

SPECIFICATION FOR COMPOSITE SURFACING WELDING RODS AND ELECTRODES



SFA-5.21



(Identical with AWS Specification A5.21-80)

Scope

This specification prescribes requirements for composite surfacing welding rods and electrodes. The specification covers straight length bare and covered composite welding rods for use with the oxyfuel, gas tungsten arc, and atomic hydrogen welding processes. This specification also covers straight length bare and covered electrodes for use with the shielded metal arc welding process.

Note 1. 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 2. 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 were available. It is intended that subsequent editions of this specification will incorporate these other filler metals as industry standardization occurs. Certain aspects of this specification may be helpful or pertinent to the gas metal arc welding process, but such coverage is only incidental.

1. Classification and Acceptance

1.1 Classification. Composite surfacing welding rods and electrodes are classified on the basis of the chemical composition of the weld metal with the exception of the composite tungsten-carbide welding rods and electrodes (see Tables 1 and 2). Composite tungsten-carbide surfacing welding rods and electrodes are classified on the basis of the chemical composition of the carbon steel tube (see Table 3), the chemical composition of the tungsten-carbide granules (see Table 4), and

the mesh size distribution and percent by weight of the tungsten-carbide granules contained in the carbon steel tube (see Tables 5 and 6). Any composite surfacing 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. AWS 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 welding rods and electrode deposits (except tungsten-carbide rods or electrodes) shall conform to the requirements prescribed for their classification in Tables 1 and 2, respectively. The chemical composition of the carbon steel tube and tungsten-carbide granules of tungsten-carbide rods and electrodes shall conform to the requirements of Tables 3 and 4, respectively. 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, without excessive spatter, when used within the current ranges

TABLE 1
CHEMICAL REQUIREMENTS FOR COMPOSITE SURFACING WELDING RODS, PERCENT

AWS Classification	Carbon	Manganese	Tungsten	Chromium	Molybdenum	Iron	Vanadium	Silicon	Total other elements
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	—	1.0 to 2.5	1.0

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.

TABLE 2
CHEMICAL REQUIREMENTS FOR COMPOSITE SURFACING ELECTRODES, PERCENT

AWS Classification	Carbon	Manganese	Tungsten	Nickel	Chromium	Molybdenum	Iron	Vanadium	Silicon	Phosphorous	Total other elements
EFe5-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	0.70	—	1.0
EFe5-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	0.70	—	1.0
EFe5-C	0.3 to 0.5	0.50	1.0 to 2.5	—	3.0 to 5.0	5.0 to 9.0	remainder	0.8 to 1.2	0.70	—	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	11.0 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

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.

TABLE 3
CHEMICAL REQUIREMENTS FOR CARBON STEEL TUBES FOR TUNGSTEN-CARBIDE
WELDING RODS AND ELECTRODES, PERCENT

Carbon	Manganese	Phosphorus	Sulfur	Silicon	Nickel	Chromium	Molybdenum	Vanadium
0.10	0.45	0.02	0.03	0.01	0.30 ^a	0.20 ^a	0.30 ^a	0.08 ^a

a. Single values shown are nominal percentages, except for those marked with footnote a which indicate maximum percentages.

TABLE 4
CHEMICAL REQUIREMENTS FOR TUNGSTEN-CARBIDE GRANULES, PERCENT

Carbon	Cobalt	Tungsten	Nickel	Molybdenum	Iron	Silicon
3.6 to 4.2	0.3	94.0 min.	0.3	0.60	0.5	0.3

Note 1. Single values shown are maximum percentages, except where otherwise indicated.

Note 2. Chemical analysis shall be made on tungsten-carbide granules that have been well cleaned to remove all flux or other surface contamination.

TABLE 5
MESH SIZE AND WEIGHT PERCENT OF TUNGSTEN-CARBIDE GRANULES
CONTAINED IN TUNGSTEN-CARBIDE WELDING RODS

AWS Classification	Mesh size of tungsten-carbide granules		Weight percent of tungsten- carbide granules
	Tyler standard	U.S. standard	
RWC-5/8	thru 5 – on 8	thru 5 – on 8	60
RWC-8/12	thru 8 – on 10	thru 8 – on 12	60
RWC-12/20	thru 10 – on 20	thru 12 – on 20	60
RWC-20/30	thru 20 – on 28	thru 20 – on 30	60
RWC-30/40	thru 28 – on 35	thru 30 – on 40	60
RWC-30	thru 28	thru 30	60
RWC-40	thru 35	thru 40	60
RWC-40/120	thru 35 – on 112	thru 40 – on 120	60

Note 1. The tolerances on the weight percent of tungsten-carbide granules in the welding rod shall be plus 4.0 percent and minus 1.5 percent of the amount specified.

Note 2. The mesh size of the tungsten-carbide granules may vary from that specified above provided that no more than 5.0 percent maximum by weight of the granules is retained on the thru or "pass" sieve, and that no more than 20.0 percent maximum by weight passes the on or "hold" sieve.

