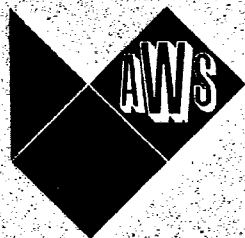


ANSI/AWS A5.13-80

Specification for Solid Surfacing Welding Rods and Electrodes



AMERICAN WELDING SOCIETY

ANSI/AWS A5.13-80

**Specification for
Solid Surfacing
Welding Rods
and Electrodes**

**Superseding
AWS A5.13-70**

**Prepared by
AWS Committee on Filler Metal**

**Under the Direction of
AWS Technical Activities Committee**

**Approved by
AWS Board of Directors, April 25, 1980**

AMERICAN WELDING SOCIETY, INC.
2501 N.W. 7th Street, Miami, FL 33125

Library of Congress Number: 80-67164
International Standard Book Number: 0-87171-196-6

© 1980 by American Welding Society
All rights reserved

Note: By publication of this specification, the American Welding Society does not insure anyone utilizing the specification against liability arising from the use of such specification. A publication of a specification by the American Welding Society does not carry with it any right to make, use, or sell any patented items. Each prospective user should make an independent investigation.

This specification is subject to revision at any time by the responsible technical committee. It must be reviewed every five years and if not revised, it must be either reapproved or withdrawn. Comments (recommendations, additions, or deletions) and any pertinent data that may be of use in improving this specification are requested and should be addressed to AWS headquarters. Such comments will receive careful consideration by the responsible technical committee and you will be informed of the committee's response. Guests are invited to attend all meetings of AWS committees to express their comments verbally. Procedure for appeal of an adverse decision concerning your comments are provided in the Rules of Operation for AWS Technical Committees. A copy of these rules can be obtained from the American Welding Society, 2501 N.W. 7th Street, Miami, FL 33125.

Printed in the United States of America

Contents

<i>Personnel</i>	vi
<i>Scope</i>	1
<i>1. Classification and Acceptance</i>	1
1.1 Classification	1
1.2 Acceptance	1
1.3 Chemical Composition Requirements	1
1.4 Usability	1
1.5 Retests	4
<i>2. Manufacture</i>	4
2.1 Method of Manufacture	4
2.2 Welding Rods and Bare Electrodes, Finish and Uniformity	4
2.3 Covered Electrodes	4
2.4 Exposed Core	4
2.5 Standard Sizes and Lengths	4
2.6 Packaging	4
2.7 Marking	4
2.8 Electrode Identification	7
2.9 Rounding Off Procedures	7
2.10 Certification	7
<i>3. Details of Tests</i>	7
3.1 Required Tests	7
3.2 Material for Test Plates	7
3.3 Usability Test	7
3.4 Chemical Analysis	7
<i>Appendix: Guide to AWS Classification of Surfacing Welding Rods and Electrodes</i>	9
A1. Introduction and Classification System	9
A2. RFe5 and EFe5 High Speed Steel Filler Metals	9
A3. EFeMn Austenitic Manganese Steel Electrodes	11
A4. RFeCr-A and EFeCr-A Austenitic High Chromium Iron Filler Metals	13
A5. RCoCr and ECoCr Cobalt-Base Filler Metals	14
A6. Copper-Base Alloy Filler Metals	17
A7. RNiCr and ENiCr Nickel-Chromium-Boron Filler Metals	19
<i>Bibliography</i>	22

Personnel

AWS Committee on Filler Metal

<i>R. J. Christoffel, Chairman</i>	General Electric Company
<i>D. C. Helton, 1st Vice-Chairman</i>	Alloy Rods Division, Allegheny Ludlum Industries, Inc.
<i>J. F. Saenger, Jr., 2nd Vice-Chairman</i>	Linde Division, Union Carbide Corporation
<i>G. Hallstrom, Jr., Secretary</i>	American Welding Society
<i>B. L. Alia</i>	American Bureau of Shipping
<i>L. Anderson</i>	Marion Power Shovel Division, Dresser Industries, Inc.
<i>D. F. Betz</i>	Crane Midwest Fittings Company
<i>J. T. Biskup*</i>	Canadian Welding Bureau
<i>R. S. Brown</i>	Carpenter Technology Corporation
<i>J. Caprarola</i>	Airco, Inc.
<i>L. J. Christensen</i>	Chicago Bridge and Iron Company
<i>W. T. DeLong</i>	Teledyne McKay Company
<i>P. B. Dickerson</i>	Aluminum Company of America
<i>H. W. Ebert</i>	Exxon Research and Engineering Company
<i>H. N. Farmer, Jr.</i>	Stoody Company
<i>J. P. Frandsen</i>	Nuclear Fuel Department, General Electric Company
<i>E. H. Franks</i>	General Electric Company
<i>F. E. Gibbs</i>	Kaiser Aluminum and Chemical Corporation
<i>M. F. Godfrey</i>	United States Federal Highway Administration
<i>J. R. Hannahs</i>	Midwest Testing Laboratories
<i>R. L. Harris</i>	Tennessee Valley Authority
<i>T. Hellerstrom*</i>	ESAB, Inc.
<i>R. B. Hitchcock*</i>	Consultant
<i>J. W. Hunt</i>	Buick Motor Division, General Motors Corporation
<i>P. A. Kammer</i>	Eutectic Corporation
<i>J. J. King</i>	Naval Ship Engineering Center
<i>A. N. Kugler*</i>	Consulting Engineer
<i>G. A. Kurisky*</i>	Maryland Specialty Wire
<i>R. K. Lee*</i>	Consultant
<i>W. F. McLaughlin</i>	Chrysler Corporation
<i>J. H. Mesick</i>	Huntington Alloy Products, Inc.
<i>G. E. Metzger</i>	Air Force Materials Laboratory
<i>J. W. Mortimer</i>	Consultant
<i>J. E. Norcross</i>	Welding Industry Consultant
<i>R. L. Peaslee</i>	Wall Colmonoy Corporation
<i>E. W. Pickering, Jr.</i>	Combustion Engineering, Inc.
<i>E. E. Pochapsky</i>	United States Steel Corporation
<i>C. V. Prestowitz</i>	Arcos Corporation
*Advisory Member	

PERSONNEL

<i>J. Read*</i>	Canadian Liquid Air Ltd.
<i>S. D. Reynolds, Jr.</i>	U.S. Nuclear Power Commission
<i>D. Rozet</i>	Reid Avery Company
<i>J. R. Ruff*</i>	Naval Sea Systems Command
<i>H. S. Sayre*</i>	Consultant
<i>N. G. Schreiner</i>	Consultant
<i>R. J. Shillinsky*</i>	Daniel International
<i>R. C. Shutt</i>	Lincoln Electric Company
<i>R. G. Spinks*</i>	Lincoln Electric Company
<i>R. C. Steveling</i>	Alloy Rods Division, Allegheny Ludlum Industries, Inc.
<i>R. W. Straiton</i>	Bechtel, Inc.
<i>H. B. Taylor</i>	Steel Division, Cyclops Corporation
<i>R. D. Thomas, Jr.</i>	Consultant
<i>A. E. Wiehe</i>	Hobart Brothers Company
<i>W. A. Wiehe</i>	Rexarc, Inc.
<i>W. L. Wilcox</i>	Scott Paper Company
<i>F. J. Winsor</i>	Foster Wheeler Energy Corporation
<i>K. G. Wold</i>	Aqua-Chem, Inc.
<i>T. J. Wonder</i>	SVERDRUP/ARO, Inc.

Subcommittee on Surfacing Filler Metal

<i>H. N. Farmer, Jr., Chairman</i>	Stoody Company
<i>G. Hallstrom, Jr., Secretary</i>	American Welding Society
<i>H. S. Avery*</i>	Abex Research Center
<i>J. T. Biskup*</i>	Canadian Welding Bureau
<i>J. B. Bolton</i>	DRILCO Division, Smith International, Inc.
<i>C. E. Braner</i>	Amsco Division, Abex Corporation
<i>F. Broshjeit</i>	Ferrell Conn., Division of USM Corporation
<i>S. DeBoer</i>	E. R. Joseph Company
<i>M. M. Dudas</i>	Ford Steel Company
<i>R. J. Dybas</i>	General Electric Company
<i>G. Hamill</i>	Arcos Corporation
<i>D. S. Hammock</i>	Poly Cast, Inc.
<i>R. B. Hitchcock*</i>	Consultant
<i>B. M. Krantz</i>	Sandvik Welding Products
<i>R. F. Miller</i>	Teledyne McKay
<i>J. Read*</i>	Canadian Liquid Air Ltd.
<i>J. W. Tackett</i>	Stellite Division of Cabot Corporation
<i>D. A. Wells</i>	E. I. duPont de Nemours
<i>W. A. Wiehe</i>	Rexarc, Inc.
<i>K. G. Wold</i>	Aqua-Chem, Inc.

*Advisory Member

Specification for Solid Surfacing Welding Rods and Electrodes

Issued, 1956; Revised, 1970, 1980

Scope

This specification prescribes requirements for solid bare surfacing welding rods for use with the oxyfuel and gas tungsten arc welding processes. This specification also covers solid bare surfacing electrodes for use with the gas metal arc process and solid covered surfacing electrodes for use with the shielded metal arc welding process.

Note: The values stated in U.S. customary units are to be regarded as the standard. The SI units are given as equivalent values to the U.S. customary units. The published sizes and dimensions in the two systems are not identical and, for this reason, conversion from a published size or dimension in one system will not always coincide with the published size or dimension in the other. Suitable conversions, encompassing published sizes of both, can be made, however, if appropriate tolerances are applied in each case.

Note: No attempt has been made to classify all filler metals within the limits of the above scope. This specification covers only those filler metals that have approximate industrial standardization and for which technical data are available. A list of other commonly used filler metals is given in Table A1 of the Appendix. It is intended that subsequent editions of this specification will incorporate these other filler metals as industrial standardization occurs.

1. Classification and Acceptance

1.1 Classification. Bare surfacing welding rods and elec-

trodes are classified on the basis of their chemical composition as manufactured. Covered surfacing electrodes are classified on the basis of the chemical composition of their undiluted weld metal. Any welding rod or electrode classified under one classification shall not be classified under any other classification of this specification.

1.2 Acceptance. At the option and expense of the purchaser, any or all of the test requirements of this specification may be used as a basis for acceptance of the products covered by this specification. A5.01, Filler Metal Procurement Guidelines, may be referred to for lot definitions and frequency of testing.

1.3 Chemical Composition Requirements. The chemical composition of the bare welding rods and electrodes shall conform to the requirements prescribed for their classification in Table 1. The chemical composition of the undiluted weld metal for covered electrodes shall conform to the requirements prescribed for their classification in Table 2. The details of the test are specified in 3.4.

1.4 Usability. A test, as described in 3.3, is prescribed to demonstrate the usability of the filler metals. In order to be classified under this specification, the filler metals shall be capable of yielding the following usability test results:

1.4.1 For welding rods, the metal shall flow freely and smoothly over the surface of the plate without boiling or excessive activity.

1.4.2 Electrodes shall operate smoothly and without excessive spatter when used within the current ranges recommended by the manufacturer. Slag shall be readily removed with hand tools.

