, but should be considered in applications where its higher strength reduces metal thickness required, and where the quantity of metal justifies a mill purchase.

A7.6 ERTi-4. Grade 4 is the highest strength unalloyed (or Commercially Pure—CP) grade. Grade 4 is rarely used in corrosion service, but has been used (under AMS Specifications) in aircraft components where its higher strength can reduce the weight of components like bulkheads and firewalls.

A7.7 ERTi-5. Grade 5 (Ti 6Al-4V), commonly called "6-4," is the most common and widely used alloy grade due to its relatively low cost and good availability. It has a UTS of 130,000 psi [895 MPa] minimum, good weldability, and can be heat treated to a higher strength or toughness. Grade 5 is used in aircraft components such as landing gear, wing spars, and compressor blades. Its corrosion resistance is generally comparable to Grade 2 and it is often used in corrosion service where higher strength is required, particularly in shafts, high strength bolting, and keys.

A7.8 ERTi-7. Grade 7 has the same mechanical properties as Grade 2. The 0.12 wt % palladium addition improves corrosion performance under mildly reducing conditions or where crevice or under-deposit corrosion is a problem. ERTi-7 can be considered for welding Grade 2 or 16 where improved corrosion performance is desired.

A7.9 ERTi-9. Grade 9 (Ti 3Al-2.5V) is a "half" alloy version of Grade 5 and is used for applications where better ductility, formability, and weldability are needed, but lower UTS is acceptable. Grade 9 can be produced in welded or seamless tube and pipe. It is used in applications like oil production tubulars and bicycle frames.

A7.10 ERTi-11. Grade 11 has the same mechanical properties as Grade 1. The minimum 0.12 wt % palladium addition improves corrosion performance under mildly reducing conditions or where crevice or under-deposit corrosion is a problem. It is widely used in components for chlorine electrodes and for explosive cladding where enhanced corrosion performance is required. ERTi-11 can be considered for welding Grade 1 or 17 where improved corrosion performance is desired.

A7.11 ERTi-12. Grade 12 (Ti 0.8Ni0.3Mo) is an intermediate strength grade originally developed to provide enhanced crevice-corrosion resistance in high temperature brines, but at lower cost than Grade 7. The improved performance is believed to be the result of Ni++ and Mo++ ions that alter the surface electrochemistry of the material in the crevice or under a surface deposit. Grade 12 has better elevated temperature properties than Grade 2 or 3 and is sometimes specified for pressure vessels or piping for its superior strength alone.

A7.12 ERTi-13. Grade 13 has the same yield strength as Grade 1, but a higher specified minimum UTS. The ruthenium segregates preferentially to the nickel-rich phase so that a lower amount of ruthenium provides effective protection compared to grades where ruthenium acts as the sole corrosion-enhancing alloy. Ruthenium

