

Lesson 17

RP 577 Welding Inspection and Metallurgy

RP-577 Welding Inspection and Metallurgy

Lesson 17

INTRODUCTION

Much of the content of RP-577 has been gathered from other technical and Code publications. Overall it is a fine publication and represents a lot of hard work.

Since many of these subjects are covered in previous lessons, such as several of the NDE processes and Welding procedures this lesson will not address those same issues again, unless there is added information not presented previously.

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INTRODUCTION

RP-577 should be taken quite seriously during study. It is a new document on the examination, and as such you should expect approximately 10 questions from it.

You may even prefer to use this document as your primary source for the study of welding and NDE as it is specifically pointed at in-service inspection methods.

However the ASME Code Sections V, VIII Div.1 and, IX must not be neglected as they are still a part of the examination.

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INTRODUCTION

The parts of RP-577 covered in the lesson will not be addressed completely. The effort will be to introduce the topics of RP-577 and familiarize the student with its content and study responsibilities. However a question and answer study exercise has been provided for exam preparation.

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Lesson Objectives

- **Become familiar with definitions and welding inspection terminology**
- **Understand the tasks and processes required to perform welding inspections.**
 - **Tasks Prior to Welding.**
 - **Tasks during Welding Operations**
 - **Tasks upon Completion of Welding**
 - **Non-conformances and Defects**
 - **NDE Examiner Certification**
 - **Safety Precautions**

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Lesson Objectives

- **Introduce the welding process types and their advantages and disadvantages based on intended application, these include:**
 - **Shielded Metal Arc Welding (SMAW)**
 - **Gas Tungsten Arc Welding (GT AW)**
 - **Gas Metal Arc Welding (GMAW)**
 - **Flux Core Arc Welding (FCAW)**
 - **Submerged Arc Welding (SAW)**
 - **Stud Arc Welding (SW)**

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Lesson Objectives

- **Introduce Non-Destructive Examinations methods not covered in previous class lessons and their applications, to include;**
 - **Types of Discontinuities**
 - **Materials Identification methods**
 - **Visual Examination (VT)**
 - **Alternating Current Field Measurement (ACFM)**
 - **Eddy Current Inspection (ET)**
 - **Hardness Testing**
 - **Pressure and Leak Testing (LT)**
 - **Weld Inspection Data Recording**

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Lesson Objectives

- **Outline basic application of metallurgy to the welding processes, including;**
 - **The Structure of Metals and Alloys**
 - **Physical Properties**
 - **Mechanical Properties**
 - **Preheating**
 - **Post-weld Heat Treatment**
 - **Hardening**
 - **Material Test Reports**
 - **Weldability of Steels**
 - **Weldability of High-alloys**

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Lesson Objectives

- **Present the nature of and remedies for Refinery and Petrochemical Plant Welding Issues, such as;**
 - **General Issues in welding**
 - **Hot Tapping and In-service Welding**
 - **Lack of Fusion with GMAW-S Welding Process**

Other Items to be discussed

- **Welding Terminology and Welding Symbols**
- **Actions to Address Improperly made production welds.**
- **Guide to common filler metals selection**
- **Example RT reports**

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We will begin with **Section 3 - Definitions** on **page 2**.

Once again we will not attempt to cover any of these items in their entirety during class. This is to be considered an introduction to RP-577 and to the subject material on the exam Body of Knowledge.

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Definitions

Many of the definitions listed are common and probably many of these you already know. However what you and I think of as being one thing, they may use a different term for.

Example: Penetrameter is an outdated term it is now called an Image Quality Indicator (IQI).

We will go through a few of the less known definitions, but subjects from RP-577 are largely a read and remember task for the exam.

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Definitions

‘Some of the less known’

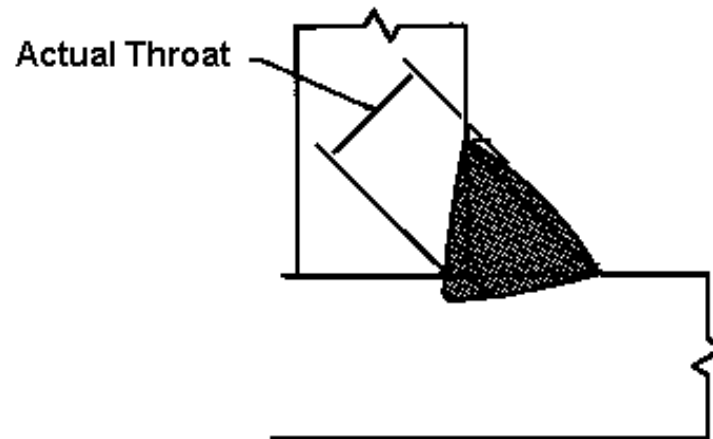
autogenous weld: A fusion weld made without filler metal. (The most common of these types of welds is made on tubing and performed with Gas Tungsten Arc Welding often using an automated welding device)

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Definitions

- **actual throat:** The shortest distance between the weld root and the face of a fillet weld.



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Definitions

Be sure to spend some time learning to recognize definitions!

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Section 4

Welding Inspection page 4.

The focus of Section 4 is to detail the tasks that are considered the responsibility of the Inspection group as well other concerned parties who will design, examine, or perform welding.

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The other issues that the inspector must address as part of tasks prior to welding are;

NDE Information

Welding Equipment and Instruments

Heat Treatment and Pressure Testing

Materials

Weld Preparation

Preheat

Welding Consumables

The items above are very similar in there language as to the individual of the various group's responsibilities, concentrate on the **INSPECTOR'S** tasks during your studies.

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While Section 4 of RP-577 is rather lengthy, it follows a definite outlined pattern.

The emphasis should be on items that you do not have actual work experience with.

For example if you have not followed a PWHT procedure spend your time studying these items as opposed to something you have experience with.

Do not overlook items such as Safety Precautions or Documentation during your studies.

Class Quiz

1. An autogenous weld is a fusion weld made _____ filler metal.

- a. with
- b. without
- c. with or without

Fill in the blanks:

2. The inspector's responsibilities prior to welding can include a. _____ b. _____

c. _____ d. _____

Solutions

1. An autogenous weld is a fusion weld made _____ filler metal.

b. without

2. The inspector's responsibilities prior to welding can include a. _____ b. _____

c. _____ d. _____

a. Look for missing details and information

b. Determine if the planned testing is adequate

c. Look for Code and specification violations in the plan

d. Identify possible welding problems

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Welding Processes

- These 6 welding process types and their advantages and disadvantages based on intended application should be thoroughly understood prior to examination day. The following is a brief overview of;

- **Shielded Metal Arc Welding (SMAW)**
- **Gas Tungsten Arc Welding (GT AW)**
- **Gas Metal Arc Welding (GMAW)**
- **Flux Core Arc Welding (FCAW)**
- **Submerged Arc Welding (SAW)**
- **Stud Arc Welding (SW)**

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5.2 Shielded Metal Arc Welding (SMAW)

SMAW is the most widely used of the various arc welding processes. SMAW uses an arc between a covered electrode and the weld pool. It employs the heat of the arc, coming from the tip of a consumable covered electrode, to melt the base metal. Shielding is provided from the decomposition of the electrode covering, without the application of pressure and with filler metal from the electrode.