TABLE 6
MESH SIZE AND WEIGHT PERCENT OF TUNGSTEN-CARBIDE GRANULES
CONTAINED IN TUNGSTEN-CARBIDE ELECTRODES

AWS Classification	Mesh size of tungsten-carbide granules		Weight percent of tungsten- carbide granules
	Tyler standard	U.S. standard	
EW-12/30	thru 10-on 28	thru 12-on 20	60
EW-20/30	thru 20-on 28	thru 20-on 30	
EW-30/40	thru 28-on 35	thru 30-on 40	
EW-40	thru 35	thru 40	
EW-40/120	thru 35-on 115	thru 40-on 120	

Note 1. The tolerances on the weight percent of tungsten-carbide granules in the electrode shall be plus 4.0 percent and minus 1.5 percent of the amount specified.

Note 2. The mesh size of the tungsten-carbide granules may vary from that specified above, provided that no more than 5.0 percent maximum by weight of the granules is retained on the thru or "pass" sieve, and that no more than 20.0 percent maximum by weight passes the on or "hold" sieve.

recommended by the manufacturer. Slag, if present, shall be readily removed with hand tools.

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

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 filler metal 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. Composite welding rods and bare electrodes shall be of uniform quality and free from segregation, oxides, slivers, depressions, scratches (excluding seams), scale, 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 composite core wire electrodes, provided

that in any case no "fingernailing"¹ shall occur during welding.

The concentricity shall 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 injurious blistering or flaking of the covering within the ranges of current recommended by the manufacturer.

2.3.4 The composite core and covering shall be free of defects that would interfere with uniform performance of the electrodes.

2.4 Exposed Core. Covered electrodes for manual welding shall be bare or free from coating for a distance of about $\frac{3}{4}$ in. (20 mm), but not more than $1\frac{1}{4}$ in. (32 mm), for making contact with the holder. The arc end of covered electrodes shall be sufficiently bare 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 $\frac{1}{8}$ in. (3.2 mm) or the diameter of the composite core, whichever is smaller.

¹ This term indicates that the electrode covering, at the 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

2.5.1 Standard sizes and lengths of welding rods are shown in Table 7. Standard sizes and lengths of electrodes are shown in Table 8.

2.5.2 Standard sieve analyses for the tungsten-carbide granules contained in the tubular tungsten-carbide welding rods and electrodes shall be as shown in Tables 5 and 6. Sieve analyses shall be made in accordance with ASTM B214, Sieve Analyses of Granular Metal Powders.² Special Sieve analyses, other than the standard ones, shall be as agreed upon by the supplier and the purchaser.

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, 50, 60, or 100 lb (2.3, 4.5, 11, 23, 27, or 45 kg) net weight.³

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 numbers

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 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.

²ASTM Standards can be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

³Other standard weights are available upon agreement between purchaser and supplier.

TABLE 7
STANDARD SIZES AND LENGTHS OF COMPOSITE WELDING RODS

AWS Classification	Diameter, ^a		Length, ^b	
	in.	mm	in.	mm
RFe5-A	1/8	3.2	14	350
RFe5-B	5/32	4.0	18	450
	3/16	4.8		
RFeCr-A1	1/4	6.4	28	700
	5/16	8.0		
	3/8	9.5		
RWC-5/8	3/8	9.5	14	350
			18	450
			28	700
RWC-8/12	1/4	6.4	14	350
			18	450
			28	700
RWC-12/20	3/16 ^c	4.8 ^c	14	350
	1/4	6.4	18	450
	3/8	9.5	28	700
RWC-20/30	5/32	4.0	14	350
	3/16	4.8		
	1/4	6.4		
	3/8	9.5		
RWC-30/40	1/8	3.2	18	450
	5/32	4.0		
	3/16 ^c	4.8 ^c		
	1/4	6.4		
RWC-30	3/8	9.5	28	700
	1/8	3.2	14	350
			18	450
RWC-40	3/16 ^c	4.8 ^c	28	700
	1/8	3.2	14	350
			18	450
RWC-40/120	3/16	4.8	28	700
	1/8	3.2	14	350
	5/32	4.0		
	3/16 ^c	4.8 ^c		
	1/4	6.4		

a. Diameter of composite welding rods, measured at approximately 90 deg from the seam, shall not vary more than ± 20 percent from the nominal.

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. The diameter of the 3/16 in. (4.8 mm) size may vary + 30 percent from the nominal size.