Table A.2
Guide to Choice of Filler Metal for General Purpose Titanium Welding

ASTM Base Metal Grade	Base Metal UTS (min.) ksi [MPa]	Base Metal YS (min.) ksi [MPa]	Nominal Composition	Recommended Filler Metal	Alternate Filler Metals	Comments
1	35 [240]	20 [138]	Ti (unalloyed)	ERTi-1	—	—
2	50 [345]	40 [275]	Ti (unalloyed)	ERTi-2	—	ERTi-1 is no longer recommended for Grade 2 in structural applications
2H	58 [400]	40 [275]	Ti (unalloyed)	ERTi-2	—	Identical to Grade 2 except for higher tensile strength
3	65 [450]	55 [380]	Ti (unalloyed)	ERTi-3	—	ERTi-2 is no longer recommended for Grade 3 in structural applications
4	80 [550]	70 [483]	Ti (unalloyed)	ERTi-4	—	—
5	130 [895]	120 [828]	Ti 6Al-4V	ERTi-5	—	—
6	—	—	—	NA[a]	—	—
7	50 [345]	40 [275]	Ti 0.15Pd	ERTi-7	—	—
7H	58 [400]	40 [275]	Ti 0.15Pd	ERTi-7	—	Identical to Grade 7 except for higher tensile strength
—	—	—	—	NA[a]	—	—
9	90 [620]	70 [483]	Ti 3Al-2.5V	ERTi-9	—	—
—	—	—	—	NA[a]	—	—
11	35 [240]	20 [138]	Ti 0.15Pd	ERTi-11	—	—
12	70 [483]	50 [345]	Ti 0.8Ni-0.3Mo	ERTi-12	—	—
13	40 [275]	25 [170]	Ti 0.5Ni-0.05Ru	ERTi-13	—	—
14	60 [410]	40 [275]	Ti 0.5Ni-0.05Ru	ERTi-14	—	—
15	70 [483]	55 [380]	Ti 0.5Ni-0.05Ru	ERTi-15A	—	"A" suffix used to distinguish from obsolete ERTi-15 composition
16	50 [345]	40 [275]	Ti 0.05Pd	ERTi-16	ERTi-7	ERTi-7 provides comparable mechanical properties and equal or better corrosion resistance
16H	58 [400]	40 [275]	Ti 0.05Pd	ERTi-16	—	Identical to Grade 16 except for higher tensile strength
17	35 [240]	20 [138]	Ti 0.05Pd	ERTi-17	ERTi-11	ERTi-11 provides comparable mechanical properties and equal or better corrosion resistance
18	90 [620]	70 [483]	Ti 3Al-2.5V ELI-0.05Pd	ERTi-18	—	—
19	115 [793]	110 [759]	Ti 3Al-8V-6Cr-4Zr-4Mo	ERTi-19	—	—

(Continued)

Table A.2 (Continued)
Guide to Choice of Filler Metal for General Purpose Titanium Welding

ASTM Base Metal Grade	Base Metal UTS (min.) ksi [MPa]	Base Metal YS (min.) ksi [MPa]	Nominal Composition	Recommended Filler Metal	Alternate Filler Metals	Comments
20	115 [793]	110 [759]	Ti 3Al-8V-6Cr-4Zr-4Mo-0.05Pd	ERTi-20	—	—
21	115 [793]	110 [759]	Ti 3Al-15Mo-2.5Nb-0.2Si	ERTi-21	—	—
—	—	—	—	NA[a]	—	—
23	120 [828]	110 [759]	Ti 6Al-4V ELI	ERTi-23	—	—
24	130 [895]	120 [828]	Ti 6Al-4V-0.05Pd	ERTi-24	—	—
25	130 [895]	120 [828]	Ti 6Al-4V-0.5Ni-0.5Pd	ERTi-25	—	—
26	50 [345]	40 [275]	Ti 0.10Ru	ERTi-26	ERTi-7	ERTi-7 provides comparable mechanical properties and equal or better corrosion resistance
26H	58 [400]	40 [275]	Ti 0.10Ru	ERTi-26	ERTi-7	Identical to Grade 26 except for higher tensile strength
27	35 [240]	20 [138]	Ti 0.10Ru	ERTi-27	ERTi-1	ERTi-11 provides comparable mechanical properties and equal or better corrosion resistance
28	90 [620]	70 [483]	Ti 3Al-2.5V ELI-0.10Ru	ERTi-28	ERTi-18	ERTi-18 provides comparable mechanical properties and comparable corrosion resistance
29	120 [828]	110 [759]	Ti 6Al-4VELI-0.10Ru	ERTi-29	—	—
30	50 [345]	40 [275]	Ti 0.3Co-0.05Pd	ERTi-30	—	—
31	65 [450]	55 [380]	Ti 0.3Co-0.05Pd	ERTi-31	—	—
32	100 [689]	85 [586]	Ti 5Al-1Sn-1Zr-1V-0.8Mo	ERTi-32	—	—
33	50 [345]	40 [275]	Ti 0.4Ni-0.015Pd-0.015Ru-0.14Cr	ERTi-33	—	—
34	65 [450]	55 [380]	Ti 0.4Ni-0.015Pd-0.015Ru-0.14Cr	ERTi-34	—	—
35	—	—	—	NA[a]	—	—
36	65 [450]	60 [410]	Ti 45Nb	ERTi-36	—	—
37	—	—	—	NA[a]	—	—
38	130 [895]	115 [794]	Ti 4Al-2.5V-1.5Fe	ERTi-38	—	—

[a] Either there is no current ASTM Grade or no corresponding AWS Filler Metal Grade.