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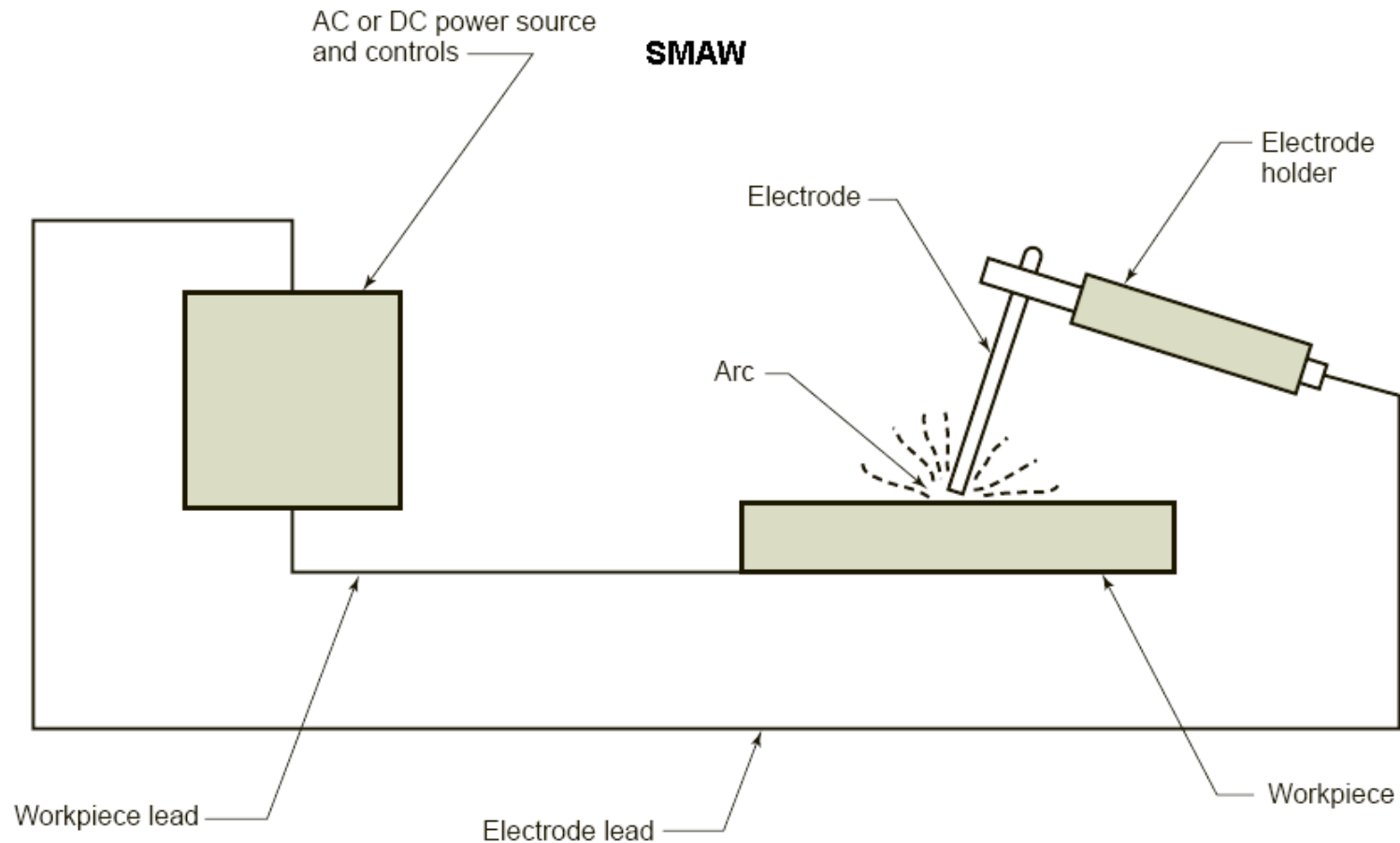
5.2 Shielded Metal Arc Welding (SMAW)

- Either alternating current (ac) or direct current (dc) may be employed, depending on the welding power supply and the electrode selected.
- A constant-current **(CC) power supply** is preferred. SMAW is a manual welding process. See Figures 1 and 2 for schematics of the SMAW circuit and welding process.

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5.2 Shielded Metal Arc Welding (SMAW)



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5.2 Shielded Metal Arc Welding (SMAW)

- **Advantages**

- Simple, inexpensive and portable
- Useable in tight places
- Less sensitive to wind and drafts than other processes
- Useable with most common metals and alloys

- **Limitations**

- Slow welding compared to GMAW or SAW
- Cleaning problems due to slag left from electrode covering

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Study each of the six welding processes in order to recognize these by a written descriptions. Get to know the advantages and disadvantages of all six.

Class Quiz

1. A welding process that uses a consumable electrode and whose shielding gas is generated by the decomposition of the rod covering is the process _____.

- a. GMAW
- b. FCAW
- c. SMAW
- d. GTAW

2. The welding process that is well suited to making superior root passes because of good penetration is _____.

- a. FCAW
- b. SAW
- c. GMAW-S
- d. GTAW

Class Quiz

3. Globular transfer can be utilized with the _____ process.

- a. FCAW
- b. SMAW
- c. GMAW
- d. GTAW

4. The welding process in which the welding arc is not normally visible is the _____ process.

- a. GMAW-S
- b. SAW
- c. FCAW
- d. GTAW

Solutions

1. A welding process that uses a consumable electrode and whose shielding gas is generated by the decomposition of the rod covering is the _____ process.

c. SMAW

2. The welding process that is well suited to making superior root passes because of good penetration is the _____.

d. GTAW

3. Globular transfer can be utilized with the _____ process.

c. GMAW

4. The welding process in which the welding arc is not normally visible is the _____ process.

b. SAW

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Appendix A Terminology and Symbols

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We will defer the NDE and Metallurgy coverage for now and stay with the welding topics from RP-571. Appendix A consists of 5 pages of graphics. The topics are;

A.1 Weld Joint Types

A.2 Weld Symbols

A.3 Weld Joint Nomenclature

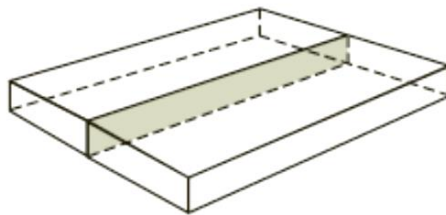
A.4 Electrode Identification

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A.1 Weld Joint Types

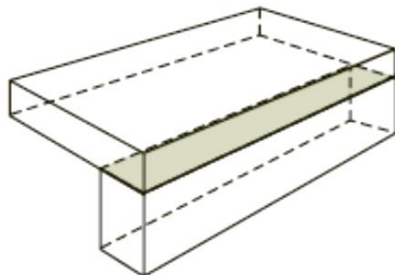
- You may be required to identify any of these joints based on a description or a sketch.



(A) Butt Joint

Applicable Welds

Bevel-groove	U-groove
Flare-bevel-groove	V-groove
J-groove	Edge-flange
Square-groove	Braze



(B) Corner Joint

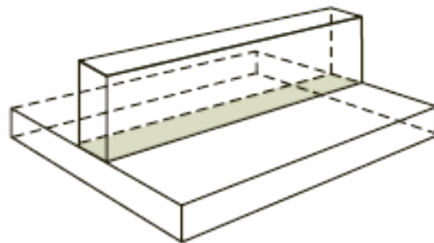
Applicable Welds

Fillet	V-groove
Bevel-groove	Plug
Flare-bevel-groove	Slot
Flare-V-groove	Spot
J-groove	Seam
Square-groove	Projection
U-groove	Braze

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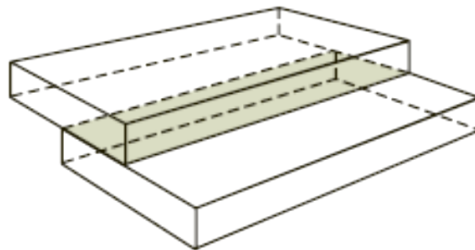
A.1 Weld Joint Types



(C) T-Joint

Applicable Welds

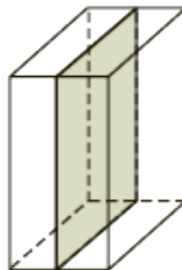
Fillet	Slot
Bevel-groove	Spot
Flare-bevel-groove	Seam
J-groove	Projection
Square-groove	Braze
Plug	



(D) Lap Joint

Applicable Welds

Fillet	Slot
Bevel-groove	Spot
Flare-bevel-groove	Seam
J-groove	Projection
Plug	Braze



(E) Edge Joint

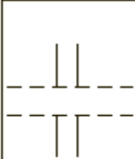
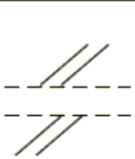
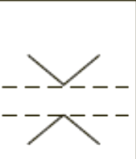
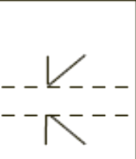
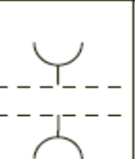
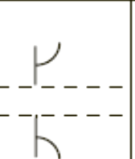
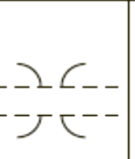
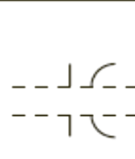
Applicable Welds

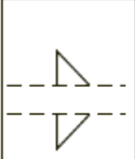
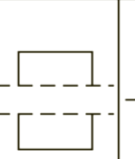
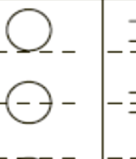
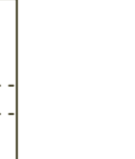
Bevel-groove	U-groove
Flare-bevel-groove	V-groove
Flare-V-groove	Edge
J-groove	Seam
Square-groove	

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A.2 Weld Symbols

Groove							
Square	Scarf	V	Bevel	U	J	Flare-V	Flare-bevel
							

Fillet	Plug or slot	Stud	Spot or projection	Seam	Back or backing	Surfacing	Flange	
							Edge	Corner
								

Note: The reference line is shown dashed for illustrative purposes.