TABLE 8
STANDARD SIZES AND LENGTHS OF COMPOSITE
ELECTRODES

AWS Classification	Diameter, ^a		Length,	
	in.	mm	in.	mm
EFe5-A	1/8	3.2	14	350
EFe5-B	5/32	4.0	18	450
EFe5-C	3/16 ^c	4.8 ^c		
EFeMn-A	1/4	6.4	14	350
EFeMn-B	5/16	8.0		
EFeCr-A1	3/8	9.5		
EWC-12/30	1/4	6.4	14	350
EWC-20/30	3/16	4.8 ^c	14	350
EWC-30/40	1/8	3.2	14	350
EWC-40	1/8	3.2	14	350
	3/16 ^c	4.8 ^c		
EWC-40/120	1/8	3.2	14	350
	5/32	4.0		
	3/16 ^c	4.8 ^c		
	1/4	6.4		

a. Diameter of composite electrodes, measured approximately 90 deg from the seam, shall not vary more than ± 20 percent from the nominal.

b. Lengths of composite electrodes shall not vary more than $\pm 1/4$ in. (10 mm) from the nominal.

c. The diameter of the 3/16 in. (4.8 mm) size may vary +30 percent from the nominal size.

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 or 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 Welding 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

2.7.4 For 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. HEAT RAYS (INFRARED RADIATION from flame or hot metal) can injure eyes.

- Read and understand the manufacturer's instructions and your employer's safety practices.
- Keep your head out of the fumes.
- Use enough ventilation or 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 Welding 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, and within 2-1/2 in. (65 mm) of that grip end.

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

2.8.3 The ink used for imprinting shall provide sufficient contrast with the electrode covering in order that the numbers and letters of the electrode classification shall be readable before and after normal welding applications.

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

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 Material 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 composite welding rods and electrodes:

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

3.4.1.2 For covered electrodes and RFeX-X rods, 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).

3.4.1.3 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. Postheat 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.

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

3.4.2 Chemical analysis of carbon steel tubes for tungsten-carbide welding rods and electrodes:

3.4.2.1 The chemical composition of the carbon steel tube and the tungsten-carbide granules shall be determined separately. Prior to beginning analysis of the carbon steel tube, determine the percent by weight of the tungsten-carbide in the tube using the following procedure:

(1) Record the weight of one or more tungsten-carbide welding rods or electrodes after removing any coatings present.

(2) Remove the tungsten-carbide from the tube and clean it by washing with water and treating with 1-1 hydrochloric acid, as required, to remove any flux, powdered iron, graphite, etc. Heating of the acid may be required. A hot or cold 1-1 hydrochloric acid will not attack cast tungsten-carbide an appreciable amount in less than an hour.

(3) Weigh the cleaned and dried tungsten-carbide granules and calculate the percent tungsten-carbide from the initial weight of the tube.

3.4.2.2 An adequate sample of the carbon steel tube, sufficient for retest if necessary, shall be obtained to make the prescribed chemical analysis.

3.4.2.3 Chemical analysis may be made by any suitable method agreed upon by the supplier and the purchaser. In case of dispute, the procedure outlined in the latest edition of ASTM E350, Standard Methods for Chemical Analysis of Carbon Steel, Low Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron, shall be the reference method.

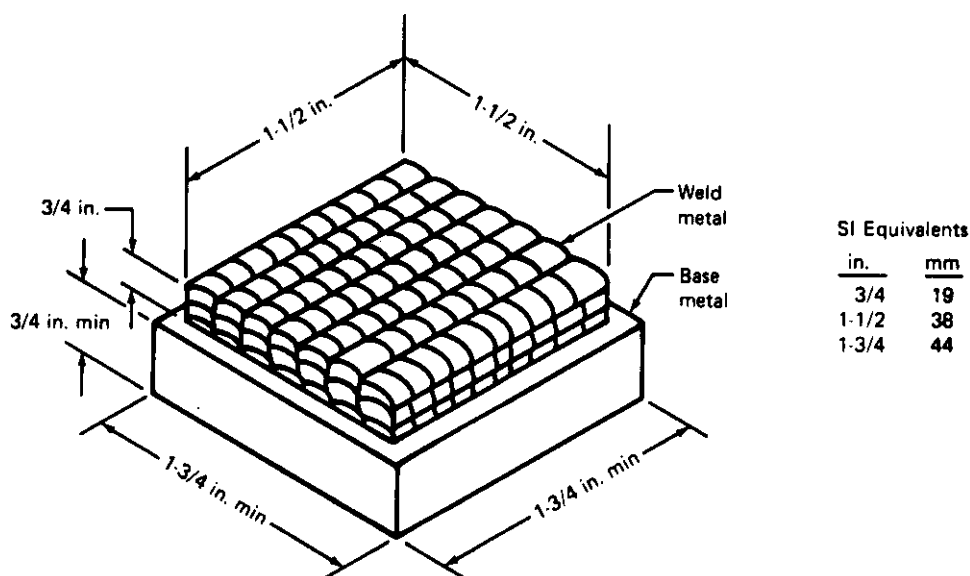


FIG. 1 CHEMICAL ANALYSIS TEST PAD

3.4.3 Chemical analysis of tungsten-carbide granules from tungsten-carbide welding rods and electrodes:

3.4.3.1 The sample of tungsten-carbide granules for chemical analysis should be thoroughly cleaned. If the washing and treating with 1-1 hydrochloric acid has not cleaned the granules, a light etch may be required. Since the tungsten-carbide granules will dissolve in concentrated nitric acid containing hydrofluoric acid, the sample to be cleaned shall be covered with

nitric acid in a platinum or pyrex glass container and heated while hydrofluoric acid is added drop by drop until the particles are clean.

