

Recommended Practices for Surfacing and Reconditioning of Industrial Mill Rolls



American Welding Society



Key Words—Surfacing, hardfacing, mill rolls,
reconditioning

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Recommended Practices for Surfacing and Reconditioning of Industrial Mill Rolls

1st Edition

Prepared by the
American Welding Society (AWS) D14 Committee on Machinery and Equipment

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

This standard provides guidance, based upon experience, for preparing, building up and overlaying by welding, postweld heat treating, finish machining, inspecting, and record-keeping of new and reconditioned industrial mill rolls.



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Foreword

This foreword is not a part of AWS D14.7/D14.7M:2005, *Recommended Practices for Surfacing and Reconditioning of Industrial Mill Rolls*, but is included for informational purposes only.

With the increasing use of welding to repair and build up industrial rolls, the AWS D14 Committee on Machinery and Equipment saw a need to provide guidance in this application of welding so that standard procedures and recommendations could be established. With the critical applications in which these rolls are often used, it is important to have guidelines for properly repairing or reconditioning them.

While welding (mainly submerged arc welding) has been used for repairs and recondition of industrial mill rolls for a number of years prior to the issuance of this standard, it was felt that an industry standard should be developed to provide guidance in the proper application of this process. Work on this first edition began in the mid-1990s and has culminated in the publication of this standard in 2005.

Your comments for improving the *Recommended Practices for Surfacing and Reconditioning of Industrial Mill Rolls* are welcome. Submit comments to the Managing Director, Technical Services Division, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126; telephone (305) 443-9353; fax (305) 443-5951; e-mail info@aws.org; or via the AWS web site <<http://www.aws.org>>.

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Recommended Practices for Surfacing and Reconditioning of Industrial Mill Rolls

1. Scope

An industrial mill roll can be defined as any roll or cylindrical body that transports, processes, guides or performs a function in creating a product in the heavy metals, paper, plastic, or lumber industries. These rolls can come in many shapes and sizes (as shown in Figure 1), and include, but are not limited to, table rolls, guide rolls, caster rolls, pinch rolls, leveler rolls, straightener rolls, bridle rolls, and blocker rolls.

This standard provides guidance, based upon experience, for preparing, building up and overlaying by welding, postweld heat treating (PWHT), finish machining, inspecting, and record-keeping of new and reconditioned industrial mill rolls. While mainly used in the primary metal-working industry, industrial mill rolls are also used in other applications. Because common practice predominately employs submerged arc welding (SAW), this document emphasizes SAW. However many of the principles are applicable, with suitable modifications, to gas metal arc welding (GMAW), flux cored arc welding (FCAW), and electroslag cladding.

This standard makes use of both U.S. Customary Units and the International System of Units (SI). The measurements may not be exact equivalents; therefore each system should be used independently of the other without combining in any way. The designation D14.7 uses U.S. Customary Units. The designation D14.7M uses SI Units. The latter are shown in appropriate columns in tables and figures or within brackets []. Detailed dimensions on figures are in inches. A separate tabular form that relates the U.S. Customary Units with SI Units may be used in tables and figures.

Safety and health issues and concerns are beyond the scope of this standard, and therefore are not fully addressed herein. Safety and health information is available from other sources, including, but not limited to, ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, and applicable federal and state regulations.

Welding symbols shown on drawings should be compatible with those shown in AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*. Special conditions or deviations should be fully explained by added notes, details, or definitions.

2. Normative References

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

2.1 AWS References¹

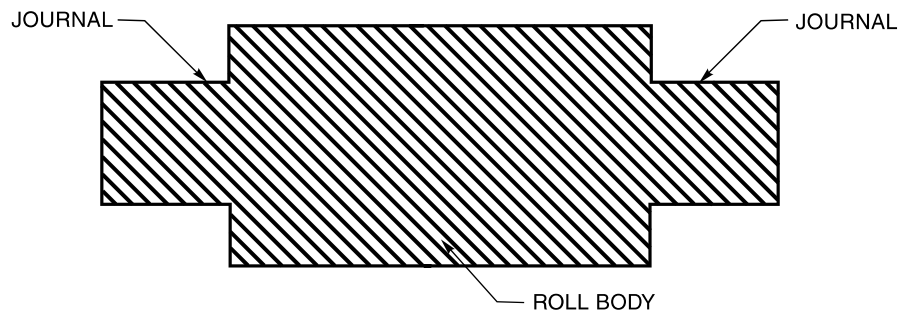
1. AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*
2. AWS A3.0, *Standard Welding Terms and Definitions*
3. AWS A5.17, *Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding*
4. AWS A5.23, *Specification for Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*
5. AWS B4.0, *Standard Methods for Mechanical Testing of Welds*

2.2 ASTM References²

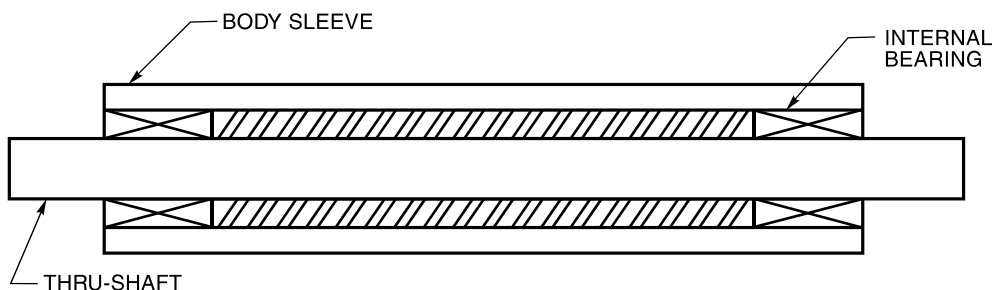
1. ASTM A 388, *Standard Practice for Ultrasonic Examination of Heavy Steel Forgings*

¹ AWS standards are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

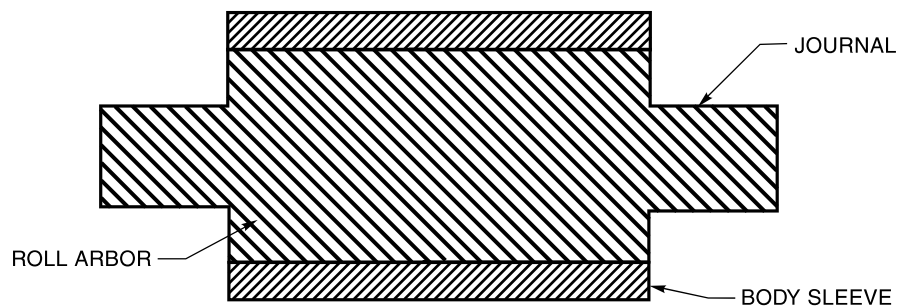
² ASTM standards are published by the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.



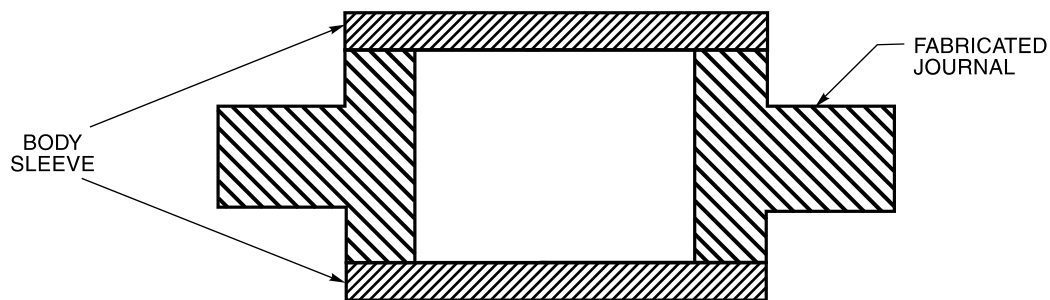
(A) SOLID ROLL WITH INTEGRAL JOURNALS



(B) CYLINDER ROLL WITH INTERNAL BEARING AND THRU-SHAFT



(C) SOLID ROLL WITH SLEEVED BODY AND INTEGRAL JOURNALS



(D) CYLINDER ROLL WITH FABRICATED JOURNALS

Figure 1—Typical Roll Types and Nomenclature

2. ASTM E 165, *Standard Test Method for Liquid Penetrant Examination*

3. ASTM E 709, *Practice for Magnetic Particle Examination*

4. ASTM G 48, *Standard Test Methods for Pitting and Crevice Corrosion Control Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution*

3. Definitions

Welding terms used in this standard are in accordance with AWS A3.0, *Standard Welding Terms and Definitions*, which should be referred to for a complete list of terms used in welding. The terms that follow are defined specifically for the purpose of this recommended practice and may be a variation of the term as defined in AWS A3.0.

buildup, industrial rolls. A process of either filling in a void or enlarging an undersized component roll. This process can be performed on a roll body or journal. The weld buildup used in this process typically matches or exceeds the mechanical properties of the base metal.

buttering. The process of creating an intermediate weld layer that allows an overlay or buildup material to be used without creating a crack sensitive alloy. A butter layer provides good weldability between a base metal and an overlay. The butter layer(s) used in this process typically dilutes and mixes with the base material to create a weldable alloy.

dilution. The change in chemical composition of the weld metal caused by the admixture of the base metal or previous weld metal in the weld bead. It is

expressed as the percentage of base metal or previous weld metal in the weld bead.

journal. The part of the roll which provides support for the roll and can contain components like bearings, seals, and chocks (see Figure 1).

overlay, industrial rolls. The process of creating the final composition and mechanical properties of the surface of the roll. The welding overlay is intended to enhance or restore the service performance of the roll (see Figure 2).

roll body. The part of the roll area which is in contact with the product being supported, transported, or shaped (see Figure 1).

spalling. The breaking of weld metal particles away from the base metal or previous hardfacing layers.

4. Base Materials for Rolls, Arbors, Sleeves, and Fabricated Journals

4.1 Overview. The selection of materials for rolls is generally based on the conditions the roll will see in service and whether the roll is to be reconditioned or overlaid at some point in its life. The material procurement specification for a new roll should include material grade, method of manufacture (casting, forging, rolling, etc.), heat treatment and hardness. For a reconditioned roll, efforts should be made to establish the composition and hardness for both the base metal and the surfaces to be reconditioned. Mechanical properties, thermal processing, and weldability of the material are important considerations generally incorporated into the specification for the roll.

4.2 Chemical Composition. Different base materials require different welding techniques and precautions to prevent cracking. Requirements for preheat, postweld

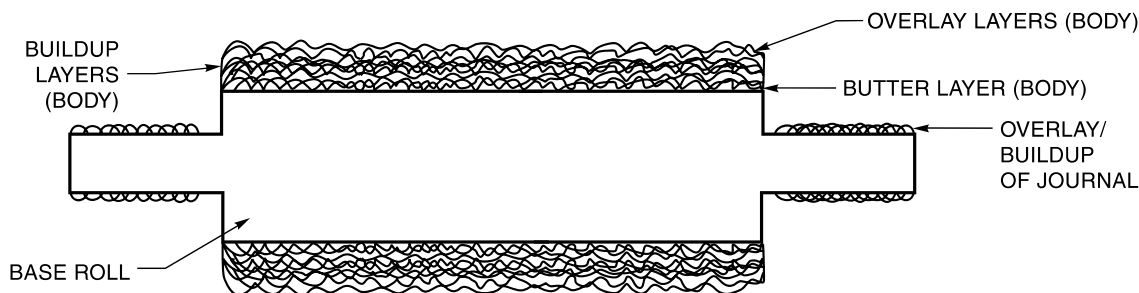


Figure 2—View of Typical Roll Cross Section

heat treatment, and interpass temperature all vary with carbon equivalent (CE_{IIW}). Therefore, it is essential that the compositions of base materials be known before welding. Chemical analysis is recommended to provide information regarding the general weldability of the base metal, the presence of elements detrimental to welding (i.e., high P, high S, or high V), and the sensitivity to stress relief cracking. Table 1 shows the chemical composition of commonly used forged roll materials.

4.3 Weldability. AWS A3.0 defines weldability as “the capacity of the material to be welded under the imposed fabrication conditions into a specific, suitably designed structure and to perform satisfactorily in the intended service.” Weldability is also the ability to weld a material without introducing any cracks or other defects and to achieve the desired properties for the intended application. Over the years, attempts have been made to provide single numbers to characterize the weldability of steels to cover heat-affected zone (HAZ) hardenability and HAZ hydrogen cracking tendency. The most useful formula for hardenability was simplified by a subcommittee of the International Institute of Welding (IIW) into the following “carbon equivalent” formula (Equation 1):

Equation 1:

$$CE_{IIW} = \%C + \%Mn/6 + \% (Cr + Mo + V)/5 + \% (Ni + Cu)/15$$

Note: Generally, steels with CE_{IIW} values above 0.5 are more difficult to weld.

Table 2 shows the CE_{IIW} of commonly used forged roll materials and the suggested minimum preheat temperatures. Generally, the higher the carbon equivalent, the higher the required preheat temperature.

4.4 Mechanical Properties. The two most important mechanical properties for the roll prior to overlaying are yield strength and toughness. The yield strength, at room temperature or at the elevated temperatures the roll might see in service, should be high enough to support the load and resist permanent bending. The toughness of the roll, as measured by the Charpy V-notch impact test, is an indication of the resistance to catastrophic failure from small defects or surface cracks that might initiate and propagate during service. The tests used to measure these properties are generally performed in accordance with appropriate ASTM standard procedures.

Occasionally rolls are procured to hardness requirements only. The approximate yield strength and tensile strength properties of the roll can be estimated from the Brinell hardness, using the following general rules of thumb:

1. Tensile Strength (ksi) is approximately (Brinell Hardness–10)/2

2. Yield Strength (ksi) of a quenched and tempered low alloy steel roll is typically 75% to 80% of the tensile strength.

Table 1 shows the mechanical properties of commonly used forged roll materials. Other materials not listed in the table may be used. Technical information for these materials can usually be obtained from the roll supplier.

Table 1
Typical Chemical Composition and Mechanical Properties of Typical Forged Roll Materials^a

Grade	C	Mn	Si	Ni	Cr	Mo	V	Yield Strength		CVN Notch Toughness ^b	
								ksi	MPa	ft-lb	J
4130	0.30	0.50	0.22	0.20	0.90	0.20	0.05	75	515	60	81
4140	0.40	0.85	0.22	0.20	0.90	0.20	0.05	90	620	65	88
4340	0.40	0.80	0.30	1.80	0.80	0.25	0.05	130	895	20	27
8620	0.20	0.80	0.22	0.50	0.50	0.17	—	45	310	90	136
SCM822M	0.23	0.80	0.24	0.65	1.10	0.40	0.07	83	570	160	217
13CrMo44	0.13	0.55	0.22	—	0.95	0.55	—	50	345	50	68
16CrMo44	0.17	0.65	0.22	0.20	1.00	0.42	0.05	70	485	200	271
FXLC130	0.19	1.00	0.30	1.30	1.15	0.39	—	115	795	20	27
Astralloy V	0.23	0.90	0.30	3.50	1.40	0.30	—	150	1035	20	27
21CrMoV511	0.22	0.40	0.35	0.40	1.30	1.03	0.28	100	690	100	136

^a Select data extracted from: Handerhan, K., The Importance of Fracture Mechanics in the Design of Forged Continuous Caster Rolls, Table IV, *Proceedings from the 1989 Mechanical Working and Steel Processing Conference*.

^b Test Temperature: 70°F [21°C]

Source: Data provided courtesy of the Elwood City Forge Company.

Table 2
Carbon Equivalent and Associated Preheat
Temperatures of Typical Forged Materials

Grade	CE _{IW}	Minimum Preheat Temperature, °F [°C]
4130	0.63	350 [180]
4140	0.79	450 [230]
4340	0.87	500 [260]
8620	0.50	300 [150]
SCM822M	0.72	400 [205]
13CrMo44	0.52	250 [120]
16CrMo44	0.59	325 [165]
FXLC130	0.75	425 [220]
Astralloy	0.95	550 [290]
21CrMoV511	0.83	425 [220]

Source: Data provided courtesy of The Stoodly Company and derived from the graphs in Figure 3.

4.5 Thermal Processing. The heat treatment given a roll is important in that it not only establishes the required mechanical properties, but also, to some extent, controls the performance of the roll during service. Ideally, the selection of the base material and its thermal processing should be such that the roll is resistant to degradation of its mechanical properties during operation at elevated temperatures.

5. Surface Preparation

5.1 General

5.1.1 Proper preparation of the surface of a roll for weld overlay is critical to the success of the welding of new rolls and reconditioning of used rolls. The roll should be cleaned, inspected, and cleared of all linear indications (cracks) and other defects that could cause potential failures. A qualified inspector (qualified to SNT TC-1A, QC1, or other equivalent programs) should conduct the inspection of the prepared surface. The surfaces of the roll should be premachined to provide allowance for the specified deposit thickness and proper welding techniques. Many cleaning processes can expose employees and the environment to potentially harmful fumes and particulates. Surface preparation practices should be reviewed for compliance to applicable safety and environmental regulatory standards, and material safety data sheets (MSDSs) should be consulted.

5.1.2 To determine the areas of the roll that require welding, the existing condition of the roll should be compared to the drawing/specifications as agreed upon by the

end user and Manufacturer. Consideration should be given to areas adjacent to the weld, since the welding and heating operations may alter these surfaces to an out-of-tolerance condition. Similarly, other areas of the roll, such as long, small diameter journals, may distort during welding which should be considered when developing a scope of the work.

5.2 Stress Relieving Prior to Processing

5.2.1 Overview. It is common practice in many shops to perform a stress relief heat treatment on used rolls before beginning the repair process. The stress relief treatment should be conducted at a temperature that does not alter the mechanical properties of the roll's base material. This thermal treatment serves to reduce stresses from both processing and service conditions. It can also reduce the hardness of the roll surface to facilitate easier machining and undercutting for repair.

5.2.2 Parameters. The stress relief temperature is based upon the chemical composition of the base material but is typically between 900°F [480°C] and 1150°F [620°C]. Heating and cooling rates are a function of the mass, configuration, and composition of the roll's base material. These can range from a slow rate of 15°F [8°C] per hour to a fast rate of 200°F [110°C] per hour. There is significant risk that heating too quickly or causing temperature nonuniformity can cause the roll's base material to catastrophically fail. The soak time at maximum temperature is usually based on 0.5 hour per inch [25 mm] of roll material thickness. These types of treatments are usually performed in a furnace that has temperature uniformity within a range of 50°F [30°C] during the heating, soak and cooling steps of the treatment. The capability of the furnace should be known before processing rolls.

5.2.3 Precautions. It might be necessary to protect areas of the roll such as journals, keyways, etc., from scaling during thermal treatment. A suitable high-temperature protective coating may be used to protect areas not intended for subsequent repair.

5.3 Surface Condition. The roll should be free of grease, oil, paint, scale, rust and other contaminants prior to inspection and welding. The condition of the roll surface should be compatible with the inspection method used.

5.4 Methods of Cleaning

5.4.1 Degreasing. The surface of the roll may be cleaned of grease and other hydrocarbon products by using a suitable degreasing solvent. Additional cleaning as required should be performed to provide a clean surface.

5.4.2 Baking. The roll can be cleaned in a furnace by heating to a temperature sufficient to burn off greases and paints. Temperatures during cleaning should remain below the typical base metal tempering range or the properties of the roll could be altered.

5.4.3 Machining. Machining is an efficient method of removing rust, scale, and dirt from the roll surface in preparation for inspection and welding. Additional degreasing and cleaning may be necessary to remove oil or coolant residue from the surface and to clean the areas of the roll which were not premachined.

5.4.4 Grinding, Blasting, or Brushing. Hand grinding, sand blasting or wire brushing can be used to remove burnt or loose residue from the roll surface. When wire brushing, an appropriate type of wire brush suitable with the roll material should be used. Hand grinding can be beneficial for localized cleaning.

5.5 Inspection after Cleaning. Inspection of the roll is recommended after cleaning to develop a scope of the work for repairs and to ensure that the roll is properly prepared for welding. Inspections should be performed and documented as called for by quality requirements, internal or external. A qualified inspector (qualified to SNT TC-1A, QC1, or other equivalent programs) should conduct the inspection of the prepared surface. A typical form for recording incoming inspection results is shown in Figure C.1 of Annex C.

5.5.1 Visual Inspection. The roll should be inspected for its general condition and obvious damage such as open cracks, spalls, and gouges. The heat identification number, which can be used to track the data on roll life and repair history of the roll, should be recorded. The identification numbers should be permanent markings and should be enhanced, if necessary.