Note: Properties in solution treated condition. Material is normally purchased in this condition and heat treated as required.

addition improves corrosion performance under mildly reducing conditions or where crevice or under-deposit corrosion is a problem. Grade 13 has a lower alloy cost than Grades 11, 17, and 27 due to lower ruthenium content. This alloy was developed and is primarily used in Japan.

A7.13 ERTi-14. Grade 14 has the same yield strength as Grade 2, but a higher specified minimum UTS. The ruthenium segregates preferentially to the nickel-rich phase so that a lower amount of ruthenium provides effective protection compared to grades where ruthenium acts as the sole corrosion-enhancing alloy. Ruthenium addition improves corrosion performance under mildly reducing conditions or where crevice or under-deposit corrosion is a problem. Grade 14 has a lower alloy cost than Grades 2, 7, and 26 due to lower ruthenium content. This alloy was developed and is primarily used in Japan.

A7.14 ERTi-15A. Grade 15 has the same yield strength as Grade 3, but a higher specified minimum UTS. The ruthenium segregates preferentially to the nickel phase so that a lower amount of ruthenium provides effective protection compared to grades where ruthenium acts as the sole corrosion-enhancing alloy. Ruthenium addition improves corrosion performance under mildly reducing conditions or where crevice or under-deposit corrosion is a problem. There is no corresponding standard ruthenium or palladium grade with this strength level. This alloy was developed and is primarily used in Japan. The suffix letter A distinguishes this composition from an earlier and now obsolete Grade 15, but has no other significance.

A7.15 ERTi-16. Grade 16 has the same mechanical properties as Grades 2, 7, and 26. It is often referred to as a "lean palladium grade." The minimum 0.04 wt % palladium addition improves corrosion performance under mildly reducing conditions or where crevice or under-deposit corrosion is a problem. Grade 16 has a lower alloy cost than Grade 7 and comparable performance except under the most aggressive corrosion conditions. Welding with ERTi-7 overcomes slightly lower corrosion resistance of welds made with matching filler metal.

A7.16 ERTi-17. Grade 17 has the same mechanical properties as Grades 1, 11, and 26. It is often referred to as a "lean palladium grade." The minimum 0.04 wt % palladium addition improves corrosion performance under mildly reducing conditions or where crevice or under-deposit corrosion is a problem. Grade 17 has a lower alloy cost than Grade 11 and comparable performance except under the most aggressive corrosion conditions. Welding with ERTi-11 overcomes slightly lower corrosion resistance of welds made with matching filler metal.

A7.17 ERTi-18. Grade 18 (Ti 3Al-2.5V-0.5Pd) is comparable in mechanical and metalworking properties to Grades 9 and 28. The palladium addition improves the alloy corrosion resistance. Grade 18 was developed originally for energy industry applications like hypersaline brine tubulars, including coiled tubing.

A7.18 ERTi-19. Grade 19 (Ti 3Al-8V-6Cr-4Mo-4Zr) alloy (Ti38644), commonly known as Beta C, is a commonly used high strength beta alloy utilized in certain marine and energy industry applications. Its applications include welded tubulars in energy industry (oil and gas industry, geothermal brines), aircraft springs, and some ordinance applications. Grade 19's filler metal matches its base metal composition except for oxygen range, and lower N, C, Fe, and H.

A7.19 ERTi-20. Grade 20 (Ti 3Al-8V-6Cr-4Mo-4Zr-0.05Pd) alloy (Ti38644Pd), commonly known as Beta C Palladium, is a commonly used high strength beta alloy utilized in certain marine and energy industry applications. Its applications include welded tubulars in energy industry (oil and gas industry, geothermal brines), aircraft springs, and some ordinance applications. Grade 20's filler metal matches its base metal composition except for oxygen range, and lower N, C, Fe, and H.

A7.20 ERTi-21. Grade 21 (Ti 15Mo-3Nb-3Al-0.2Si) is a strip-producible beta titanium alloy with excellent corrosion resistance, due to the high Mo content. It can be easily welded in the annealed or solution-treated condition and subsequently aged to achieve the desired strength. This alloy is mostly used in aerospace components, but it can also apply to the Chemical Processing Industry (CPI) and Oil & Gas in both fabricated components and as a fastener. Grade 21's filler metal matches its base metal composition except for oxygen range, and lower N, C, Fe, and H.