1.4.3 The surface of the test pad, after being ground, shall be free from defects visible to the naked eye.

2 / SOLID SURFACING WELDING RODS AND ELECTRODES

Table 1
Chemical requirements for bare surfacing welding rods and electrodes

AWS Classification	Carbon, per cent	Manganese, per cent	Cobalt, per cent	Tungsten, per cent	Nickel, per cent	Chromium, per cent	Molybdenum, per cent	Iron, per cent	Vanadium, per cent	Copper, per cent	Aluminum, per cent	Zinc, per cent	Silicon, per cent	Lead, per cent	Tin, per cent	Phosphorus, per cent	Total other elements, per cent
RFe5-A	0.7 to 1.0	0.50	—	5.0 to 7.0	—	3.0 to 5.0	4.0 to 6.0	remainder	1.0 to 2.5	—	—	—	0.50	—	—	—	1.0
RFe5-B	0.5 to 0.9	0.50	—	1.0 to 2.5	—	3.0 to 5.0	5.0 to 9.5	remainder	0.8 to 1.3	—	—	—	0.50	—	—	—	1.0
RFeCr-Al	3.7 to 5.0	2.0 to 6.0	—	—	—	27.0 to 35.0	—	remainder	—	—	—	—	1.10 to 2.5	—	—	—	1.0
RCrCr-A	0.9 to 1.4	1.00	remainder	3.0 to 6.0	3.0	26.0 to 32.0	1.0	3.0	—	—	—	—	2.0	—	—	—	0.50
RCrCr-B	1.2 to 1.7	1.00	remainder	7.0 to 9.5	3.0	26.0 to 32.0	1.0	3.0	—	—	—	—	2.0	—	—	—	0.50
RCrCr-C	2.0 to 3.0	1.00	remainder	11.0 to 14.0	3.0	26.0 to 33.0	1.0	3.0	—	—	—	—	2.0	—	—	—	0.50
RCuZn-E ^b	—	0.30	—	—	—	—	—	1.50	—	56.0 min	0.01 ^a	remainder	0.04 to 0.25	0.05 ^a	2.00 to 3.00	—	0.50
ERCuSi-A ^b	—	1.5 ^c	—	—	—	—	—	0.5	—	94.0 min	0.01 ^a	1.5 ^a	2.8 to 4.0	0.02 ^a	1.5 ^a	—	0.50
ERCuAl-A2 ^b	—	—	—	—	—	—	—	1.5	—	remainder	9.0 to 11.0	0.02	0.10	0.02 ^a	—	—	0.50
ERCuAl-A3	—	—	—	—	—	—	—	3.0 to 5.0	—	remainder	10.0 to 11.0	0.10	0.10	0.02 ^a	—	—	0.50
RCuAl-C	—	—	—	—	—	—	—	3.0 to 5.0	—	remainder	12.0 to 13.0	0.02	0.04	0.02	—	—	0.50
RCuAl-D	—	—	—	—	—	—	—	3.0 to 5.0	—	remainder	13.0 to 14.0	0.02	0.04	0.02	—	—	0.50
RCuAl-E	—	—	—	—	—	—	—	3.0 to 5.0	—	remainder	14.0 to 15.0	0.02	0.04	0.02	—	—	0.50
ERCuSn-A ^b	—	—	—	—	—	—	—	—	—	93.5 min	0.01 ^a	—	—	0.02 ^a	4.0 to 6.0	0.10 to 0.35	0.50
RCuSn-D	—	—	—	—	—	—	—	—	—	88.5 min	0.01 ^a	—	—	0.05 ^a	9.0 to 11.0	0.10 to 0.30	0.50
RNiCr-A	0.30 to 0.60	—	1.50	—	remainder	8.0 to 14.0	—	1.25 to 3.25	2.00 to 3.00 per cent boron	—	—	—	1.25 to 3.25	—	—	—	0.50
RNiCr-B	0.40 to 0.80	—	1.25	—	remainder	10.0 to 16.0	—	3.00 to 5.00	2.00 to 4.00 per cent boron	—	—	—	3.00 to 5.00	—	—	—	0.50
RNiCr-C	0.50 to 1.00	—	1.00	—	remainder	12.0 to 18.0	—	3.50 to 5.50	2.50 to 4.50 per cent boron	—	—	—	3.50 to 5.50	—	—	—	0.50

Note 1: Analysis shall be made for the elements for which specific values are shown in this table. If, however, the presence of other elements is indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements is not present in excess of the limits specified for "total other elements" in the last column in the table.

Note 2: Single values shown are maximum percentages, except where otherwise specified.

a. Total other elements, including the elements marked with footnote a, shall not exceed the value specified.

b. This AWS classification is intended to be identical with the same classification that appears in the latest edition of AWS A5.7, Specification for Copper and Copper Alloy Bare Welding Rods and Electrodes.

c. One or more of these elements may be present within the limits specified.

Table 2
Chemical requirements^a for covered surfacing electrodes

AWS Classification	Carbon, per cent	Manganese, per cent	Cobalt, per cent	Tungsten, per cent	Nickel, per cent	Chromium, per cent	Molybdenum, per cent	Iron, per cent	Vanadium, per cent	Copper, per cent	Aluminum, per cent	Zinc, per cent	Silicon, per cent	Lead, per cent	Tin, per cent	Phosphorus, per cent	Total other elements, per cent
EFe5-A	0.7 to 1.0	0.60	—	5.0 to 7.0	—	3.0 to 5.0	4.0 to 6.0	remainder	1.0 to 2.5	—	—	—	0.80	—	—	—	1.0
EFe5-B	0.5 to 0.9	0.60	—	1.0 to 2.5	—	3.0 to 5.0	5.0 to 9.5	remainder	0.8 to 1.3	—	—	—	0.80	—	—	—	1.0
EFe5-C	0.3 to 0.5	0.60	—	1.0 to 2.5	—	3.0 to 5.0	5.0 to 9.0	remainder	0.8 to 1.2	—	—	—	0.80	—	—	—	1.0
EFeMn-A	0.5 to 0.9	11.0 to 16.0	—	—	2.75 to 6.0	0.50	—	remainder	—	—	—	—	1.3	—	—	0.03	1.0
EFeMn-B	0.5 to 0.9	13.0 to 16.0	—	—	—	0.50	0.6 to 1.4	remainder	—	—	—	—	0.3 to 1.3	—	—	0.03	1.0
EFeCr-Al	3.0 to 5.0	4.0 to 8.0	—	—	—	26.0 to 32.0	2.0	remainder	—	—	—	—	1.0 to 2.5	—	—	—	1.0
ECoCr-A	0.7 to 1.4	2.0	remainder	3.0 to 6.0	3.0	25.0 to 32.0	1.0	5.0	—	—	—	—	2.0	—	—	—	0.50
ECoCr-B	1.0 to 1.7	2.0	remainder	7.0 to 9.5	3.0	25.0 to 32.0	1.0	5.0	—	—	—	—	2.0	—	—	—	0.50
ECoCr-C	1.75 to 3.0	2.0	remainder	11.0 to 14.0	3.0	25.0 to 33.0	1.0	5.0	—	—	—	—	2.0	—	—	—	0.50
ECuSi ^c	—	1.5	—	—	b	—	—	0.50	—	remainder	0.01	—	2.4 to 4.0	0.02 ^b	1.5	b	0.50
ECuAl-A2 ^c	—	b	—	—	b	—	—	0.5 to 5.0	—	remainder	7.0 to 9.0	b	1.0	0.02 ^b	b	—	0.60
ECuAl-B ^c	—	b	—	—	b	—	—	2.5 to 5.0	—	remainder	8.4 to 10.0	b	1.0	0.02 ^b	b	—	0.60
ECuAl-C	—	—	—	—	—	—	—	3.0 to 5.0	—	remainder	12.0 to 13.0	0.02	0.04	0.02	—	—	0.50
ECuAl-D	—	—	—	—	—	—	—	3.0 to 5.0	—	remainder	13.0 to 14.0	0.02	0.04	0.02	—	—	0.50
ECuAl-E	—	—	—	—	—	—	—	3.0 to 5.0	—	remainder	14.0 to 15.0	0.02	0.04	0.02	—	—	0.50
ECuSn-A ^c	—	b	—	—	b	—	—	0.25	—	remainder	0.01	b	b	0.02 ^b	4.0 to 6.0	0.05 to 0.35	0.50
ECuSn-C ^c	—	b	—	—	b	—	—	0.25	—	remainder	0.01	b	b	0.02 ^b	7.0 to 9.0	0.05 to 0.35	0.50
ENiCr-A	0.30 to 0.60	—	1.50	—	remainder	8.0 to 14.0	—	1.25 to 3.25	2.00 to 3.00 per cent boron	—	—	—	1.25 to 3.25	—	—	—	0.50
ENiCr-B	0.40 to 0.80	—	1.25	—	remainder	10.0 to 16.0	—	3.00 to 5.00	2.00 to 4.00 per cent boron	—	—	—	3.00 to 5.00	—	—	—	0.50
ENiCr-C	0.50 to 1.00	—	1.00	—	remainder	12.0 to 18.0	—	3.50 to 5.50	2.50 to 4.50 per cent boron	—	—	—	3.50 to 5.50	—	—	—	0.50

Note 1: Analysis shall be made for the elements for which specific values are shown in this table. If, however, the presence of other elements is indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements is not present in excess of the limits specified for "total other elements" in the last column in the table.

Note 2: Single values shown are maximum percentages, except where otherwise specified.

a. The analysis given is for deposited weld metal.

b. Total other elements, including the elements marked with footnote b, shall not exceed the value specified.

c. This AWS classification is intended to be identical with the same classification that appears in the latest edition of AWS A5.6, Specification for Cast and Copper Alloy Covered Electrodes.

4 / SOLID SURFACING WELDING RODS AND ELECTRODES

1.5 Retests. If any test fails, two additional tests of that particular test, as taken from the original test assembly or from new test assemblies, shall be performed, and the results of both shall meet the requirements prescribed for that test.

2. Manufacture

2.1 Method of Manufacture. The electrodes and rods may be made by any method that will yield a product conforming to the requirements of this specification.

2.2 Welding Rods and Bare Electrodes — Finish and Uniformity. Welding rods and bare electrodes shall be of uniform quality and free from segregation, oxides, slivers, seams, or other irregularities that would adversely affect the welding properties or the operation of the welding equipment.

2.3 Covered Electrodes

2.3.1 The covering on covered electrodes of all sizes shall be concentric to the extent that the maximum core-plus-one-covering dimension shall not exceed the minimum core-plus-one-covering dimension by more than 7 percent of the minimum core-plus-one-covering dimension for wrought core wire electrodes, or by more than 10 percent for cast core wire electrodes, provided that in any case no "fingernailing"¹ shall occur during welding. The concentricity may be measured by any suitable means.

2.3.2 The covering shall be such that it is not readily damaged by ordinary handling.

2.3.3 The covering shall be such that heating of the electrode during welding shall not cause blistering or flaking of the covering within the ranges of current recommended by the manufacturer.

2.3.4 Core wire and coverings shall be free of defects that would interfere with uniform performance of the electrodes.

2.4 Exposed Core

2.4.1 The grip portion of covered electrodes for manual welding shall be free from covering for a distance no less than 3/4 in. (20 mm) nor more than 1-1/4 in. (32 mm) for making contact with the holder. The arc end of each covered electrode shall be sufficiently bare and the covering sufficiently tapered to permit easy striking of the arc. The length of the bare portion of the arc end (measured from the end to the point where full cross section of the covering is obtained) shall not exceed 1/8 in. (3.2 mm) or the diameter of the core wire, whichever is smaller.

1. This term indicates that the electrode covering at the arc end is being consumed unevenly around the circumference of the core wire. Thus, instead of the covering remaining symmetrical with respect to the core wire, it protrudes beyond the core wire in much the same manner as a fingernail protrudes beyond the end of a finger.

2.5 Standard Sizes and Lengths. Standard sizes and lengths of welding rods are shown in Table 3, and standard sizes and lengths of electrodes are shown in Table 4.