5.5.2 Dimensional Inspection. The roll should be identified and inspected to determine out-of-tolerance conditions which would affect the performance of the roll in service. Dimensional inspection should include the body, bearing journals, seal journals, and drive journals. Indicated runout of journals should be measured and the results considered when establishing the Scope of Work.

5.5.3 Nondestructive Examination. 100% nondestructive examination of all roll surfaces is recommended. The roll should be inspected by one or more of the following nondestructive examination methods:

1. Liquid penetrant testing (PT) (see ASTM E 165),
2. Magnetic particle testing (MT) (see ASTM E 709),
3. Ultrasonic examination (UT) (see ASTM A 388),

4. Hardness testing (may be conducted to verify the nature of the surface prior to overlaying).

The acceptance criteria for the tests should be established between the end user and the Manufacturer.

5.6 Premachining for Welding

5.6.1 General. All of the areas for welding should be machined undersize to allow for the specified weld deposit thickness. Additional metal removal may be required if buttered and/or buildup layers are needed between the base metal and final weld deposit. When premachining the body of the rolls, the deposit thickness per pass should be considered so that final machining occurs within the last overlay layer and not the interface between two layers. Generally, areas requiring welding should be undercut by machining to a minimum of 0.040 in. [1 mm] per side.

5.6.2 Radius and Transition Areas. To prevent stress risers and slag inclusions, welding in sharp corners and square shoulders should be avoided. When premachining, transitions between different diameters should be sloped at a 15° angle or greater and the corner radius should be at least 1/4 in. [6 mm] or greater.

5.6.3 Defect Removal

5.6.3.1 Hand Grinding. Short, shallow defects that are small in number can be removed by hand grinding.

5.6.3.2 Machining. To remove numerous or deep discontinuities, the area should be machined using a circumferential method by plunge or side cutting as necessary with a lathe tool. After the discontinuity is removed, the sides of the groove should be beveled and the root should be radiused to permit complete fusion during the welding operation.

5.7 Inspection after Machining. Nondestructive examination should be performed using one or more of the methods listed in 5.5.3 to insure the complete removal of all unacceptable indications.

5.8 Documentation and Reporting. The documentation and reporting of all inspections should be completed as called for by quality requirements, internal and external. Refer to Figure C.1, Annex C for typical inspection documentation.

6. Welding Consumables

6.1 Overview. The vast majority of surfacing and reconditioning of industrial mill rolls is done by the submerged arc welding (SAW) process. SAW with strip electrodes is also used. A limited amount of work is done by flux cored arc welding (FCAW) and very minor

amounts are done by shielded metal arc (SMAW), gas tungsten arc (GTAW), or gas metal arc welding (GMAW). Limited thermal spray has also been applied.

This section briefly describes SAW consumables. Consumables for SAW include both flux and filler metal. (Additional details are found in Annex A.)

6.2 Flux Types. Fluxes may be produced by:

1. Melting the various oxides and fluorides together, then crushing to size (fused fluxes);
2. Mixing powdered oxides, fluorides, and possibly metallic ingredients with a water glass binder, pelletizing, and drying the particles that result (bonded fluxes);
3. Mechanically mixing the ingredients without a bonding agent.

From the point of view of metallurgical reactions during welding, a given flux may be described as acid, basic, or neutral depending on the various oxides and fluorides present in the flux (see A4 for details). Finally, a given flux may contain alloying elements to be added to the weld metal, or it may be unalloyed. Each flux characteristic has an influence on the welding results with a given welding electrode. Since the SAW fluxes commonly used for industrial mill rolls are not classified, it is usually beneficial to establish a relationship with the flux supplier to understand the flux characteristics and to obtain recommendations for flux storage and handling.

6.3 Wire Electrodes. Except for a few mild steel electrodes classified according to AWS A5.17, *Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding*, wire electrodes for industrial mill rolls are generally not classified by AWS. Solid mild steel electrodes are used for buttered layers and some buildup (often in the journal area of a roll). But most buildup and overlaying are done with tubular wire electrodes.

These tubular electrodes may be designed to deposit low-alloy steel (usually for buildup), tool steel (usually for cladding work rolls, guide rolls, and the like where corrosion resistance is not an issue), or stainless steel (where corrosion resistance is important, such as continuous caster rolls which operate in an environment including spray water as well as mold compounds). A given wire is generally designed for use with a particular flux to obtain optimum deposit composition and properties. Therefore, it is important to follow the wire manufacturer's recommendations for flux selection.

Wire electrodes for industrial mill roll welding are often supplied in drums containing as much as 750 lbs [340 kg] or more. The wire in the drums is laid loosely around a center, not tightly wound as might be on a reel or coil. The wire loops can shift if the drum is tilted or

rolled, which can result in tangling when the wire is subsequently fed out of the drum into the welding station. Drums should be maintained vertical at all times, to avoid tangling of the wire.

7. Properties of Weld Deposits

7.1 General. The choice of filler metals for journal repair, weld buildup, and overlay is primarily dictated by the composition of the roll material and the roll operating conditions. For rolling applications that are conducted at room or ambient temperature, the hardness and the compressive strength of the overlay may be the only consideration. For hot rolling applications, the elevated temperature hardness and strength as well as the ductility are important considerations. This situation could further be complicated if corrosive conditions accompany the rolling operation. Typically, buildup and overlay welding materials fall into the following four categories for industrial roll welding:

1. Mild steel for journal repair and roll body buttering,
2. Low alloy steel for journal repair and roll body buildup,
3. Stainless steel (12% Cr) overlay, and
4. Tool steel overlay.

As noted above, the mild steel deposition is typically aimed to produce an undiluted low-carbon deposit of no more than 1.6% Mn and 0.8% Si. However, dilution from the roll body material will generally produce a somewhat higher carbon low-alloy steel deposit. Such deposits are often adequate for journals. The other three general alloy categories are aimed at roll body performance and requirements based on the in-service conditions of the roll. The optimum deposit composition and heat treatment will change from application to application.

7.2 Properties and Composition of Buildup Materials

7.2.1 Properties. Except for chemical composition, all properties of buildup materials should be tested in the heat treated condition. The heat treatment of the test pad prepared for such tests should correspond to the heat treatment the roll will experience during surfacing and reconditioning.

7.2.2 Composition. Buildup materials are used to bring the journal and roll dimensions up to where sufficient overlay material can be deposited so that the machined surface of the overlay is at the required chemical composition and therefore has the required properties for the application. The composition of the buildup

alloys can range from very basic carbon steel to complex low-alloy steel and have been described in the earlier section. Some of the typical compositions used for industrial mill rolls are shown in Table 3. Generally, the simple carbon steels are used to build up dimensions on rolls, which do not require high compressive strengths in their applications.

Another situation where these low carbon steel compositions might be used is where the roll base material is of a high-carbon, high-hardenability material. The deposition of a low-carbon steel will minimize formation of brittle zones in the first layer of the butter material and therefore reduce the risk of cracking. Low-alloy steel deposits serve to provide high compressive strength and a tough matrix, which slows crack propagation.

For solid (hard) wire filler metals, composition usually refers to that of the solid (hard) wire itself as specified by AWS. With tubular wire, the composition refers to that of the weld deposit. The composition should be determined from a pad that is deposited using the welding parameters and flux and wire combination that represent the actual welding condition. Typically, four or more layers of weld metal are deposited to make the pad. The chemical analysis is conducted on the last layer. A typical method can be found in AWS A5.23, *Specification for Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*, for preparing a weld pad for chemical analysis.

7.2.3 Hardness. The hardness of the weld deposit reflects its tensile strength. It is primarily governed by the carbon content, although the manganese, silicon, and alloy (e.g., Cr, Mo) levels can also influence it. A rela-

tively hard weld deposit may not be desirable because it could be more prone to cracking. The hardness of the buildup materials will change as a function of the service temperature of the rolls. A room temperature hardness range may be included in the purchasing specification for the buildup materials. A method of deposition (number of layers and welding parameters) as well as the acceptance/rejection range should be agreed upon between the Purchaser and the Manufacturer.

7.2.4 Tensile Properties. The buildup materials are generally chosen so that their tensile strength matches the tensile properties of the base material. The tensile properties are typically evaluated with the weld metal in the heat-treated condition. Tensile properties can be requested as a part of the specification. The details of testing should be worked out between the Purchaser and the Manufacturer. The methods of weld deposition and testing are well covered by AWS filler metal specifications AWS A5.17, *Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding*, AWS A5.23, *Specification for Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*, and test specification AWS B4.0, *Standard Methods for Mechanical Testing of Welds*. Typical tensile properties of the low-alloy buildup overlays listed in Table 3 are shown in Table 4.

7.2.5 Impact Toughness. The impact toughness of the buildup material has a significant effect on the ability of a crack that has developed in the overlay material to propagate into the roll. The impact toughness is governed by several factors:

1. Composition of the weld deposit,
2. Preheat and interpass temperature,

Table 3
Typical All-Weld-Metal Compositions Used for Industrial Mill Rolls

	Low Alloy Build-Up			12% Cr Stainless Steel Overlay				Tool Steel Overlay	
	BU1	BU2	BU3	SS1	SS2	SS3	SS4	TS1	TS2
C	0.15	0.15	0.05	0.16	0.04	0.15	0.12	0.28	0.16
Mn	0.9	0.8	0.6	1.2	1.0	1.2	1.1	1.5	1.2
Si	0.5	0.4	0.4	0.5	0.6	0.5	0.4	0.4	0.6
Cr	1.7	0.5	1.4	12.0	13.0	12.0	13.0	6.5	6.0
Ni	—	0.5	2.4	—	4.5	2.0	2.5	—	—
Mo	0.6	0.2	0.4	—	1.0	1.0	1.0	1.0	1.4
V	—	—	—	—	—	0.15	0.18	0.15	—
W	—	—	—	—	—	—	—	1.0	1.1
Nb	—	—	—	—	—	—	0.18	—	—
As-Welded Hardness (HRC)	30	23	25	46	36	44	47	52	45

Source: Data provided courtesy of The Stoodly Company.

Table 4
Typical Properties of
Low Alloy Buildup Materials
Deposited Using Neutral SAW Fluxes

	BU1 ^a	BU2 ^a	BU3 ^b
Tensile Strength, ksi [MPa]	125 [860]	99 [680]	99 [680]
Yield Strength, ksi [MPa]	112 [770]	85 [585]	87 [600]
Elongation, %	19	24	23
Reduction in Area, %	58	65	—
Impact Toughness, ft-lbs [J] @ 70°F [21°C]	75 [102]	102 [138]	—

^a PWHT 6 hrs @ 1175°F [635°C]

^b PWHT 2 hrs @ 1200°F [650°C]

Source: Data provided courtesy of The Stoodly Company.

3. Welding heat input,
4. PWHT temperature and time, and
5. Types of welding flux and wire.

Acidic fluxes will result in deposits of relatively low impact toughness when compared to the basic fluxes. Even among the basic fluxes, the makeup of the fluxes can result in significantly different oxygen and inclusion contents in the overlay, thus affecting the toughness. Typical impact toughness of the buildup materials is shown in the Table 4.

Additionally, toughness may be influenced by repeated heating and cooling thermal cycles as well as exposure to elevated temperatures. Many of the buildup materials that are essentially chromium-molybdenum steels can embrittle in service depending on their composition (particularly those with higher levels of residual elements P, Sn, Sb, or As) and the thermal history to which they have been subjected.

7.3 Properties and Composition of Overlay Materials

7.3.1 Composition. The composition of overlay materials can range from simple low-alloy steels to stainless steels and tool steel materials. Typical compositions are shown in Table 3. As in the case of the buildup materials, the compositions are defined by the wire/flux combination, welded in a predefined manner. Generally, the composition of the undiluted weld metal is specified. The method of deposition used to produce the weld pad for chemical analysis and the associated welding parameters should be agreed upon between the consumable supplier and the user.

The composition of the overlay determines its as-welded hardness, room and elevated temperature strength, and corrosion resistance. Other significant properties are resistance to fire-cracking (thermal fatigue) and resistance to wear which are primarily governed by the hot hardness (hardness at service temperatures).

7.3.2 Hardness. The as-welded hardness of an overlay is determined primarily by its carbon content. The higher the carbon content, the higher is the hardness of the overlay. The resistance to tempering is an important characteristic since welded rolls are usually postweld heat treated (PWHT) to relieve residual stresses and restore some ductility from the as-welded condition. Carbide formers, such as V, Nb, and W, are added to the composition to improve the resistance to tempering. Table 5 shows the change in hardness (at room temperature) as a function of tempering temperature for the stainless and tool steel overlays described in Table 3. It is clear that the unstabilized overlays such as SS1 and SS2 soften rapidly with temperatures approaching 1100°F [595°C]. The finished hardness of the overlay should be agreed upon between the roll manufacturer and the user.

7.3.3 Elevated Temperature Strength and Ductility. For rolls that are used at relatively high temperatures (such as continuous caster rolls), the elevated temperature strength and ductility may be properties of concern. The yield strength and ductility at elevated temperature will govern the ability of the overlay to withstand plastic deformation. Table 6 shows elevated temperature properties for two commonly used stainless steel overlays. As expected, higher strengths imply lower ductility. The need for elevated temperature properties should be specified separately between the supplier and the user.

7.3.4 Impact Toughness. The impact toughness of overlays has significance in that this property will dictate

Table 5
Hardness (HRC) as a Function of Heat
Treatment for 12% Cr Stainless and Tool
Steel Overlays (4 Hours at Temperature)

°F [°C]	SS1	SS2	SS3	SS4	TS1	TS2
900 [480]	44	36	46	45	52	46
1000 [540]	32	30	38	41	50	35
1100 [595]	27	24	33	34	40	32 ^a
1200 [650]	23	23	32	33	36	30 ^a

^a Estimated

Source: Data provided courtesy of The Stoodly Company.

Table 6
Tensile Properties as a Function of Temperature for Some Stainless Overlays^a

Test Temperature °F [°C]	Tensile Strength ksi [MPa]		Yield Strength ksi [MPa]		Elongation (%)		Reduction in Area (%)	
	SS1	SS4	SS1	SS4	SS1	SS4	SS1	SS4
70 [21]	143.6 [990]	167.0 [1151]	118.4 [816]	132.6 [914]	19	12	60	35
800 [425]	109.8 [757]	130.7 [901]	93.3 [643]	112.7 [777]	15	7	64	22
1000 [540]	83.1 [573]	106.2 [732]	72.2 [498]	72.2 [498]	25	13	76	55
1200 [650]	50.4 [347]	69.9 [482]	34.6 [239]	34.6 [239]	36	24	87	72

^a SS1 PWHT: 1000°F/8 hrs [540°C/8 hrs]

SS4 PWHT: 1150°F/8 hrs [620°C/8 hrs]

Source: Data provided courtesy of The Stoodly Company.

the ease with which a crack, once initiated, will propagate through the overlay. The impact toughness of overlay materials is governed primarily by their compositions and is relatively modest for the popular martensitic stainless steel overlays currently in use (see Table 7).

7.3.5 Fire-Cracking (Thermal Fatigue) Resistance.

For rolls that are subjected to repeated heating and cooling cycles, such as continuous caster rolls, the fire-cracking resistance of the overlay is a property of concern. In general, stabilized grades of stainless steel overlays (such as SS4) have better fire-cracking resistance when compared to the unstabilized compositions (such as SS1). The need for thermal fatigue testing may be agreed upon as a separate requirement between the supplier/user of the filler metal and the end user of the finished roll. Resistance to thermal shock cracking has been quantified by the following simplified Equation 2:

$$\text{Equation 2}^3: Q = K/E$$

where:

Q = thermal shock resistance, BTU/hr-ft [W/m]

K = thermal conductivity, BTU/ft-hr-°F [W/m °C]

σ = yield strength at maximum exposure temperature, ksi [MPa]

α = thermal expansion coefficient, per °F [°C]

E = modulus of elasticity, ksi [MPa]

From this equation, it is evident that resistance to thermal shock cracking is directly proportional to thermal conductivity and yield strength and inversely proportional to the thermal expansion coefficient and modulus of elasticity.

7.3.6 Corrosion Resistance. For rolls that are exposed to corrosive media (such as caster rolls), the corrosion resistance of a particular layer of the overlay material may be of concern. Generally, the higher the carbon content, the lower the corrosion resistance at a given chromium level. However, alloy elements which form carbides in preference to chromium carbides, (e.g., Mo, V, Nb, W) can serve to prevent chromium depletion and help retain the corrosion resistance properties. Further, in stainless steel overlays, extended PWHT can sensitize (i.e., produce depletion of chromium in the zones immediately adjacent to grain boundaries) the overlay, making it more prone to general corrosion. Corrosion testing of overlays may be arranged as a separate requirement.

7.3.7 Fatigue. Wide-body rolls without support between the end bearing journals can be susceptible to fatigue. In general, the higher yield strength in stainless

Table 7
Impact Toughness of
Some Stainless Steel Overlays

	ft-lbs @ 70°F [J @ 21°C]	
	As-Welded	PWHT ^a
SS1	5.7 [7.7]	9.7 [13.2]
SS4	4.8 [6.5]	8.2 [11.1]

^a SS1 PWHT: 1000°F/8 hrs (540°C/8 hrs)

SS4 PWHT: 1150°F/8 hrs (620°C/8 hrs)

Source: Data supplied courtesy of Millcraft-SMS Services.

³ Benedyk, J. C., D. J. Moracz, and J. F. Molloce, Thermal Fatigue Behavior of Die Materials for Aluminum Die Casting, *Trans. 6th SDCE International Die Congress*, Cleveland, Ohio, Nov. 16–19, 1970.

overlays will delay fatigue crack initiation but will not slow fatigue crack propagation.

8. Welding Techniques and Process Control

8.1 Overview. This section includes details of preheat and interpass temperature control, welding parameters, and postweld heat treatment. A typical form for recording weld processing parameters is shown in Figure C.5 in Annex C.

8.2 Preheat and Interpass Temperature. The benefits of preheat and maintaining interpass temperature are to:

1. Prevent underbead cracking and weld spalling. Underbead cracks can occur in the heat-affected zone of the base metal and cause spalling of the deposit or cracking of the part in service. Preheat can reduce the cooling rate and minimize the brittleness and crack-sensitivity of the HAZ.
2. Decrease shrinkage stresses. Shrinkage stresses build up when weld metal contracts during cooling. Preheat reduces the temperature difference between weld metal and base metal thus decreases the susceptibility to cracking.
3. Reduce hydrogen damage. Preheat slows down the cooling rate, speeds hydrogen evolution from the roll, minimizes diffusion into the base metal, and thus reduces hydrogen-induced cracking.

8.2.1 Determination of Preheat and Interpass Temperature.⁴ The determination of the required preheat temperature is primarily governed by the base material composition of the roll. The carbon content of the roll material and the alloy composition have a large bearing on the required preheat temperature. Although there are numerous techniques available to determine preheat temperature, Figure 3 shows a simplified approach. The carbon content of the roll is plotted on the X axis of this chart and the intersection of this line with the appropriate total alloy content line gives the required preheat temperature on the Y-axis. In the example shown in Figure 3, the roll's carbon content is 0.86% and the total alloy content is 4%, resulting in a required preheat temperature of 675°F [360°C]. The estimated preheat temperatures using this approach are shown in Table 2 for the forged rolls. For very high carbon rolls, the preheat temperatures indicated in Figure 3 may exceed practical limits as far as operator discomfort and slag removal are concerned. Wherever possible, the highest required preheat temperature should be used.

In many cases when the overlay material is a martensitic stainless steel or a tool steel, the type of overlay material will dictate the preheat temperature. In such cases, the

preheat temperature needs to be above the martensite start temperature (M_s temperature). The M_s temperature may be calculated from various empirical formulae that are available in the literature. One such formula⁵ is:

$$M_s (^\circ\text{F}) = 1020 - 630(\%C) - 72(\%Mn) - 63(\%V) \\ - 36(\%Cr) - 31(\%Ni) - 18(\%Cu) \\ - 18(\%Mo) - 9(\%W) + 27(\%Co) + 54(\%Al)$$

$$M_s (^\circ\text{C}) = [M_s (^\circ\text{F}) - 32] \times 5/9$$

Generally, for the martensitic stainless steels and tool steels described in Table 3, preheat temperatures used are in the 500–600°F [260–315°C] range. Overlay welding performed with roll body temperatures below the M_s temperature will cause differential tempering in the area adjacent to the fusion line of subsequent overlay weld passes. This may cause uneven roll surface wear thus resulting in a corrugated surface effect. Therefore, it is important that the roll body temperature be kept above the M_s temperature until all welding has been completed.