A7.21 ERTi-23. Grade 23 (Ti 6Al-4V) is comparable in chemical composition to Grade 5, but slightly lower aluminum and lower levels of oxygen and other interstitial elements improve fabricability, weldability, and toughness. Grade 23 is used in many high strength industrial applications such as shafts where very high strength, but better toughness and fabricability than Grade 5 is desired. This grade is often specified for marine and offshore energy production components that are exposed to low temperature seawater due to higher fracture toughness values than Grade 5.

A7.22 ERTi-24. Grade 24 (Ti 6Al-4V-0.5Pd) is comparable in mechanical and metalworking properties to Grade 5. The palladium addition improves the alloy corrosion resistance. The alloy was developed originally for energy industry applications like hypersaline brine tubulars.

A7.23 ERTi-25. Grade 25 (Ti 6Al-4V-0.5Pd) is comparable in mechanical properties to Grade 5. The palladium and nickel improve the alloy corrosion resistance.

A7.24 ERTi-26. Grade 26 has the same mechanical properties as Grades 2, 7, and 16. The minimum 0.08 wt % ruthenium addition improves corrosion performance under mildly reducing conditions or where crevice or under-deposit corrosion is a problem in a manner similar to the 0.04 wt % palladium addition in Grade 16. Grade 26 has a lower alloy cost than Grade 7 or 16. Corrosion performance is comparable to Grade 16, and also to Grade 7 except under the most aggressive corrosion conditions. Welding with ERTi-7 overcomes slightly lower corrosion resistance of welds made with matching filler metal.

A7.25 ERTi-27. Grade 27 has the same mechanical properties as Grades 1, 11 and 17. The minimum 0.08 wt % ruthenium addition improves corrosion performance under mildly reducing conditions or where crevice or under-deposit corrosion is a problem in a manner similar to the 0.04 wt % palladium addition in Grade 17. Grade 26 has a lower alloy cost than Grade 11 or 27. Corrosion performance is comparable to Grade 17, and also to Grade 7 except under the most aggressive corrosion conditions. Welding with ERTi-11 overcomes slightly lower corrosion resistance of welds made with matching filler metal.

A7.26 ERTi-28. Grade 28 (Ti 3 Al-2.5V-0.1Ru) is comparable in mechanical properties and fabricability to Grades 9 and 18. The minimum 0.08 wt % ruthenium addition improves corrosion performance under mildly reducing conditions or where crevice or under-deposit corrosion is a problem in a manner similar to the 0.04 wt % palladium addition in Grade 18. Grade 28 has a lower alloy cost than Grade 18 and its corrosion performance is comparable to Grade 18. It was developed originally for energy industry applications like hypersaline brine tubulars where better formability and weldability are needed.

A7.27 ERTi-29. Grade 29 (Ti 6Al-4V-0.1Ru) is comparable in mechanical and fabricability properties to Grade 23. The minimum 0.08 wt % ruthenium addition improves corrosion performance under mildly reducing conditions or where crevice or under-deposit corrosion is a problem. It was originally developed and widely used for energy industry applications like tubulars for downhole oil and gas production and hypersaline geothermal brine applications.

A7.28 ERTi-30. Grade 30 has the same mechanical properties as Grade 2. The ruthenium addition improves corrosion performance under mildly reducing conditions or where crevice or under-deposit corrosion is a problem. This alloy was developed and is primarily used in Japan.

A7.29 ERTi-31. Grade 31 has the same mechanical properties as Grade 3. The ruthenium addition improves corrosion performance under mildly reducing conditions or where crevice or under-deposit corrosion is a problem. This alloy was developed and is primarily used in Japan.

A7.30 ERTi-32. Grade 32 (Ti 5Al-1Sn-1Zr-1V-0.8Mo) is a high strength alloy with fracture toughness values in seawater in excess of 100 MPa $m^{1/2}$. Grade 32 evolved from Navy efforts to develop a high toughness, weldable, corrosion-resistant alloy for pressure hulls. High fracture toughness is critical when finding a use in auxiliary systems and equipment on Navy ships as well as for some energy industry applications. This alloy is commonly called 5-1-1-1 or five triple one.