2.6 Packaging. Welding rods and electrodes shall be suitably packaged to protect against damage during handling, shipping, or under normal dry storage conditions in bundles or containers of 5, 10, 25, 60 or 100 lbs (2.3, 4.5, 11, 23, 27, or 45 kg) net weight.²

2.7 Marking

2.7.1 The outside of each unit package shall be legibly marked with the following information:

2.7.1.1 Specification and classification number

2.7.1.2 Standard size and net weight

2.7.1.3 Lot, control, or heat number

2.7.2 Marking of any or all overpacking of unit packages with items listed in 2.7.1 shall be optional with the manufacturer.

2.7.3 Bare electrodes and rods wound on spools shall be identified by the specification and classification number, trade designation, and size and net weight, with the lot, heat, or control number placed on at least one flange of the spool in such a manner that this identification cannot be readily removed.

2.7.4 For other than oxyfuel rods, all packages of filler metal, or all individually packaged units enclosed within a larger package(s), shall carry the following precautionary labeling or its equivalent, as a minimum, prominently displayed in legible type:

WARNING: Protect yourself and others. Read and understand this label. FUMES AND GASES can be dangerous to your health. ARC RAYS can injure eyes and burn skin. ELECTRIC SHOCK can kill.

- Read and understand the manufacturer's instructions and your employer's safety practices.
- Keep your head out of the fumes.
- Use enough ventilation, exhaust at the arc, or both, to keep fumes and gases from your breathing zone and the general area.
- Wear correct eye, ear, and body protection.
- Do not touch live electrical parts.
- See American National Standard Z49.1, Safety in Welding and Cutting, published by the American Welding Society, 2501 N.W. 7th Street, Miami, Florida, 33125; OSHA Safety and Health Standards, 29 CFR 1910, available from the U.S. Government Printing Office, Washington, D.C. 20402.

Do Not Remove This Label

2. Other standard weights are available upon agreement between purchaser and supplier.

Table 3
Standard sizes and lengths of welding rods

AWS Classification	Wrought				Cast			
	Diameter, in. mm ^a		Length, in. mm ^b		Diameter, in. mm ^c		Length, in. mm	
RFe5b-A	1/8	3.2			1/8	3.2		
	5/32	4.0			3/16	4.8		
RFe5b-B	3/16	4.8	14	350	1/4	6.4	8 to 14	200 to 350
	1/4	6.4	18	450	5/16	8.0		
RFeCr-Al	5/16	8.0	28	700	3/8	9.5		
	3/8	9.5			3/8	9.5		
RC0Cr-A					1/8	3.2		
					5/32	4.0	8	200
RC0Cr-B					3/16	4.8		
					1/4	6.4	to	to
RC0Cr-C					5/16	8.0		
					3/8	9.5	24	610
RCuZn-E	1/4	6.4	36	900				
	1/16	1.6						
RCuSi-A	3/32	2.4						
ERCuSn-A ^e	1/8	3.2						
RCuSn-D	5/32	4.0	36	900				
ERCuAl-A2 ^e	3/16	4.8						
ERCuAl-A3 ^e	1/4	6.4						
	3/32	2.4						
RCuAl-C	1/8	3.2						
RCuAl-D	5/32	4.0	36	900				
RCuAl-E	3/16	4.8						
	1/4	6.4						
					5/32	4.0		
RNiCr-A					3/16	4.8		
RNiCr-B					1/4	6.4	8 to 24 ^d	200 to 610 ^d
RNiCr-C					5/16	8.0		
					3/8	9.5		

a. Diameters shall not vary more than ± 15 percent from the nominal. All classifications are not available in all diameters.

b. Lengths shall not vary more than the following from the standard:

28 in. (700 mm) and shorter $\pm 1/4$ in. (6.4 mm)

36 in. (900 mm) $\pm 3/8$ in. (10 mm)

c. Diameters shall not vary more than $\pm 1/32$ in. (0.8 mm) from the nominal.

d. Longer lengths, up to 12 ft (3660 mm), can be furnished upon agreement between supplier and purchaser.

e. These classifications are also available wound on spools in conformance to the latest edition of AWS A5.7, Specification for Copper and Copper Alloy Bare Welding Rods and Electrodes.

6 / SOLID SURFACING WELDING RODS AND ELECTRODES

Table 4
Standard sizes and lengths of covered electrodes

AWS Classification	Wrought core wire				Cast core wire			
	Diameter,		Length,		Diameter,		Length,	
	in.	mm ^a	in.	mm ^b	in.	mm ^d	in.	mm
EFe5-A	1/8	3.2			1/8	3.2	8 to 14	200 to 350
EFe5-B	5/32	4.0	14	350	3/16	4.8		
EFe5-C	3/16	4.8	18	450	1/4	6.4	10 to 14	250 to 350
EFeMn-A	1/4	6.4	28	700	5/16	8.0		
EFeCr-Al	5/16	8.0			3/8	9.5		
					1/8	3.2		
					5/32	4.0		
ECoCr-A	3/32	2.4	12	300	3/16	4.8		
ECoCr-B	1/8	3.2	14	350	1/4	6.4	10 to 14	250 to 350
ECoCr-C	5/32	4.0	13	450	5/16	8.0		
	3/16	4.8	18	450	3/8	9.5		
ECuSi,								
ECuAl-A2	3/32	2.4	11	280				
ECuAl-B	1/8	3.2						
ECuAl-C	5/32	4.0	14	350				
ECuAl-D	3/16	4.8						
ECuAl-E	1/4	6.4	18	450				
ECuSn-A								
ECuSn-C								
					5/32	4.0		
ENiCr-A					3/16	4.0		
ENiCr-B					1/4	6.4	8 to 14	200 to 350
ENiCr-C					5/16	8.0		
					3/8	9.5		

a. Diameters shall not vary more than the following from the nominal:
 5/32 in (4.0 mm) and smaller ± 0.003 in. (0.08 mm)
 Over 5/32 in (4.0 mm) ± 0.004 in. (0.10 mm)

Diameters given are for core wire for covered electrodes.

b. Lengths of wrought core wire shall not vary more than $\pm 1/4$ in. (6.4 mm) from the nominal.

c. Diameters shall not vary more than $\pm 1/32$ in. (0.8 mm) from the nominal.

2.7.5 For oxyfuel rods, all packages of filler metal, or all individually packaged units enclosed within a larger package(s), shall carry the following precautionary label or its equivalent, as a minimum, prominently displayed in legible type:

WARNING: Protect yourself and others. Read and understand this label. FUMES AND GASES can be dangerous to your health. HEAT RAYS (INFRARED RADIATION from flame or hot metal) can injure your eyes.

- Read and understand the manufacturer's instructions and your employer's safety practices.
- Keep your head out of the fumes.
- Use enough ventilation, exhaust at the flame, or both, to keep fumes and gases from your breathing zone and the general area.
- Wear correct eye, ear, and body protection.
- See American National Standard Z49.1, Safety in Welding and Cutting, published by the American Welding Society, 2501 N.W. 7th Street, Miami, Florida, 33125; OSHA Safety and Health Standards, 29 CFR 1910, available from the U.S. Government Printing Office, Washington, D.C. 20402.

Do Not Remove This Label

2.8 Electrode Identification. All covered electrodes shall be identified in accordance with the following:

2.8.1 At least one legible imprint of the applicable AWS classification shall be applied to the electrode covering as near as practical to the grip end of the core wire, but not more than 2-1/2 in. (65 mm) from that grip end.

2.8.2 The numbers of the imprinted electrode classification shall be of bold block type and of sufficient size to be legible.

2.8.3 The ink used for imprinting shall provide sufficient contrast with the electrode covering so that the numbers and letters are legible, both before and after normal welding applications.

2.8.4 The prefix letter E in the electrode classification may be omitted from the imprint of the electrode covering.

2.9 Rounding-off Procedures. For purposes of determining conformance with this specification, an observed or calculated value shall be rounded off to the nearest unit in the last right-hand place of figures used in expressing the limiting value for other values in accordance with the rounding-off method of ASTM E29, Recommended Practice for Indicating Which Places of Figures are to be Considered Significant in Specified Limiting Values.³

3. ASTM Standards can be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19013.

2.10 Certification. For all material furnished under this specification, the manufacturer certifies (by meeting the requirements of 2.7) that the material, or representative material, has passed the tests required for classification by this specification. When required by the purchaser, the manufacturer shall furnish a copy of the results of those tests.

3. Details of Tests

3.1 Required Tests. The tests specified in 1.3 and 1.4 shall be conducted in accordance with the requirements of this Section 3. Usability tests and chemical analysis may be made on welding rods and electrodes of any size.

3.2 Materials for Test Plates. The base metals for both the usability test and chemical analysis shall conform to one of the following specifications or their equivalent:

3.2.1 ASTM Specification A285, Pressure Vessel Plates, Carbon Steel, Low and Intermediate Tensile Strength, Grade A or equivalent

3.2.2 ASTM Specification A36, Structural Steel

3.3 Usability Test

3.3.1 A test pad shall be prepared using techniques, position, and other factors as specified by the manufacturer.

3.3.2 The surface of the pad shall be ground smooth and clean, after which the surface shall be visually examined.

3.4 Chemical Analysis

3.4.1 Chemical Analysis of Bare Welding Rods and Electrodes. An adequate sample of bare welding rod or electrode, sufficient for retest if necessary, shall be obtained to make the prescribed chemical analysis.

3.4.2 Chemical Analysis of Covered Electrodes

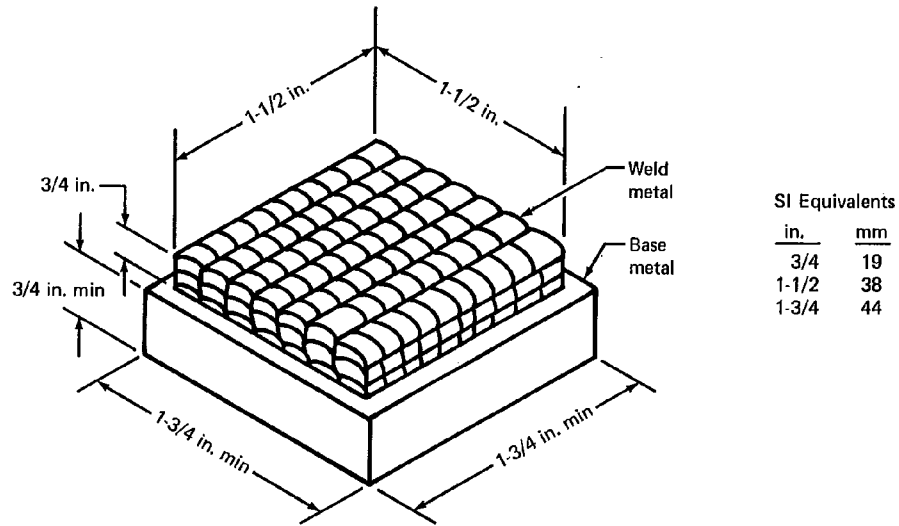
3.4.2.1 All surfacing on the chemical analysis pad shall be done in the flat position.

3.4.2.2 For covered electrodes, the test pad shall be prepared as shown in Fig. 1, using the welding procedures specified by the manufacturer as to factors not covered herein. The full length of each covered electrode shall be used, with the stub length not to exceed 1-3/4 in. (45 mm).

3.4.2.3 The top surface of the test pad shall be removed and discarded, and an adequate sample of weld metal, sufficient for retest, if necessary, shall then be removed from the test pad by any appropriate means. Postweld heat treatment may be used to soften the test pad to facilitate removal. Metal for the sample shall not be removed closer than 1/4 in. (6.4 mm) from the base metal. No oil or other lubricant shall be used when removing the sample.