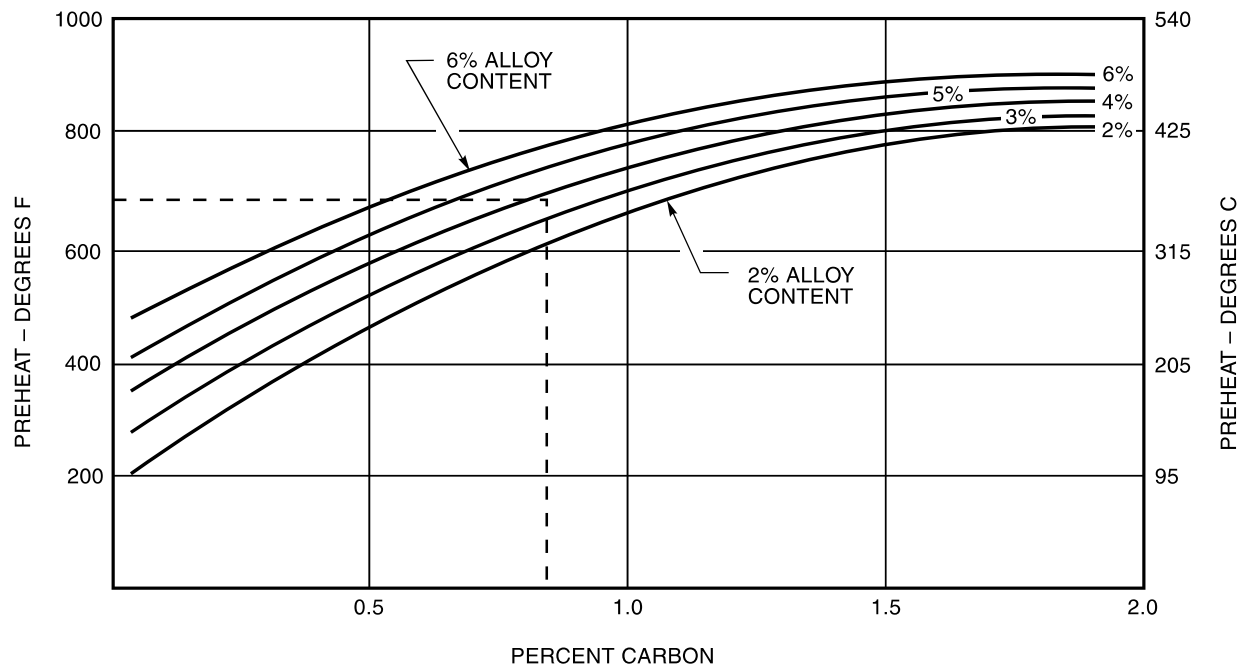
The mass of the roll will determine the soaking time that is required to get the entire body of the roll to the desired preheat temperature. Figure 4 shows the soaking time required for the center of the roll to reach the required preheat temperature after the surface of the roll has reached the required temperature. In the example shown in Figure 4, for a 44 in. [1.1 m] diameter roll, the soaking time required for the roll to reach uniform temperature through the center of the roll is 16 hours.

The optimum way to bring the roll to preheat temperature is to use a furnace with a temperature controlled combustion system. Alternatively, a heat shield can be built around the roll and several burners can be positioned below the roll. The roll has to be continuously turned during the entire preheat cycle. Temperature indicating crayons, infrared sensors, or contact pyrometers can be used to monitor the temperature.

8.2.2 Dimensional Effects of Preheat and Interpass Temperature. It should be recognized that preheating of the roll will cause expansion of both its length and its diameter. These are not entirely small effects. For example, a roll 84 in. [2.1 m] in length at room temperature will increase in length by about 0.4 in. [10 mm] when preheated to 600°F [315°C]. Likewise, a 30 in. [760 mm] diameter roll at room temperature will increase in diameter by about 0.11 in. [2.8 mm] when preheated to the same temperature. These effects have to be taken into account in designing the tooling to support the roll during welding, and to place the welding head. Figure 5 can be used to estimate the increase in diameter of rolls up to 50 in. [1.27 m] O.D. for preheat temperatures up to 750°F [400°C].

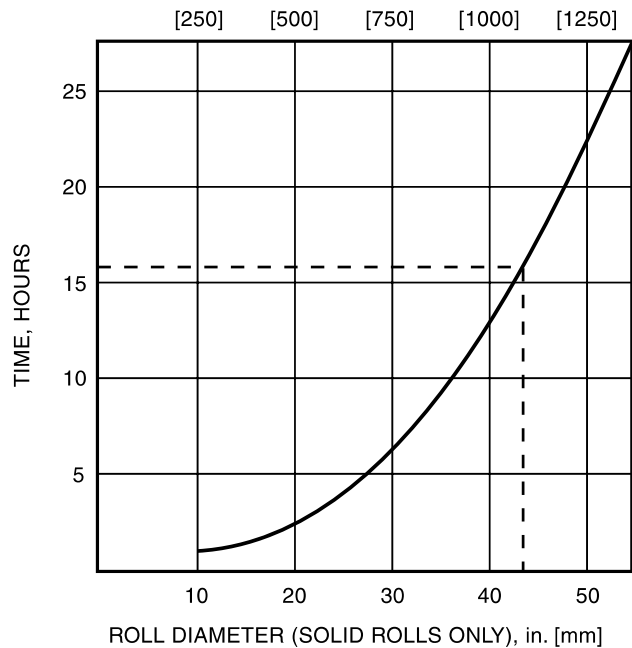
⁴ Adapted from: Farmer, Howard, *Steel Mill Roll Reclamation*, Stoodly Technical Report, Second Edition, 1975.

⁵ Adapted from Farmer, Howard, *Steel Mill Roll Reclamation*, Stoodly Technical Report, Second Edition, 1975.



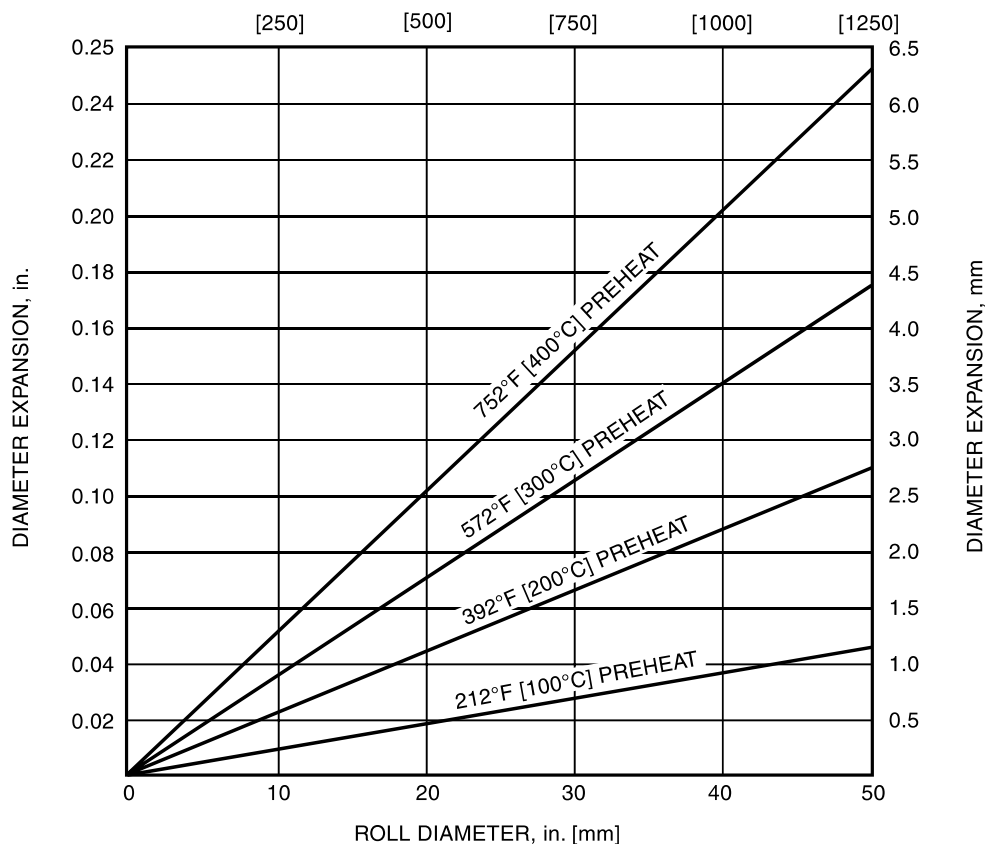
Source: Adapted from Farmer, Howard, *Steel Mill Roll Reclamation*, Stoodly Technical Report, Second Edition, 1975. Adapted to provide metric scale for preheat.

Figure 3—Preheat Temperature as a Function of Carbon and Alloy Content



Source: Adapted from Farmer, Howard, *Steel Mill Roll Reclamation*, Stoodly Technical Report, Second Edition, 1975. Adapted to provide metric scale for roll diameter.

Figure 4—Required Soak Time at Temperature to Heat the Roll Through Its Diameter as a Function of Diameter



Source: Figure provided courtesy of McKay Welding Products. Adapted to provide metric scales.

Figure 5—Preheat Temperature Effect on Roll Diameter Expansion

8.2.3 Considerations for Thick Deposits. Generally, buildup materials can be applied to unlimited thicknesses so long as the preheat temperatures required for the base material are maintained. Stainless overlays, also, in general can be applied relatively thick without the potential for cracking. However, tool steel deposits, especially those that exceed HRC 45, when applied in thickness greater than 1 in. [25 mm] may be susceptible to cracking and spalling during welding. This is caused by the build up of excessive residual stresses due to the high yield strength of these materials. An intermediate stress relief, generally 950°–1000°F [510°–538°C], can sometimes be used to alleviate this problem. The specifics of the stress relief temperature and time should be obtained from the manufacturer of the consumables.

8.3 Body Run-Off Rings

8.3.1 It is sometimes desirable to weld run-off or extension rings to the body before the start of the repair process. The rings should be applied after the roll has been preheated to the start weld temperature.

8.3.2 The rings allow the weld to extend beyond the edge of the roll body while supporting the flux and molten slag pool. They also provide an area for arc initiation and termination, areas which are often adversely affected by slag defects and crater cracks.

8.3.3 The run-off rings should be of sufficient thickness to prevent burn-through during welding. They should also be selected from a grade of steel that will not adversely alter the properties of the overlay at the edge of the roll body.

8.4 Welding Parameters

8.4.1 Typical ranges of welding parameters for 3/32 in. [2.5 mm], 1/8 in. [3.2 mm], and 5/32 in. [4 mm] tubular submerged arc welding wires are shown in Table 8. The following should be noted when applying these ranges:

1. When the lower end of the current range is used, the lower end of the voltage range applies. Likewise, when the higher end of the current range is used, the higher end of the voltage range applies.

Table 8
Typical Parameters for Tubular Submerged Arc Wires

Diameter	3/32 in. [2.4 mm]	1/8 in. [3.2 mm]	5/32 in. [4.0 mm]
Current, Amperes	350 to 500	400 to 550	450 to 600
Volts, DCEP	25 to 29	26 to 31	27 to 32
Contact-Tip-to-Work Distance	1 to 1-1/4 in. [25 to 32 mm]	1-1/4 to 1-1/2 in. [32 to 38 mm]	1-1/4 to 1-1/2 in. [32 to 38 mm]
Deposition Rate	14 to 22 lb/h [6.4 to 10 kg/h]	16 to 24 lb/h [7.3 to 10.9 kg/h]	17 to 25 lb/h [7.7 to 11.4 kg/h]

Source: Data supplied courtesy of The Lincoln Electric Company.

2. Deposition rates are approximate for single arc application.

3. Using currents at the lower end of the range on the first layer will reduce dilution.

4. The welding current is the main parameter that influences the weld deposition rate. The electrode melt-off rate increases with increased current, causing increased deposition rates.

5. Some fabricators prefer to set wire feed speed instead of setting current, because deposition rate remains constant when wire feed speed remains constant, while current may vary due to variations in contact-tip-to-work distance as the roll rotates under the welding head.

6. At a given current, a smaller diameter wire will have a higher deposition rate than a larger diameter wire due to higher current density applied across the smaller cross-section of the smaller diameter wire.

Some more specific effects are noted in detail in the following paragraphs.

8.4.2 Most Critical Variables. The most important welding variables are wire diameter, wire feed speed (which largely determines welding current), welding travel speed, welding voltage and polarity, contact-tip-to-work distance (CTWD), and bead-to-bead overlap. These variables are interrelated, so that any one or more cannot be independently varied without affecting proper settings for the others.

8.4.3 Effects of Wire Feed and Travel Speeds. Wire feed speed and welding travel speed for a proper bead size need to be correlated. A common way to adjust travel speed in concert with wire feed speed to obtain a proper bead size without oscillation is to use a constant ratio of wire feed speed to travel speed, depending upon

wire diameter. If the ratio of wire feed speed to travel speed is held constant for a given wire diameter, then the weld buildup will have constant cross-sectional area. Table 9 provides wire feed speed to travel speed ratios for several wire diameters that provide approximately the same weld buildup cross-sectional area that works well on most roll diameters. A smaller ratio may be required for proper bead shape on small diameter rolls (less than 10 in. [250 mm] diameter).

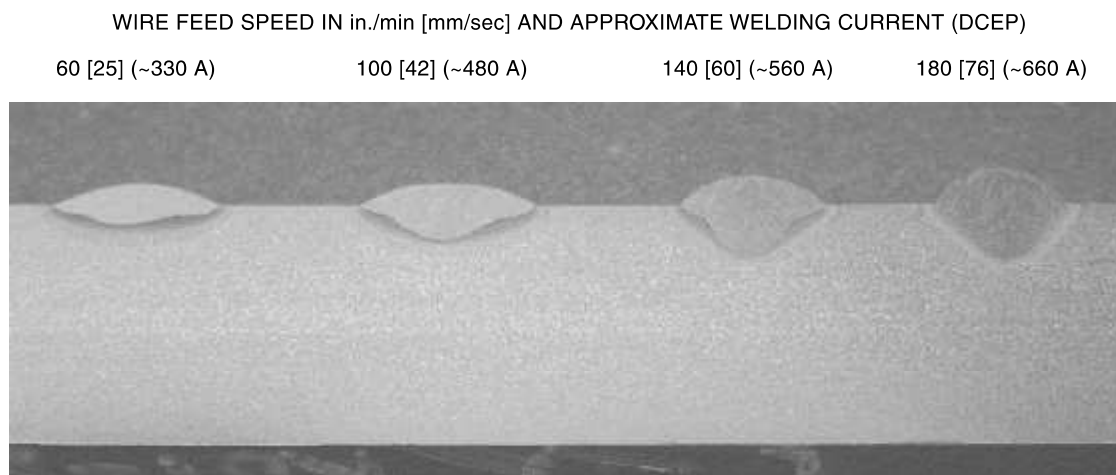
8.4.3.1 If the weld buildup cross-sectional area is too large, bead shape deteriorates because the edges tend to roll over. The weld deposit may also tend to spill off the roll. If the weld buildup cross-sectional area is too small, a given total buildup requires an excessive number of weld passes, which adds to cost.

8.4.3.2 At a fixed ratio of wire feed speed to travel speed with a given electrode diameter, increasing the wire feed speed tends to increase the penetration and dilution, and to make the bead cross section narrower and higher. Figure 6 shows this effect for a 1/8 in. [3.2 mm] wire.

Table 9
Wire Feed Speed to Travel Speed Ratios Which Produce a Weld Buildup Cross-Sectional Area of about 0.06 in.² [40 mm²]

Wire Diameter, in. [mm]	3/32 [2.4]	1/8 [3.2]	5/32 [4.0]	3/16 [4.8]
Ratio of Wire Feed Speed to Travel Speed	8.8	5.0	3.2	2.2

Source: Data supplied courtesy of The Lincoln Electric Company.



Note: The depth of penetration increases as the wire feed speed (current) is increased. The weld bead width is somewhat decreased with increasing wire feed speed.

Source: Figure supplied courtesy of The Lincoln Electric Company.

Figure 6—Overlay Beads Deposited at Wire Feed Speed (WFS) to Travel Speed Ratio of 5 to 1, 1/8 in. [3.2 mm] Wire Diameter, 28 Volts DCEP

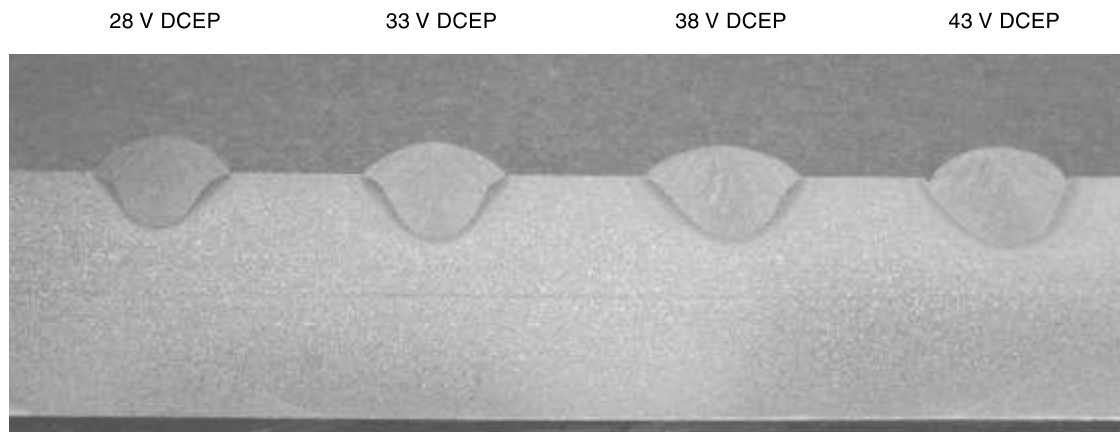
8.4.4 The Effect of Voltage. The tendency for a higher, narrower bead shape with increasing wire feed speed can be partially offset by increasing voltage, as shown in Figure 7. However, higher voltage increases the tendency for arc blow and may cause undercut to occur. Evidence of undercut can be seen in the weld made at the highest voltage level shown in Figure 7. At wire feed speeds near the low end of the usable range for a given wire size, DC electrode negative (DCEN) polarity produces a higher, narrower bead, with less penetration and less dilution, than does the more commonly used DC electrode positive (DCEP) polarity. At higher wire feed speeds, this effect largely disappears, as shown in Figure 8.

8.4.5 The Effect of Contact-Tip-to-Work Distance (CTWD). If the wire feed speed is fixed and the voltage is fixed, then increasing the CTWD tends to reduce the current, penetration, and dilution. Also, at longer CTWD, more voltage is used in preheating the wire, so that less is available for the arc with a constant potential power source. This behavior results in the bead becoming somewhat narrower and higher.

As CTWD increases, consistent wire placement becomes more difficult because any curvature in the wire as it exits the contact tip results in wandering of the arc. Conversely, short CTWD makes wire placement easier

because the arc has less tendency to wander. But excessively short CTWD can result in porosity with the tubular metal cored wires commonly used for industrial mill roll welding. In practice, CTWD between 1 and 2 in. [25 to 50 mm] is most commonly used, with the longer CTWD favored for larger diameter wires and the shorter CTWD favored for smaller diameter wires.