A7.31 ERTi-33. Grade 33 has the same mechanical properties as Grade 2. The ruthenium and palladium additions improve corrosion performance under mildly reducing conditions or where crevice or under-deposit corrosion is a problem. This alloy was developed and is primarily used in Japan.

A7.32 ERTi-34. Grade 34 has the same mechanical properties as Grade 3. The ruthenium and palladium additions improve corrosion performance under mildly reducing conditions or where crevice or under-deposit corrosion is a problem. This alloy was developed and is primarily used in Japan.

A7.33 ERTi-36. Grade 36 (Ti-45Nb) is matched to ASTM Grade 36 (UNS R58450). Except for oxygen, all other intentional alloy additions are similar to the base metal. This alloy can be used in welded applications and provides improved corrosion resistance compared to Grades 7, 16, and 26 in some environments. This alloy may provide improved ignition resistance compared to other titanium grades in high oxygen, partial pressure environments.

A7.34 ERTi-38. Grade 38 (Ti 4Al-2.5V-1.5Fe) is matched to ASTM Grade 38 and ASME Code Case 2532 (UNS R54250). Except for oxygen, all other intentional alloy additions are similar to the base metal. This is a high strength alloy intended for welded applications at temperatures somewhat higher than other titanium grades. ERTi-38 is the highest strength titanium alloy accepted for ASME Code construction.

A8. Special Tests

It is recognized that supplementary tests may be required for certain applications. In such cases, tests to determine specific properties, such as corrosion-resistance, scale-resistance, or strength at elevated temperatures may be required; AWS A5.01 contains provisions for ordering such tests. This clause is included for the guidance of those who desire to specify such special tests. Those tests may be conducted as agreed upon between the purchaser and supplier.

A8.1 Corrosion or Scaling Tests. Although welds made with fillers in this specification are commonly used in corrosion and heat-resisting applications, tests for those properties are not included in the specification. When required for a particular application, tests can be conducted on specimens taken from either a weld pad or a welded joint. Specimens from a joint are suitable for qualifying the welding procedure (for a specific application involving corrosion or oxidation resistance) but not for qualifying the electrode. Tests on specimens from a joint have the disadvantage of being a combined test of the properties of the weld metal, the heat-affected zone (HAZ), and the unaffected base metal. With them, it is more difficult to obtain reproducible data (when a difference exists in the properties of the metal in the various parts of the specimen). Specimens taken from a joint have the advantage of being able to duplicate the joint design and the welding sequence planned for fabrication.

A8.1.1 Specimens for testing the corrosion or oxidation resistance of the weld metal alone are prepared by following the procedure outlined in A8.1.2 of the specification. The pad size should be at least 3/4 in [19 mm] in height, 2-1/2 in [65 mm] in width, and 1 + 5/8 n(in) [25 + 16 n{mm}] in length, where n represents the number of specimens required from the pad. Specimens measuring 1/2 × 2 × 1/4 in [13 × 50 × 6.4 mm] are machined from the top of the pad in a manner such that the 2 in [50 mm] dimension of the specimen is parallel with the 2-1/2 in [65 mm] dimension of the pad and the 1/2 in [13 mm] dimension is parallel with the length of the pad.

A8.1.2 The heat treatment, surface finish, and marking of the specimens prior to testing should be in accordance with standard practices for tests of similar alloys in the wrought or cast forms. The testing procedures should correspond to those of ASTM G 4, *Standard Guide for Conducting Corrosion Tests in Field Applications*, or ASTM G 31, *Standard Practice for Laboratory Immersion Corrosion Testing of Metals*, as the case may be.

A9. Discontinued Classifications

Some classifications have been discontinued, from one revision of this specification to another. This results either from changes in commercial practice or changes in the classification system used in the specification. The classifications that have been discontinued are listed in Table A.1, along with the year in which they were last included in the specification.

A10. General Safety Considerations

A10.1 Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in annex clause A5. Safety and health information is available from other sources, including, but not limited to Safety and Health Fact Sheets listed in A10.3, ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*,[10] and applicable federal and state regulations.

A10.2 Safety and Health Fact Sheets. The Safety and Health Fact Sheets listed below are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at http://www.aws.org. The Safety and Health Fact Sheets are revised and additional sheets are added periodically.