3.4.2.4 Chemical analysis may be made by any suitable method agreed upon by the manufacturer and the purchaser.

8 / SOLID SURFACING WELDING RODS AND ELECTRODES

**Fig. 1—Chemical analysis test pad**

Appendix: Guide to AWS Classification of Surfacing Welding Rods and Electrodes

A1. Introduction and Classification System

A1.1 Introduction. This guide is appended to the specification as a source of information; *it is not mandatory and does not form a part of the specification.*

The specification itself is intended to provide both the manufacturer and the purchaser with a means of production control and a basis of acceptance through mutually acceptable, sound, standard requirements.

This guide has been prepared as an aid to prospective users of the welding rods and electrodes covered by the specification in determining which classification of filler metal is best suited for a particular application, with due consideration to the particular requirements for that application.

A1.2 Classification System

A1.2.1 The system for identifying welding rod and electrode classifications used in this specification follows the standard pattern used in other AWS filler metal specifications. The letter E at the beginning of each classification indicates an electrode, and letter R indicates a welding rod. The letters ER indicate a filler metal that may be used as either a bare electrode or rod. The letters immediately after the E, R, or ER are the chemical symbols for the principal elements in the classification. Thus, CoCr is cobalt-chromium alloy, CuZn is a copper-zinc alloy, etc. Where more than one classification is included in a basic group, the individual classifications in the group are identified by the letters A, B, C, etc., as in ECuSn-A. Further subdividing is done by using a 1, 2, etc., after the last letter, as the 2 in ECuAl-A2.

A1.2.2 Some years ago, the committee designated surfacing filler metals as shown in Table A1.

The correlation between these old designations and the new classifications covered by this specification is indicated in Table A2.

A1.3 Ventilation during Welding

A1.3.1 Three major factors in arc welding that govern the amount of contamination to which welders or welding operators may be exposed are:

A1.3.1.1 Dimensions of space in which welding is to be done (with special regard to height of ceiling)

A1.3.1.2 Number of welders or welding operators working in that space

A1.3.1.3 Possible evolution of hazardous fumes, gases, or dusts according to the metals and shielding gases involved

A1.3.2 American National Standard Z49.1, Safety in Welding and Cutting, discusses the ventilation that is required during welding and should be referred to for details. Attention is particularly drawn to Section 8, "Health Protection and Ventilation."

A2. RFe5 and EFe5 High-Speed Steel Filler Metals

A2.1 Introduction and Applications. The RFe5 welding rods and EFe5 electrodes have proved very popular for applications where hardness is required at service temperatures up to 1100° F (595° C) and where good wear resistance and toughness are also required. These filler metals are essentially high-speed steels, modified slightly for welding applications.

The three classifications are approximately interchangeable, except that Fe5-A and Fe5-B (with high carbon) are more suitable for cutting and machining (edge-holding) applications; EFe5-C (with lower carbon) is most suitable for hot working and for applications requiring toughness. Some typical surfacing applications are cutting tools, shear blades, reamers, forming dies, shearing dies, guides, ingot tongs, broaches and other similar tools.

10 / SOLID SURFACING WELDING RODS AND ELECTRODES

Table A1
Surfacing filler metals
(old designations)

I. Ferrous
A. Hardenable alloys
1. Carbon steels
a. Low (0.19% C max)
b. Medium (0.20-0.60%C)
c. High (0.61-1.50%C)
2. Low alloy steels
a. Low carbon
b. Medium carbon
c. High carbon
d. Cast-iron types
3. Medium alloy steels
a. Medium carbon
b. High carbon
c. Cast-iron types
4. Medium high alloy
a. Low carbon
b. Medium carbon
c. High carbon
d. Cast-iron types (1.5% C min)
5. High-speed steel
B. Austenitic steels
1. Chromium and Cr-Ni
a. Low carbon
b. High carbon, low nickel
c. High carbon, high nickel
2. High manganese
C. Austenitic—not usually heat-treated
1. High chromium iron
2. High alloy iron
a. 1.7 percent carbon
b. 2.5 percent carbon
c. Very high alloy
II. Cobalt base alloys
A. Low alloy
B. High alloy
III. Carbides
A. Inserts
B. Composite
C. Powder
IV. Copper base
A. Copper-zinc
B. Copper-silicon
C. Copper-aluminum
V. Nickel base
A. Nickel-copper
B. Nickel-chromium
C. Nickel-chromium-tungsten-molybdenum
D. Nickel-chromium-boron

A2.2 Hardness. The Rockwell hardness of the undiluted Fe5 filler metals in the as-welded condition is in the range of C 55 to C 60. Where a machining operation is required, hardness may be reduced to approximately C 30 by an annealing treatment.

Table A2
Surfacing filler metals
(new classifications)

AWS classification	Old designation
Fe5	IA5
FeMn	IB2
FeCr	IC1
CoCr-A	IIA
CoCr-C	IIB
CuZn	IVA
CuSi	IVB
CuAl	IVC
NiCr	VB

A2.3 Hot Hardness. Hardness at elevated temperatures (hot hardness) is a very important property of weld deposits of these filler metals. Tungsten and molybdenum are probably the most influential elements present in obtaining this property. Due to the large size of these atoms and their low diffusion rates, the carbides do not coalesce but stay in very small particles. At temperatures up to 1100° F (595° C), the as-deposited Rockwell hardness of C 60 falls off very slowly to approximately C 47 (448 Brinell). At higher temperatures, it falls off more rapidly. At about 1200° F (650° C), the maximum Rockwell hardness is about C 30 (283 Brinell).

A2.4 Impact. The Fe5 filler metals as-deposited can only withstand medium impact without cracking. After tempering, the impact resistance is increased appreciably.

A2.5 Oxidation Resistance. Deposits of the Fe5 filler metals, because of the high molybdenum content, will oxidize readily. When heat treatments are required, a non-oxidizing furnace atmosphere salt bath or borax coating should be used to prevent decarburization.

A2.6 Corrosion Resistance. The Fe5 weld metal can withstand atmospheric corrosion, but is not effective in providing resistance to liquid corrosion.

A2.7 Abrasion. The high-stress abrasion resistance of these filler metals, as-deposited, at room temperature is much better than low carbon steel, but they are not considered high abrasion resistance alloys. Resistance to deformation at elevated temperatures up to 1100° F (593° C) is their outstanding feature, and this may aid hot abrasion resistance.

A2.8 Metal-to-Metal Wear and Mechanical Properties in Compression. Deposits of Fe5 filler metals are well suited for metal-to-metal wear, especially at elevated temperatures. They have a low coefficient of friction, and the ability to take a high polish and retained their hardness at elevated temperatures. The compressive strength is very good and will fall or rise with the tempering temperature used.

A2.9 Machinability. These filler metals, after deposition, often have to be annealed for machining operations. For machinability, when thoroughly annealed, they are rated at 65, as compared with a 1 percent carbon tool steel, which has a rating of 100. Full hardness can be regained by heat-treating procedures discussed herein.

A2.10 Identification. The Fe5 filler metals, in the hardened or as-deposited condition, are highly magnetic. When spark tested, they give off a very small, thin stream of sparks approximately 60 in. (1500 mm) long. Close to the grinding wheel, the spark is red; at the end, it is a straw color.

A2.11 Metallography. The Fe5 filler metals, when deposited, contain highly alloyed tetragonal martensite, highly alloyed retained austenite, and undissolved complex carbides. Molybdenum has been used to replace tungsten found in many other high-speed tool steels such as the 18-4-1 grade (18 percent tungsten, 4 percent chromium, and 1 percent vanadium). Molybdenum forms the same type of complex double carbide with iron and carbon as does tungsten. Since molybdenum is an element of smaller atomic weight than tungsten (approximately one-half), it will produce twice as many atoms of alloying elements in the steel as will tungsten when added in the same weight percentage. This appears to be a partial reason for the fact that 1 percent molybdenum can be substituted for approximately 2 percent tungsten.

The carbon content of high-speed steel is usually fixed within narrow limits. Carbon as low as 0.5 percent will not permit maximum hardness because of the presence of appreciable amounts of ferrite. As the carbon increases, the quenched hardness increases because of the absence of ferrite and because of the increased amount of carbon dissolved in the austenite. Chromium is present in this deposit at 3.0 to 5.0 percent, as this appears to be the right percentage for the best compromise between hardness and toughness. In conjunction with the carbon content, chromium is mainly responsible for the great hardenability of this deposit.

A2.12 Heat Treatment. A summary of the heat-treating data follows:

Preheat. Preheat is usually used, although in some instances, no preheating is required. When a preheat is used, the minimum is 300° F (150° C).

Annealing (1550 to 1650° F) (845 to 900° C). This treatment is applicable only when dictated by machining requirements.

Hardening. Hardening is necessary only if part has been annealed for machining.

Preheat. 1300 to 1500° F (705 to 815° C).

Harden. 2200 to 2250° F (1200 to 1230° C), air or oil quench.

Double Temper. 1025° F (550° C) 2 hours air cool to room temperature; 1025° F (550° C), 2 hours, air cool to room temperature.

Due to the high molybdenum content of these filler metals, weld deposits are susceptible to decarburization at

high temperature. Consequently, in heat treatment and annealing, care must be used to prevent decarburization.

A2.13 Welding Characteristics. The procedure for applying Fe5 filler metals is similar to that employed for other surfacing materials. The work must be carefully cleaned of all foreign material prior to welding. All cracked or spalled metal should be removed to ensure sound fusion of weld and base metals. Definite welding instructions depend upon the specific job and welding process to be employed. Preheating, although generally recommended, is not used in all surfacing applications but is dependent upon the shape, size, and composition of the part to be surfaced. Peening of each bead after deposition is sometimes employed to reduce stresses in the weldment.

A3. EFeMn Austenitic Manganese Electrodes

A3.1 Introduction and Applications. The two classifications of EFeMn electrodes are substantially equivalent except that the yield strength of EFeMn-B weld deposits is higher than that of EFeMn-A. For track work, the higher yield is considered an asset.

The applications where surfacing with EFeMn electrodes are most appropriate are those dealing with metal-to-metal wear and impact, where the work-hardening quality of the deposit becomes a major asset. Soft rock crushing operations, involving limestone or dolomite, for example, can also benefit from such protection. Abrasion by angular quartz particles does not seem to be altered in laboratory tests by work-hardening manganese steel. Severe service with quartz abrasion is best dealt with by using manganese steel as a tough base metal and surfacing with a martensitic iron. Under very high-stress conditions, such as those in a jaw crusher, experience may demonstrate that all wear-resistant metals except manganese steel are too brittle. Surface protection then becomes a matter of replacing worn metal with more EFeMn filler metal, which is common. Railway frogs and crossings are also reclaimed in this way. Extensive areas, as in crushers and power shovel parts, are usually protected with a combination of weld deposits and filler bars, which are flats and rounds of manganese steel, welded in place. Such protection may be applied up to 3 in. (76 mm) thick, which is near the upper thickness limit of common surface protection methods.

A3.2 Hardness. The normal hardness of these weld deposits is 170 to 230 BHN, but this is misleading, since they work-harden very readily to 450 to 550 BHN.

A3.3 Hot Hardness. Reheating above 500 to 600° F (250 to 315° C) may cause serious embrittlement. Thus, hot hardness is not a property that can be exploited.

A3.4 Impact. The EFeMn electrodes, as-deposited, are usually considered the outstanding engineering materials for heavy impact service.

12 / SOLID SURFACING WELDING RODS AND ELECTRODES

A3.5 Oxidation Resistance and Corrosion Resistance. The EFeMn weld metal is similar to ordinary carbon steels in this respect and is not oxidation or corrosion resistant.