3.4.3.2 After the tungsten-carbide particles have been cleaned, the mesh size distribution shall be determined by the method cited in 2.5.2.

3.4.3.3 Chemical analysis of the cleaned tungsten-carbide granules may be made by any suitable method agreed upon by the supplier and the purchaser.

Appendix: Guide to AWS Classification of Composite 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 classified 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 the letter R indicates a welding rod.

A1.2.2 For the high-speed steels, austenitic manganese steels, and austenitic high chromium irons, the letters immediately after the E or R are the chemical symbols for the principal elements in the classification. Thus FeMn is an iron-manganese steel, and FeCr is an iron-chromium 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, etc., as in EFeMn-A. Further subdividing is done by using a 1, 2, etc., after the last letter.

A1.2.3 For the tungsten-carbide classifications, the WC immediately after the E or R indicates that the filler metal consists of a mild steel tube filled with granules of fused tungsten-carbide. The numbers following the WC indicate the mesh size limits for the tungsten-carbide granules. The number preceding the slash indicates the sieve size for the "pass" screen,

and that following the slash indicates the sieve size for the "hold" screen. Where only one sieve size is shown, this indicates the size of the screen through which the granules must pass.

A1.2.4 This specification classifies composite surfacing filler metals. Surfacing welding rods and electrodes made from wrought core wire are covered by AWS A5.13, Specification for Solid Surfacing Welding Rods and Electrodes. A description of available surfacing filler metals is contained in the Appendix to that specification.

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.

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.

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 (233 Brinell).

A2.4 Impact. The Fe5 filler metals as-deposited can withstand only 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 that of low carbon steel, but they are not considered high abrasion resistance alloys. Resistance to deformation at elevated temperatures up to 1100° F (595° 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 retain 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 to 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 is outlined as 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: 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 hr., air cool to room temperature; 1025° F (550° C), 2hr., 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 Steel 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.

For surfacing with EFeMn electrodes, most appropriate applications 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, like 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 perhaps 3 in. (76 mm) thick, and represents the approximate 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 (260 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.

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. Abrasion resistance to high- and low-stress abrasion is moderate against hard abrasives like quartz.

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

Dry Quartz Sand Erosion Factor: 0.41 to 0.56 (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 hr. at 1850° F (1010° C) is usually sufficient for this purpose. The weld deposit should be free of cracks if this is 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 overlays 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 were recommended.

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.

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

A3.14.4 Bare EFeMn electrodes are frequently 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 peening, 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./mm (5.1 mm/s) should be avoided. In any case, a weaving bead that has a cross-sectional area greater than 0.18 in² (116 mm²) (for example, 0.8 in. [20 mm] wide by 0.2 in. [5.1 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-Al and EFeCr-Al Austenitic High Chromium Iron Filler Metals

A4.1 Introduction and Applications. The RFeCr-Al welding rods and EFeCr-Al 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-Al 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 3x 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 its resistance to thermal shock and thermal fatigue.

A4.4 Impact. FeCr-Al 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-Al filler metals is comparatively low and is 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-Al 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 abrasion increases, their performance declines. As deposited, the resistance of FeCr-Al is only mediocre under high-stress grinding abrasion, and its use 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-Al filler metals are expected to have a yield strength (0.1 percent offset) of between 80,000 to 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-Al 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 spaced resinoid bond for off-hand high-speed work, and a slightly softer (P) vitrified bond for off-hand low-speed use.

A4.11 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-Al 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 200, 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.

A4.12 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.

A4.13 Welding Characteristics. In oxyfuel gas welding, flat position welding with a 3x 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-Al filler metals is similar to that used for other surfacing electrodes.

A5. Tungsten-Carbide Welding Rods and Electrodes

A5.1 Introduction and Applications

A5.1.1 These welding rods and electrodes are usually sold as steel tubes containing 60 percent carbide granules by weight (designated 60:40), but lower tungsten carbide percentages are available for certain applications. The carbide is a mixture of WC and W₂C tungsten-carbides that is produced by melting, solidifying, crushing, and sizing the carbide with screens. The size of the carbide granules has an important influence on weld deposit properties and is appropriately included by the various grades in the specification. The shape of the carbide granules is also important. Granules approaching cubes or spheres are desired.

A5.1.2 The requirements for tungsten-carbide granules given in the specification may be applied to tungsten-carbide purchased in bulk. Some users apply the loose granules by welding, and others prefer to make their own welding rods by filling tubes.