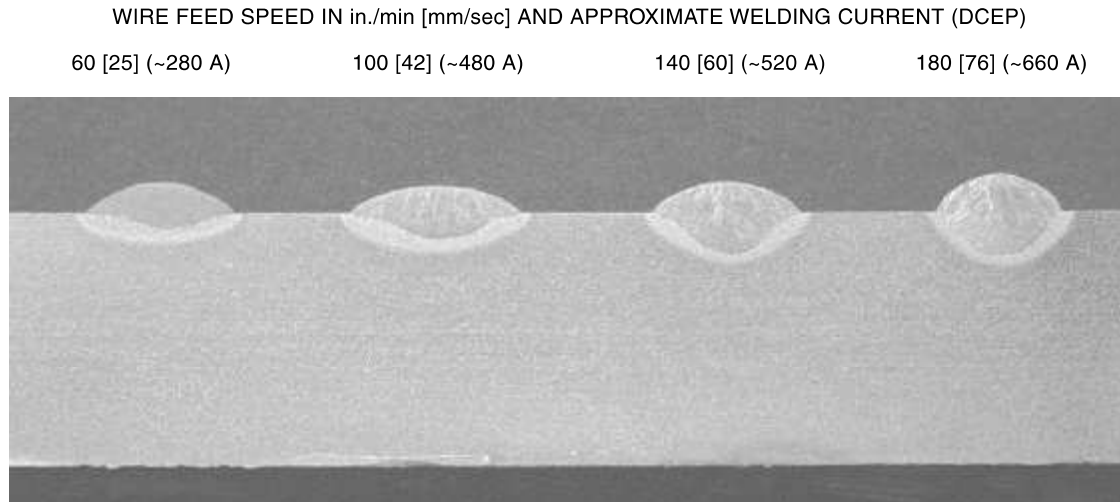
8.4.6 The Effect of Bead Placement. It is common practice to align the wire for each succeeding bead in a layer of buildup or overlay with the edge of the preceding bead. This practice results in approximately 50% overlap of one bead on the preceding bead. The result is generally a nearly flat surface contour with little tendency for slag entrapment. But the penetration profile undulates between weld layers, and, if subsequent machining to even the surface happens to expose parts of the interfaces between layers, preferential corrosion may occur in an exposed portion of a lower layer (see 8.4.8.4 for additional discussion of this effect). If this is of concern, it is advisable to reduce the indexing or “stepover” of the arc to align the wire so that it impinges entirely on, but near the edge, of the previous bead. This practice results in over 60% overlap of the bead on the previous bead, reduces penetration into the substrate or previous layer of weld deposit, and provides a much less undulating interface between layers. This effect is shown in Figure 9.



Note: The bead width is increased and the bead height is decreased with increasing voltage, and that undercut appears at the highest voltage.

Source: Figure supplied courtesy of The Lincoln Electric Company.

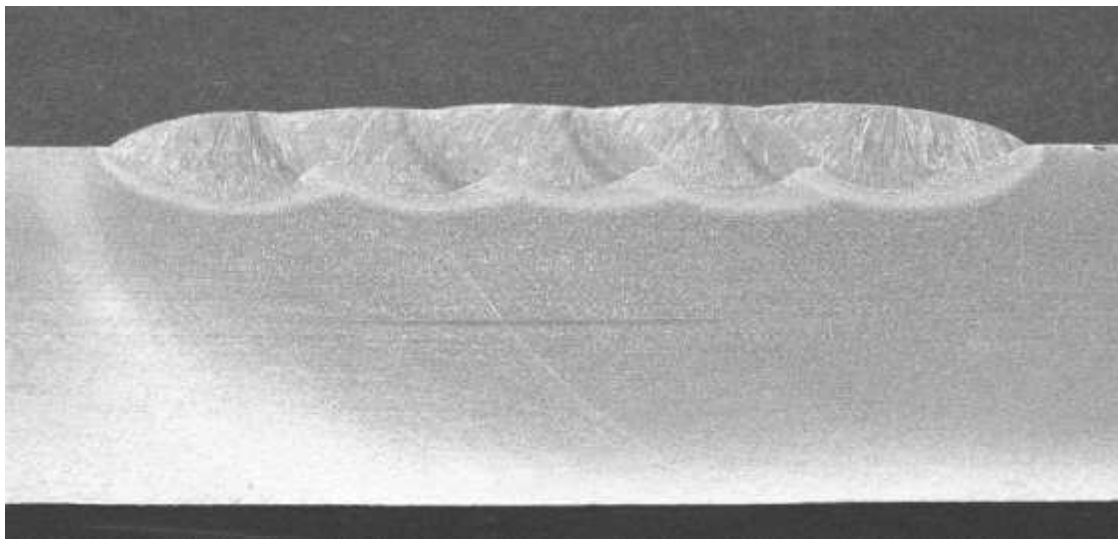
Figure 7—Overlay Beads Deposited at 180 ipm [76 mm/sec] Wire Feed Speed, 1/8 in. [3.2 mm] Wire Diameter, Varying Voltage



Note: Note the very shallow penetration at 60 ipm [25 mm/sec] wire feed speed versus the companion DCEP weld in Figure 6. The effect is present to a lesser effect at 100 ipm [42 mm/sec] wire feed speed and largely disappears at the higher wire feed speeds.

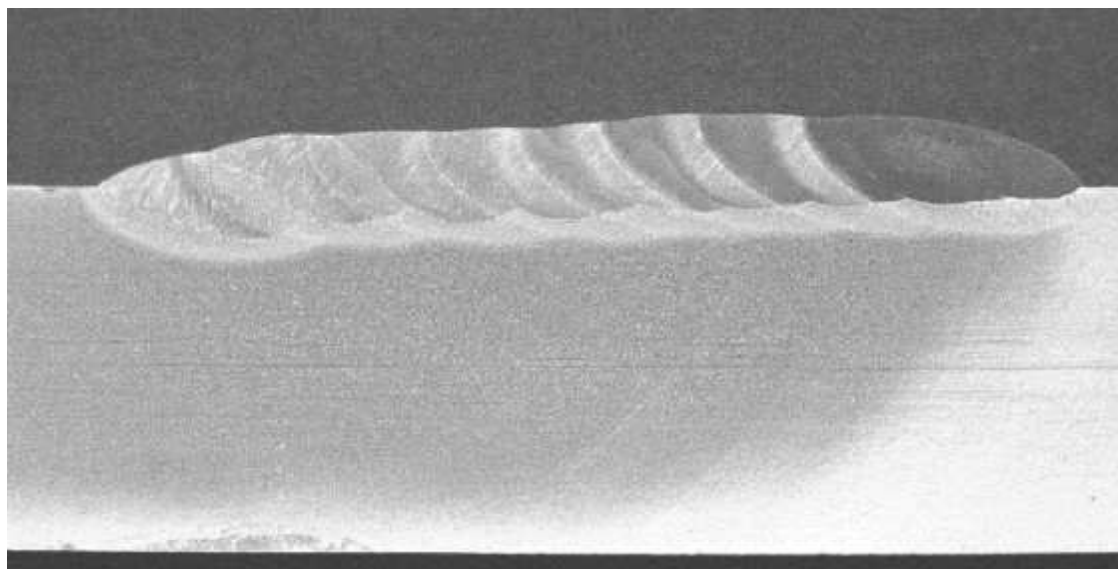
Source: Figure supplied courtesy of The Lincoln Electric Company.

Figure 8—Overlay Beads Deposited at Wire Feed Speed (WFS) to Travel Speed Ratio of 5 to 1, 1/8 in. [3.2 mm] Wire Diameter, 28 Volts DCEN



(A) 0.40 in. [10 mm] STEPOVER (“NORMAL” STEPOVER)

Note the undulation of the interface between the overlay and the base metal.



(B) 0.25 in. [6 mm] STEPOVER (“SHORT” STEPOVER)

Note the greatly reduced undulation of the interface between the overlay and the base metal. The weld beads from left to right successively climb out of the base metal, resulting in low dilution after the first few beads.

Source: Figure supplied courtesy of The Lincoln Electric Company.

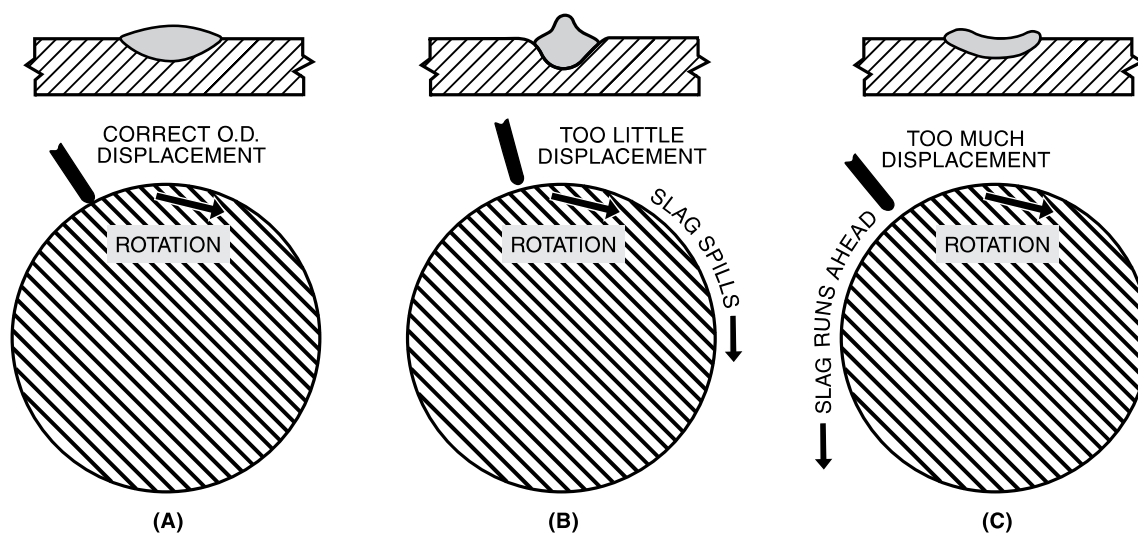
Figure 9—Effect of Stepover at 100 ipm [42 mm/sec] Wire Feed Speed (480 A) with 1/8 in. [3.2 mm] Wire, DCEP

8.4.7 Effect of Electrode Location. The position of the electrode with respect to the roll top center (RTC)—eccentric distance and eccentric angle—is very important to achieve good bead shape and good slag removal. The wire should be positioned so that the molten weld pool solidifies as it passes top center with the wire directed towards the roll center. A position too far from center will produce flat or concave beads with increased chances of centerline cracking. A position too close to center will produce narrow convex beads and undercut at the edges. Examples of these conditions are illustrated in Figure 10. A correct lead position produces a bead with a slight crown and long lines of solidification which usually exceed twice the width of the weld bead.

Lead positions of 3/4 in. [19 mm] to 1-3/4 in. [45 mm] (approximately 5% of the roll diameter) are typical for rolls up to 42 in. [1070 mm] diameter. Suggested lead positions for rolls ranging from 3 in. [75 mm] to >72 in. [1830 mm] are shown in Table 10.

The rotating surface speed is the number of inches [millimeters] passing a given point in one minute. Both the speed of the roll rotation and the roll diameter affect the surface speed. As the surface speed is increased the width of the weld bead decreases and the bead height increases.

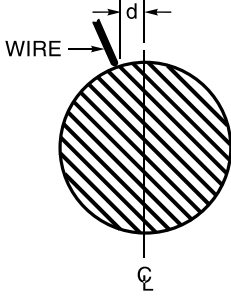
A correct lead produces a bead with a slight crown and long lines of solidification which usually are one to two



Source: Adapted from Farmer, Howard, Steel Mill Roll Reclamation, Stoody Technical Report, Second Edition, 1975.

Figure 10—Effect of Electrode Position on Bead Shape, Slag Spillage, and Flux Spillage

Table 10
Suggested Electrode Displacement from Roll Top Dead Center

	Diameter of Base Metal Surface		Electrode Displacement (d) Ahead of Roll Top Center (RTC)	
	in.	mm	in.	mm
	3 to 18	75 to 460	3/4 to 1	19 to 25
	18 to 36	460 to 910	1-1/4 to 1-1/2	32 to 38
	36 to 42	910 to 1070	1-1/2 to 1-3/4	38 to 44
	42 to 48	1070 to 1220	1-3/4 to 2	44 to 51
	48 to 72	1220 to 1830	2 to 2-1/2	51 to 64
	over 72	over 1830	3	75

Note: The electrode should be perpendicular to the roll surface regardless of displacement.

Source: Data supplied courtesy of The Lincoln Electric Company. Table 10 figure adapted from The Lincoln Electric Company.

times the width of the weld bead. Examples of these conditions are shown in Figure 11.

8.4.8 The Effect of Dilution. The composition of the overlay on the working surface is dependent on the degree of dilution resulting from the welding process. The degree of dilution governs the properties of the overlay regarding hardness, strength, and corrosion resistance. The degree of dilution determines the number of layers required to achieve true weld metal composition. Generally, low dilution is preferred when surfacing rolls so as to achieve the desired properties of the overlay as quickly and economically as possible.

8.4.8.1 Some of the factors and how they affect dilution are:

1. *Preheat/Interpass Temperature:* Higher preheat/interpass temperatures result in greater dilution.

2. *Welding Current:* Higher current (wire feed speed) increases dilution.

3. *Travel Speed:* Slower welding speeds reduce dilution over the range of travel speeds normally used in roll welding.

4. *Electrode Polarity:* DCEN reduces dilution when compared to DCEP at the same current level. This effect is important near the low end of the wire feed speed (current) range for which a given electrode diameter is suitable, but it is much less important at higher wire feed speeds. However, DCEN may limit travel speed and deposition rate due to the tendency for undercut. Also DCEN deposits may be more prone to porosity due to lower resistance heating of the wire before it reaches the arc.

5. *Stepover:* Increasing stepover (i.e., the distance the wire is indexed relative to the previous deposit before depositing the next bead) increases dilution.

6. *Layers of Weld:* The effect of base metal dilution is reduced as the number of layers of weld is increased (see Table 11).

7. *Electrode Diameter:* A large diameter electrode reduces dilution as compared to a smaller diameter electrode at the same current levels.

8. *Number of Electrodes:* Twin electrodes reduce dilution as compared to a single electrode at the same deposition rate.



Figure 11—Effect of Lead Position on Bead Solidification Lines

Table 11
Calculated Cr Content of Various Layers of Overlay vs. Dilution
for a Flux-Wire Combination Producing 13% Cr All-Weld-Metal

% Dilution	% Cr for Each Layer Number					
	Layer 1	Layer 2	Layer 3	Layer 4	Layer5	Layer 6
20%	10.40	12.48	12.90	12.98	13.00	13.00
30%	9.10	11.83	12.65	12.89	12.97	12.99
40%	7.80	10.92	12.17	12.67	12.87	12.95
50%	6.50	9.75	11.38	12.19	12.59	12.80
60%	5.20	8.32	10.19	11.32	11.99	12.39

9. *Oscillation Speed and Voltage:* Both variables should be optimized as a function of the welding procedures to create a uniform weld bead with consistent quality. Both variables may slightly affect penetration and dilution, but their effect on weld bead contour, width, and quality is more dramatic.

10. *Contact-Tip-to-Work Distance (CTWD):* Increasing CTWD reduces dilution.

8.4.8.2 SAW, particularly with the DC electrode positive (DCEP) polarity, is usually a high dilution welding process. In SAW-DCEP welding, dilution may approach or exceed 50%. If a flux/wire combination is chosen based upon a specific desired all-weld-metal composition, it is important to consider what the composition of various layers of weld overlay will be. For example, if a flux/wire combination is used which produces an all-weld-metal composition of 13% Cr, the chromium content of each overlay layer may be calculated as a function of dilution to make an overlay on a chromium-free substrate as illustrated in Table 11.

8.4.8.3 Obtaining a 12% Cr content in the third layer of overlay requires that the dilution be limited to a little more than 40% with this hypothetical flux/wire combination. Since the manufacturer(s) of the flux and wire have no control over the dilution or number of layers that will be deposited by the welder, the normal specification for weld deposit applies to “undiluted” weld metal with a particular wire and flux. “Undiluted” may mean four, five, or six layers of weld metal. This is a matter which should be clearly understood and agreed to between the Manufacturer(s) and the user. If deposit composition other than undiluted weld metal is specified, the required number of layers should be specified along with clearly defined welding conditions, including wire feed speed, voltage, polarity, travel speed, electrode extension, and stepover.

8.4.8.4 Reducing the stepover, so that the arc impinges primarily on previously deposited weld metal of the same layer, can be used to reduce dilution, as compared to the normal stepover where the arc impinges on the toe of the previous weld bead in a given layer.

Changing the stepover or indexing of the welding head relative to the previously deposited metal, besides directly influencing dilution, also influences the shape of the interface between layers of weld metal. Generally, a stepover that produces 50% overlap of the previously deposited metal will produce a pronounced undulation of the interface between layers. Often, three layers of weld overlay are deposited, and the third layer will have significantly different composition than the second layer (see Table 11). Depending on the final machining depth, the peaks of the second layer may be exposed, resulting

in a surface of varying composition which becomes susceptible to preferential corrosion attack in the lower alloyed second layer.

In continuous caster rolls of steel mills, this condition leads to the so-called “dark bands” of preferential corrosion on the roll surface which are often (mistakenly) attributed to heat-affected zone damage. Reducing stepover so that the overlap of a bead on the previously deposited weld metal is about 60% to 70% will markedly reduce the undulations of the interface between layers and reduce the susceptibility to this preferential corrosion.

8.4.8.5 Another approach for dealing with dilution to reduce the number of layers needed to achieve a particular minimum alloy content in a given number of layers (often three layers), is for the wire manufacturer to over-alloy a tubular wire to accommodate appreciable dilution in the specified number of layers under the specified welding conditions.

8.5 Considerations Specific to Journal Repair, Buildup, or Overlay

8.5.1 Butter Layers. When overlaying rolls of relatively high carbon content (typically 1.0% and above), it is advisable to deposit a butter layer with a low carbon steel filler metal that has high compressive strength. This will prevent the pickup of excessive amounts of carbon from the base material into the overlay which can lead to embrittlement and spalling in service. One such butter layer composition is BU3 shown in Table 3. It is critical that correct procedures with regard to preheat and inter-pass temperatures are followed when overlaying high carbon content rolls.

8.5.2 Journal Buildup and Repair

8.5.2.1 Journals or bearing seat areas can be built up or weld repaired by, but not limited to, the SAW, FCAW, GMAW, and SMAW processes. In all cases, a low hydrogen welding practice should be utilized.

8.5.2.2 Typical welding consumables consist of mild steel and low-alloy steel grades. The selection is generally based upon hardness as a function of PWHT. A suitable wire/flux combination should be selected to allow qualification of the welding procedure for unlimited thickness. The consumables should produce good weldability, sound weld deposit, and postweld-heat-treated properties that are comparable to the base material.

8.5.2.3 Journal areas requiring repair should be machined at no less than 1/16 in. [1.6 mm] radially below finish size. The repair welding should not terminate in the fillet radius area that joins the journal to the body shoulder. The weld repair should terminate either

prior to the fillet radius area or be welded continuous through the radius onto the shoulder.

8.5.2.4 The journal areas to be welded should be preheated to the minimum recommended preheat temperature of the base material or welding consumable. Journals can be locally preheated or furnace preheated. The entire journal area should be preheated and maintained at or above the minimum recommended temperature prior to any weld buildup or buttering. The preheat and interpass temperature should be sufficient to prevent cracking. A soak time is needed to allow the journal to be heated through its entire cross section and minimize temperature differentials between the surface and interior. Thermal shock may cause cracking of the base material.

8.5.2.5 The buildup process consists of overlaying a journal prior to surfacing.

8.5.2.6 A buttering process consists of creating a transitional zone between base material and buildup and/or between buildup and overlay. Buttering is intended to provide chemical compatibility between the overlay and the base metal, thereby improving weldability.

8.5.2.7 Undercut areas should be prepared so that each included angle and the weld joint are a minimum of 15° with a radius at the root. This weld joint preparation is intended to provide good sidewall tie-in and to avoid slag entrapment.

8.5.2.8 A proper welding technique should be utilized to maintain an even and concentric buildup. Proper welding techniques should provide a relatively flat surface prior to surfacing that will result in a consistent overlay composition and thickness. It may be necessary to machine the buildup surface prior to final overlay if the buildup layers are not uniform or display excessive hills and valleys.

A welding technique that utilizes multiple arcs or oscillations as compared to stringer beads will increase the heat input to the work piece. This increase in heat input can affect the mechanical properties of the base material and increase the potential for distortion.

8.5.2.9 A postweld heat treatment is recommended after welding. A slow cool after weld repair is necessary prior to heat-treating. Cooling rates less than 50°F [30°C] per hour are typically used. For critical parts, the journals are sometimes wrapped in ceramic fiber blankets to further reduce the cooling rate.

Because a large depth of repair can cause a high restraint situation that may lead to cracking, it may be necessary to perform intermediate postweld heat treatment(s) in cases of highly restrained welds.

At times, areas of journals that are final-machined surfaces need to be protected to prevent scale formation during postweld heat treatment. It is recommended that finished journals be protected with a suitable anti-scaling coating that is service-rated for the specified postweld heat treatment temperature.