A3.6 Abrasion. Resistance to high- and low-stress abrasion is moderate against hard abrasives like quartz, as shown by the following:

Wet Quartz Sand Abrasion Factor — 0.75 to 0.85 (as compared to SAE 1020 Steel as 1.00).

Dry Quartz Sand Erosion Factor — 0.41 to 0.56 (as compared to SAE 1020 Steel as 1.00).

The assumption that abrasion resistance increases with hardness has not been confirmed with carefully controlled testing using quartz as an abrasive.

A3.7 Metal-to-Metal Wear and Mechanical Properties in Compression. Metal-to-metal wear resistance is frequently excellent. The yield strength in compression is low, but any compressive deformation rapidly raises it until plastic flow ceases. This behavior is an asset in battering, pounding, and bumping wear situations.

A3.8 Machinability. Machining is very difficult with ordinary tools and equipment; finished surfaces are usually ground.

A3.9 Identification. Because of the unusual response to heating of the EFeMn weld metal, correct identification before welding is very important. A small magnet and a grinding wheel usually suffice, since a clean ground surface is substantially nonmagnetic, and grinding sparks are plentiful in contrast to the nonmagnetic stainless steels.

A3.10 Metallography. The chief constituent of EFeMn weld deposits is austenite, the nonmagnetic form of iron that can hold considerable carbon in solid solution. Austenite that is nearly saturated with carbon is responsible for the properties of these filler metals.

The austenite is not entirely stable. It will reject some of the carbon at intermediate temperatures or during deformation. This takes the form of manganese-iron carbides as fine particles, as films at grain boundaries, as flat, brittle plates, and in pearlite. Carbide precipitation in any of these forms leads to increased hardness and brittleness. Deformation (work-hardening from pounding, etc.) raises hardness most effectively with the least loss in toughness. Carbide precipitation, caused by slow cooling from the completely austenitic range or by reheating the tough structure, is undesirable.

The normal tough structure of manganese steel is produced in manufacture by water quenching from above 1800° F (980° C). Weld deposits depend on modified compositions to approximate this toughness after air-cooling from the welding temperature.

A3.11 EFeMn-A (Nickel-Manganese). Nickel additions to the standard grade of manganese steel produce no apparent changes in yield strength, but there is a distinct trend toward higher elongation. The quenching rate is perhaps less critical, but quenching is still necessary to obtain the maximum toughness.

A lower carbon content is much more effective in conferring toughness without quenching. As added nickel seems to prevent the lower intrinsic toughness of the straight 12 percent Mn steels with low carbon, an alloy of 0.50 to 0.90 percent carbon and about 3 to 5 percent nickel has become popular for welding electrodes. This alloy exhibits greater resistance to embrittlement from reheating up to 800° F (425° C) than the standard grade.⁴

A3.12 EFeMn-B (Molybdenum-Manganese). The addition of molybdenum to manganese steel tends to raise its yield strength. Like nickel, it increases the toughness of the lower carbon types and can be used interchangeably to produce a satisfactory welding electrode. Either approximately 3 to 5 percent nickel or 1/2 to 1-1/2 percent molybdenum will stabilize the tensile strength of the low carbon type near the standard level of 120,000 psi (827 MPa) after heat treatment. The associated elongation with 1/2 to 1-1/2 percent molybdenum is not so high, but it has a compensating higher yield strength. Deposits of EFeMn-B electrodes have given satisfactory performance in such exacting applications as railway switches and frogs, where battered down castings are rebuilt with molybdenum-manganese weld deposits.

A3.13 Heat Treatment. Weld deposits are usually not heat-treated, since the filler metals are formulated to be "air toughening." However, it sometimes may be advisable to heat-treat a weldment to restore the toughness of a manganese base embrittled by too much reheating. Water quenching after 2 hours at 1850° F (1010° C) is usually sufficient for this purpose. The weld deposit should be free of cracks if this is to be done; otherwise, oxidation of the cracks may cause considerable structural damage and cancel the benefits of the toughening heat treatment.

A3.14 Welding Characteristics

A3.14.1 If EFeMn filler metal is deposited on carbon or low alloy steel, the transition zone may be too low in manganese and, thus, develop a martensitic structure, which can permit spalling of the weld deposit because of brittleness. Such use of an austenitic manganese steel overlay for abrasion resistance is generally not recommended, since an air-hardening steel or martensitic iron is usually more satisfactory.

A3.14.2 Manganese steel is so popular for battering metal-to-metal wear that it has seen considerable service as an overlay on carbon steels despite its tendency to develop martensite. For many years, it has been used as an overlay on large steel mill coupling boxes, pinions, spindles, and other items working under heavy impact load. Cracking has been observed, but since the contacting faces are enclosed, highly stressed edges are avoided, and, perhaps because large surface areas are in contact, the surface protection technique has been considered satisfactory. Four layers of the manganese steel overlay are recommended.

4. Specification for Austenitic Manganese Steel Castings (ASTM Designation: A 128)

A3.14.3 Not all users of this procedure may be so fortunate in avoiding trouble from the brittle fusion zone. One way to avoid cracking is to "butter" the carbon steel with a layer of austenitic stainless steel. This blends well with carbon or low alloy steels and manganese steel without forming brittle structures. The EFeMn filler metal may then be welded on top of the stainless steel deposit without sacrificing the toughness of austenite.

A3.14.4 Bare EFeMn electrodes are sometimes used. Acceptable welds can be produced with sufficient power, and the high melting rates are considered an asset. Covered electrodes permit the use of lower power, are easier for an inexperienced welder to use, and minimize annoying short circuits in restricted space, but generally have a lower melting rate. Direct current, reverse polarity is preferred for both covered and bare electrodes.

A3.14.5 While manganese steel has high ductility when strained in one direction, the two- and three-dimensional stresses that occur in weld deposits can and frequently do cause failure with no apparent ductility. The undesirable weld bead tensile stresses that develop on cooling can be changed to compressive stress by peening the deposit. Such peening, preferably with a pneumatic hammer, flows the outer surface, and the deformation relieves the tension that would otherwise cause cracks. The opening, for which a machinist's ball peen hammer is suitable, should be done promptly after deposition of one or even half an electrode. In no case should a bead longer than 9 in. (230 mm) be left without immediate peening.

A3.14.6 The weld metal is weakest while hot. Since it is easiest to deform at red or yellow heats and since cracking is most likely to occur above 1500° F (815° C), it is advisable to peen the bead as quickly as practicable.

A3.14.7 There is experimental evidence that arc power, arc length, bead size, and melting rate are related to bead cracking. Unless the beads can be quickly and properly peened, arc power above 3.5 kw or melting rates above 12 in./min (5.1 mm/s) should be avoided. In any case, a weaving bead that has a cross-sectional area greater than 0.18 in.² (116 mm²) (for example 0.8 in. [20 mm] wide by 0.2 in. [5 mm] high above the base; which may mean about 0.40 in. [10 mm] thick) is desirable. These conditions may not prevent underbead cracking, but they should minimize fissuring in the weld.

A3.14.8 Much use of surfacing with EFeMn electrodes is to build up worn manganese steel parts. To avoid embrittling this base metal, it should be kept below 500° F (260° C) within 2 in. (51 mm) from the weld by water cooling, intermittent welding, or other procedures.

A4. RFeCr-A and EFeCr-A Austenitic High Chromium Iron Filler Metals

A4.1 Introduction and Applications. The RFeCr-A welding rods and EFeCr-A electrodes have proved very popular for facing agricultural machinery parts. Arc welding is used on heavy materials and large areas; oxyfuel

welding is used for thin sections. Plowshares can be considered as a typical application because these filler metals flow well enough to produce a thin edge deposit, and the wear conditions in sandy soil are typically those of erosion or low-stress scratching abrasion. It is significant that the FeCr-A filler metals become unsuitable in very rocky soil because of the associated impact. Industrial applications include coke chutes, steel mill guides, sandblasting equipment, brick making machinery, etc.

A4.2 Hardness. The as-welded hardness when deposited by oxyfuel welding will vary with carbon content. The average Rockwell hardness of 104 production quality control tests was C 56.1 with an observed range of C 51 to C 62, representing a range of 4.3 to 5.2 percent carbon. Macrohardness values, such as Rockwell or Brinell numbers, will increase slowly as carbon increases. Such figures reflect the greater proportion of the hard carbides in the softer matrix but do not reliably indicate abrasion resistance.

Since dilution is not expected in normal oxyfuel welding, the chief variable is carbon pickup from the flame adjustment. With a 3× feather-to-cone reducing flame, a pickup of 0.4 percent carbon has been observed if the welding rod is on the low side of the carbon range. On the high side of the carbon range, a neutral flame can slightly decarburize the deposit.

The austenitic matrix can work-harden somewhat under impact, but since the consequent deformation leads to cracking, impact service is avoided.

A4.3 Hot Hardness. Hardness falls slowly with increasing temperatures up to about 800 to 900° F (425 to 480° C) and thereafter falls rapidly and also becomes strongly affected by creep. At 900° F (480° C), the instantaneous Rockwell hardness is about C 43, and 3 minutes under load will cause an apparent drop to near C 37. At 1200° F (650° C), the instantaneous value may be no higher than C 5, and the apparent loss due to creep in 3 minutes may be as much as 45 points on the "C" scale. However, the loss of hardness due to tempering is negligible in comparison with many martensitic alloys, and the drop in hardness shown by hot testing is practically recovered on cooling to ordinary temperatures.

Very little is known about the resistance of these filler metals to thermal shock and thermal fatigue.

A4.4 Impact. FeCr-A deposits may withstand very light impact without cracking, but cracks will form readily if blows produce plastic deformation. These filler metals are seldom used under conditions of medium impact and are generally considered unsuitable for heavy impact where cracking is objectionable. Dynamic compression stresses above 60,000 psi (413 MPa) should be avoided.

A4.5 Oxidation Resistance. The high chromium content of these filler metals confers excellent oxidation resistance up to 1800° F (980° C) and they can be considered for hot wear applications where their hot plasticity is not objectionable.

A4.6 Corrosion Resistance. The matrix chromium content of the deposited FeCr-A filler metals is comparatively low and, thus, not very effective in providing resistance to liquid corrosion. These deposits will rust in moist air and are not stainless, but are more stable than ordinary iron and steel.

A4.7 Abrasion. Resistance to low-stress scratching abrasion is outstanding and is related to the volume of the hard carbides. Deposits of FeCr-A will wear about one-eighteenth as much as soft (SAE 1020) steel against rounded quartz sand grains and against sharp angular flint fragments. As stress on the abrasion increases, their performance declines. As deposited, FeCr-A is only mediocre under high-stress grinding abrasion and is usually not advantageous for such service.

A4.8 Metal-to-Metal Wear. Low-stress abrasion produces a good polish with a resulting low coefficient of friction. Where the polish is produced by metal-to-metal wear, performance is also good. Resistance to galling is considered better than for ordinary hardened steel because tempering from frictional heat is negligible. Austenite alone is prone to gall, and its presence may lead to unfavorable performance. Also, the hard carbides can stand in relief through wear of the austenite and cut or cause excessive wear of a mating surface. Therefore, metal-to-metal service should be approached cautiously. Rolling mill guides have been found to be appropriate applications.

A4.9 Mechanical Properties in Compression. In compression, the deposited FeCr-A filler metals are expected to have a yield strength (0.1 percent offset) of between 80,000 and 140,000 psi (551 to 965 MPa) with an ultimate strength from 150,000 to 280,000 psi (1034 to 1930 MPa). They will show about 1 percent elastic deformation and tolerate from 0.5 to 3 percent additional plastic deformation before failure at the ultimate. Like other cast iron types, their tensile strength is low, and tension should be avoided in designs for their use.