Figure A-2—Symbols for Various Weld Joint

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A.3 Supplementary Weld Symbols

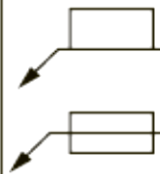
Weld all around	Field weld	Melt through	Consumable insert (square)	Backing or spacer (rectangle)	Contour		
					Flush or flat	Convex	Concave
							

Figure A-3—Supplementary Symbols for Welds

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A.4 Weld Joint Nomenclature

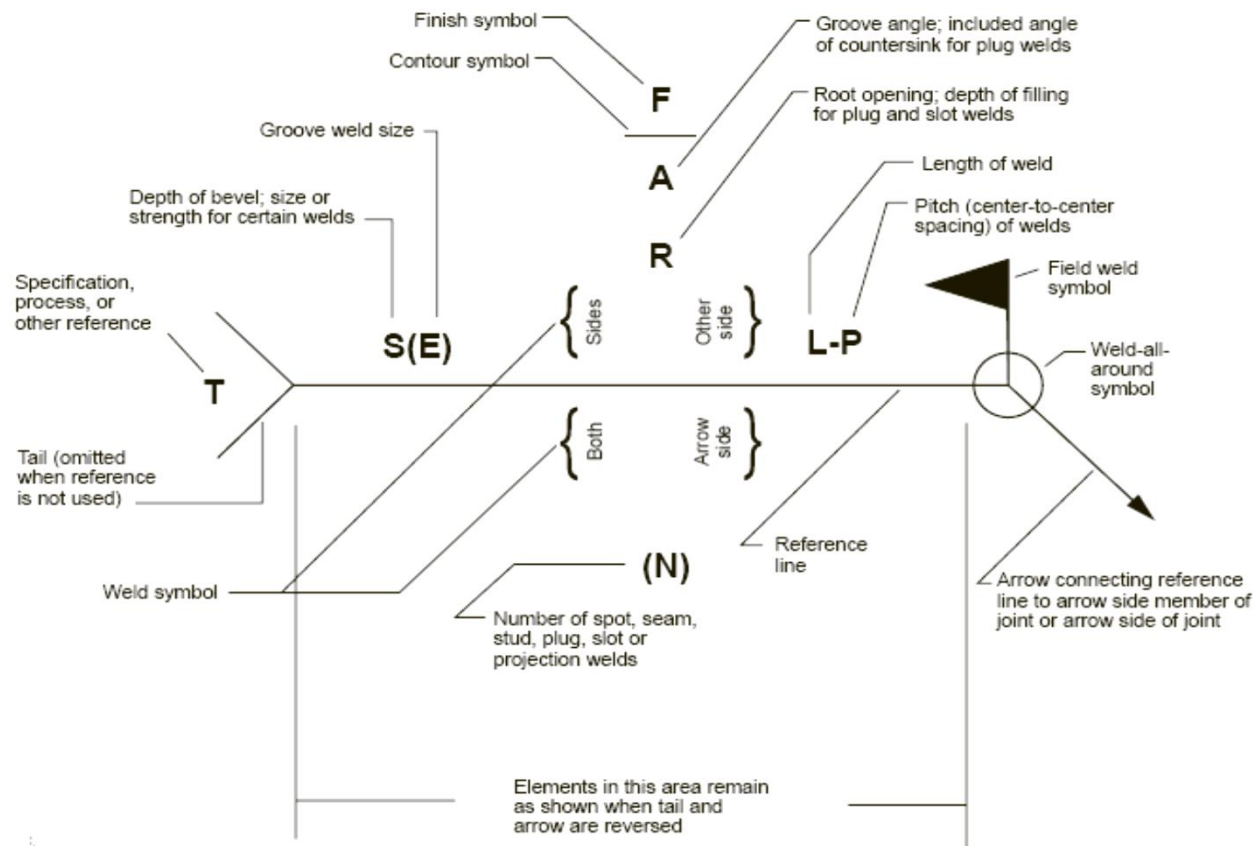
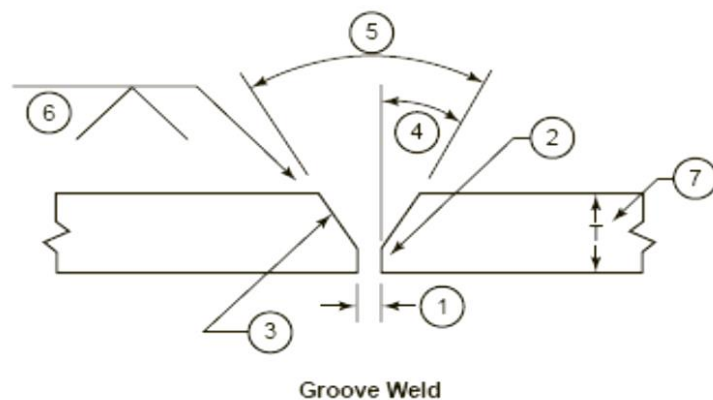


Figure A-4—Standard Weld Symbols

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A.5 Weld Joint Nomenclature



- | | |
|-------------------------|--|
| 1. Root Opening: | A separation at the joint root between the workpieces. |
| 2. Root Face: | That portion of the groove face adjacent to the joint root. |
| 3. Groove Face: | The surface of a joint member included in the groove. |
| 4. Bevel Angle: | The angle formed between the prepared edge of a member and a plane perpendicular to the surface of the member. |
| 5. Groove Angle: | The total included angle of the groove between workpieces. |
| 6. Groove Weld Size: | The joint penetration of a groove weld. |
| 7. Plate Thickness (T): | Thickness of the base metals to be welded. |

Figure A-5—Groove Weld Nomenclature

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A.6 Electrode Identification SMAW

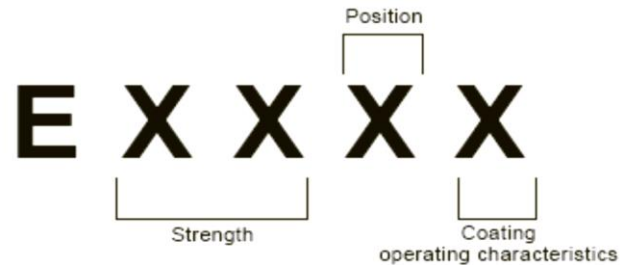


Figure A-6—SMAW Welding Electrode Identification System

You can be required answer Closed Book questions on the AWS Classification shown in these figures.

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A.7 Electrode Identification GMAW/GTAW

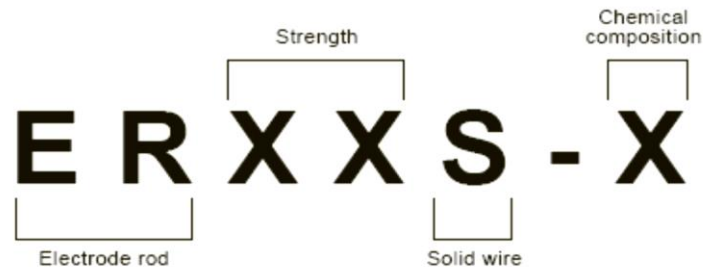


Figure A-7—GMAW/GTAW Welding Electrode Identification System

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A.8 Electrode Identification FCAW

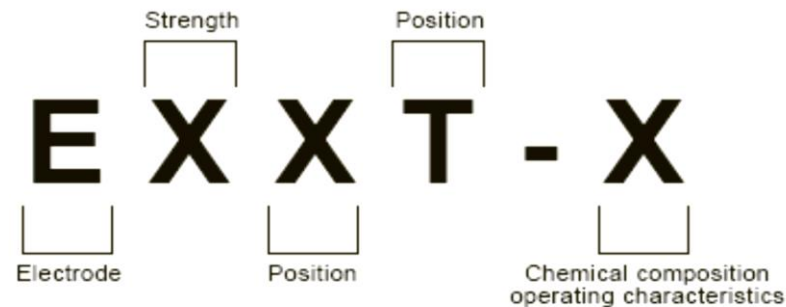
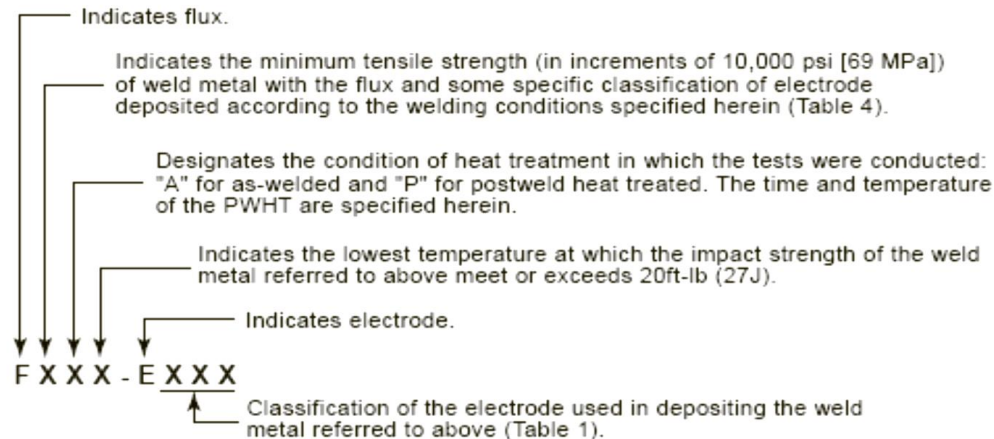