8.5.3 Overlay

8.5.3.1 The overlay layers are most commonly deposited by the SAW process or the FCAW self-shielded, open arc process, but other processes may be used.

8.5.3.2 A wire/flux combination should be selected to provide good weldability, a sound weld deposit, and when used, postweld-heat-treatment properties that meet the service requirements or the customer specifications.

8.5.3.3 A minimum preheat and interpass temperature range should be maintained throughout the welding process. The preheat and minimum interpass temperatures are usually above the martensite start temperature (M_s) to avoid premature transformation of the weld metal that could lead to cracking. Maintaining the proper interpass temperature range also helps in controlling bead shape, which helps to reduce the chance of slag entrapment. Not maintaining proper preheat can result in non-uniform hardness and mechanical properties, and may result in cracking.

8.5.3.4 The number of weld layers should be predetermined by customer specifications and/or final thickness requirements.

8.5.3.5 On multiple-head welding systems, attention should be paid to the “tie-in” area of the roll. A tie-in area is caused by the crossover or overlapping of the welding beads when multiple welding heads are used. The deposit of the last rotation of one bead must tie in completely to the deposit of the first rotation of another bead. When bead placement is not optimal, slag entrapment or lack of fusion may result at the tie-in area.

8.5.3.6 In circumferential weld overlaying, the longitudinal movement of the welding head can be accomplished by “stepover” or “spiral indexing” techniques (see Figure 12). A stepover is the longitudinal distance moved by the welding head after each weld bead is deposited over the entire 360° of the roll circumference. In the spiral indexing technique, the welding head moves continuously along the longitudinal axis of the roll creating a spiral bead. In either case, the percent of overlap should be controlled to control dilution, maintain proper bead profile, ensure “tie-in” to previous bead, and avoid slag entrapment. It is recommended with multiple layers of overlay (when using this technique) that the bead

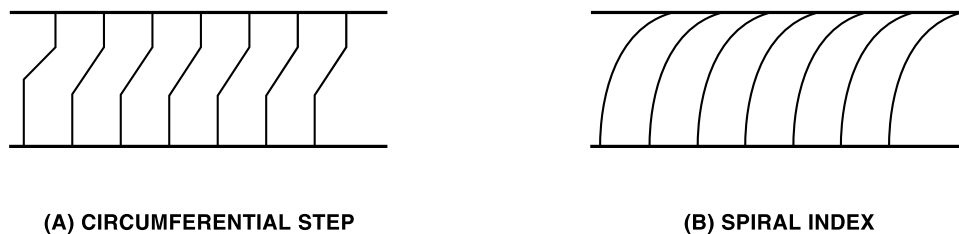


Figure 12—Stepover Techniques

placement and stepover area be offset approximately 1/2 bead width from the previous bead.

8.5.3.7 A postweld heat treatment is typically utilized. In postweld heat treatment, the first step is a slow cool process in which the roll is cooled after welding down to and below the martensite finish temperature (M_f). This temperature can be typically 210°F [100°C]. The M_f temperature depends on the composition of the weld metal and should be provided by the consumable supplier. The next step is to uniformly heat the roll at a controlled rate to a predetermined tempering temperature. The roll is then uniformly maintained at this temperature for a specific soak time to achieve the desired mechanical properties. The postweld heat treatment of the roll should be done at a temperature which is below the original tempering temperature of the base material to avoid changing the mechanical properties of the base material. The supplier of the weld consumables should be contacted for specific temper response properties of the overlay to assure that the desired or specified properties can be achieved.

8.5.3.8 If the overlay is used in the “as-welded” condition, a separate heat treatment may be needed for the buildup material or journal repair prior to overlay.

8.6 Postweld Heat Treatment

8.6.1 Overview. There are different kinds of postweld-heat-treatments (PWHT) including annealing, normalizing, stress relieving, and tempering. Annealing and normalizing are performed at a temperature above the critical (re-austenitizing) temperature while stress relieving and tempering are performed at a temperatures below the critical temperature. The roll re-manufacturing industry generally concentrates on using the sub-critical heat treatments and makes no distinction between the stress relieving and tempering processes. It is often

just referred to as “temper treatment” and normally takes place between 900°F and 1150°F [480°C and 620°C].

8.6.2 Typical heat treatment for welded rolls involves allowing the rolls to slow cool from the welding temperature at a rate less than 100°F/h [55°C/h] to approximately 100°F [55°C] below the overlay material’s martensite start (M_s) temperature (see 8.2.1). The roll is then held at that temperature for several hours to allow the entire roll to reach a uniform temperature. The roll is then gradually heated to 900°F to 1150°F [480°C to 620°C] for tempering. The heating rates should be slow enough (50°F/h to 150°F/h [30°C/h to 90°C/h]) so as not to exceed the tempering temperature. The tempering time depends on the roll diameter and the desired hardness level but is typically 1/2 hour per in. [25 mm] of the roll diameter. Cooling from the tempering temperature should also be slow (less than 200°F/h [110°C/h]) to at least 500°F [260°C].

Tempering heat treatments reduce the residual stresses introduced by the welding thermal cycle in the overlay materials. PWHT also reduces the weld metal hardness and improves its ductility. As a result of the tempering treatment, a more desirable combination of strength, hardness, and toughness can be obtained for the overlay material.

8.6.3 In addition to the tempering time and temperature, the hardness of the overlay material also depends on the alloy present in the weld metal. Alloying the weld deposit with molybdenum, vanadium, niobium or tungsten helps to retain the hardness level after exposure to a given tempering temperature. For example, the SS3 and SS4 have an equal or lower as-welded weld metal hardness than that of SS1 (Table 3), but after tempering the SS3 and SS4 deposits become appreciably harder than the SS1 deposit (Table 5).

8.6.4 In some rolls overlaid with tool steels, more than one tempering cycle may be needed to produce the desired properties. This process may be required because the higher alloyed tool steel overlay materials may form additional martensite during the cooling phase of the first tempering cycle. It is therefore often recommended to perform a second PWHT to temper the freshly formed martensite and produce more uniform properties.

8.6.5 For accurate heat treatment temperature controls, calibrated pyrometric equipment, such as thermocouples, should be used to verify that the specified temperature and time at temperature are achieved. Chart recorders may also be necessary for documentation and quality control purposes.

9. Procedure Qualification and Tests

9.1 Procedure Qualifications (WPS). There are three recommended levels for procedure qualification. The applicable levels should be reached by agreement between the buyer and the contractor. These recommended levels are shown in Table 12.

9.1.1 WPS Forms. Regardless of which level or levels are chosen, there should be a Welding Procedure Specification (WPS) for each welding process that lists essential or nonessential variables. A recommended form for the WPS is given in Annex C. For a list of essential and nonessential variables see Table 13.

9.1.2 Procedure Requalification. Changes may be made in the nonessential variables to suit production requirements without requalification of the procedure provided such changes are documented in either an amendment to the original WPS or a new WPS. A change in any essential variable should require the contractor to notify the buyer to determine if and how requalification is to be performed.

9.2 Procedure Qualification Record (PQR). The specific facts involved in qualifying a WPS should be recorded in a form called a PQR, which should document the essential variables of the specific welding process or processes, as listed in Table 13, and the test results. Recommended forms are given in Annex C.

9.2.1 WQTR Forms. If the welding process or processes employed are automatic or semi-automatic, then procedure qualification will normally suffice for welder or operator qualification. If the welding process or processes employed are manual, then welder qualification is recommended. Recommended forms for Welder Qualification Test Record (WQTR) are given in Annex C.

9.2.1.1 Level 1 Qualification. Level 1 procedure qualification consists of a plate test as shown in Figure 13. The purpose of this level of qualification is to determine the suitability for use of a given combination of consumables before undertaking extensive procedure qualifications. This level of procedure qualification can be utilized for journal repair, body buildup, or body overlaying. The welding parameters for a plate test quite often do not represent the parameters required to weld a rotating roll of varying diameter. Therefore the results of Level 1 qualification are only an approximation for roll procedure qualification. While Level 1 qualification may be used to qualify procedures for journal repair and buildup, it is not recommended to use Level 1 qualifications to approve the procedure for roll overlay. It is recommended that at least five layers of weld overlay be deposited for testing.

9.2.1.2 Level 2 and 3 Qualifications. Level 2 and 3 procedure qualifications consist of a roll/cylinder test as shown in Figure 14. The purpose of these qualifications are to impose more stringent requirements on the contractor and to be able to test and qualify both the procedures and material properties that closely represent the actual welded roll. If the procedure qualification is to be performed for overlays where buildup and buttered layers are used, it is recommended that the qualification be performed whereby these layers are deposited before application of the overlay.

9.3 Type of Tests Required. The necessary tests that may be performed to qualify a welding procedure are given in Table 12.

9.3.1 Chemical Composition Analysis. A chemical composition analysis should be obtained from the test coupon. In the case of the plate test (Level 1), the analysis represents the all-weld metal composition. Samples should be taken as close to the top surface as possible to minimize dilution from the base metal. In the case of the roll/cylinder test (Levels 2 and 3) the test can be at the finished overlay thickness specified by the buyer. Where the overlay radial thickness is high (typically > 5/8 in. [16 mm]), it is not necessary to deposit the entire thickness on the test roll. Thinner overlays than required for actual roll applications can be used for qualification purposes as long as the overlay is of sufficient thickness to avoid dilution from the base metal.

9.3.2 Hardness. Hardness testing is to be performed after PWHT (if applicable). For the plate test, the hardness readings should be taken on the machined surface of the weld metal. For the roll/cylinder test, the hardness readings should be taken at the maximum and minimum overlay thicknesses specified by the buyer. The recommended locations of the hardness impressions are shown in Figure 15.

Table 12
Sample Types vs. Qualification Levels

	Level 1	Level 2	Level 3
Plate	X	—	—
Roll/Cylinder	Optional	X	X
Chemical	X	X	X
Hardness	X	X	X
Soundness	X	X	X
CVN	Optional	X	X
Tensile	Optional	X	X
Thermal Fatigue	—	—	Optional
Hot Hardness	—	—	Optional
Temper Response	—	Optional	X
Microstructure	—	—	Optional
Temper Embrittlement	—	—	Optional
Corrosion	—	—	Optional
Wear Resistance	—	—	Optional
Chemistry Profile by Depth	—	Optional	X

Table 13
Welding Process Variables

Variable No.	Variable	Welding Process								
		SAW			FCAW			GMAW		
		A ^a	B ^b	C ^c	A ^a	B ^b	C ^c	A ^a	B ^b	C ^c
Joint Variables										
(1)	Groove Design	X			X			X		
(2)	± Backing									
(3)	– Backing (complete joint penetration welds)	X			X			X		
(4)	+ Backing									
(5)	> Fit-up Gap									
(6)	Penetration									
Material Variables										
(1)	Group Number		X			X			X	
(2)	> Thickness of 5/8 in. [16 mm] over Max. Qualified		X			X			X	
(3)	t > Thickness Qualified	X			X			X		
(4)	> Pass Thickness Limit	X			X			X		
(5)	> Base Metal Thickness (GMAW-S)							X		
(6)	M-Number	X			X			X		
(7)	M-Number from 9-A to 9-B	X			X			X		
Filler Metal Variables										
(1)	Cross-Section or Wire Speed									
(2)	< t or Chemical Composition									
(3)	Size of Filler Metal									
(4)	F-Number	X			X			X		

(Continued)

Table 13 (Continued)
Welding Process Variables

Variable No.	Variable	Welding Process								
		SAW			FCAW			GMAW		
		A ^a	B ^b	C ^c	A ^a	B ^b	C ^c	A ^a	B ^b	C ^c
Filler Metal Variables (Cont'd)										
(5)	Chemical Composition (i.e., A-No.)	X			X			X		
(6)	> Diameter	X			X			X		
(7)	± Supplementary Deoxidizers									
(8)	Flux Classification	X								
(9)	Chemical Composition by > or < of Alloy Flux	X								
(10)	Size of Flux Particles			X						
(11)	Filler Metal Classification		X	X		X	X		X	X
(12)	± Consumable Insert									
(13)	± Filler Metal									
(14)	Flux Type or Chemical Composition									
(15)	Filler Metal and Flux Brand Named	X			X					
(16)	Wire to Strip or Vice Versa									
(17)	Guide Type									
(18)	Method of Addition									
(19)	Chemical Composition									
(20)	FCAW-S to FCAW-G or vice versa				X					
(21)	± Supplemental Filler Metal		X			X			X	
(22)	± Supplemental Powder Filler Metal	X								
(23)	> Supplemental Powder Filler Metal	X								
(24)	Chemical Composition by > or < Supp. Powder	X								
Positions										
(1)	+ Position	X			X			X		
(2)	Position to Vertical					X			X	
Preheat										
(1)	< 100°F [38°C]	X			X			X		
(2)	Temperature			X			X			X
(3)	> Maximum Interpass Temperature		X			X			X	
Postweld Heat Treatment										
(1)	PWHT	X			X			X		
(2)	± Solution PWHT for M-8 Base Metal	X			X			X		
Gas										
(1)	± Trailing or Chemical Composition									
(2)	Gas or Gas Mixture				X			X		
(3)	Flow Rate				X			X		
(4)	Chemical Composition and Flow Rate									

(Continued)

Table 13 (Continued)
Welding Process Variables

Variable No.	Variable	Welding Process								
		SAW			FCAW			GMAW		
		A ^a	B ^b	C ^c	A ^a	B ^b	C ^c	A ^a	B ^b	C ^c
Gas (Cont'd)										
(5)	+ Backing Gas or Rate or Composition									X
(6)	Environmental									
Electrical Characteristics										
(1)	Current Type (I), Polarity, > Heat input		X			X			X	
(2)	Mode of Metal Transfer						X			X
(3)	± Pulsed Current									
(4)	± 15% Current or Voltage									
(5)	Beam Parameters (EBW)									
(6)	Pulsing Frequency									
(7)	Current Type or Polarity, or ± I or V			X			X			X
Technique										
(1)	Current Type (I), Polarity, > Heat input			X			X			X
(2)	Bead Technique			X			X			X
(3)	Method of Back Gouging			X			X			X
(4)	Oscillation			X			X			X
(5)	Multiple Pass to Single Pass per Side			X			X			X
(6)	Single to Multiple Electrode, or Vice Versa		X			X			X	
(7)	Chamber									
(8)	Melt-in to Keyhole or Vice Versa									
(9)	± Retainers			X			X			X
(10)	Gun Angle									
(11)	Electrode Spacing			X			X			X
(12)	Type or Model of Equipment									
(13)	> Absolute Pressure (Vacuum)									
(14)	Filament Configuration									
(15)	+ Wash Pass									
(16)	1 to 2 Sides or Vice Versa									
(17)	< Travel Speed over 10%		X			X			X	

^a The symbol A when marked with an "X" signifies that the given variable is essential and should be documented in both the PQR and WPS. If this variable is changed from that qualified (i.e., documented on the PQR), the WPS should be requalified.

^b The symbol B when marked with an "X" signifies that the given variable is essential only when fracture toughness is a requirement. When fracture toughness is a requirement, these variables are the same as those in Note a.

^c The symbol C when marked with an "X" signifies that the given variable is nonessential and may be changed on the WPS without requalification, but the WPS should be revised.

^d Unless the consumables are classified under AWS specifications.

Legend:

<u>Change</u>		<u>Welding Processes</u>
< = Decrease	t = Thickness	SAW: Submerged Arc Welding
+ = Addition	↑ = Uphill	FCAW: Flux Cored Arc Welding
- = Deletion	↓ = Downhill	GMAW: Gas Metal Arc Welding
> = Increase		

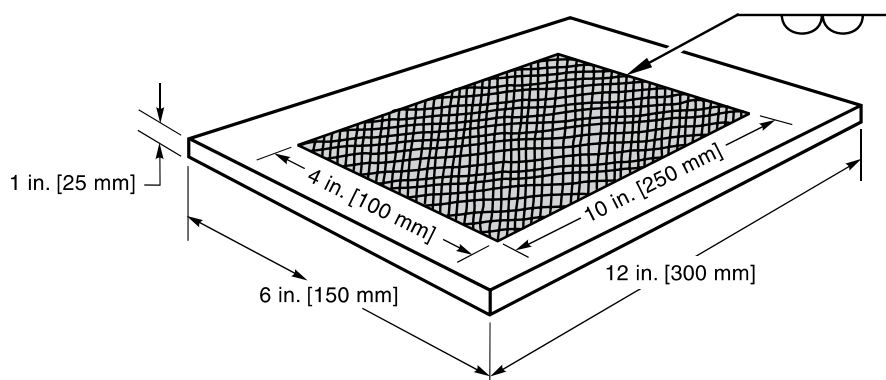


Figure 13—Basic Bead on Plate Sample for Level 1 Qualification

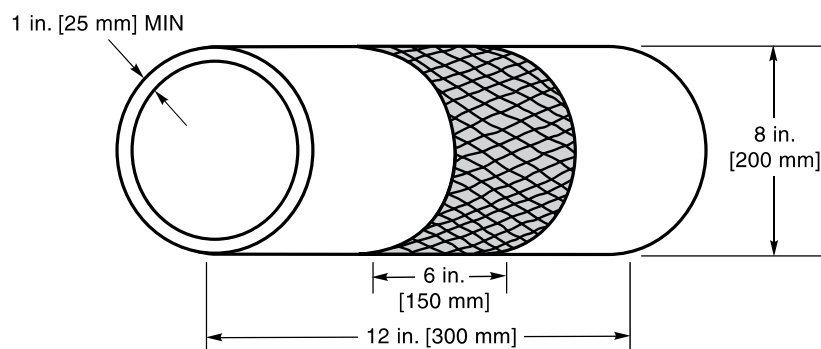
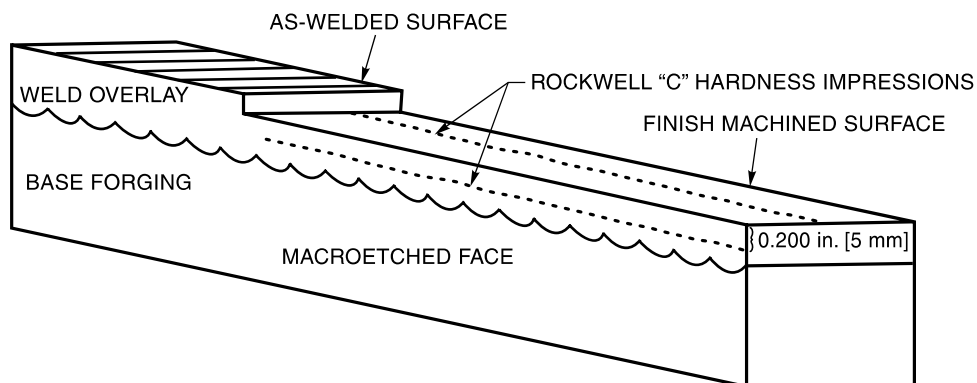


Figure 14—Roll Cylinder Sample for Level 1, 2, or 3 Qualification



Notes:

1. Samples 1A1, 2B1, and 2C1 from Figure 16 are to be used for Rockwell “C” hardness testing after samples are macroetched.
2. Rockwell “C” hardness impressions are to be taken at two locations:
 - Along a 6 in. [150 mm] line located on the finish machined surface, at 1/2 in. [13 mm] intervals.
 - Along a 6 in. [150 mm] line located 0.200 in. [5 mm] beneath the finish machined surface, at 1/2 in. [13 mm] intervals.

Source: Figure supplied courtesy the United States Steel Corporation—Technical Center.