A4.10 Machinability. The FeCr-A deposits are considered commercially unmachinable with cutting tools and are also very difficult to grind. For machine shop use, the recommended grinding wheels are aluminum oxide abrasive with a 24-grit size, hard (Q) and medium space resinoid bond for off-hand high-speed work, and a slightly softer (P) vitrified bond for off-hand low-speed use.

A4.11 Identification. When welding rods are mixed, the FeCr-A filler metals can frequently be identified by (1) brittleness of the cast rod, (2) nonmagnetic behavior, (3) their very dull, lifeless spark that is short and produced with difficulty, and (4) sometimes by the presence of fine needle-like Cr_7C_3 crystals on a fracture section. A spot test for cobalt (see A5.11, "CoCr Identification") will distinguish it from the somewhat similar CoCr-C filler metals. The magnetic permeability is about 1.03 with a magnetizing force of 24 oersteds.

A4.12 Metallography. Deposits of these filler metals consist of hard carbides of the chromium carbide (Cr_7C_3) type dispersed in a matrix of austenite that is stable during slow cooling. The FeCr-A classification does not apply to those high chromium irons that are subject to pearlite formation, martensitic hardening, and other manifestations of austenite transformation.

The Cr_7C_3 carbides have a diamond pyramid hardness (DPH) or Vickers pyramid number (VPN) of approximately 2000, are harder than quartz, and, thus, confer resistance to scratching abrasion by most common materials. The austenite matrix is softer (about 450 DPH) and somewhat plastic. It can be eroded from around the carbides and may not give them competent support under conditions of high-stress abrasion. The austenite is rich in dissolved carbon as welded. Much of it separates out as spine-like crystals of Cr_7C_3 during cooling; some crystallizes as smaller particles, and some remains in solid solution. The hard carbides are brittle and fracture readily.

A4.13 Heat Treatment. The austenite, which is stabilized partly by dissolved chromium and partly by manganese, does not transform by usual steel hardening reactions. It can precipitate some carbon in dispersed form during aging heat treatments, but this hardening is minor and is neglected in practical surfacing operations.

A4.14 Welding Characteristics. In oxyfuel gas welding, flat position welding with a $3\times$ feather-to-cone reducing flame is recommended. The coefficient of thermal expansion is about 50 percent greater than that of carbon steels and irons. Contraction stresses are prone to crack the deposit, and, while these cracks may do no harm, they may be minimized by preheating and postheating techniques. The use of a flux may be helpful in dealing with dirt, scale, and other undesirable surface contamination; but on a clear, bright metal surface such as grinding produces, flux is ordinarily unnecessary. A good bond can be produced on all iron base materials, provided the base metal is not damaged by the high temperature conditions of welding and weld cooling. In arc welding, the procedure for applying FeCr-A filler metals is similar to that used for other surfacing electrodes.

A.5 RCoCr and ECoCr Cobalt-Base Filler Metals

A5.1 Introduction and Applications. The contact surfaces of exhaust valves in aircraft, truck, bus, and diesel engines are frequently surfaced with the softer alloys. Much CoCr-A filler metal is used for this purpose. Its success is attributed to its combination of heat, corrosion, and oxidation resistance. It is also used for valve trim in steam engines, on pump shafts, and on similar parts subject to corrosion and erosion. The higher carbon filler metals, CoCr-B and CoCr-C, are used in those applications where greater hardness and abrasion resistance are needed, but where impact resistance is not mandatory.

A5.2 Hardness. The usual hardness ranges are shown in Table A3. CoCr-A filler metal is usually employed as a precise oxyacetylene welded overlay with little if any base metal dilution. When so deposited, it is likely to be near Rockwell C 42 in hardness.

Table A3
Usual hardness of cobalt-
base weld deposits (70° F) (21° C)

	Hardness, Rockwell C		
	CoCr-A	CoCr-B	CoCr-C
Oxyfuel gas welded	38 to 47	45 to 49	48 to 58
Arc welded	23 to 47	34 to 47	43 to 58

a. Lower values can be expected in single layer deposits due to dilution with the base metal.

CoCr-C filler metal may be used for wear resistance in rougher service where precision and quality are less important but hardness and carbide volume may be significant. Oxyfuel gas deposits are expected to be near Rockwell C 55, which is comparable to the hardness of the austenitic chromium irons (FeCr-A). Arc welded deposits are much more variable. Some experience with these is shown in Table A4.

Many surfacing alloys are softened permanently by heating to elevated temperatures. CoCr filler metals are an exception. While they do exhibit lower hardness while hot, they return to approximately their original hardness upon cooling and can be considered immune to tempering.

A5.3 Hot Hardness. Elevated temperature strength and

hardness are outstanding properties of this group. They are generally considered superior to other surfacing alloys where these properties are required above 1200° F (650° C). In the range from 1000 to 1200° F (540 to 650° C), their relative advantage is not always clear, and below 1000° F (540° C) other classifications may be better. The hot hardness expectancy is shown in Table A5.

Creep, which is plastic flow that occurs under sustained loading, is ordinarily a high temperature problem. In weld deposits, it appears as a slow yielding; in hardness tests, this shows as an apparent lowering of hardness as the time period of a hardness indentation is increased. Evidence of this is shown in Table A6.

At temperatures above 1000 to 1200° F (540 to 650° C), weld deposits of these CoCr filler metals have greater resistance to creep than other commercially available surfacing alloys for which data are available. This distinction and their hardness at 1200° F (650° C) and above are the primary reasons for their selection for use in many applications.

A5.4 Impact. Resistance to flow under impact increases with carbon content in this group. CoCr-C weld deposits are quite brittle and crack readily when impact flow does occur. CoCr-A deposits, while they deform more easily, can withstand some plastic flow under compression before cracking. However, a tough martensitic steel is considered superior in both flow resistance and toughness.

A5.5 Oxidation Resistance. The presence of over 25 percent chromium promotes the formation of a thin, tightly-adherent protective scale under oxidizing conditions. For deposits of these filler metals at temperatures up to 1800° F (980° C), this means a scaling rate below 0.10

Table A4
Arc welded deposits

Room temperature hardness data on CoCr-C arc welded deposits									
Sample	Carbon, percent	Average hardness		Average hardness by layers					
		Rockwell C	Brinell	Brinell			Rockwell C		
				1	2	3	1	2	3
B	2.28	47	465	389	497	509	41	48	53
G	1.83	40	391	328	399	444	32	43	47
H	2.12	49	437	368	455	489	44	51	53
E	2.95	47	448	381	433	528	42	46	53

Range of hardness observed from 3 coupons for each sample, 3 readings for each of 3 positions on each of 3 layers

Sample	Brinell hardness			Rockwell C hardness		
	1	2	3	1	2	3
B	357 to 440	443 to 557	390 to 640	33 to 46	38 to 50	48 to 56
G	297 to 353	373 to 415	429 to 478	27 to 35	38 to 45	44 to 50
H	324 to 384	413 to 483	450 to 514	41 to 45	41 to 53	51 to 56
E	351 to 443	322 to 514	465 to 578	37 to 45	34 to 53	50 to 55

Table A5
Instantaneous hardness values

Temperature,		CoCr-A					CoCr-C			
		Rockwell C for sample number given					Rockwell C for sample number given			
		B	G	H-a	H-b	E	B	G	HJ	E
650	345	29.6	33.3	26.5	29.8	41.0	43.7	35.7	41.2	46.1
850	455	24.3	26.8	21.5	28.5	36.6	41.0	31.9	38.0	40.6
1050	565	20.0	21.8	19.1	22.7	32.2	35.6	29.8	35.1	30.5
1200	650	15.9	19.7	16.4	21.8	25.8	29.9	24.3	29.0	27.9
1400	760	46.8 ^a	45.8 ^a	44.7 ^a	49.8 ^a	49.8 ^a	53.9 ^a	53.0 ^a	53.4 ^a	51.3 ^a

a. These are Rockwell A values.

Table A6
Average hardness with 1- and 4-minute holding times

Time under load		Temperature, °F °C		CoCr-A					CoCr-C			
				Brinell hardness for sample number given					Brinell hardness for sample number given			
				B	G	H-a	H-b	E	B	G	H	E
1 min	850	455	297	320	291	309	388	381	319	426	429	
4 min	850	455	307	350	269	306	376	394	304	409	422	
1 min	1200	650	250	274	221	250	304	363	268	326	328	
4 min	1200	650	235	243	237	220	278	363	234	296	298	

in. (2.5 mm) per year in common oxidizing atmospheres. Scaling resistance to combustion products of internal combustion engines is also generally adequate, even in the presence of lead compounds from "doped" fuels.

A5.6 Corrosion Resistance. CoCr filler metals, as deposited, are recognized as "stainless" and are frequently useful where both abrasion and corrosion are involved. They can be considered corrosion resistant in the less severe media, in foods, and in air, and they may even have good resistance in some corrosives such as nitric, acetic, citric, formic, lactic, sulfuric, sulfurous, and trichloroacetic acids. However, if an application that involves corrosion is under consideration, general statements about corrosion should be confirmed by a field test, if possible. It should include all service factors, as minor variables are sometimes decisive. In any event, a recognized authority in the field of corrosion should be consulted.

A5.7 Abrasion. Carbon content has much to do with the response to abrasion. At 1.0 percent carbon (CoCr-A), the performance is inferior to that of carbon steel; at 2.5 percent carbon (CoCr-C), the resistance to high-stress grinding abrasion is good. Under the low-stress conditions of scratching abrasion, laboratory tests indicate that CoCr-C oxyfuel gas welds may wear at one-twentieth the rate of carbon steel, while for CoCr-A deposits, the rate is near one-fifth.

There has been considerable field use of CoCr-C filler metal to withstand abrasion. Some of this experience dates back to the time when the cobalt-base filler metals were practically the only surfacing materials available. It should be noted that equivalent performance can currently be obtained with iron-base filler metals if heat and corrosion are unimportant service factors.

A5.8 Metal-to-Metal Wear. The CoCr filler metals are well suited for metal-to-metal wear because of their ability to take a high polish and their low coefficient of friction.

A5.9 Mechanical Properties in Compression. Some reported properties appear in Table A7.

A5.10 Machinability. None of the deposits from these filler metals is easily machinable, and the difficulties increase along with increased carbon content. However, CoCr-A deposits are regularly machined, preferably with sintered carbide tools. With deposits of CoCr-C classification, grinding is the accepted method of finishing.

A5.11 Identification. Filler metals of these three classifications may usually be distinguished by their relative hardness and brittleness. They are nonmagnetic and thus may be screened from the magnetic iron-base alloys. The spark test will differentiate them from austenitic manganese steel, FeMn. However, the austenitic chromium irons, FeCr-A, are so similar to the CoCr-C classification

Table A7
Compression properties of cast cobalt-base alloys

	Co-Cr-A	CoCr-C
Yield strength (0.1 percent offset), ksi	64 to 76	85 to 110
Ultimate compression strength, ksi	150 to 230	250 to 270
Plastic deformation, percent	5 to 8	1 to 2
Brinell hardness	350 to 420	480 to 550

a. Cast values are included because weld metal data are not available.

SI equivalents					
ksi	MPa	ksi	MPa	ksi	MPa
64	441	85	586	230	1586
76	524	110	758	250	1724
		150	1034	270	1861

that the following test or some other test may be necessary for differentiation.