Figure A-8—FCAW Welding Electrode Identification System

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A.9 Electrode Identification SAW



EXAMPLE

F7A6-EM12K is a complete designation. It refers to a flux that will produce weld metal which, in the as-welded condition, will have a tensile strength no lower than 70,000 psi and Charpy V-notch impact strength of at least 20 ft-lb at -60°F when deposited with an EM12K electrode under the conditions called for in this specification.

Figure A-9—SAW Welding Electrode Identification System

Class Quiz

1. The type of electrode that has an AWS designation that is represented as E X X X X is used with the_____ process.

- a. GMAW
- b. SMAW
- c. GTAW
- d. SW

2. A rod is designated as ER-70 S. It would be used with the ____ process and has a deposited tensile strength of ____ psi.

- a. GTAW - 70,000
- b. GMAW - 70,000
- c. Both a and b above.

Class Quiz

3. For the _____ process the electrode has the form E X X T-X. The T represents _____ and the second X indicates _____.

- a. FCAW -Tubular - Position
- b. GMAW - Position - Position
- c. FCAW – Position - Position
- d. GMAW – Tubular - Position

4. For SAW the F in the designator means _____.

- a. the flow rate of shielding gas used.
- b. the flux used
- c. it will use a ferrous flux
- b. the electrode is ferrous

Solutions

1. The type of electrode that has an AWS designation that is represented as E X X X X is used with the _____ process.

b. SMAW

2. A rod is designated as ER-70 S. It would be used with the _____ process and has a deposited tensile strength of _____ psi.

c. Both a and b above.

3. For the _____ process the electrode has the form E X X T-X. The T represents _____ and the second X indicates _____.

c. FCAW – Position – Position

4. For SAW the F in the designator means _____.

b. the flux used

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Appendix B

Actions To Address Improperly Made Production Welds

The following flow charts are the recommended method of addressing problems during welding. Here again we have case of just having to try and remember where this information is and possibly answer a Open Book question as regards the proper corrective action based on the listed circumstances.

Appendix B – Actions to Address Improperly Made Production Welds

Production welds made by an unqualified welder or an improper welding procedure should be addressed to assure the final weldments meet the service requirements. A welder may be unqualified for several reasons including expired qualification, not qualified for the thickness, not qualified in the technique, or not qualified for the material of construction. Figure B-1 details some potential steps to address the disposition of these welds.

A welding procedure may be improper if the weldment is made outside the range of essential variables (and supplementary essential variables, if required) qualified for the WPS. Figure B-2 details some potential steps to address weldments made with an improper welding procedure.