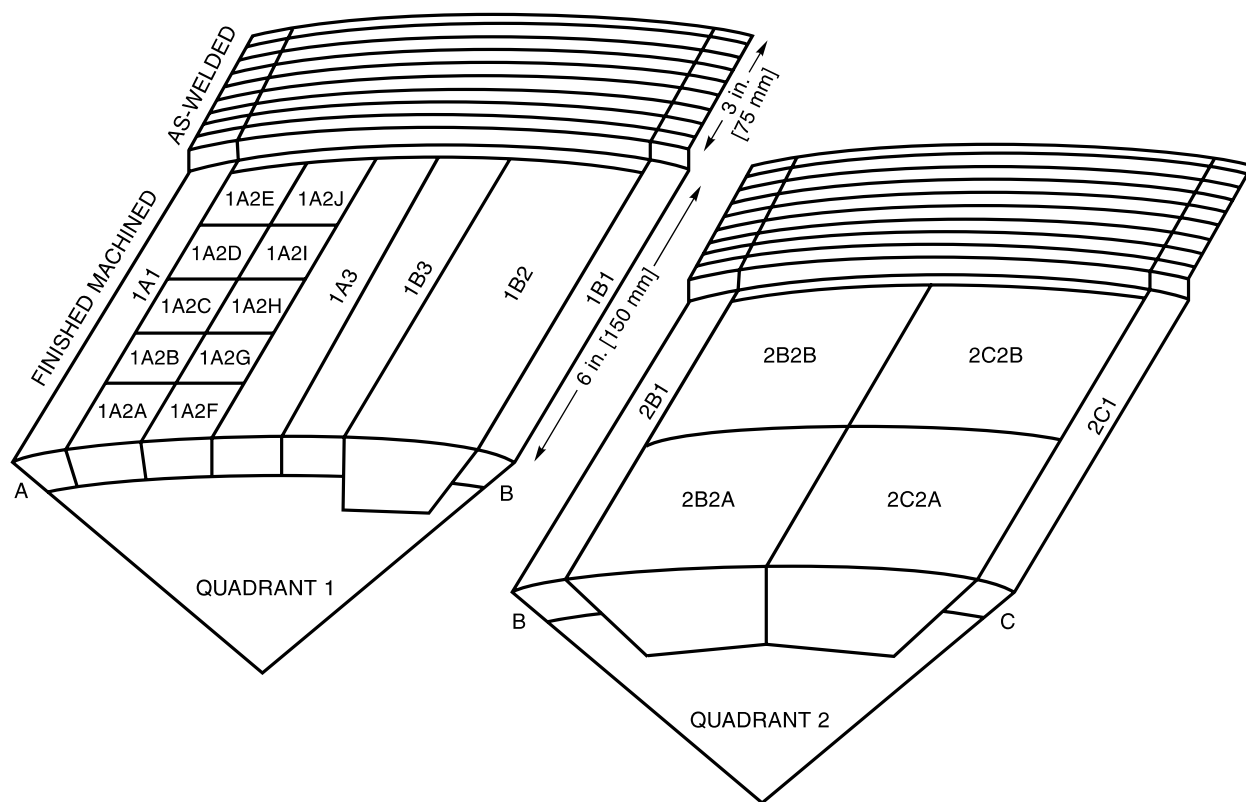
**Figure 15—Roll Qualification Tests—Qualification of Hardfacing—
Location of Rockwell Hardness Test Samples 1A1, 2B1, 2C1**

9.3.3 Soundness. The weld overlay surface should be examined by the Magnetic Particle Inspection method (ASTM E 709, *Practice for Magnetic Particle Examination*), providing the material is magnetic. If the material is nonmagnetic, then examination is typically by the Liquid Penetrant Inspection Method (ASTM E 165, *Standard Test Method for Liquid Penetrant Examination*). Magnetic particle or liquid penetrant testing should be performed after machining the surface of the overlay.

One face of a cross-section coupon should be ground smooth and etched with a suitable etchant to give a clear

definition of the weld metal and heat-affected zone (HAZ). Visual examination of the cross section of the weld metal should show complete fusion. The weld metal and HAZ should be free of cracks. The recommended locations of the etch test samples are shown in Figures 15 and 16.

9.3.4 Impact. Charpy V-notch samples can be removed (minimum 3 samples, see Figures 17 and 18) to test notch toughness. Test procedures and apparatus for Charpy V-Notch testing should conform to the requirements of AWS B4.0, *Standard Methods for Mechanical*

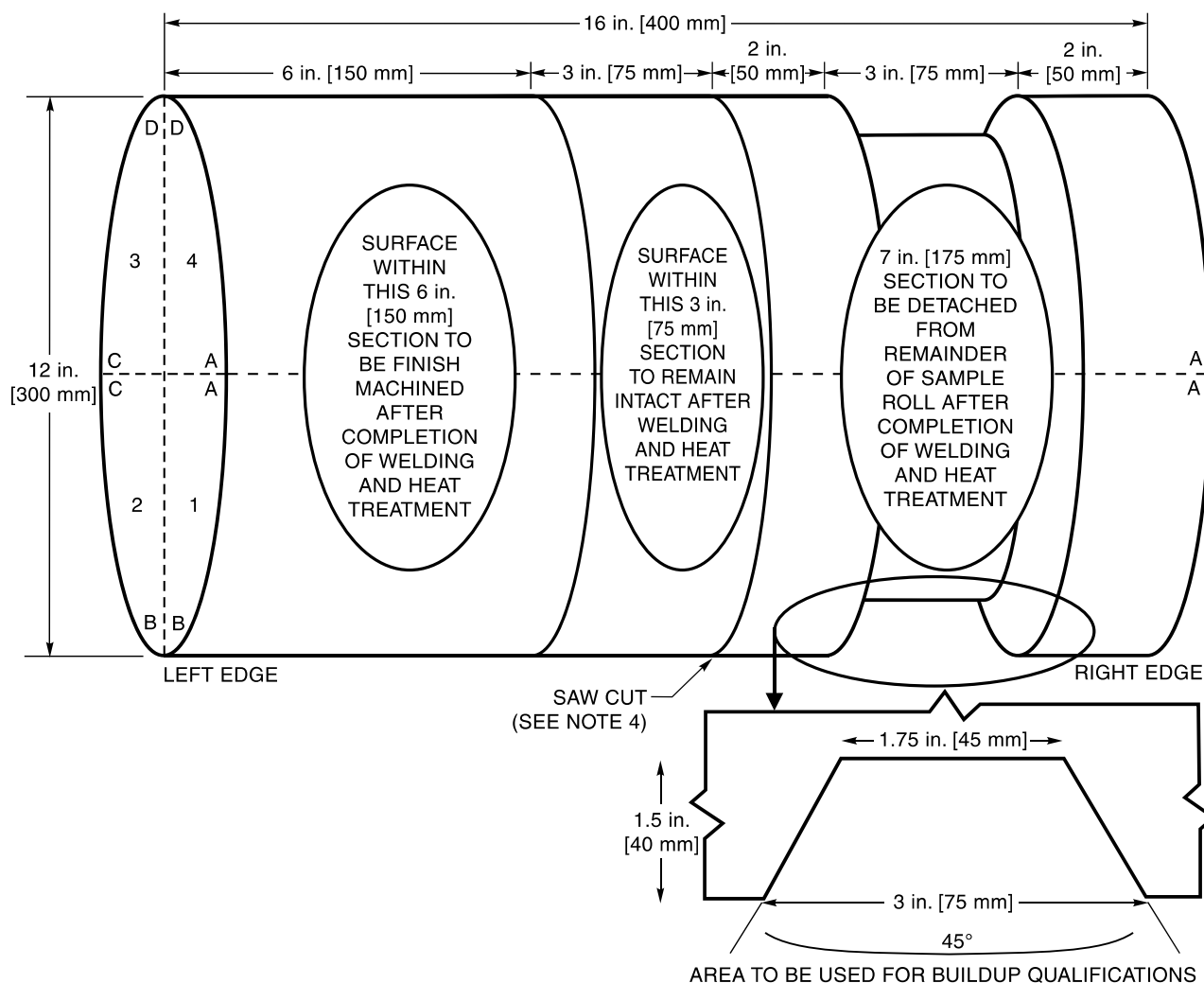


Notes:

1. Quadrants 1 and 2 of the hardfacing qualification portion of the test roll are to be used for sampling/testing by the vendor. Quadrant 3 is to be sent to the Purchaser's chosen testing laboratory; quadrant 4 is to be retained by the Vendor.
2. 1A1, 1B1, 2B1, and 2C1 are to be removed as full-length sections 9 in. [225 mm] long, 1 in. [25 mm] wide, 1 in. [25 mm] deep. All four sections should be macroetched and checked for weld thickness and cleanliness.
 - (i) 1A1 is to be used for Rockwell hardness testing (Figure 15) and chemical analysis.
 - (ii) 1B1 is to be used for metallographic samples and microhardness testing.
 - (iii) 2B1 is to be used for Rockwell hardness testing (Figure 15).
 - (iv) 2C1 is to be used for Rockwell hardness testing (Figure 15) and characterization of intentional hardfacing interruptions.
3. 1A2 is to be removed and sectioned into ten (10) pieces, 1 in. [25 mm] long, 1 in. [25 mm] wide and 1 in. [25 mm] deep. These samples will be used for temper resistance testing.
4. 1A3 and 1B3 are to be removed as sections 6 in. [150 mm] long, 1 in. [25 mm] wide and 1 in. [25 mm] deep for corrosion testing.
5. 1B2 is to be removed as a section 6 in. [150 mm] long, 2 in. [50 mm] wide and 2 in. [50 mm] deep for hot hardness testing.
6. 2B2 is to be removed and cut into two (2) pieces, 3 in. [75 mm] long, 3 in. [75 mm] wide and 2 in. [50 mm] deep for fire-crack testing.
7. 2C2 is to be removed and cut into two (2) pieces, 3 in. [75 mm] long, 3 in. [75 mm] wide and 2 in. [50 mm] deep for fire-crack testing.

Source: Figure supplied courtesy the United States Steel Corporation—Technical Center; adapted to add metric dimensions.

**Figure 16—Roll Qualification Tests—Qualification of Hardfacing—
Sample Layout and General Description**

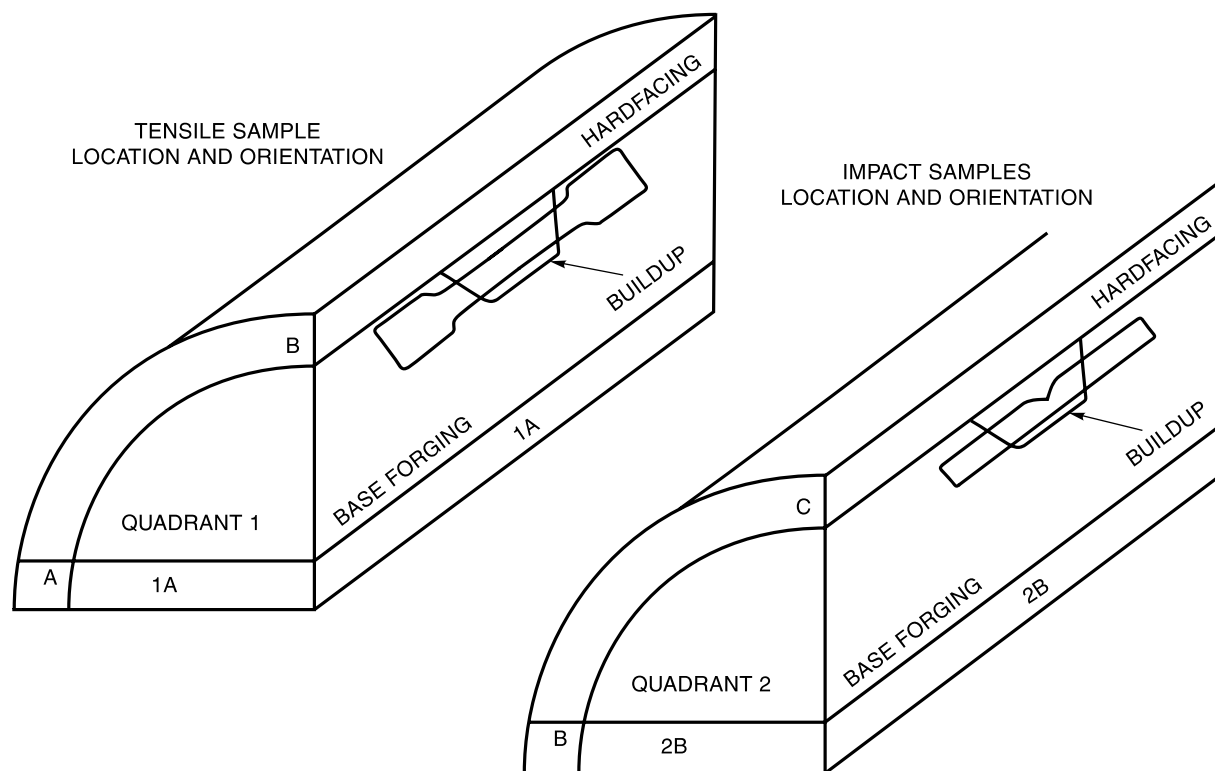


Notes:

1. The sample roll configuration, as specified above, should be machined from an appropriate size forging which conforms to the roll body composition and mechanical property specifications.
2. The machined groove is to be repaired using an appropriate buildup material and weld technique as documented in the WPS.
3. After the buildup material has been applied within the groove area, hardfacing alloy is to be applied across the entire roll surface using appropriate materials and weld techniques as documented in the WPS.
4. Three intentional hardfacing weld interruptions should be performed at location C-C: 1), within the initial layer at 2 in. [50 mm] from the left edge, 2) within the middle layer at 3 in. [75 mm], and 3) the final layer at 4 in. [100 mm] from the left edge of the test roll. All other starts/stops should be done near location A-A.
5. Upon successful completion of the welding processes and post-weld heat treatment, the left side (9 in. [225 mm]) of the test roll should be saw cut from the right side (7 in. [175 mm]) at the indicated location, to facilitate qualification testing of the hardfacing and buildup materials, respectively.

Source: Figure supplied courtesy the United States Steel Corporation—Technical Center; adapted to add metric dimensions.

**Figure 17—Roll Buildup Qualification Tests—
Sample Roll Configuration Prior to Welding**



Notes:

1. Quadrants 1 and 2 of the buildup qualification portion of the test roll are to be used for sampling/testing by the vendor. Quadrant 3 is to be sent to the Purchaser's testing laboratory. Quadrant 4 is for retention by the vendor.
2. Samples 1A and 2B are to be removed as full length sections, 7 in. [175 mm] long, 6 in. [150 mm] wide, and 1 in. [25 mm] thick. Both sections should be macroetched and checked for weld thickness and cleanliness.
3. A minimum of two (2) tensile samples are to be removed from the "B" side of Quadrant 1. The reduced section of each sample should be located within the buildup region of the test roll. The tensile samples should conform to AWS B4.0 for a 0.500 in. [13 mm] diameter round specimen.
4. A minimum of four (4) Charpy V-notch impact specimens are to be removed from the "C" side of Quadrant 2. The notched portion of each sample should be located entirely within the buildup region of the test roll and oriented as indicated in the above schematic. The Charpy V-notch specimens should conform to the requirements of AWS B4.0.

Source: Figure supplied courtesy the United States Steel Corporation—Technical Center; adapted to add metric dimensions.

**Figure 18—Roll Buildup Qualification Tests—
Qualification of Buildup—Location of Test Samples**

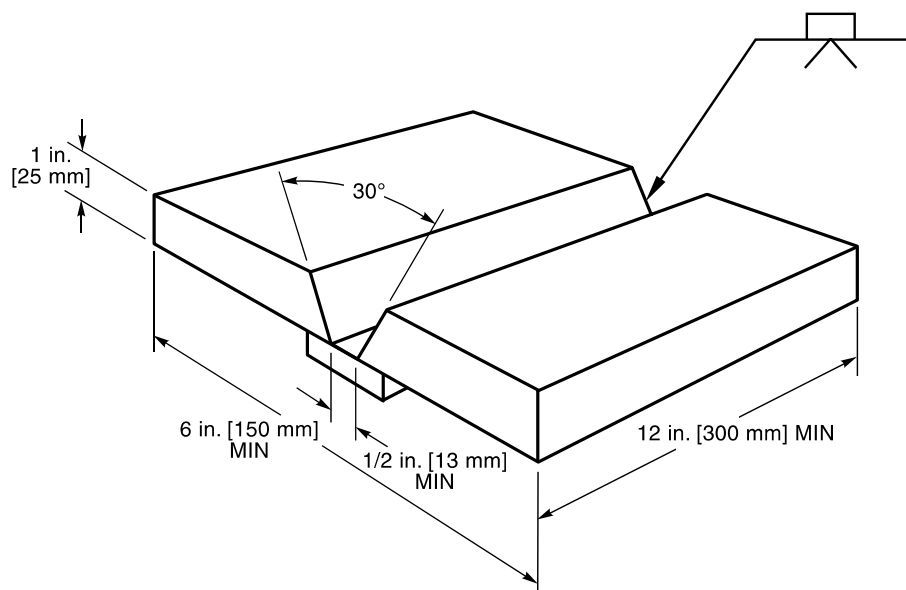
Testing of Welds. Testing temperature should be specified by the Purchaser.

For Level 1 qualification of buildup materials, impact test sample can be taken from weld metal using the test configuration shown in Figure 19. It should be assured that the notch is placed in undiluted weld metal. For Level 2 or 3 qualification of buildup material, refer to Figure 18. For all levels of qualification involving the overlay, test configuration shown in Figure 19 should be used.

9.3.5 Tension Tests. Generally, tension tests are recommended only for buildup and journal repair qualification. These types of tests usually are secured from unlimited thickness all-weld-metal coupons taken from plate tests for Level 1 qualifications as shown in Figure

19. If Level 2 or 3 qualification is required then the buildup tension test sample are to be secured from the roll/cylinder as shown in Figure 18. Testing is to be in accordance with AWS B4.0, *Standard Methods for Mechanical Testing of Welds*. Acceptance criteria should meet the Purchaser's requirements or the roll manufacturer's specifications.

9.3.6 Thermal Fatigue. This test is intended to judge the suitability of the overlay material for a service environment that includes thermal shock. It is the responsibility of the buyer to specify the test parameters (test heating and cooling rates, time at temperature, cooling method, etc.) that represent the service environment. The locations of the test coupons are shown in Figure 16. It should be



Notes:

1. When radiography is used for the testing, no tack welds should be in the test area.
2. The backing thickness should be 1/2 in. [13 mm] min; backing width should be 3 in. [75 mm] min when not removed for radiography, otherwise 1 in. [25 mm] min.

Figure 19—Level 1 Tensile Test for Journal and Buildup Materials

recognized that there is no standardized test method to evaluate thermal fatigue performance of overlays. Generally, this test is conducted to compare the performance of new overlay materials against existing overlays.

9.3.7 Hot Hardness. This test is intended to judge the ability of the overlay to maintain its strength, as measured by hardness, at elevated temperatures. Typically a sample is removed from the roll/cylinder and hardness tested at room temperature 70°F [20°C]. Then the sample is heated to test temperatures of 600°F [315°C], 800°F [425°C], 1000°F [535°C], 1100°F [595°C], and 1200°F [650°C] and held at each of these temperatures for two hours. Hardness indentations are made while the sample is at these test temperatures and either directly read or calculated after the sample has cooled to room temperature. Experience has shown that the above recommended test temperatures give a good indication of the hot hardness of overlays. However users can select other temperatures for this test. The sample location is shown in Figure 16.

9.3.8 Temper Response. This test is intended to measure the overlay's resistance to softening as a function of time and temperature. A series of test samples is removed from the roll/cylinder. Samples are tempered in a furnace for 5, 10, 20, 50, and 100 hours at 1100°F

[595°C] and a second series of samples is tempered at 1200°F [650°C] for the same length of time. Hardness readings are taken after the samples cool to room temperature. The buyer should specify the test temperatures if other temperatures are to be used. It is recommended that the tempering temperatures selected are representative of the roll service environment. The test sample locations are shown in Figure 16.

9.3.9 Microstructure. This test is intended to reveal the microstructural detail of the overlay in the final condition supplied for an intended service. It is useful in detecting micro-cracks both in the overlay and heat-affected-zone (HAZ). The contractor should select an appropriate etchant to document the features of the microstructure as related to the intended service environment. The location of the test sample is shown in Figure 16.

9.3.10 Temper Embrittlement. This test is intended to measure the resistance of buildup materials to temper embrittlement. The test samples should be removed from the roll/cylinder coupon shown in Figures 17 and 18. Various heat treatment schedules have been employed to evaluate temper embrittlement. The schedule should be agreed upon by the Contractor and Purchaser. A suggested schedule, which lasts about 10 days, is as follows:

1. Heat to 1100°F [593°C], hold 1 hour;
2. Furnace cool at 10°F [5.5°C] per hour to 1000°F [538°C] and hold for 15 hours;
3. Furnace cool at 10°F [5.5°C] per hour to 975°F [524°C] and hold for 24 hours;
4. Furnace cool at 10°F [5.5°C] per hour to 925°F [496°C] and hold for 60 hours;
5. Furnace cool at 10°F [5.5°C] per hour to 875°F [468°C] and hold for 100 hours;
6. Furnace cool at 50°F [28°C] per hour to 600°F [315°C], then air cool to ambient.