Identification Test. Clean 1- and 2-in. (25 and 51 mm) lengths of the filler metal and place in 250 mL beakers. Cover with dilute HCl (one part concentrated HCl and one part water), and heat. In a few minutes, the following may be observed:

Filler metal	Color of solution	Dissolving action
CoCr-A	blue	slow
CoCr-B	blue	slow
CoCr-C	blue	slow
FeCr-Al	green	fast

A5.12 Metallography

A5.12.1 These filler metals contain 25 to 33 percent chromium, which confers oxidation resistance, and 3.0 to 14 percent tungsten, which promotes elevated temperature strength, while the cobalt base gives corrosion resistance and provides a stable solid solution matrix. Carbon is an important element that contributes strength and, in combination with chromium, forms hard carbides that may provide abrasion resistance. Different levels of carbon and tungsten are responsible for the distinctive properties of the three classifications.

A5.12.2 The solid solution matrix of CoCr weld deposits is harder than the austenite of the iron-carbon system and the chromium-nickel-iron stainless steels. In the matrix, complex carbides appear that increase the overall hardness and brittleness. In CoCr-A deposits, these may be small and well dispersed. In deposits of CoCr-C, characteristic spines and pseudohexagonal crystals, related to the Cr_7C_3 carbides of the high chromium irons (FeCr-A), are plentiful. They may be associated with many fine carbides, and complex eutectiferous structures are common. Structural complexity increases with carbon content as well as with other elements, such as iron, that mingle from base metal fusion.

A5.12.3 Oxyacetylene welding may increase the carbon content of the deposit, while arc welding tends to reduce carbon and at the same time dilute the CoCr deposit with elements from the base metal. These changes will be reflected in the structures.

A5.12.4 The solid solution matrix has a hardness near 40 Rockwell C. The Cr_7C_3 type carbides may be expected to show a Vickers microhardness between 1500 and 2000 VPN. However, despite the hard carbide crystals, the general hardness (as measured by Rockwell or Brinell tests) seldom exceeds Rockwell C 60 or 600 BHN because of the softer supporting matrix.

A5.13 Heat Treatment. The CoCr filler metals are not subject to hardening transformations like steel and have negligible response to heat treatment. Occasionally, a stress relief treatment may appear advisable to minimize cracking, but usually they go into service in the as-welded condition.

A5.14 Welding Characteristics. For oxyacetylene welding, a 3X feather-to-cone reducing flame is recommended. Preheating the cleaned surface with a neutral flame up to 800° F (425° C) is advisable for heavy sections. For shielded metal arc welding, dc reverse polarity is used, with a short arc. For a 1/4-in. (6.4 mm) diameter electrode, a current of approximately 190 to 200 A is recommended. All deposits should be cooled slowly to prevent cracking.

A6. Copper-Base Alloy Filler Metals

A6.1 Introduction and Applications. The copper-base alloy filler metals classified by this specification are used to deposit overlays and inlays for bearing, corrosion resistant, and wear resistant surfaces.

ERCuAl-A2 filler metal and ECuAl-A2 electrodes are used for surfacing bearing surfaces between the hardness ranges of 130 to 190 BHN as well as corrosion resistant surfaces. The ERCuAl-A3, RCuAl-C, ECuAl-B, and

18 / SOLID SURFACING WELDING RODS AND ELECTRODES

ECuAl-C filler metals are used primarily for the surfacing of bearing surfaces requiring the higher hardness ranges of 140 to 290 BHN.

Classifications RCuAl-C, RCuAl-D, RCuAl-E, ECuAl-C, ECuAl-D, and ECuAl-E are used to surface bearing and wear resistant surfaces requiring the higher hardnesses of 230 to 390 BHN, such as gears, cams, sheaves, wear plates, dies, etc.

The RCuSi-A and ECuSi filler metals are used primarily for the surfacing of corrosion resistant surfaces. Generally, the copper-silicon deposits are not recommended for bearing service.

The copper-tin (CuSn) filler metals are used primarily to surface bearing surfaces where the lower hardness of these alloys is required, for surfacing corrosion resistant surfaces, and, occasionally, for wear resistant applications.

Many of the filler metals classified by this specification can also be used for joining like and dissimilar metals (see AWS A5.6-76, Specification for Copper and Copper Alloy Covered Electrodes, and AWS A5.7-77, Specification for Copper and Copper Alloy Bare Welding Rods and Electrodes) as well as for casting repairs.

A6.2 Hardness. Deposit hardness will vary with the welding process used and the manner in which the metal is deposited. For example, deposits made with the gas metal arc and gas tungsten arc process will be higher in hardness than deposits made with the oxyfuel gas and shielded metal arc processes, because lower losses of aluminum, tin, silicon, and zinc are encountered in the remelting process due to the better shielding from oxidation. In oxyfuel gas welding, excessive "puddling" of the molten weld metal will cause excessive losses of the hardening elements, producing deposits of lower hardness than those specified. See Table A8 for hardness ranges of these alloys.

Table A8
Weld deposit hardness

AWS Classifications	Brinell hardness of deposit,		Welding Process Applicable
	3000 kg load	500 kg load	
ERCuAl-A2	130-150		GTAW, GMAW
ECuAl-A2	115-140		SMAW
ERCuAl-A3	140-180		GTAW, GMAW
ECuAl-B	140-180		SMAW
ERCuAl-C	250-290		GTAW
ECuAl-C	180-220		SMAW
RCuAl-D	310-350		GTAW
ECuAl-D	230-270		SMAW
RCuAl-E	350-390		GTAW
ECuAl-E	280-320		SMAW
ECuSi		80-100	SMAW
ERCuSi-A		80-100	OFW, GMAW, GTAW
ERCuSn-A		70-85	GRAW, GMAW
ECuSn-A		70-85	SMAW
ECuSn-C		85-100	SMAW
RCuSn-D		90-110	GTAW
RCuZn-E		130 min	OFW

A6.3 Hot Hardness. The copper-base alloy filler metals are not recommended for use at elevated temperatures since the mechanical properties and, especially, hardness will tend to decrease consistently as the temperature increases above 400° F (205° C).

A6.4 Impact. The impact resistance of CuAl-A2 deposits will be the highest of the copper-base alloy classifications. As the aluminum content increases, impact resistance decreases markedly. CuSi weld deposits have good impact properties. The CuSn filler metals, as-deposited, have low impact values, due to the coarse grain structure and the lower strength inherent in these alloys. The CuZn-E deposits have very low impact values.

A6.5 Oxidation Resistance. Deposits of the CuAl filler metals form a protective oxide coating upon exposure to the atmosphere. Oxidation resistance of the CuSi deposit is fair, while that of CuSn filler metals would be comparable to that of pure copper.

A6.6 Corrosion Resistance. These copper-base alloy filler metals are used rather extensively to surface areas subjected to corrosion from many acids, mild alkalis, and salt water. The only exception is filler metal of the CuZn-E classification. The filler metals producing deposits of higher hardness, that is, 120 to 200 BHN (3000 kg load), may be used to surface areas subjected to corrosive action as well as erosion from liquid flow for such applications as condenser heads and turbine runners.

A6.7 Abrasion. None of the copper-base alloy deposits is recommended for use where severe abrasion is encountered in service.

A6.8 Metal-to-Metal Wear. The CuAl filler metals producing deposits from 130 to approximately 390 BHN (3000 kg load) are used to overlay surfaces subjected to excessive wear from metal-to-metal contact, such as gears, cams, sheaves, wear plates, dies, etc. For example, CuAl-E filler metals are used to surface dies, both male and female, for drawing and forming stainless and carbon steels and aluminum.

All of the copper-base alloy filler metals classified by this specification are used to deposit overlays and inlays for bearing surfaces, with the exception of the CuSi filler metals. Silicon bronzes are considered poor bearing alloys. Copper-base alloy filler metals should be selected for a bearing surface producing a deposit of 50 to 75 Brinell hardness numbers under that of the mating metal or alloy. Equipment is designed so that the bearing will wear in preference to the mating part. Slight porosity in the deposit is sometimes acceptable for bearing service. In fact, CuZn-E, which is a leaded bronze, was designed to produce a porous deposit to retain oil primarily for additional lubrication purposes in the overlay of locomotive journal boxes.

A6.9 Mechanical Properties in Compression. Deposits of the CuAl filler metals have high elastic limits and ultimate strengths in compression ranging from 25,000 to

65,000 psi (172 to 448 MPa) and 120,000 to 171,000 psi (827 to 1174 MPa), respectively. The elastic limit of CuSi deposits is around 22,000 psi (152 MPa) with an ultimate strength in compression of 60,000 psi (414 MPa). The CuSn deposits will have an elastic limit of 11,000 psi (76 MPa), and an ultimate strength of 32,000 psi (221 MPa). The mechanical properties of the leaded bronzes, CuZn-E, are very low in compression with an elastic limit of about 5000 psi (34 MPa) and an ultimate strength of 20,000 psi (138 MPa).

A6.10 Machinability. All of these copper-base alloy deposits can be machined if a machined surface is required.

A6.11 Identification. All of the copper-base alloy deposits are nonmagnetic and non-sparking in the general sense of the word. In fact, so-called "non-sparking" tools are produced from some of the hard CuAl alloys listed in this specification.

A6.12 Metallography. The CuSi alloys are composed of alpha (single-phase) producing rather fine-grained deposits. The 5 to 8 percent phosphor bronzes, CuSn, have an alpha structure similar to alpha brass, but as the tin content increases, delta particles form. Unlike the CuSi alloys, deposits of CuSn filler metals have a coarse, dendritic grain structure unless precautions are taken during welding to refine the grain through hot peening or subsequent heat treatment, or both. Deposits of CuAl-A2 filler metals are composed of light colored alpha crystals in a darker colored beta matrix. As the aluminum content increases, light blue gamma particles will appear in the darker beta matrix in increasing amounts. CuAl alloys may be etched with either ferric chloride or ferric nitrate etchants. Deposits of the lead-tin alloy, RCuSn-E, will have an alpha structure with grey particles of free lead unevenly distributed throughout.

A6.13 Heat Treatment. Ordinarily, no heat treatment is needed in surfacing with copper-base alloy filler metals.

A6.14 Welding Characteristics. When surfacing iron-base metals or alloys with copper-base alloy filler metals, a minimum amount of dilution from the base metal is desired.

A6.15 Welding Rods. Generally, a preheat is not necessary unless the part is exceptionally large; in this case, a 200° F (93° C) preheat may be desirable to facilitate the smooth flow of the weld metal. At no time should the preheat temperature be above 400° F (205° C) when applying the first layer. On subsequent layers, an interpass temperature of approximately 200° F to 600° F (93 to 315° C) will simplify deposition of the weld metal.

Generally, a deposit thickness of 1/4 in. (6.4 mm) is most desirable, built up with a minimum of three layers. If welding rods are used with the oxyacetylene, carbon arc, or gas tungsten arc processes, dilution from the base plate can be easily controlled by proper precoating (tinning) of the surface on the first layer. Excessive dilution from the

base plate will produce hard spots in the deposit that are difficult to machine.

A6.16 Electrodes. In shielded metal arc or gas metal arc welding, base metal pickup can be held to a minimum only through the use of a fast, wide weave bead technique in depositing the initial layer. Generally, the initial layer should be made by weaving passes in widths four to six times the core wire diameter. Subsequent layers may be applied in any manner. The deposit should be at least 3/16 in. (4.8 mm) in thickness in order to develop the hardness specified. Generally, a deposit thickness of 1/4 in. (6.4 mm) is most desirable, built up with a minimum of three layers. On large sections, a preheat of 300° F (150° C) should be used, and interpass temperatures should not exceed 600° F (315° C).

A7. RNiCr and ENiCr Nickel-Chromium-Boron Filler Metals

A7.1 Introduction and Application. For the RNiCr welding rods and ENiCr electrodes, chemical composition as specified herein does not determine the physical properties as clearly as it does for the other filler metals classified by this specification. The overlapping composition ranges represent current commercial practices. Deposit hardness increases from NiCr-A to NiCr-C, but machinability and toughness decrease. Selection is generally based upon consideration of these factors.