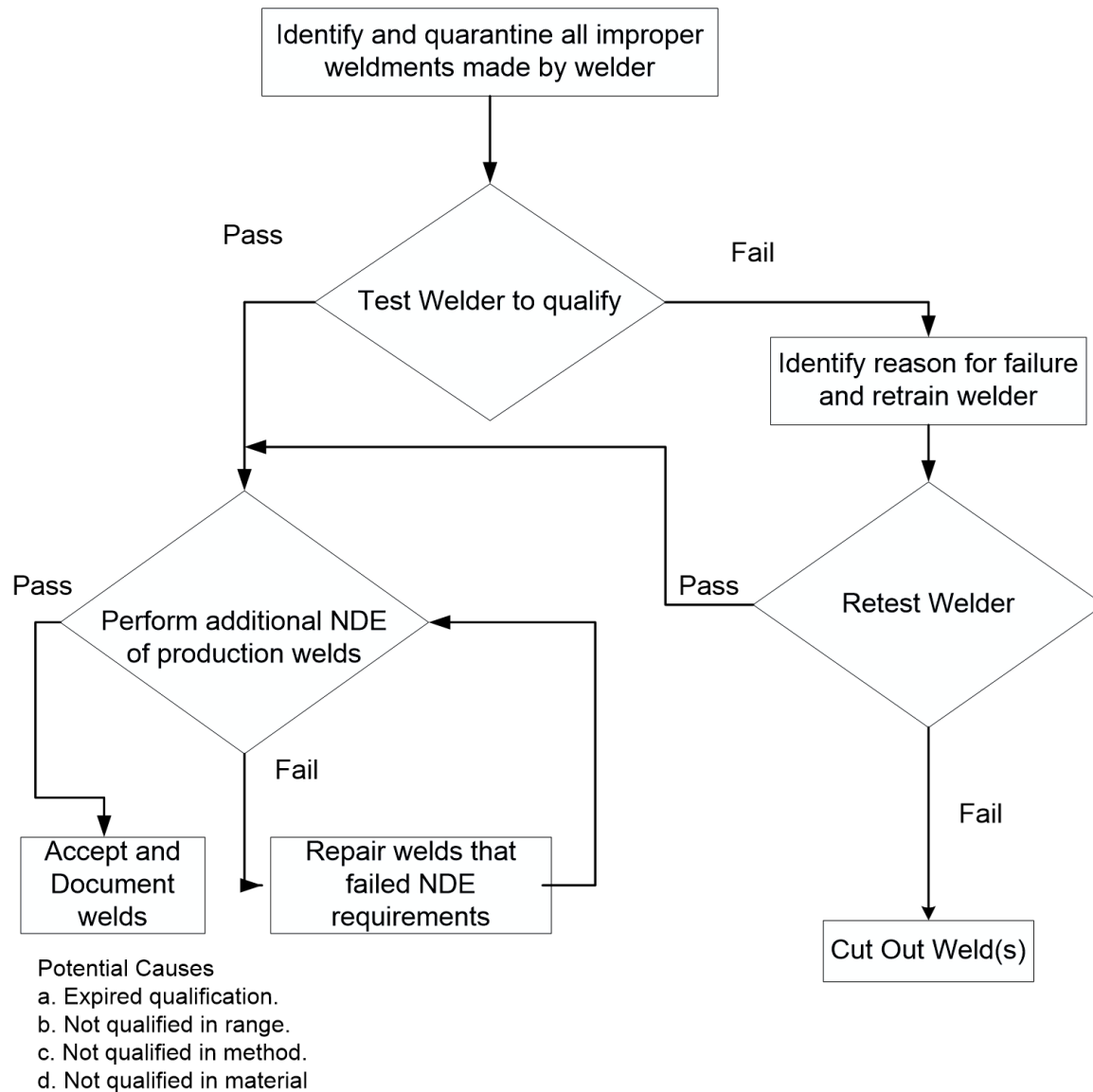


Figure B -1 Suggested Actions for Welds Made by an Incorrect Welder

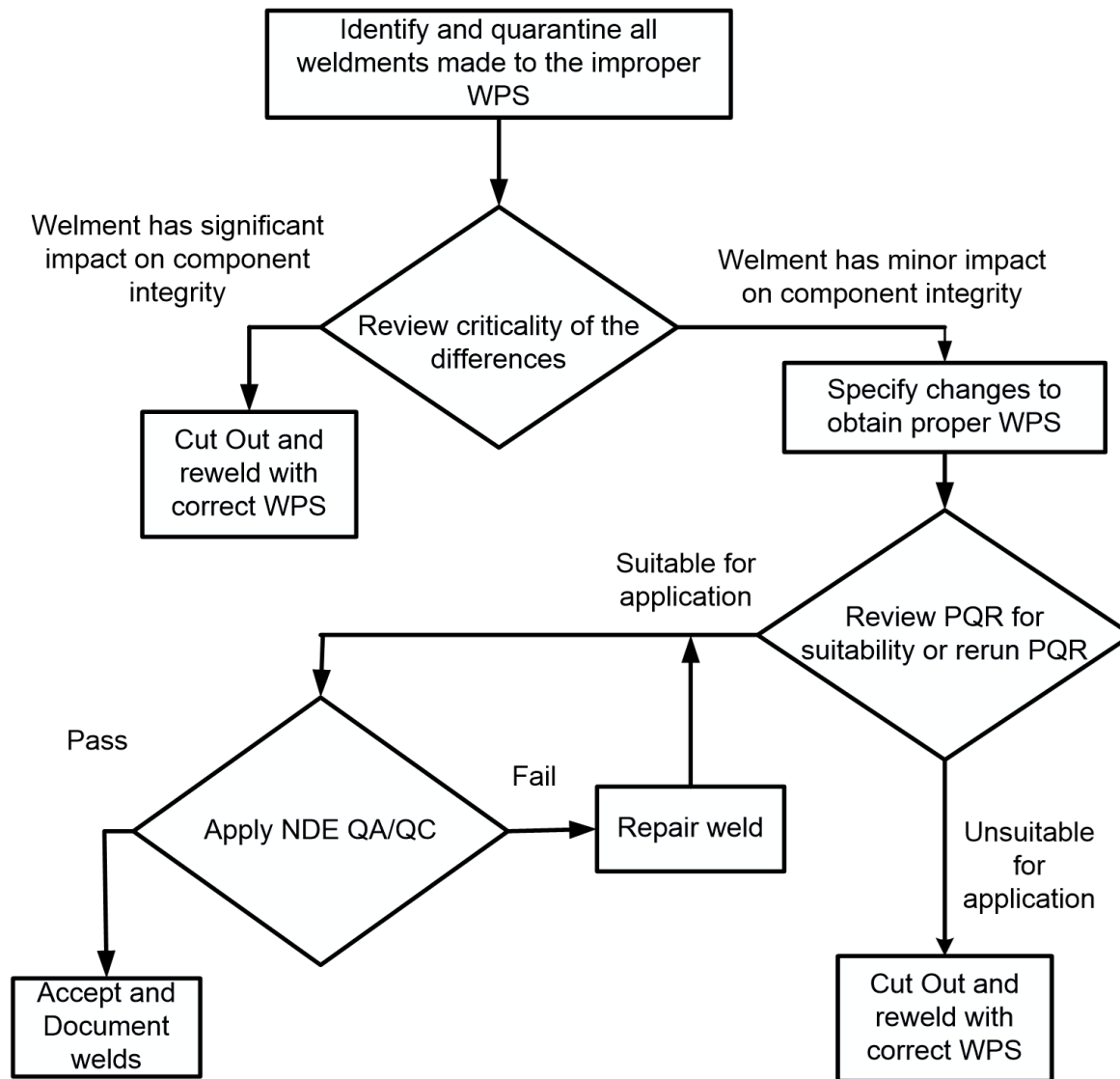


Figure B-2 Steps to Address Production Welds Made to an Improper WPS

Appendix D Page 95

Expect “Look Up Questions” from these tables.

APPENDIX D—GUIDE TO COMMON FILLER METAL SELECTION

Tables D-1 and D-2 provide generally accepted electrode selections for the base materials shown. They do not attempt to include all possible choices. Welding consumables not shown for a particular combination of base materials shall be approved by the purchaser.

Table D-1—Common Welding Consumables for SMAW of Carbon and Low-alloy Steel

Base Material Note 1, 2, 4	Carbon Steel	Carbon-Molybdenum Steel	1&1/4 Cr-1/2 Mo Steel	2 1/4 Cr-1 Mo Steel	5Cr-1/2 Mo Steel	9Cr-1 Mo Steel	2 1/4 Nickel Steel	3 1/2 Nickel Steel	9% Nickel Steel
Carbon Steel	AB ³	AC	AD	AE	AF	AG	AJ	AK	*
Carbon-Molybdenum Steel		C	CD	CE	CF	CH	*	*	*
1&1/4 Cr-1/2 Mo Steel			D	DE	DF	DH	*	*	*
2 1/4 Cr-1 Mo Steel				E	EF	EH	*	*	*
5Cr-1/2 Mo Steel					F	FH	*	*	*
9Cr-1 Mo Steel						H	*	*	*
2 1/4 Nickel Steel							J	JK	LM
3 1/2 Nickel Steel								K	LM
9% Nickel Steel									LM

Legend

- A AWS A5.1 Classification E70XX low hydrogen⁵
- B AWS A5.1 Classification E6010 for root pass⁵
- C AWS A5.5 Classification E70XX-A1, low hydrogen
- D AWS A5.5 Classification E70XX-B2L or E80XX-B2, low hydrogen
- E AWS A5.5 Classification E80XX-B3L or E90XX-B3, low hydrogen
- F AWS A5.5 Classification E80XX-B6 or E80XX-B6L, low hydrogen
- G AWS A5.5 Classification E80XX-B7 or E80XX-B7L, low hydrogen
- H AWS A5.5 Classification E80XX-B8 or E80XX-B8L, low hydrogen
- J AWS A5.5 Classification E80XX-C1 or E70XX-C1L, low hydrogen
- K AWS A5.5 Classification E80XX-C2 or E70XX-C2L, low hydrogen
- L AWS A5.11 Classification ENiCrMo-3
- M AWS A5.11 Classification ENiCrMo-6
- * An unlikely or unsuitable combination. Consult the purchaser if this combination is needed.

Notes:

¹ Table A-1 refers to coated electrodes. For bare wire welding (SAW, GMAW, GTAW), use equivalent electrode classifications (AWS A5.14, A5.17, A5.18, A5.20, A5.23, A5.28). Refer to the text for information on other processes.

² Higher alloy electrode specified in the table should normally be used to meet the required tensile strength or toughness after post-weld heat treatment. The lower alloy electrode specified may be required in some applications to meet weld metal hardness requirements.

³ Other E60XX and E70XX welding electrodes may be used if approved by the purchaser.

⁴ This table does not cover modified versions of Cr-Mo alloys.

⁵ See API RP 582, Section 6.1.3.

Expect “Look Up Questions” from these tables.

Table D-2—Common Welding Consumables for SMAW of Stainless Steels

Base Material Note 1, 2, 3	Type 405 Stainless Steel	Type 410S Stainless Steel	Type 410 Stainless Steel	Type 304 Stainless Steel	Type 304L Stainless Steel	Type 304H Stainless Steel	Type 310 Stainless Steel	Type 316 Stainless Steel	Type 316L Stainless Steel	Type 317L Stainless Steel	Type 321 Stainless Steel	Type 347 Stainless Steel
Carbon and Low-alloy Steel	AB	AB	AB	AB	AB	AB	AB	AB	AB	AB	AB	AB
Type 405 Stainless Steel	ABC	ABC	ABC	AB	AB	AB	AB	AB	AB	AB	AB	AB
Type 410S Stainless Steel		ABC	ABC	AB	AB	AB	AB	AB	AB	AB	AB	AB
Type 410 Stainless Steel			ABC	AB	AB	AB	AB	AB	AB	AB	AB	AB
Type 304 Stainless Steel				D	DH	DJ	A	DF	DGH	DI	DE	DE
Type 304L Stainless Steel					H	DHJ	A	DF	GH	HI	DE	DE
Type 304H Stainless Steel						J	A	DFJ	DGHJ	DIJ	DEJ	EJ
Type 310 Stainless Steel							K	AK	A	A	A	A
Type 316 Stainless Steel								F	FG	FI	EF	EF
Type 316L Stainless Steel									G	GI	EG	EG
Type 317L Stainless Steel										I	EI	EI
Type 321 Stainless Steel											E	E
Type 347 Stainless Steel												E

Legend

- A AWS A5.4 Classification E309-XX
- B AWS A5.11 Classification ENiCrFe-2 or -3⁴
- C AWS A5.4 Classification E410-XX [(0.05% C max. and heat treatment @1400°F (760°C) required)]
- D AWS A5.4 Classification E308-XX
- E AWS A5.4 Classification E347-XX
- F AWS A5.4 Classification E316-XX
- G AWS A5.4 Classification E316L-XX
- H AWS A5.4 Classification E308L-XX
- I AWS A5.4 Classification E317L-XX
- J AWS A5.4 Classification E308H-XX
- K AWS A5.4 Classification E310-XX

Notes:

¹ Table D-2 refers to coated electrodes. For bare wire welding (SAW, GMAW, GTAW), use equivalent electrode classifications (AWS A5.9, A5.14). Refer to the text for information on other processes.

² The higher alloy electrode specified in the table is normally preferred.