A5.1.3 Though crushed sintered tungsten-carbide bonded with cobalt or other constituents has been used in similar welding rods, it is not covered by the specification because it is usually considered inferior for the purpose. Cobalt may also be melted with tungsten-carbide and the product cast into small inserts or slugs. These are welded into place to provide localized abrasion resistance, but such carbide inserts for this useful technique are not covered by this specification. A quick field inspection for tungsten-carbide particles to determine if the carbide is alloyed with other constituents is to empty a tube and pass a small magnet over the carbide granules. Tungsten-carbide that contains an appreciable amount of iron, cobalt, or nickel will be attracted to the magnet. An excess of magnetic material will indicate the need for a chemical analysis check.

A5.1.4 The tungsten-carbide welding rods and electrodes are used to make overlays whose abrasion resistance currently surpasses that of any other available hardfacing material. They are typically used to armor the cutting teeth and gage holding surfaces of rock drill bits; the wearing surfaces of mining, quarrying, digging, and earth moving equipment; and a multitude of parts where the roughness of the weld deposit (as

it wears) is not a handicap, but where the high abrasion resistance is needed.

A5.1.5 The deposits do not consist of hard carbides in a soft steel matrix as might be supposed. When the sheath of carbon steel melts during welding, it dissolves enough of both tungsten and carbon to form a hard matrix that is a competent support for the hard granules that it anchors in place. This matrix has characteristics that range from those of air-hardening tungsten steel to cast-iron structures containing considerable secondary tungsten-iron carbides.

A5.1.6 Surface roughness of abraded deposits depends upon initial granule size and welding procedures. Abrasion resistance depends largely upon the volume of undissolved carbides and is generally better for oxyfuel gas welds.

A5.2 Hardness. The hardness of good quality cast tungsten-carbide is:

Vickers pyramid number	About 2400
Rockwell "A"	9 to 95
Knoop K ₁₀₀	1500
Scratch (Mohs scale about the same as silicon carbide)	9.4

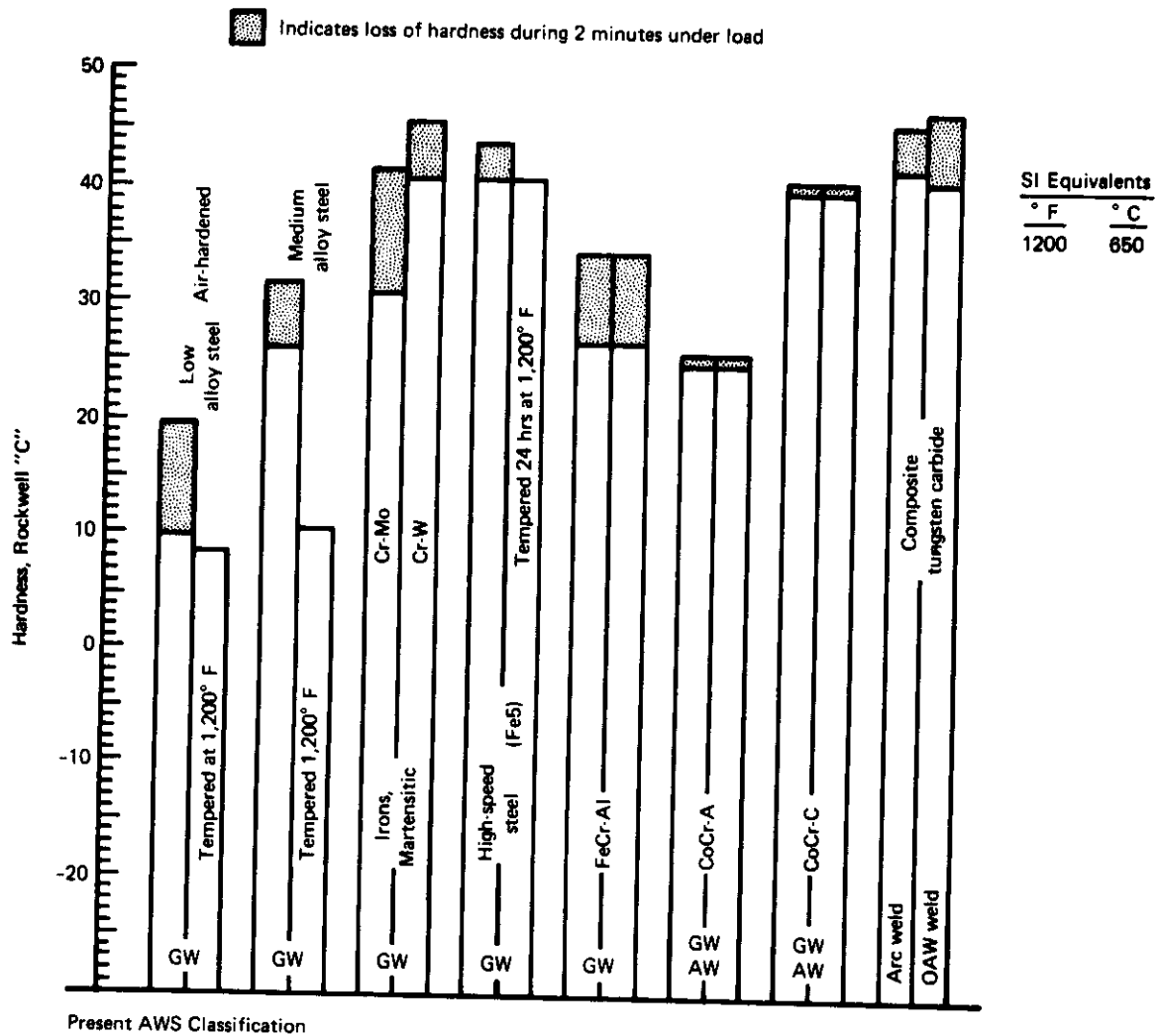
The microhardness of the 6.1 percent C tungsten-carbide crystals WC in the cast carbide is Knoop (K₁₀₀) 1880. The hardness of the bonding metal will vary from RC30 for a deposit of 10 mesh particles (40-60) in a carbon steel tube, to RC60 for 100 mesh particles deposited with a carburizing flame from a carbon steel tube.