A10.3 AWS Safety and Health Fact Sheets Index (SHF)[11]

No.	Title
1	*Fumes and Gases*
2	*Radiation*
3	*Noise*
4	*Chromium and Nickel in Welding Fume*
5	*Electrical Hazards*
6	*Fire and Explosion Prevention*
7	*Burn Protection*
8	*Mechanical Hazards*
9	*Tripping and Falling*
10	*Falling Objects*
11	*Confined Spaces*
12	*Contact Lens Wear*
13	*Ergonomics in the Welding Environment*
14	*Graphic Symbols for Precautionary Labels*
15	*Style Guidelines for Safety and Health Documents*
16	*Pacemakers and Welding*
17	*Electric and Magnetic Fields (EMF)*

[10] ANSI Z49.1 is published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

[11] AWS standards are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

No.	Title
18	*Lockout/Tagout*
19	*Laser Welding and Cutting Safety*
20	*Thermal Spraying Safety*
21	*Resistance Spot Welding*
22	*Cadmium Exposure from Welding & Allied Processes*
23	*California Proposition 65*
24	*Fluxes for Arc Welding and Brazing: Safe Handling and Use*
25	*Metal Fume Fever*
26	*Arc Viewing Distance*
27	*Thoriated Tungsten Electrodes*
28	*Oxyfuel Safety: Check Valve and Flashback Arrestors*
29	*Grounding of Portable and Vehicle Mounted Welding Generators*
30	*Cylinders: Safe Storage, Handling, and Use*
31	*Eye and Face Protection for Welding and Cutting Operations*

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Annex B
Guidelines for the Preparation of Technical Inquiries

This annex is not part of AWS A5.16/5.16M:2007, *Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods*, but is included for informational purposes only.

B1. Introduction

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all interpretations are made by the committee that is responsible for the standard. Official communication concerning an interpretation is directed through the AWS staff member who works with that committee. The policy requires that all requests for an interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the complexity of the work and the procedures that must be followed, some interpretations may require considerable time.

B2. Procedure

All inquiries shall be directed to:

Managing Director
Technical Services Division
American Welding Society
550 N.W. LeJeune Road
Miami, FL 33126

All inquiries shall contain the name, address, and affiliation of the inquirer, and they shall provide enough information for the committee to understand the point of concern in the inquiry. When the point is not clearly defined, the inquiry will be returned for clarification. For efficient handling, all inquiries should be typewritten and in the format specified below.

B2.1 Scope. Each inquiry shall address one single provision of the standard unless the point of the inquiry involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the inquiry along with the edition of the standard that contains the provision(s) the inquirer is addressing.

B2.2 Purpose of the Inquiry. The purpose of the inquiry shall be stated in this portion of the inquiry. The purpose can be to obtain an interpretation of a standard's requirement or to request the revision of a particular provision in the standard.

B2.3 Content of the Inquiry. The inquiry should be concise, yet complete, to enable the committee to understand the point of the inquiry. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annex) that bear on the inquiry shall be cited. If the point of the inquiry is to obtain a revision of the standard, the inquiry shall provide technical justification for that revision.

B2.4 Proposed Reply. The inquirer should, as a proposed reply, state an interpretation of the provision that is the point of the inquiry or provide the wording for a proposed revision, if this is what the inquirer seeks.

B3. Interpretation of Provisions of the Standard

Interpretations of provisions of the standard are made by the relevant AWS technical committee. The secretary of the committee refers all inquiries to the chair of the particular subcommittee that has jurisdiction over the portion of the standard addressed by the inquiry. The subcommittee reviews the inquiry and the proposed reply to determine what the response to the inquiry should be. Following the subcommittee's development of the response, the inquiry and the response are presented to the entire committee for review and approval. Upon approval by the committee, the interpretation is an official interpretation of the Society, and the secretary transmits the response to the inquirer and to the *Welding Journal* for publication.

B4. Publication of Interpretations

All official interpretations will appear in the *Welding Journal* and will be posted on the AWS web site.