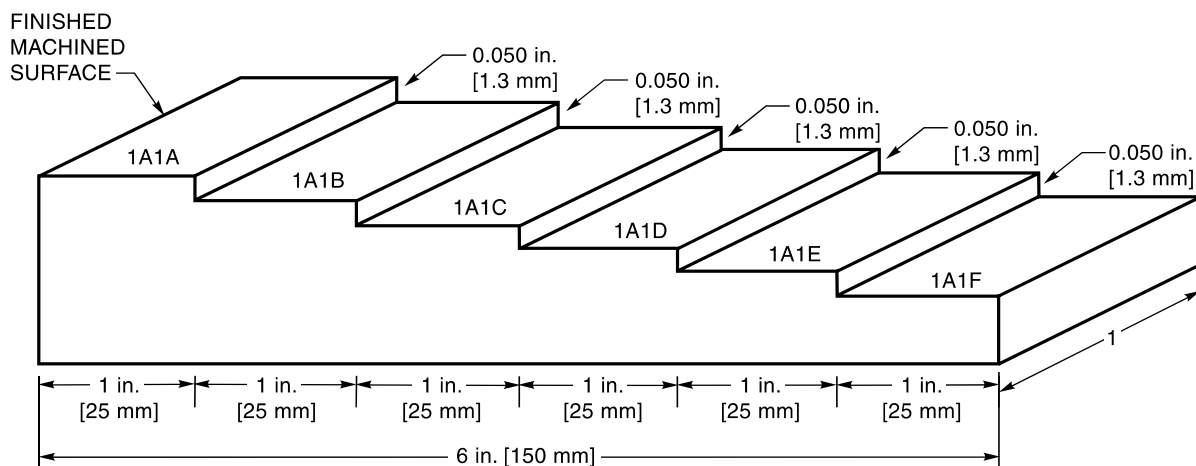
9.3.11 Corrosion. This test is intended to measure the resistance of the overlay material to corrosive attack. The test samples should be removed from the roll/cylinder coupon as shown in Figure 16. The test should be conducted in accordance with ASTM G 48, Practice A⁶ or other suitable test methods, except that the samples from the roll surface are to contain at least two adjacent weld beads. This test can provide comparative data when a base reference can be established. However the test

⁶Tests have been conducted in accordance with ASTM G 48 Practice A. However, this test is rather severe and proper interpretation of the results is difficult.

should not be used to predict service life of the roll overlay.

9.3.12 Wear. This test is intended to measure the resistance of the overlay materials to wear. The test samples should be removed from the roll/cylinder coupon. The buyer should determine the type of wear test based on knowledge of the service environment. Tests can be wet or dry, room or elevated temperature, and low or high load. This test can provide comparative data when a base-level reference can be established. However this test should not be used to predict service life of roll overlays. A number of wear tests may be applied, including ASTM G 65, G 77, and G 83, but none of these tests simulate the situation in industrial mill roll service. Interpretation of test results should be mutually agreed between the Contractor and Purchaser.

9.3.13 Composition Profile. This test is intended to measure the variation in composition of the overlay when the roll working diameter is reduced from start size to scrap size. The buyer should specify the start and scrap diameters and the number of composition test locations. The composition test sample should be removed from the roll/cylinder coupon and machined to a configuration as shown in Figure 20. This test is intended to establish the effect of weld dilution and verify that roll working surface composition will conform to the buyer's specification as the roll diameter is reduced in service to scrap diameter.



Notes:

1. Sample 1A1 is used for chemical analyses after it has been macroetched and hardness tested.
2. Locations of the surfaces to be analyzed: five incremental steps of 0.050 in. [1.3 mm] into the surface, starting from a location on the original finished machined surface.

Source: Figure supplied courtesy the United States Steel Corporation—Technical Center; adapted to add metric dimensions.

Figure 20—Roll Qualification Tests—Qualification of Hardfacing—Location of Chemical Analysis Samples—Sample 1A1

10. Repair and Correction

10.1 General

10.1.1 This section covers the repairs and/or corrections of nonconformances found during inspections. Nonconformances include deviations of the dimensional and surface finish requirements of the drawing, rejectable nondestructive examination indications, or additional requirements agreed to by the Purchaser and Manufacturer which are not met. It covers repairs and/or corrections to the base roll forging (journals or body), the weld buildup of the roll body, the weld buildup of the roll journals, and the roll body overlay.

10.1.2 The determination as to the disposition of nonconformance should ultimately be at the discretion of the Purchaser unless otherwise agreed upon between the Purchaser and the Manufacturer. It is recommended that acceptance/rejection criteria be established and agreed to by the Purchaser and the Manufacturer prior to the initiation of work.

10.1.3 Repair or correction work performed by those other than the Manufacturer should have approval from the Manufacturer and should be performed in accordance with the Manufacturer's and Purchaser's requirements.

10.2 Examples of Nonconformance

10.2.1 Roll body and journal nonconformance may include discontinuities, defects, and imperfections caused by the welding, heat treatment, or machining operations. Some examples are listed below:

1. Tool breakage during the final machining operation;
2. Linear indications, trapped flux/slag, pitting, porosity;
3. Nonuniform hardness and/or hardness measurements not within the specified range;
4. Insufficient material to finish to required diameter;
5. Handling damage;
6. Chemical analysis of the weld overlay not within the specified range;
7. Incorrect heat treatment cycle; and
8. Dimensional and surface finish deviations from drawing requirements.

10.3 Purchaser's and Manufacturer's Obligations

10.3.1 Due to the diversity of rolls and their applications covered by this standard, it would be inappropriate, if not impossible, to cover all methods for repairing or correcting nonconformances. Therefore, the Purchaser

and the Manufacturer should agree to the essential criteria for the repair or correction of nonconformance.

10.3.2 It should be the obligation of the Manufacturer to submit a detailed manufacturing process to the Purchaser/user, which addresses the repair/correction of nonconformance. The Manufacturer should address the following items.

1. Third party work;
2. Repair options and types;
3. Acceptance and Rejection criteria;
4. Purchaser and User notification and reporting;
5. System to address each nonconformance; and
6. The Purchaser may require a separate WPS for repair welding to correct nonconformance.

10.3.3 It should be the obligation of the Purchaser to provide the Manufacturer, when necessary, with the operating conditions of each roll type. This information should provide the Manufacturer with as much information as possible so that the Manufacturer can successfully develop, submit, and implement a manufacturing process which addresses the items in 10.3.2.

11. Finish Machining and Final Inspection

11.1 Setup. If bearing journals or other critical areas of the roll have not been welded and conform to drawing specification, the roll should be lined up to these areas to prevent runout. The roll should be centered as necessary to ensure that all critical surfaces will be concentric.

11.2 Rough Machining. Normally, rough machining is necessary to remove excess stock, relieve residual stresses, and prepare the surface for inspection prior to final machining. Stock allowed for final machining should be kept to a minimum so that subsequent inspections of the roll surface will be as close as possible to the final dimension. Also, chemical analysis of the overlay close to the final size may be required. The stock allowance is dependent upon the final machining methods, roll material, and the drawing specifications. Weld fusion lines between welded and unwelded areas of the roll should be undercut to remove stress risers.

11.3 In-Process Inspection. One or more of the following inspection methods should be performed to ensure that the roll will satisfy drawing specifications after final machining.

11.3.1 Visual Inspection. The roll should be visually inspected for surface defects and noncleanup of the welded surfaces. A qualified inspector (qualified to SNT TC-1A, QC1, or other equivalent programs as agreed to by the Purchaser and Manufacturer) should conduct the inspection of the prepared surface.

11.3.2 Dimensional Inspection. Dimensional inspection should be performed to ensure all areas can be acceptable after final machining. Total indicated runout of all critical surfaces should be verified and the roll centered as necessary to ensure concentricity at final machining.

11.4 Final Machining. All welded surfaces should be machined to drawing specifications. Particular attention should be given to high stress areas such as inside corners at shoulders and grooves. The radii in these areas should be to drawing dimensions and should be free of tool marks, which could cause stress risers and potential failure.

11.5 Final Inspection. All inspection criteria and acceptance standards should be mutually agreed to by Purchaser and Manufacturer. One or more of the following inspection methods should be performed to determine areas of nonconformance.

11.5.1 Visual Inspection. Visually inspect the roll for obvious defects, stress risers, appearance and proper identification. A qualified inspector (qualified to SNT TC-1A, QC1, or other equivalent programs) should conduct the inspection of the prepared surface.

11.5.2 Dimensional Inspection. The roll should be inspected for conformance to dimensional tolerances.

11.5.3 Nondestructive Examination. Nondestructive examinations should be performed per 5.5.3. In addition, surface finish tests may be required.

11.5.4 Chemical Analysis. Chemical analysis of the overlay material may be required. Care should be taken to insure that the sample analyzed is representative of the working surface of the roll. This is of particular concern with stainless steel overlays where the working surface should be located within the top layer (refer to “dark bands” in 8.4.8.4).

11.6 Nonconformance. Refer to Section 10 for information on actions for nonconformance.

11.7 Documentation and Reporting. The documentation and reporting of all inspections should be completed as required by customers and QA agencies, internal and external. A typical form for reporting final inspection results is shown in Figure C.1.

12. Quality Assurance

12.1 General. The Manufacturer should be responsible for the development of a system to ensure quality. This system should be developed to encompass all roll types or be easily modified to suite particular roll applications. The system should be developed by the Manufacturer and be capable of meeting both the requirements of this standard and the Purchaser’s quality control system. A written description of the system should be submitted to the Purchaser in addition to the documentation referenced by this standard and the Purchaser. All documentation including quality system documents should be mutually agreed to by the Manufacturer and the Purchaser prior to the initiation of work. It is recommended that proprietary information be protected by a written agreement between the Manufacturer and the Purchaser.

12.2 Quality System Outline. Listed below are recommended guidelines for items which should be addressed in the written description of the Manufacturer’s quality control system.

12.2.1 Authority and Responsibility. The authority and responsibility of those in charge of the Manufacturer’s quality control system should be clearly established. Persons performing quality control functions should have adequate training and authority to identify quality control issues, reject nonconforming product, and implement immediate corrective actions required to resolve nonconformance problems within the Manufacturer’s organization. An organizational chart illustrating the relationships between management, engineering, purchasing, manufacturing, inspection, quality, and quality control, should be a requirement of the Purchaser and be part of the Manufacturer’s quality control system documentation.

12.2.2 Drawing and Specification Control. The Manufacturer’s quality control system should provide procedures that ensure that the latest applicable drawings, specifications and procedures are consistently utilized for manufacturing, inspection, and testing.

12.2.3 Material Control. The Manufacturer should include a system of purchasing and receiving control that ensures that the material received is properly identified and that this identification remains with the product throughout processing. Documentation, including all material certifications and material test reports, should satisfy the requirements of the Purchaser’s quality system. In addition a system for material handling and storage should exist and should satisfy the requirements of both this recommended practice and the Purchaser’s quality system.

12.2.4 Examination and Inspection. The Manufacturer's quality control system should provide a written description of the entire manufacturing process including examination and inspection procedures.

12.2.5 Correction of Nonconformities. The Manufacturer's quality control system should provide methods for addressing the correction of nonconformities. The system should also provide a documented reporting format to the Purchaser which addresses not only methods for correction of nonconformities but corrective actions which should be implemented to prevent future nonconformities.

12.2.6 Nondestructive Examination. The quality control system should include provisions for identifying the nondestructive examination procedures the Manufacturer will implement to conform to the requirements of this standard and the Purchaser's requirements.

12.2.7 Heat Treatment. The quality control system should provide controls to ensure that heat treatments, when applicable, are implemented in accordance with the requirements of this standard in addition to those of the Purchaser.

12.2.8 Key Input and Output Process Variables/Characteristics. The quality control system should provide a format to monitor, measure, and document key process variables. Process variables should meet the recommendations of this standard, be mutually agreed to by the Manufacturer and Purchaser, and fulfill the requirements of the Purchaser's quality system.

12.2.9 Documentation. The quality control system should supply the Purchaser pertinent, mutually agreed to information for each roll or batch of rolls on a timely basis. The required information should be in accordance with this standard and the requirements of the Purchaser.

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Annex A (Informative)

Flux and Wire Consumables

This annex is not a part of AWS D14.7/D14.7M:2005, *Recommended Practices for Surfacing and Reconditioning of Industrial Mill Rolls*, but is included for informational purposes only.

A1. Flux-to-Wire Relationship

Submerged arc welding (SAW) has the possibility to significantly alter the composition of the weld deposit as compared to that of the filler wire, depending upon the specific flux used and, to a certain extent, upon the ratio of flux melted to wire melted. The flux to wire melt ratio in turn depends largely upon voltage (arc length) and wire feed speed and diameter, though electrode extension, flux composition and density, travel speed, and arc polarity also play roles. If everything else is held constant, increasing voltage increases the arc length and therefore increases the flux-to-wire ratio. On the other hand, increasing wire feed speed (current) increases the volume of metal reacting with a given volume of flux, decreasing the flux-to-wire ratio. As the flux to wire ratio increases, the potential for changes from the wire composition to the deposit composition increases. Then the actual change which occurs depends upon the specific flux used as well as upon the flux-to-wire ratio.

A2. Flux Types

There is no AWS classification system for fluxes alone. Mild steel and low alloy steel SAW wires and the fluxes with which they are used are classified by AWS according to the mechanical properties and deposit composition produced under standardized welding conditions by a specific flux/wire combination. That classification then conveys little or no information about performance of the flux with another wire, especially a high carbon wire or a high chromium wire. So flux classification has little meaning in metalworking roll welding, except when AWS provides for classification with the wire in use. However, fluxes can be described to a certain extent without AWS (or other) classification. There are two

types of descriptions which can convey considerable information about a flux and its potential for producing a change from the wire composition to the deposit composition. These descriptions are methods of manufacture and metallurgical characteristics.

A3. Flux Types by Method of Manufacture

A3.1 Fused Fluxes. Some SAW fluxes are manufactured by melting the mineral components in a furnace into a homogeneous liquid. The molten flux is then discharged from the furnace and cooled. Cooling can be achieved either by spraying the molten flux with a water stream, or by pouring it into a chill mold or through chill rolls. The solidified flux is then crushed to desired size for handling and weldability. Such fluxes are termed “fused” fluxes. It is not possible for fused fluxes to contain metal components (Mn, Si, Cr), so that the possibility of composition change, from the wire composition to the deposit composition, is somewhat limited, but not eliminated, with fused fluxes. In particular, significant pickup of Mn and/or Si can occur when a manganese silicate based flux is used with a high carbon or high chromium wire.

A3.2 Bonded Fluxes. Other SAW fluxes are manufactured by mixing finely divided powdered minerals, and possibly powdered deoxidizers and/or alloy elements as well, with a viscous liquid bonding agent, typically “water glass” (silicates of sodium, potassium, and/or lithium dissolved in water). By controlled mixing, pelletizing, and sintering, flux particles are produced containing all of the constituent minerals, deoxidizers, and alloy elements, if added. The binder prevents the various powdered constituents from separating. Such fluxes are termed “bonded” or “agglomerated” fluxes. When

deoxidizers and/or alloy elements are added to the flux, the potential for composition changes from the wire to the deposit is increased. However, not all bonded fluxes contain metallic materials.

A3.3 Recycled Slag (Crushed Slag). Some welding shops will collect the SAW slag generated during welding and send it to a crushing operation (internal or external) to be crushed to a size suitable for reuse as a welding flux. Since this slag has reacted with the welding wire already, as well as having reacted with any scale or dirt present during welding, the crushed slag will not be identical in composition and reaction potential with the original virgin flux. In particular, if the virgin flux contained deoxidizers and/or alloy elements, these will have been consumed (transferred to the weld pool) during the original melting, so they are not available in the crushed slag, which has become a new welding flux. If SAW slag is collected from more than one source, reactions with more than one wire could have taken place, which increases the possible variation in the new flux. If the practice of collecting SAW slag, crushing it, and reusing it as new SAW flux is adopted, it is recommended that a “closed loop” system be used, to provide for quality assurance. This means that only slag obtained from using a particular wire in one shop be collected, kept free of contaminants (including moisture), crushed, and used as new flux.

A3.4 Mechanically Mixed Fluxes. It is possible to mechanically mix, or blend, two or more fluxes to make a new, different flux. Mechanically mixed fluxes can have a tendency to separate again because of density differences among the various flux particles blended into the new flux, so they should be handled carefully to avoid vibrations, which promote separation. Crushed slag alone generally does not have welding characteristics (bead shape, wetting) that are as good as those of the virgin flux. Therefore, when crushed slag, as described in A3.3, is supplied as a new SAW flux, it is common to blend the crushed slag with virgin flux in a specific proportion so that this mechanical mixture is considered to be the new flux. In any case, the original manufacturer of the virgin flux cannot be considered the manufacturer of the crushed slag or of a blend of crushed slag with virgin flux because the product has been altered beyond the original manufacturer’s control. In a closed loop system using crushed slag, the welding shop may be considered the flux manufacturer. In an open loop system using crushed slag, the slag crusher (blender) may be considered the flux manufacturer. In either a closed loop system or an open loop system of slag crushing and reuse as SAW flux, the user of the flux should verify the quality assurance system covering the new flux.

A4. Flux Types by Metallurgical Characteristics

A4.1 Basic Versus Acid Flux. From a metallurgical point of view, a SAW flux used in metalworking roll welding can be described as basic, acid, active, neutral, and/or alloy. A flux can be both basic and active, or both acid and active. Basicity or acidity are determined by the various oxides present in the flux. Flux that contains a large portion of silica is generally acid. Flux that contains little silica is generally basic. A “Basicity Index” (B.I.) was defined by the International Institute of Welding (IIW) as:

$$\text{B.I.} = \frac{\text{CaO} + \text{MgO} + \text{BaO} + \text{SrO} + \text{Na}_2\text{O} + \text{K}_2\text{O} + \text{Li}_2\text{O} + \text{CaF}_2 + 0.5 \text{ MnO} + 0.5 \text{ FeO}}{\text{SiO}_2 + 0.5 \text{ Al}_2\text{O}_3 + 0.5 \text{ TiO}_2 + 0.5 \text{ ZrO}_2}$$

where the weight percent of each constituent is entered in the formula above. A flux whose B.I. is less than 1.0 is termed “acid.” A flux whose B.I. is greater than 1.5 is termed “basic.” A flux whose B.I. is between 1.0 and 1.5 is termed “neutral,” although this latter term can lead to some confusion because “neutral” is also used as a term for a flux which does not produce much change in deposit Mn and Si when large voltage changes occur as noted in A4.2.

Acid fluxes, when used with wires high in chromium and carbon, tend to produce both carbon and chromium reduction in the deposit as compared to the wire composition, and the magnitude of the change depends upon flux-to-wire ratio. On the other hand, basic fluxes produce very little change in deposit carbon and chromium content as compared to the wire composition, and there is little effect of large changes in flux-to-wire ratio.

A4.2 Active Versus Neutral Fluxes. Active fluxes contain enough metallic Mn and/or Si so that rather large changes in deposit Mn and/or Si content occur with large changes in flux-to-wire ratio. A “Wall Neutrality Number” (N) has been defined as:

$$N = 100 (|\Delta \% \text{ Si}| + |\Delta \% \text{ Mn}|)$$

where $|\Delta \% \text{ Si}|$ is the absolute value of the change in all-weld-metal silicon content, and $|\Delta \% \text{ Mn}|$ is the absolute value of the change in all-weld-metal manganese content, obtained at 36 volts as compared to welding at 28 volts, all other conditions maintained constant. If N is greater than 40, the flux is said to be “active.” If N is 40 or less, the flux is said to be “neutral.” However, because of possible confusion with “neutral” as a term applied to a flux with B.I. of 1.0 to 1.5, the term “nonactive” will be used instead when N not greater than 40 is meant in the remaining discussion. An increase in Mn or Si may produce a significant increase in deposit hardness, particu-

larly when the deposit is mild steel buttering or low alloy steel buildup.