³ See API RP 582, Section 6.3, for weld metal delta ferrite requirements.

⁴ See API RP 582, Section 6.2.2, for the temperature limitation for nickel-based filler metals.

Expect “Look Up Questions” from these tables.

Table D-3—Copper-nickel and Nickel-based Alloys

Base Material Note ¹	70-30 & 90-10 Cu-Ni	Alloy 400 (N04400)	Nickel 200 (N02200)	Alloy 800 (N08800), 800H (N08810), 800HT (N08811)	Alloy 600 (N06600)	Alloy 625 (N06625)	Alloy 825 (N08825)	Alloy C-22 (N06022)	Alloy C-276 (N10276)	Alloy B-2 (N10665)	Alloy G-3 (N06985)	Alloy G-30 (N06030)
Carbon and Low-alloy Steel	BC	BC	C	A	A	A	A	D	E	F	G	H
300-Series Stainless Steel	BC	AC	AC	A	A	A	A	D	E	F	G	H
400-Series Stainless Steel	B	B	AC	A	A	A	A	D	E	F	G	H
70-30 & 90-10 Cu-Ni	B	B	C	C	C	C	C	*	*	*	*	*
Alloy 400 (N04400)		B	BC	A	A	A	A	A	A	F	A	A
Nickel 200 (N02200)			C	AC	AC	AC	AC	CD	CE	CF	CG	CH
Alloy 800 (N08800), 800H (N08810), 800HT (N08811)				KJ	A	A	A	DJ	EJ	FJ	GJ	HJ
Alloy 600 (N06600)					A	AJ	A	DJ	EJ	FJ	GJ	HJ
Alloy 625 (N06625)						J	J	DJ	EJ	FJ	GJ	HJ
Alloy 825 (N08825)							J	DJ	EJ	FJ	GJ	HJ
Alloy C-22 (N06022)								D	EJ	FJ	GJ	HJ
Alloy C-276 (N10276)									E	FJ	GJ	HJ
Alloy B-2 (N10665)										F	GJ	HJ
Alloy G-3 (N06985)											G	HJ
Alloy G-30 (N06030)												H

A AWS 5.11, Classification ENiCrFe-2 or -3

B AWS A5.11, Classification ENiCu-7

C AWS A5.11, Classification ENi-1

D AWS A5.11, Classification ENiCrMo-10

E AWS A5.11, Classification ENiCrMo-4

F AWS A5.11, Classification ENiMo-7

G AWS A5.11, Classification ENiCrMo-9

H AWS A5.11, Classification ENiCrMo-11

J AWS A5.11, Classification ENiCrMo-3

K AWS A5.11, Classification ENiCrCoMo-1

* An unlikely or unsuitable combination. Consult the purchaser if this combination is needed.

Note:

¹Table D-3 refers to coated electrodes. For bare wire welding (SAW, GMAW, GTAW), use equivalent electrode classification (AWS A5.14). Refer to the text for information on other processes.

Expect “Look Up Questions” from these tables.

Table D-4—Classification Changes in Low-alloy Filler Metal Designations

Material	ASME P-number (Typical)	New (Current) AWS Filler Number		Old Filler Metal Designation	
		SMAW	GTAW	SMAW	GTAW
C- $\frac{1}{2}$ Mo	3	E7018-A1	ER70S-A1, or ER80S-D2	E7018-A1	N/A ER80S-D2
1Cr- $\frac{1}{2}$ Mo and 1 $\frac{1}{4}$ Cr- 0.5Mo	4	E7018-B2L E8018-B2	ER70S-B2L ER80S-B2	E8018-B2L E8018-B2	ER80S-B2L ER80S-B2
2 $\frac{1}{4}$ Cr-1Mo	5A	E8018-B3L E9018-B3	ER80S-B3L ER90S-B3	E9018-B3L E9018-B3	ER90SB3L ER90S-B3
5Cr- $\frac{1}{2}$ Mo	5B	E8018-B6 E8018-B6L	ER80S-B6	E502-XX E502-XX	ER502
9Cr-1Mo	5B	E8018-B8 E8018-B8L	ER80S-B8	E505-XX E505-XX	ER505
Cr-1Mo- $\frac{1}{4}$ V	5B	E9018-B9	ER90S-B9	N/A	N/A

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Section 9 Non-Destructive Examination

In this section we will primarily cover the NDE process not covered in ASME Section V. For classroom instruction we will only go over the highlights, strengths and weakness of the given processes.

Once again this is a subject that will demand a lot of personal study for the candidate to do well on the exam. Expect to put **many hours** into this and the previous welding material.

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Section 9 Non-Destructive Examination

Be warned, as regards the examination the amount of detail about the actual practice of NDE in Section 9 is huge, when taken as a whole. It is really only an overview of the common NDE processes.

There are about 13 pages of text, a dozen or so Tables, and approximately 40 Figures. This is going to take a lot of study.

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Section 9 Non-Destructive Examination

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Discontinuities

The following statements from this section should give a good clue as to how the API committee will handle questions from this area.

“The inspector should choose an NDE method capable of detecting the discontinuity in the type of weld joint due to the configuration. Table 2 and Figure 11 list the common types and location of discontinuities and illustrate their positions within a butt weld. The most commonly used NDE methods used during weld inspection are shown in Table 3.”

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Section 9 Non-Destructive Examination Discontinuities

“Table 4 lists the various weld joint types and common NDE methods available to inspect their configuration. Table 5 further lists the detection capabilities of the most common NDE methods. Additional methods, like alternating current field measurement (ACFM), have applications in weld inspection and are described in this section but are less commonly used.”

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Section 9.1 Non-Destructive Examination Discontinuities

“The inspector should be aware of discontinuities common to specific base metals and weld processes to assure these discontinuities are detectable. Table 6 is a summary of these discontinuities, potential NDE methods and possible solutions to the weld process.”

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Table - 2 Common Types of Discontinuities

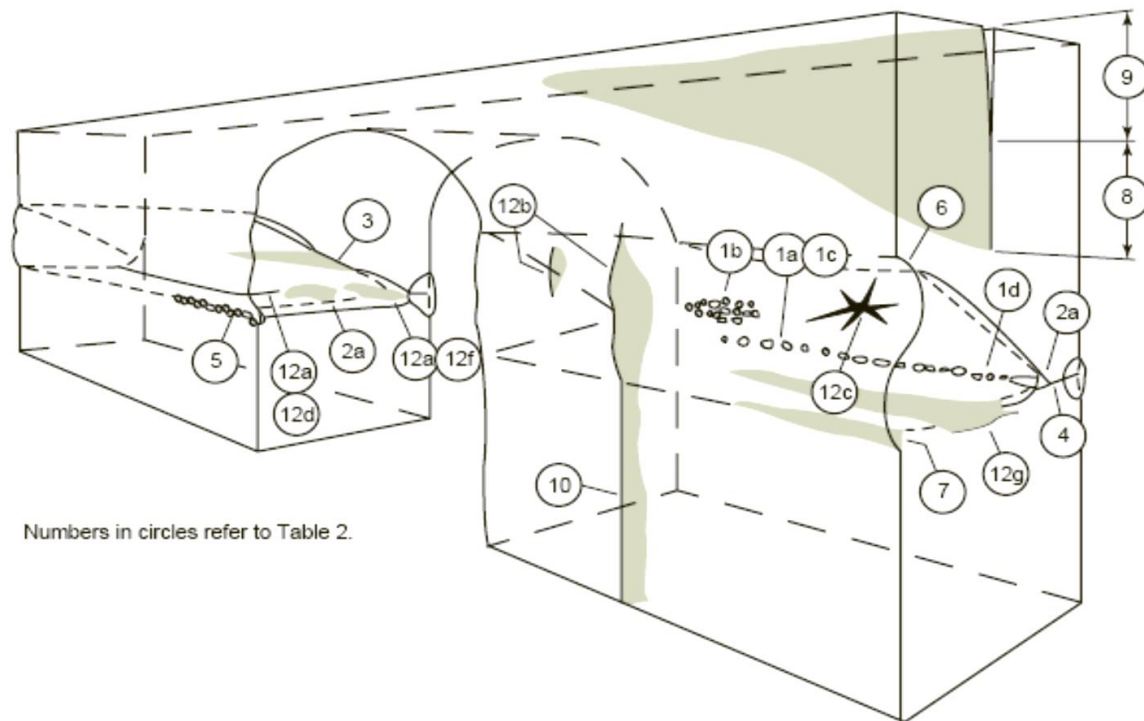
Type of Discontinuity	Location	Remarks
(1) Porosity (a) Uniformly scattered (b) Cluster (c) Piping (d) Aligned (e) Elongated	WM	Porosity could also be found in the BM and HAZ if the base metal is a casting.
(2) Inclusion (a) Slag (b) Tungsten	WM, WI	
(3) Incomplete fusion	WM/MI	WM between passes
(4) Incomplete joint penetration	BM	Weld root.
(5) Undercut	WI	Adjacent to weld toe or weld root in base metal.
(6) Underfill	WM	Weld face or root surface of a groove weld.
(7) Overlap	WI	Weld toe or root surface.
(8) Lamination	BM	Base metal, generally near midthickness of section
(9) Delamination	BM	Base metal, generally near midthickness of section.
(10) Seam and lap		Base metal surface generally aligned with rolling direction.
(11) Lamellar tear	BM	Base metal, near HAZ.
(12) Crack (includes hot cracks and cold cracks described in text) (a) Longitudinal (b) Transverse (c) Crater (d) Throat (e) Toe (f) Root (g) Underbead and HAZ	WM, HAZ, BM WM, HAZ, BM WM WM WI, HAZ WI, HAZ HAZ	Weld metal or base metal adjacent to WI. Weld metal (may propagate into HAZ and base metal). Weld metal at point where arc is terminated. Parallel to weld axis. Through the throat of a fillet weld. Root surface or weld root.
(13) Concavity	WM	Weld face or fillet weld.
(14) Convexity	WM	Weld face of a fillet weld.
(15) Weld reinforcement	WM	Weld face of a groove weld.