Deposits of the NiCr filler metals have good metal-to-metal wear resistance, good low-stress scratch abrasion resistance, corrosion resistance, and retention of hardness at elevated temperatures. A few of their applications include use on seal rings, cement pump screws, valves, screw conveyors, and cams.

A7.2 Hardness. The hardness of arc and oxyfuel gas weld deposits is shown in Table A9. Deposits of NiCr filler metals work-harden to a greater degree when considerable iron dilution is present (one layer arc weld) than when there is less iron dilution (two layer arc weld). These filler

Table A9
Hardness of weld deposits

AWS Classification	Number of layers	Oxyfuel gas weld deposit hardness, Rockwell C	Arc weld deposit hardness of covered and bare electrode, Rockwell C
NiCr-A	1	35 to 40	24 to 29
	2	35 to 40	30 to 35
NiCr-B	1	45 to 50	30 to 35
	2	45 to 50	40 to 45
NiCr-C	1	56 to 62	35 to 45
	2	56 to 62	49 to 56

Table A10
Hot hardness of weld deposits

AWS Classification	Loading interval, min	Rockwell C hardness of arc weld deposit			Rockwell C hardness of oxyfuel gas weld deposit		
		600° F (315° C)	800° F (430° C)	1000° F (540° C)	600° F (315° C)	800° F (430° C)	1000° F (540° C)
NiCr-A	0	30	29	24	34	33	29
	1	30	28	21	33	32	26
	2	30	28	20	33	32	25
	3	29	28	19	33	31	24
NiCr-B	0	41	39	33	46	45	42
	1	41	38	29	46	44	39
	2	41	38	28	45	43	38
	3	40	37	26	45	42	37
NiCr-C	0	49	46	39	55	52	48
	1	49	45	33	54	51	42
	2	48	45	32	54	51	41
	3	48	45	31	54	50	40

metals are not normally used for their work-hardening properties, since this would usually imply more impact resistance than they possess.

A7.3 Hot Hardness. On arc and oxyfuel gas weld deposits, the Rockwell C hardness readings shown in Table A10 were obtained using single specimens, tested consecutively at three temperatures without previous heat treatment.

A7.4 Impact. Deposits of NiCr filler metal will withstand light impact fairly well. However, if the impact blows produce plastic deformation, cracks are certain to appear in the NiCr-C weld metal and less likely to appear in the NiCr-A and NiCr-B deposits.

A7.5 Oxidation Resistance. NiCr deposits are oxidation resistant up to 1800° F (980° C) because of their high nickel and chromium contents. However, incipient fusion may occur near this temperature, and use of these filler metals above 1750° F (955° C) is not recommended.

A7.6 Corrosion Resistance. Deposits of NiCr filler metal are completely resistant to atmospheric, steam, salt water, and salt spray corrosion. They are also resistant to the milder acids and many common corrosive chemicals. However, if an application that involves corrosion is under consideration, general statements about corrosion should be confirmed by a field test, if possible. It should include all service factors, as minor variables are sometimes decisive. In any event, a recognized authority in the field of corrosion should be consulted.

A7.7 Abrasion. The high carbon classification, NiCr-C, of this group has excellent resistance to low-stress scratching abrasion and is particularly valuable where such abrasion and corrosion are combined. Abrasion resistance is

expected to decrease with decreasing carbon content. These filler metals are not recommended for high-stress grinding abrasion.

A7.8 Metal-to-Metal Wear. NiCr deposits have excellent metal-to-metal wear resistance and take a high polish under wearing conditions. They are particularly resistant to galling. These properties are best shown in the NiCr-C alloy.

A7.9 Mechanical Properties in Compression. Information on these properties is not available. However, data have been reported on some of the properties in compression of deposits of the NiCr-C filler metal as follows:

Modulus of elasticity psi (MPa)	32,000,000 (220 608)
Elastic limit, psi (MPa)	42,000 (290)
Yield strength, psi (MPa)	
(0.01 per cent offset)	92,000 (634)
(0.10 per cent offset)	150,000 (1034)
(0.20 per cent offset)	210,000 (1448)

All tests were run on duplicate specimens and the results are averaged.

A7.10 Coefficient of Expansion. The average coefficients of expansion (inches per inch per deg F [mm per mm per deg C]) for deposits of these filler metals are as follows:

NiCr-A	0.00000856 (0.00000476)
NiCr-B	0.00000841 (0.00000467)
NiCr-C	0.00000814 (0.00000452)

A7.11 Machinability. Deposits of NiCr filler metals may be machined with tungsten carbide tools by using slow speeds, light feeds, and heavy tool shanks. Deeper cuts and faster speeds can be obtained on the softer deposits than on the NiCr-C deposits. They are also finished by grinding, using a soft-to-medium vitrified silicon carbide

wheel. They can be ground to between 2.2 and 4.4 $\mu\text{in.}$ (0.052 and 0.113 μm) AA surface finish.* There is a tendency to load an aluminum oxide or resin-bonded wheel.

A7.12 Identification. NiCr deposits are nonmagnetic, having a permeability of 1.005 with a magnetizing force of 500 oersteds. When spark tested, they give off a short, dull, red spark without bursting. They have a higher fluidity and lower melting point than the cobalt-base filler metals, CoCr.

A7.13 Metallography. The microstructure of deposits of the NiCr filler metals consists of six-sided crystals of chromium carbides and globular white islands of chromium borides in a complex nickel eutectic (low melting) matrix. In many cases, no etchant is needed due to the character of the constituents. Polishing leaves the hard constituents standing out in relief to about the same degree as a mild etch. To accentuate the degree of relief, cold concentrated HCl or a mixture of 20 percent cold concentrated HCl and 80 percent glacial acetic acid may be used. The chromium borides have a hardness of approximately 4000 VPN.

In general, the chromium carbides and chromium borides are larger in oxyfuel gas weld deposits than in arc weld deposits. This is probably related to differences in cooling rates between the two welding processes.

A7.14 Heat Treatment. In order to prevent cracks when applying the NiCr filler metals to hardenable iron and steel alloys, preheat and postheat treatments should be used. All hardenable alloys should be preheated to 600 to 800° F (315 to 425° C). Water- and oil-hardening alloys should be slow cooled by placing them in an insulating medium or a furnace immediately after welding. Air-hardening steel should be isothermally annealed immediately after welding.

A7.15 Welding Characteristics

A7.15.1 The NiCr-B filler metal has a broad solidification range. This property, together with its low melting point, contributes to its lesser tendency to warp weldments. If it is desired to hot-form some special shape of the deposit to minimize grinding, the weldment may be heated to 1800 to 1975° F (980 to 1080° C), preferably by using an oxyacetylene torch. (1800 to 1975° F [980 to 1080° C] is in the solidification range of these alloys.) The deposit should not be held at this temperature, because it will start to flow. While in this broad range, it may be readily formed, using a suitable die and pressing by hand. It may also be shaped by scraping with a file or bar steel. Square edges on the weld may be made in this manner. The deposit will hold its contour after this forming and regain its original hardness upon cooling to room temperature.

A7.15.2 For best results during oxyfuel gas welding,

the piece to be welded should be free from oil, rust, scale, or other foreign matter. If the piece is to be undercut for surfacing, corners should be rounded. A neutral oxyfuel flame is recommended for the NiCr-C filler metal and reducing flames for the softer types, NiCr-A and NiCr-B. This gives the proper fluidity to the deposit. No flux is necessary for most applications. It is not necessary to "sweat" the surface of the base metal. These filler metals should be applied when the surface of the base metal is at a red heat. Large sections require bulk preheat to 600° F (315° C). The application is similar to brazing. The deposit will spread evenly and quietly over the heated portion of the base metal. The deposit should be smooth and should not have the normal weld appearance of a rippled surface and craters. Because of their low melting point and the brazing techniques used, these filler metals may be oxyfuel gas welded more rapidly and easily than most surfacing alloys.

A7.15.3 The NiCr filler metals may be applied to cast iron, steel, copper, and nickel-base alloys. For surfacing of high chromium steels, the fluidity is improved by using a slightly reducing flame with a feather approximately the length of the inner cone. If checking of the deposit occurs, preheating of the workpiece and slow cooling in an oven or insulating material will minimize this condition, and may eliminate checking entirely.

A7.15.4 These filler metals may be applied to low and medium carbon steels and austenitic stainless steels with no tendency for the base metal to crack. With high carbon steels and alloy steels, a preheat and postheat generally are necessary to prevent cracking of the base metal.

A7.15.5 When arc welding, the surface to be welded should be free from rust, dirt, oil, scale, and all foreign matter. The NiCr electrodes may be bare or covered. For best results, the electrode should be used on dc reverse polarity. The following current ranges are recommended:

Electrode diameter, in. (mm)	Current, A
3/16 (4.8)	130 to 180
1/4 (6.4)	180 to 240

A7.15.6 The minimum possible current setting should be used to prevent undue penetration. Preheating or postheating depends upon the type of alloy being welded and should be sufficient to prevent cracking at the fusion zone. Arc weld deposits are slightly softer and less wear resistant than oxyfuel gas weld deposits due to dilution. Hardness and wear resistance are increased by building up with two layers instead of one. The bare electrode arc deposit of these alloys will be much sounder than the average bare electrode application due to their high boron content with resultant self-fluxing properties.

A7.15.7 These alloys, when in powder form, can be deposited by spraying to form a mechanically bonded overlay (metallizing) and then fused to a smooth, dense overlay with the same metallurgical bond as that obtained with welding rod deposits. Fused overlays up to 0.060 in. (1.5 mm) in thickness are practical on surfaces of almost any contour.

*ANSI standard B46.1 requires rms surface finish to be expressed as the arithmetic average (AA). AA = 1.11 rms.

Bibliography

1. *The Welding Encyclopedia*, Seventeenth Edition, 1974.
2. *Welding Handbook*, Seventh Edition, Vol. 2, American Welding Society, 517-562.
3. *Metal Handbook*, Eighth Edition, Vol. 6, American Society for Metals, 152-166.
4. Avery, H.S., "Hot Hardness of Hard Facing Alloys," *Welding Journal*, July 1950, 552-578.
5. "Surface Protection Against Wear and Corrosion," (A Symposium), Chapter 3, American Society for Metals, 1954.
6. Avery, H.S. and Chapin, H.J., "Hard Facing Alloys of the Chromium Carbide Type," *Welding Journal*, October 1952, 917-930.
7. Avery, H.S., "Selecting Hard Facing Alloys to Resist Impact, Heat, Friction, and Abrasion," *Product Engineering*, March 1952.
8. Daemen, R., "Hard Surfacing, A Summary of Some Basic Principles," *W.I. Surfacing Journal*, Vol. 3, No. 4, October 1972, 4-9.
9. Farmer, H.N., "Factors Affecting Selection and Performance of Hardfacing Alloys," (A Symposium), Vail, Colorado, July 30-31, 1974, Climax Molybdenum Co., 85-91.
10. Wold, K.G., "Aluminum Brazes—Another Family of Hardfacing Alloys," *Welding Engineer*, Vol. 59, No. 8, August 1974, 9-11.
11. Budinski, K.G., "Surfacing I: What a Designer Needs to Know," *Welding Design and Fabrication*, Vol. 49, No. 7, July 1976, 50-53.
12. Bhansali, K.J. and Silence, W.L., "Metallurgical Factors Affecting Wear Resistance of Metals," *Metal Progress*, Nov. 1977, 38-43.
13. Redman, J.E. "Hardfacing—Where and How to Use It," *Plant Engineering*, July 10, 1975, 95-97.