A5.3 Hot Hardness. Tungsten confers hot hardness, and the matrix of these composite weld deposits retains its hardness up to 1000° F (540° C), considerably better than ordinary hardened steels (see Fig. A1).

The higher temperatures of arc welding permit more tungsten-carbide solution during arc welding; and such welds, therefore, exhibit better hot hardness than oxyfuel gas welds. The pattern of hardness versus temperature is shown in Fig. A2.

A5.4 Impact. Both the carbide granules and the weld deposits are relatively brittle and vulnerable to sudden tensile stresses. However, they have high compressive strength and can withstand light impacts that do not produce compression stress above the yield strength, which may reach 200 ksi (1379 MPa) for the matrix. Impact blows faster than 50 ft/in (15.2 ft/in) should be avoided, and the design should avoid tensile stress.

A5.5 Oxidation Resistance. Tungsten-carbide has a low resistance to oxidation. Exposed granules of tung-



Note 1: GW = oxyacetylene weld

AW = shielded metal arc weld

Note 2: Values below 20 HRC included for illustrative purposes.

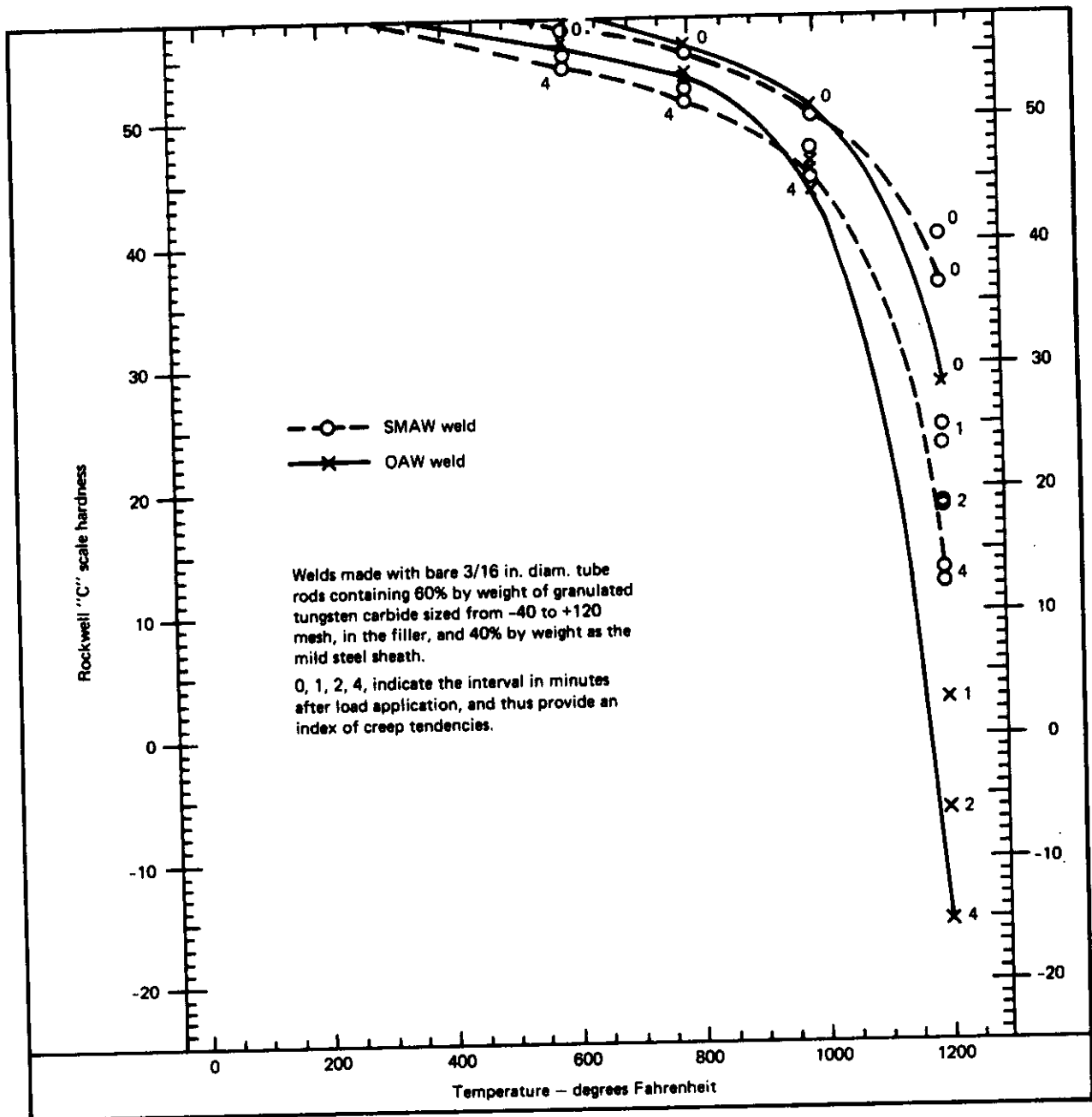
FIG. A1 APPARENT HOT HARDNESS OF HARD SURFACING ALLOYS AT 1000°F (540°C)