Study these tables extensively

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Table - 2 Common Types of Discontinuities



Numbers in Circles refer to Table 2

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Table 3 Commonly Used NDE Methods

Table 3—Commonly Used NDE Methods

Type of Test	Symbols
Visual	VT
Magnetic Particle	MT
Wet Fluorescent Magnetic Particle	WFMT
Liquid Penetrant	PT
Leak	LT
Eddy Current	ET
Radiographic	RT
Ultrasonic	UT
Alternating Current Field Measurement	ACFM

Study these tables extensively

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Table 4 - Capability of the Applicable Method for Weld Types

Joints	Inspection Methods						
	RT	UT	PT	MT	VT	ET	LT
Butt	A	A	A	A	A	A	A
Corner	O	A	A	A	A	O	A
Tee	O	A	A	A	A	O	A
Lap	O	O	A	A	A	O	A
Edge	O	O	A	A	A	O	A

Legend:

RT—Radiographic examination

UT—Ultrasonic testing

PT—Penetrant examination, including both DPT (dye penetrant testing) and FPT (fluorescent penetrant testing)

MT—Magnetic particle examination

VT—Visual testing

ET—Electromagnetic examination

A—Applicable method

O—Marginal applicability (depending on other factors such as material thickness, discontinuity size, orientation, and location)

Study these tables extensively

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**Table 5 - Capability of the
Applicable Method Vs. Discontinuity**

Joints	Inspection Methods						
	RT	UT	PT	MT	VT	ET	LT
Porosity	A	O	A	O	A	O	A
Slag inclusions	A	O	A	O	A	O	O
Incomplete fusion	O	A	U	O	O	O	U
Incomplete joint penetration	A	A	U	O	O	O	U
Undercut	A	O	A	O	A	O	U
Overlap	U	O	A	A	O	O	U
Cracks	O	A	A	A	A	A	A
Laminations	U	A	A	A	A	U	U

Study these tables extensively

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Table 6 - Discontinuities Commonly Encountered in Welding Processes

Material	Type of Discontinuity	Welding Processes	Typical NDE Method	Practical Solution
Carbon Steel	Hydrogen Cracking	SMAW, FCAW, SAW	VT, PT, MT after cool down	Low-hydrogen electrode, preheat, post heat, clean weld joint.
	Lack of fusion (LOF)	All	UT, ACFM	Proper heat input, proper welding technique.
	Incomplete Penetration	All	RT, UT, VT ¹	Proper heat input, proper joint design.
	Undercut	SAW, SMAW, FCAW, GMAW	VT, ACFM	Reduce travel speed.
	Slag Inclusion	SMAW, FCAW, SAW	RT, UT	Proper welding technique, cleaning, avoid excessive weaving.
	Porosity	ALL	RT	Low hydrogen, low sulfur environment, proper shielding.
	Burn-through	SAW, FCAW, GMAW, SMAW	RT, VT ^a	Proper heat input.
	Arc Strike	ALL	VT, MT, PT, Macroetch	Remove by grinding.
	Lack of side wall fusion	GMAW-S	UT	Proper heat input; vertical uphill.
	Tungsten Inclusion	GTAW	RT	Arc length control.

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Table 6 - Discontinuities Commonly Encountered in Welding Processes

Austenitic Stainless Steel	Solidification cracking	All	PT, ACFM	Proper filler, ferrite content, proper joint design.
	Hot cracking	SAW, FCAW, GMAW, SMAW	RT, PT, UT, ACFM	Low heat input, stringer bead.
	Incomplete Penetration	All	RT, UT	Proper heat input.
	Undercut	SAW, SMAW, FCAW, GMAW	VT, ACFM	Reduce travel speed.
	Slag Inclusion	SMAW, FCAW, SAW	RT, UT	Proper cleaning.
	Porosity	ALL	RT	Low hydrogen, low sulfur environment, proper shielding.
	Arc Strike	ALL	VT, PT, Macroetch	Remove by grinding.
	Tungsten Inclusion	GTAW	RT	Arc length control.

^aWhen the root is accessible.

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9.2 MATERIALS IDENTIFICATION

During welding inspection, the **inspector may** need to verify the conformance of the base material and filler metal chemistries with the selected or specified alloyed materials.

This may include **reviewing** the certified mill test report, reviewing stamps or markings on the components, or require PMI testing. It is the **responsibility of the owner/user** to establish a written material verification program indicating the extent and type of PMI to be conducted. Guidelines for material control and verification are outlined in **API RP 578**.

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9.3 VISUAL EXAMINATION (VT)

9.3.1 General

Visual examination is the most extensively used NDE method for welds. It includes either the direct or indirect observation of the exposed surfaces of the weld and base metal. Direct visual examination is conducted when access is sufficient to place the eye within 6 in. – 24 in. (150 mm – 600 mm) of the surface to be examined and at an angle not less than 30 degrees to the surface as illustrated in Figure 12. Mirrors may be used to improve the angle of vision. Remote visual examination may be substituted for direct examination.

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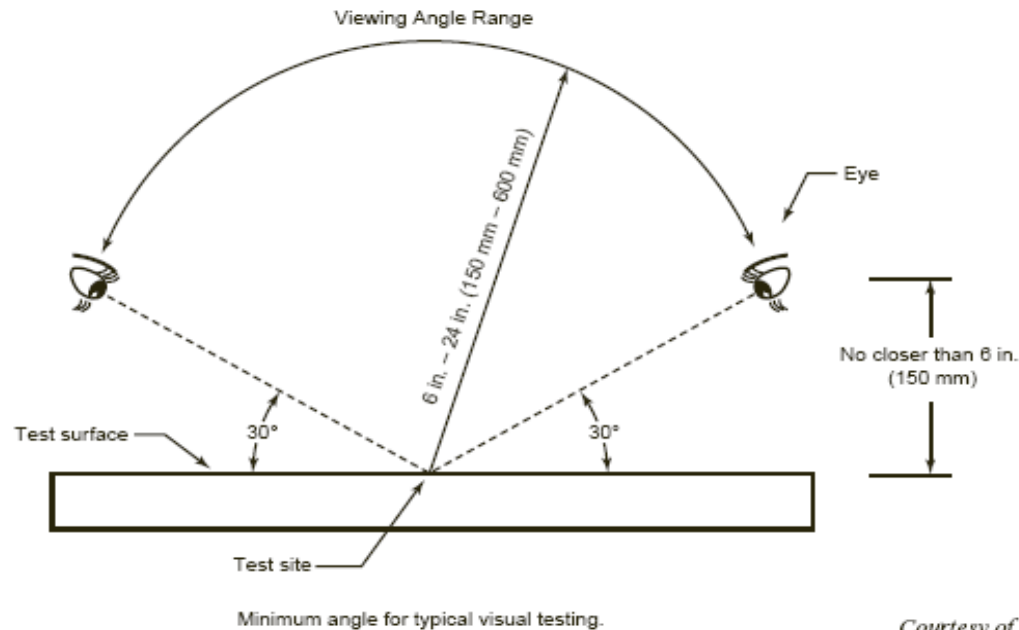
9.3 VISUAL EXAMINATION (VT)

9.3.1 General

Remote examination may use aids such as telescopes, borescopes, fiberscope, cameras or other suitable instruments, provided they have a resolution at least equivalent to that which is attained by direct visual examination. In either case, the illumination should be sufficient to allow resolution of fine detail. These illumination requirements are to be addressed in a written procedure.