B5. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

B6. AWS Technical Committees

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees or to consideration of revisions to existing provisions on the basis of new data or technology. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

AWS Filler Metal Specifications by Material and Welding Process

	OFW	SMAW	GTAW GMAW PAW	FCAW	SAW	ESW	EGW	Brazing
Carbon Steel	A5.2	A5.1	A5.18	A5.20	A5.17	A5.25	A5.26	A5.8, A5.31
Low-Alloy Steel	A5.2	A5.5	A5.28	A5.29	A5.23	A5.25	A5.26	A5.8, A5.31
Stainless Steel		A5.4	A5.9, A5.22	A5.22	A5.9	A5.9	A5.9	A5.8, A5.31
Cast Iron	A5.15	A5.15	A5.15	A5.15				A5.8, A5.31
Nickel Alloys		A5.11	A5.14	A5.34	A5.14			A5.8, A5.31
Aluminum Alloys		A5.3	A5.10					A5.8, A5.31
Copper Alloys		A5.6	A5.7					A5.8, A5.31
Titanium Alloys			A5.16					A5.8, A5.31
Zirconium Alloys			A5.24					A5.8, A5.31
Magnesium Alloys			A5.19					A5.8, A5.31
Tungsten Electrodes			A5.12					
Brazing Alloys and Fluxes								A5.8, A5.31
Surfacing Alloys	A5.21	A5.13	A5.21	A5.21	A5.21			
Consumable Inserts			A5.30					
Shielding Gases			A5.32	A5.32			A5.32	

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AWS Filler Metal Specifications and Related Documents

Designation	Title
FMC	*Filler Metal Comparison Charts*
IFS	*International Index of Welding Filler Metal Classifications*
UGFM	*User's Guide to Filler Metals*
A4.2M (ISO 8249: 2000 MOD)	*Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal*
A4.3	*Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding*
A4.4M	*Standard Procedures for Determination of Moisture Content of Welding Fluxes and Welding Electrode Flux Coverings*
A5.01	*Filler Metal Procurement Guidelines*
A5.02/A5.02M	*Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*
A5.1/A5.1M	*Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*
A5.2/A5.2M	*Specification for Carbon and Low-Alloy Steel Rods for Oxyfuel Gas Welding*
A5.3/A5.3M	*Specification for Aluminum and Aluminum-Alloy Electrodes for Shielded Metal Arc Welding*
A5.4/A5.4M	*Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding*
A5.5/A5.5M	*Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*
A5.6/A5.6M	*Specification for Covered Copper and Copper-Alloy Arc Welding Electrodes*
A5.7/A5.7M	*Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes*
A5.8/A5.8M	*Specification for Filler Metals for Brazing and Braze Welding*
A5.9/A5.9M	*Specification for Bare Stainless Steel Welding Electrodes and Rods*
A5.10/A5.10M	*Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods*
A5.11/A5.11M	*Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding*
A5.12/A5.12M	*Specification for Tungsten and Tungsten-Alloy Electrodes for Arc Welding and Cutting*
A5.13	*Specification for Surfacing Electrodes for Shielded Metal Arc Welding*
A5.14/A5.14M	*Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods*
A5.15	*Specification for Welding Electrodes and Rods for Cast Iron*
A5.16/A5.16M	*Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods*
A5.17/A5.17M	*Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding*
A5.18/A5.18M	*Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding*
A5.19	*Specification for Magnesium Alloy Welding Electrodes and Rods*
A5.20/A5.20M	*Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*
A5.21	*Specification for Bare Electrodes and Rods for Surfacing*
A5.22	*Specification for Stainless Steel Electrodes for Flux Cored Arc Welding and Stainless Steel Flux Cored Rods for Gas Tungsten Arc Welding*
A5.23/A5.23M	*Specification for Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*
A5.24/A5.24M	*Specification for Zirconium and Zirconium Alloy Welding Electrodes and Rods*
A5.25/A5.25M	*Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding*
A5.26/A5.26M	*Specification for Carbon and Low-Alloy Steel Electrodes for Electrogas Welding*
A5.28/A5.28M	*Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding*
A5.29/A5.29M	*Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding*
A5.30/A5.30M	*Specification for Consumable Inserts*
A5.31	*Specification for Fluxes for Brazing and Braze Welding*
A5.32/A5.32M	*Specification for Welding Shielding Gases*
A5.34/A5.34M	*Specification for Nickel-Alloy Electrodes for Flux Cored Arc Welding*

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