sten-carbide will oxidize to form voluminous yellow tungstic oxide at temperatures above 1000° F (540° C).

A5.6 Corrosion Resistance. Though the granules may be resistant to many media, the matrix of the standardized tube welding rod deposits is practically as vulnerable to rusting and corrosion as ordinary steel. The materials covered by this specification should not be selected if corrosion resistance is required. If their great abrasion resistance impels the risk of application

in a corrosive environment, a preliminary service test should be made to establish practicability.

A5.7 Abrasion Resistance. Composite weld deposits made from these materials are appropriate for resisting low-stress scratching or high-stress grinding abrasion. In either type, the matrix tends to abrade more rapidly, permitting the carbides to stand in relief. As long as matrix erosion does not undermine the carbide granules, this is of little concern unless the resultant roughness



is objectionable. This selective action may cause more rapid weight loss in the early stage of a given use, but the wear rate then tends to decrease and stabilize. These stages may not be apparent in a field application, but they can be demonstrated in a laboratory test. This same test shows that arc welds have behavior related to granule size and welding current, while oxyfuel gas welds are usually higher in abrasion resistance and are more consistent.

The effect of these variables is shown in the high-stress grinding results in Fig. A3.

The extreme is attained if high current arc welding is used with electrodes containing very fine granules, whereby all of the tungsten-carbide may be dissolved to form tungsten steel, and the resulting behavior is that of an air-hardening steel only.

A5.8 Metal-to-Metal Wear. Tungsten-carbide deposits are not applicable for conditions of metal-to-metal wear because the wear is chiefly in the matrix, and the carbide left in relief produces a rough surface.

A5.9 Mechanical Properties in Compression. Deposits can be made by using high-strength bonding alloys to give a deposit with high compressive strength; but the usual carbon steel binders give deposits that have a compressive strength about the same as a high carbon steel deposit.

A5.10 Machinability. Tungsten-carbide deposits are considered commercially unmachinable. The deposits are finished when required using silicon-carbide or diamond grinding wheels.

A5.11 Identification. Tungsten-carbide particles have the following properties that may be used for identification.

- (1) Nonmagnetic
- (2) High density (over 16 specific gravity)
- (3) Insoluble in most acids
- (4) Readily forms a yellow oxide when heated red hot in air
- (5) High melting point; practically impossible to melt in oxyacetylene flame
- (6) Very hard and quite brittle

A5.12 Heat Treatment. The properties of tungsten-carbide are not changed by heat treatment. However, the metal holding the particles of tungsten carbide in the surfacing layer may or may not respond to heat treatment. The response of the bonding metal depends upon the original analysis of the binder and upon the carbon and tungsten pickup during application.

Carburizing and hardening may be used to harden the bonding metal.

A5.13 Welding Characteristics

A5.13.1 The bare tubular welding rods used for oxyacetylene welding are made from carbon steel, and the techniques for oxyfuel gas welding carbon steel should be used. Oxidation of the base metal that will interfere with wetting and oxidation of the molten metal that can lead to porosity should be avoided. With adequate skill, excellent oxyacetylene deposits can be obtained. However, mechanical behavior of the melt will differ from that of carbon steel because of the included granules. Some solution of the tungsten-carbide granules during welding is expected, but the undissolved portion is important to the performance of the hard overlay. Granule distribution is influenced by manipulation of the welding torch and of the welding rod. The welder should strive for a uniform final distribution of the granules.

A5.13.2 Electric arc deposition from covered electrodes will involve little difficulty for a skilled welder, but the tungsten-carbide granules must be considered. Arc deposition temperatures are higher than those for oxyfuel gas welding, and there is a greater tendency to dissolve the tungsten-carbide granules. (The influence of this on performance is described under A5.7, Abrasion Resistance.) It is desirable to use the lowest feasible arc power in order to minimize granule solution. Granule distribution is controlled almost entirely by manipulation of the electrode. If the result is segregation of the granules in streaks, the resultant differential wear pattern in service may be undesirable. With arc deposition, the welder should also try to attain uniform granule deposition, which is more difficult than with oxyfuel gas welding.