A4.3 Alloy Fluxes. An “alloy” flux is a flux, which contains metallic alloy elements within the flux particles. These alloy elements are melted and mixed with the weld pool to add alloy elements to the deposit. For metalworking roll welding, alloy fluxes are generally used with carbon steel wires, typically AWS A5.17, *Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding*, Class EL12, to produce low alloy steel buildup or 12% Cr stainless steel overlay. Since all of the deposit alloy content comes from the flux, consistent deposit composition and properties in this situation are critically dependent upon maintaining constant flux-to-wire ratio. Rigid control of voltage, wire feed speed, stickout, and other welding variables is essential to obtain uniform deposits.

A5. Flux Storage and Handling

Flux should be protected from contamination before use. The most common and often most important contaminant is moisture. All fluxes have some tendency for moisture pickup when exposed to humid air. Fluxes are most commonly packaged by their manufacturer in multi-layer bags which afford considerable protection from atmospheric moisture. In undamaged bags and protected from contact with liquid water, flux can usually be stored for six months minimum without adverse effects during welding. Sealed plastic bags or sealed pails provide even better protection. Once the original package has been opened, storage in a heated oven at about 210°F [100°C] is commonly recommended.

Flux which has been exposed to atmospheric humidity can be returned to fully dry condition by rebaking. Typical rebake temperatures depend upon the specific flux in question. For fused fluxes, rebaking at 300 to 500°F [150 to 260°C] is commonly recommended. For bonded fluxes, 500 to 700°F [260 to 370°C] is commonly recommended. The manufacturer of the flux should be contacted for more specific flux rebaking recommendations. It should be noted that SAW flux is a rather good insulator, so that effective rebaking requires either burying a thermocouple in the center of the flux depth and monitoring at least one hour at rebake temperature at the mid-depth of the flux, or holding the flux at the rebake temperature for at least one hour per 1 in. [25 mm] of maximum flux depth in the oven. When flux is being rebaked, it is important that the oven contain no other sources of moisture.

During welding, unmelted flux particles are commonly picked up by a vacuum collection system and returned to

the flux supply system. This flux is normally heated by its proximity to molten slag during welding, which helps to keep it dry. However, a mechanically mixed flux, such as a blend of crushed slag and virgin flux, may separate in the vacuum collection and delivery system. In this case, it is advisable to separate vacuum collection from delivery back to the welding head, and provide a rebinding step between collection and delivery. Also, repeated cycles of vacuum collection and delivery back to the welding head may result in some breakdown of bonded flux particles, especially those containing metallic deoxidizers and/or alloy elements. Then, some separation of high density metallic particles from lower density mineral particles can occur, and weld deposit homogeneity may be adversely affected. The supplier of an active or alloy flux should be contacted for guidance on the number of repeated cycles of vacuum collection and delivery back to the welding head which are advisable for a particular flux.

A6. Welding Wires for Metalworking Roll Welding

Welding wires for metalworking roll welding are generally provided in large drums containing as much as 500 or 750 lb [225 or 340 kg]. Common sizes used are 3/32 in. [2.5 mm], 1/8 in. [3.2 mm], and 5/32 in. [4 mm]. 1/16 in. [1.6 mm] wire might be used on rolls of about 6 in. [150 mm] diameter or less. And 3/16 in. [4.8 mm] wire might be used on large rolls. The drums provide protection of the wire from rusting for at least six months if the drums are maintained in a dry location. Rusting of the wire is the factor which usually limits its storage life. Rusted wire can cause feeding difficulties, as well as introducing oxygen and moisture into the weld pool.

Metalworking roll welding systems use many variants of single wire SAW. Multiple welding heads may be used in various locations along a roll's length. This approach requires careful attention to tie-in between the deposit of one head and that of the next head along the roll's length, but it increases overall deposition rate to allow completion of the roll welding in less time. It also helps to maintain the roll mass at or above minimum preheat and interpass temperatures, though it requires care to not overheat the roll. Twin wires, typically 3/32 in. [2.5 mm], fed into a single weld pool can offer higher deposition rate from a single head.

Wires for SAW of metalworking rolls may be solid or tubular metal cored. Wires for buttering (applying a layer of mild steel) over the roll body or bearing journal area are commonly solid mild steel wires classified to AWS A5.17, *Specification for Carbon Steel Electrodes and*

Fluxes for Submerged Arc Welding, as EL12, EM12K, or EH14. Typically, the EL12 wire would be used for buttering with an active flux; the EM12K wire would be used with an acid flux or a nonactive basic flux; and the EH14 wire would be used with an acid nonactive flux. In all three buttering examples, the objective is to produce a low carbon deposit of low hardenability (typically with Mn less than 1.6% and Si less than 0.8%) which can act as a barrier to crack nucleation and propagation.

The same solid mild steel wires, especially the EL12 class, may be used with an alloy flux to produce a low alloy steel buildup layer, or, with another alloy flux, to produce a 12% Cr stainless steel overlay. Some of these alloy fluxes are recommended for use in DCEN welding to maximize flux (alloy) melting and minimize both wire melting and penetration. The flux manufacturer's recommendations should be consulted and carefully adhered to for such applications. A change in flux-to-wire ratio will change the deposit composition and therefore the deposit properties.

Some low alloy steel wires, some tool steel wires, and some 12% Cr stainless steel wires, are available in solid form for depositing low alloy steel buildup layers, tool steel overlay, or 12% Cr stainless steel overlay, respectively, with unalloyed flux. However, rather limited compositions are available, due to the need for the wire to be produced as a heat of steel, typically 120 000 lbs [55 000 kg] or more. To provide more flexibility for the metalworking roll welding shop, most of the wires for depositing low alloy steel buildup, tool steel or 12% Cr stainless steel overlay with unalloyed fluxes today are produced as tubular metal cored wires. These tubular wires are manufactured from a mild steel sheath and filled with the required alloy elements. Then much smaller production runs of a given wire can be manufactured, and specialized compositions are readily produced.

Solid wires offer the advantage of being mechanically hard, so that rather large variations in wire feeding drive roll design and drive roll pressure can be acceptable, though excessive pressure may cause spalling of copper flashing which then collects in contact tips and may

eventually result in clogging. Tubular wires are generally mechanically softer, and excessive drive roll pressure, especially when the drive roll shape is not contoured to the wire shape, may distort the wire and cause feeding difficulties. Distortion of tubular wire may also cause the mechanical seam which closes the tube to open partially, resulting in leakage of core material. Leakage may in turn clog the wire feeding mechanism or the contact tip. So, generally more attention to feed roll design and pressure is necessary for trouble-free feeding of tubular wires. With very soft tubular wires, U-grooved cog drive rolls may be necessary for proper wire feeding. The manufacturer of the tubular wire should be contacted for drive roll recommendations.

Solid wires are often sold on the basis of the wire composition, without regard to the weld deposit composition. This is a very acceptable practice in classifying mild steel wires. However, in the cases of depositing low alloy steel buildup, tool steel, or 12% Cr stainless steel overlay, reaction of a specific flux with chromium and carbon in the wire should be considered. As noted previously, acid fluxes tend to significantly reduce the carbon and chromium content of the weld deposit as compared to that of the wire. Since the weld deposit's carbon and chromium content respectively and largely determine the deposit hardness and corrosion resistance, it is appropriate to consider the deposit composition with a particular flux even when using solid wire.

Tubular wires for depositing low alloy steel buildup, tool steel, or 12% Cr stainless steel overlay are generally tailored to a specific flux to produce a desired all-weld-metal composition. Use of a wire designed for an acid flux with a basic flux is likely to produce appreciably higher carbon and chromium levels in weld deposits than it would with the designed acid flux. Conversely, use of a wire designed for a basic flux with an acid flux is likely to produce appreciably lower deposit carbon and chromium than it would with the designed basic flux. In either mismatch case, deposit properties may be inappropriate to the desired end. Careful evaluation of such a mismatch should be made before putting it into service.

Annex B (Informative)

Guidelines for Preparation of Technical Inquiries for AWS Technical Committees

This annex is not a part of AWS D14.7/D14.7M:2005, *Recommended Practices for Surfacing and Reconditioning of Industrial Mill Rolls*, but is included for informational purposes only.

B1. Introduction

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

B2. Procedure

All inquiries must be directed to:

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

All inquiries must contain the name, address, and affiliation of the inquirer, and they must provide enough information for the committee to fully understand the point of concern in the inquiry. Where that point is not clearly defined, the inquiry will be returned for clarification. For efficient handling, all inquiries should be typewritten and should also be in the format used here.

B2.1 Scope. Each inquiry must address one single provision of the standard, unless the point of the inquiry involves two or more interrelated provisions. That provision must be identified in the scope of the inquiry,

along with the edition of the standard that contains the provisions or that the inquirer is addressing.

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

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

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

B3. Interpretation of Provisions of the Standard

Interpretations of provisions of the standard are made by the relevant AWS Technical Committee. The secretary of the committee refers all inquiries to the chairman of the particular subcommittee that has jurisdiction over the portion of the standard addressed by the inquiry. The subcommittee reviews the inquiry and the proposed reply to determine what the response to the inquiry should be. Following the subcommittee's development of the response, the inquiry and the response are presented to the entire committee for review and approval. Upon

approval by the committee, the interpretation will be an official interpretation of the Society, and the secretary will transmit the response to the inquirer and to the *Welding Journal* for publication.

B4. Publication of Interpretations

All official interpretations will appear in the *Welding Journal*.

B5. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The Board of Directors' policy requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained

only through a written request. The Headquarters staff cannot provide consulting services. The staff can, however, refer a caller to any of those consultants whose names are on file at AWS Headquarters.

B6. The AWS Technical Committee

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

Annex C (Informative)

Recommended Forms

This annex is not a part of AWS D14.7/D14.7M:2005, *Recommended Practices for Surfacing and Reconditioning of Industrial Mill Rolls*, but is included for informational purposes only.

This annex contains five sample forms.

INSPECTION REPORT

SO No.	Roll ID	Segment ID
Roll Dia.	Roll Type	Drawing No.

Location	Print Requirements	Actual Dimensions	T.I.R. (max)	Test Status	Inspector Name	Inspection Date
A						
B						
C						
D1						
D2						
D	$(D1 + D2)/2$					
E1						
E2						
E	$(E1 + E2)/2$					
F						
G						
H						
J						
K						
L						
M						
N						
P						
Q						
R						
S						
T						
U						

Notes:

HARDNESS (R_C)					
Specification Range	Location			Inspector's Name	Inspection Date
	A	B	C		
Date					
xx to yy R_C					

Source: Figure adapted from form provided by Millcraft-SMS Services.

Figure C.1—Sample Form for Incoming and Final Inspection Records

WELDING PROCEDURE SPECIFICATION

		Weld Procedure No. _____ Revision _____ Page _____ of _____								
Applicable Code(s) _____ _____ _____ _____	Supporting PQR(s) _____ _____ _____									
Base Metal M-No. _____ Group _____ M-No. _____ Group _____ Thickness Range _____ Diameter Range _____	Joint Preparation _____ _____ _____									
Process(es) _____ _____ _____	Cleaning (Initial and Interpass) _____ _____ _____									
Position _____ Progression _____ _____	<table border="0" style="width: 100%;"> <tr> <td style="width: 50%;">Gas</td> <td style="width: 50%;">Flow Rate</td> </tr> <tr> <td>Shielding _____</td> <td>_____</td> </tr> <tr> <td>Purge _____</td> <td>Flow Rate _____</td> </tr> <tr> <td>Trailing _____</td> <td>Flow Rate _____</td> </tr> </table>		Gas	Flow Rate	Shielding _____	_____	Purge _____	Flow Rate _____	Trailing _____	Flow Rate _____
Gas	Flow Rate									
Shielding _____	_____									
Purge _____	Flow Rate _____									
Trailing _____	Flow Rate _____									
Filler Metal Process _____ Spec No. _____ F-No. _____ A-No. _____ Classification _____ Process _____ Spec No. _____ F-No. _____ A-No. _____ Other _____	Flux _____ Particle Size _____ Trade Name _____									
Preheat Preheat Temp., °F [°C] _____ Interpass Range, °F [°C] _____ _____	Postweld Heat Treatment Type _____ Temperature _____ Time _____									
Additional or supplementary requirements: _____ _____ _____										

Preparation Approval _____ Welding Engineer _____ Materials Engineering _____ Quality Assurance _____	Date _____ _____ _____ _____	Issue Date _____ Project _____ Job No. _____
--	---------------------------------------	--

Figure C.2—Sample Form for Welding Procedure Specification

PROCEDURE QUALIFICATION RECORD

PQR No. _____

Page _____ of _____

Material Spec. _____
 M-No. _____ Group _____ M-No. _____ Group _____
 Welding Processes 1. _____
 Manual or Automatic 1. _____
 Thickness Range 1. _____
 Total Qualified Thickness Range _____

to _____
 Thickness and O.D. _____
 2. _____
 2. _____
 2. _____

FILLER METAL

F-No. 1. _____ 2. _____
 A-No. 1. _____ 2. _____
 AWS Spec. 1. _____ 2. _____
 AWS Class. 1. _____ 2. _____
 Filler Size 1. _____ 2. _____
 Trade Name 1. _____ 2. _____
 3. _____

Describe filler metal if not included in AWS
 specifications _____

FLUX OR ATMOSPHERE

Trade Name 1. _____ 2. _____
 Shielding Gas 1. _____ 2. _____
 Flow Rate 1. _____ 2. _____
 Purge 1. _____ 2. _____

WELDING VARIABLES

Joint Type _____
 Position _____
 Backing _____
 Preheat _____
 Interpass Temp. Range _____
 PWHT _____
 Passes/Side 1. _____ 2. _____
 No. of Arcs 1. _____ 2. _____
 Current 1. _____ 2. _____
 Amps 1. _____ 2. _____
 Volts 1. _____ 2. _____
 Travel Speed 1. _____ 2. _____
 Oscillation 1. _____ 2. _____
 Bead Type 1. _____ 2. _____

TENSILE TESTS

Specimen No.	Dimensions		Area	Ultimate Total Load, lb [kg]	Ultimate Unit Stress psi [kPa]	Character of Failure and Location
	Width	Thickness				

GUIDED BEND TESTS

Type and Figure No.	Result	Type and Figure No.	Result

Welder's Name _____ Clock No. _____ Stamp No. _____
 (who by virtue of these tests meet welder performance requirements.)

Test Conducted by _____ Laboratory Test No. _____
 per _____ Address _____
 Date _____

We, the undersigned, certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of AWS D14.7/D14.7M, *Recommended Practices for Surfacing and Reconditioning of Industrial Mill Rolls*.

Signed _____
 (Manufacturer)
 Date _____ By _____

Figure C.3—Sample Form for Procedure Qualification Record

WELDER AND WELDING OPERATOR QUALIFICATION TEST RECORD

Welder or Welding Operator Name _____ Identification _____
 Welding Process _____ Manual _____ Semiautomatic _____ Machine _____
 (Flat, Horizontal, Overhead, or Vertical—if vertical, state whether upward or downward) in Accordance with Procedure
 Specification No. _____
 Material Specification _____
 Diameter and Wall Thickness (if pipe)—Otherwise Joint Thickness _____
 Thickness Range this Qualifies _____

FILLER METAL

Specification No. _____ Classification No. _____ F-No. _____
 Describe Filler Metal (if not covered by AWS specification) _____

Filler Metal Diameter and Trade Name _____ Flux for Submerged Arc or Gas for Gas
 Metal Arc or Flux Cored Arc Welding _____

GUIDED BEND TEST RESULTS

Type	Result	Type	Result

Test Conducted by _____ Laboratory Test No. _____
 per _____

FILLET TEST RESULTS

Appearance _____ Fillet Size _____
 Fracture Test Root Penetration _____ Macroetch _____
 (Describe the location, nature, and size of any crack or tearing of the specimen.)

Test Conducted by _____ Laboratory Test No. _____
 per _____

RADIOGRAPHIC TEST RESULTS

Film Identification	Results	Remarks	Film Identification	Results	Remarks

Test Witnessed by _____ Test No. _____
 per _____

We, the undersigned, certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of AWS D14.7/D14.7M, *Recommended Practices for Surfacing and Reconditioning of Industrial Mill Rolls*.

Manufacturer _____

Authorized by _____

Date _____

Figure C.4—Sample Form for Welder and Welding Operator Qualification Test Record

ROLL WELDING DATA SHEET

Customer	Job No.	Roll Type	Date
Drawing No.	Rev. No.	Serial No.	
Body Diameter (Finished)	Body Length		

Welding Station								
Operator and Shift								
Setup Time (hours)								
Welding Hours—Overlay								
Welding Hours—Buildup								
Total Time/Operator								
Start/End Point (%)								
Pass No.								
Weld Material								

BODY REPAIR

Consumables	Buildup Area		Overlay Area	
Specified Wire/Flux + Wire Dia.				
Lot No. of Wire				
Lot No. of Flux				
Parameters	Oscillation (Y or N)	Overlap (%)	Oscillation (Y or N)	Overlap (%)
Number of Heads				
Electrical Stickout	Spec.	Actual	Spec.	Actual
Torch Angle (°)	Spec.	Actual	Spec.	Actual
BTDC Distance	Spec.	Actual	Spec.	Actual
Roll Speed	Spec.	Actual	Spec	Actual
Stepover Setting				
Preheat Temperature	Min. Spec.	Actual	Min. Spec.	Actual
Interpass Temperature	Max. Spec.	Actual	Max. Spec.	Actual
Voltage				
Wire Speed				
Finish Diameter As Welded				
Consumables Used and Cost				
Wire Used	Total Length	Cost	Total Length	Cost
Wire Used	Total Weight	Cost	Total Weight	Cost
Flux Used	Total Weight	Cost	Total Weight	Cost
Volume of Repair				
Cost of Wire				
Cost of Flux				
Total Material Costs				

Figure C.5—Sample Form for Recording Weld Processing Parameters

JOURNAL REPAIR

Consumables	Journal 1		Journal 2	
Specified Wire/Flux + Wire Dia.				
Lot No. of Wire				
Lot No. of Flux				
Parameters				
Preheat Temperature	Min. Spec.	Actual	Min. Spec.	Actual
Interpass Temperature	Max. Spec.	Actual	Max. Spec.	Actual
Voltage				
Wire Speed				
Dimensions				
Start Diameter	A	B	C	D
Finish Diameter (Hot)	A	B	C	D
Minimum Final Diameter (Hot)	A	B	C	D
Length of Repair	Long Side	Short Side		
Consumables Used and Cost				
Wire Used	Total Weight	Cost	Total Weight	Cost
Flux Used	Total Weight	Cost	Total Weight	Cost
Volume of Repair				
No. of Journals Repaired	Welder's Name	Total Labor Time	Welder's Name	Total Labor Time

UNDERCUT MAP

Show sketch of roll and location of repairs								

Special Instructions:

Source: Figure adapted from and based on form provided by Millcraft-SMS Services.

Figure C.5 (Continued)—Sample Form for Recording Weld Processing Parameters

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Annex D (Informative)

Bibliography

This annex is not a part of AWS D14.7/D14.7M:2005, *Recommended Practices for Surfacing and Reconditioning of Industrial Mill Rolls*, but is included for informational purposes only.

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

ASTM G 65, *Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus*.

ASTM G 77, *Standard Test Method for Ranking Resistance of Materials to Sliding Wear Using Block-on-Ring Wear Test*.

ASTM G 83, *Standard Test Method for Wear Testing with a Crossed-Cylinder Apparatus*.

Benedyk, J. C., D. J. Moracz, and J. F. Molloce, Thermal Fatigue Behavior of Die Materials for Aluminum Die Casting, *Trans. 6th SDCE International Die Congress*, Cleveland, Ohio, Nov. 16–19, 1970.

Farmer, Howard, *Steel Mill Roll Reclamation*, Stooddy Technical Report, Second Edition, 1975.

Handerhan, K., The Importance of Fracture Mechanics in the Design of Forged Continuous Caster Rolls, Table IV, *Proceedings from the 1989 Mechanical Working and Steel Processing Conference*.

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List of AWS Documents on Machinery and Equipment

Designation	Title
D14.1/D14.1M	<i>Specification for Welding of Industrial and Mill Cranes and Other Material Handling Equipment</i>
D14.3/D14.3M	<i>Specification for Welding Earthmoving, Construction, and Agricultural Equipment</i>
D14.4/D14.4M	<i>Specification for Welded Joints in Machinery and Equipment</i>
D14.5	<i>Specification for Welding of Presses and Press Components</i>
D14.6/D14.6M	<i>Specification for Welding of Rotating Elements of Equipment</i>
D14.7/D14.7M	<i>Recommended Practices for Surfacing and Reconditioning of Industrial Mill Rolls</i>

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