A5.13.3 The molten steel matrix is expected to readily wet the tungsten-carbide granules and form a strong bond. If this does not occur, the presence of dirt (from the base metal) or excessive oxidation should be suspected.

A5.13.4 The following conditions have been found suitable for arc welding:

Electrode diameter,		Current,	
in.	(mm)	DCRP	AC
1/8	(3.2)	100 to 125	110 to 135
3/16	(4.8)	125 to 150	135 to 160

A5.13.5 The usual overlay is about $\frac{1}{8}$ in. (3.2 mm) thick, though skilled welders can make thinner deposits, and thicker ones are possible by using several layers. In the latter case, tension cracks in the overlay are likely.

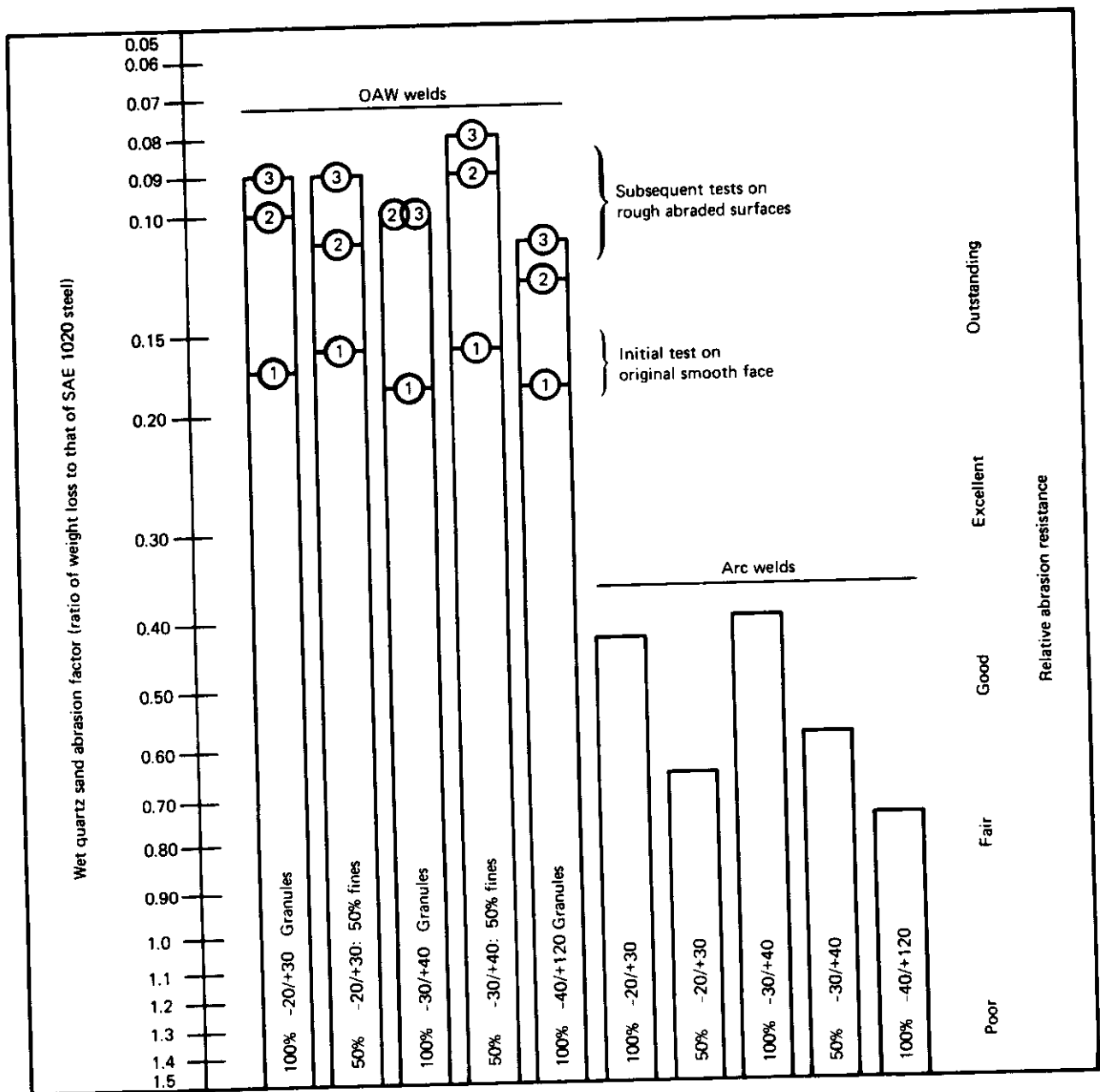


FIG. A3 ABRASION RESISTANCE OF COMPOSITE TUNGSTEN-CARBIDE WELD DEPOSITS AS AFFECTED BY GRANULE SIZE AND WELDING PROCESS

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