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Courtesy of C.J. Hellier

Figure 12 – Direct Visual Examination Requirements

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9.3 VISUAL EXAMINATION (VT)

- Complete your studies by becoming familiar with all of the remaining topics in this section.

9.3.2.1 Optical Aids

9.3.2.2 Mechanical Aids

9.3.2.3 Weld Examination Devices

- Concentrate on the various figures and the name of each inspection device, how it is used, and what it is used for. Also be aware that pictures can be part of the exam.

Example Weld Examination Device:

The inspection tool in the picture below is _____.

1. a Bridge Cam Gauge
2. a T-Fillet Weld Gauge
3. a Weld Fillet Gauge
4. an Adjustable Fillet Weld Gauge



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9.5 Alternating Current Field Measurement (ACFM)

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Principle of Operation

- The ACFM technique is an **electromagnetic non-contacting** technique that is able to detect and size surface breaking defects in a range of different materials and through coatings of varying thickness.
- This technique is **ideal for inspecting complex geometries such as nozzles, ring-grooves, grind-out areas or radiuses**. It requires minimal surface preparation and can be used at elevated temperatures up to **900°F (482°C)**.
- With its increased **sensitivity to shallow cracks**, ACFM is used for the evaluation and monitoring of **existing cracks**.

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9.5 Alternating Current Field Measurement (ACFM)

- ACFM uses a probe similar to an eddy current probe and introduces an **alternating current** in a thin skin near to the surface of any conductor. When a uniform current is introduced into the area under test, if it is defect free, the current is undisturbed.
- If the area has a crack present, the **current flows around the ends and the faces of the crack**. A magnetic field is present above the surface associated with this uniform alternating current and will be disturbed if a surface-breaking crack is present.

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Spend time becoming familiar with the various NDE methods and their proper applications. If you are familiar with most of the NDE methods then concentrate on those you may not have been exposed to, such as ACFM.

Class Quiz

1. The method of evaluating the size of a discontinuity that uses a global approach and divides into thirds a section thickness is _____.
 - a. Tip Diffraction
 - b. High Angle Longitudinal
 - c. ID Creeping Wave Method
 - d. Intensity Drop Technique
2. The technique that uses an array of transducers on either side of the weld is _____.
 - a. Time of Flight Diffraction
 - b. The Bimodal Method
 - c. Pulse Echo Raster
 - d. Pulse Echo Zone

Solution

1. The method of evaluating the size of a discontinuity that uses a global approach and divides into thirds a section thickness is _____.

c. ID Creeping Wave Method

2. The technique that uses an array of transducers on either side of the weld is _____.

d. Pulse Echo Zone

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10 Metallurgy

Solid metals are crystalline in nature and all have a structure in which the atoms of each crystal are arranged in a specific geometric pattern. The physical properties of metallic materials including strength, ductility and toughness can be attributed to the chemical make-up and orderly arrangement of these atoms.

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10 Metallurgy

- Metals in molten or liquid states have no orderly arrangement to the atoms contained in the melt. As the melt cools, a temperature is reached at which clusters of atoms bond with each other and start to solidify developing into solid crystals within the melt. The individual **crystals** of pure metal are identical except for their orientation and **are called grains**.
- As the temperature is reduced further, these crystals change in form eventually touch and where the grains touch an irregular transition layer of atoms is formed, which is called the grain boundary. Eventually the entire melt solidifies, interlocking the grains into a solid metallic structure called a casting.

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10 Metallurgy

- Knowledge of cast structures is important since the welding process is **somewhat akin to making a casting** in a foundry.
- Because of the similarity in the shape of its grains, a weld can be considered a small casting.
- A solidified weld may have a structure that looks very much like that of a cast piece of equipment. However, the thermal conditions that are experienced during welding produce a cast structure with characteristics unique to welding.

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10 Metallurgy

10.2.3 Welding Metallurgy

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We will begin our discussion here with Welding Metallurgy. Previous sections about the structures of metals are very general in nature, reading these a time or two should be sufficient preparation.

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10.2.3 Welding Metallurgy

Some Important Points

- Most typical weld metals are rapidly solidified and, like the structure of a casting described earlier, usually solidify in the same manner as a casting and have a fine grain dendritic microstructure.
- The solidified weld metal is a mixture of melted base metal and deposited weld filler metal, if used.
- The heat-affected zone (HAZ) is adjacent to the weld and is that portion of the base metal that has not been melted, but whose mechanical properties or microstructure have been altered by the preheating temperature and the heat of welding.

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10.2.3 Welding Metallurgy

Some Important Points

- There will typically be a change in grain size or grain structure and hardness in the HAZ of steel.
- The size or width of the HAZ is dependent on the heat input used during welding.
- For carbon steels, the HAZ includes those regions heated to greater than 1350°F (700°C). Each weld pass applied will have its own HAZ and the overlapping heat affected zones will extend through the full thickness of the plate or part welded.
- The third component in a welded joint is the base metal.

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10.3 Physical Properties

Some Important Points

- The physical properties of base metals, filler metals and alloys being joined can have an influence on the efficiency and applicability of a welding process.
- Examples of physical properties of a metal are the melting temperature, the thermal conductivity, electrical conductivity, the coefficient of thermal expansion, and density.

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Summary

Spend time with this material, questions would be expected to few and fairly simple on this material. However do not neglect it all together.

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11 Refinery and Petrochemical Plant Welding Issues

11.1 General

This section provides details of specific welding issues encountered by the inspector in refineries and petrochemical plants.

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11.2 Hot Tapping and In-Service Welding

- API Publication 2201 provides an in depth review of the safety aspects to be considered.
- The following is a brief summary of welding related issues.
- Two primary concerns when welding on in-service piping and equipment are burn through and cracking.
- Burn through will occur if the un-melted area beneath the weld pool can no longer contain the pressure within the pipe or equipment.

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11.2 Hot Tapping and In-Service Welding

- Weld cracking results when fast weld-cooling rates produce a hard, crack-susceptible weld microstructure.
- Fast cooling rates can be caused by flowing contents inside the piping and equipment, which remove heat quickly.

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11.2.1 Electrode Considerations

- Hot tap and in-service welding operations should be carried out only with low-hydrogen consumables and electrodes (e.g., E7016, E7018 and E7048).
- Extra-low-hydrogen consumables such as Exxxx-H4 should be used for welding carbon steels with CE greater than 0.43% or where there is potential for hydrogen assisted cracking (HAC) such as cold worked pieces, high strength, and highly constrained areas.

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11.2.1 Electrode Considerations

- Cellulosic type electrodes (e.g., E6010, E6011 or E7010) may be used for root and hot passes.
- Root pass with low-hydrogen electrodes reduces risk of Hydrogen Assisted Cracking (HAC). It also reduces risk of burn through.

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11.2.1 Electrode Considerations

It should be noted that cellulosic electrodes have the following adverse effects on the integrity of the weldment:

- a. Deep penetration, therefore higher risk of **burn-through** than low-hydrogen electrodes; and
- b. High diffusible hydrogen, therefore higher risk of **hydrogen assisted cracking**.

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11.2.2 Flow Rates

Under most conditions, it is desirable to maintain some product flow inside of any material being welded. This helps to dissipate the heat and to limit the metal temperature.

Liquid flow rates in piping shall be between 1.3 ft/ sec. and 4.0 ft/sec. (0.4 m/sec. and 1.3 m/sec.). Faster liquid flow rates may cool the weld area too quickly and thereby cause hard zones that are susceptible to weld cracking or low toughness properties in the weldment.

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11.2.2 Flow Rates

Because this is not a problem when the pipe contains gases, there is no need to specify a maximum velocity.

If the normal flow of liquids exceeds these values or if the flow cools the metal to below dew point, it is advisable to compensate by **preheating** the weld area to at least 70°F (20°C) and maintaining that temperature until the weld has been completed.

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11.2.2 Flow Rates

Some Important Points

- Welding on a line under no-flow conditions or intermittent flow conditions, e.g., a flare line, **shall not** be attempted **unless** it has been confirmed that no explosive or flammable mixture will be present.
- It shall be confirmed that no ingress of oxygen in the line is possible. In cases where this requirement cannot be met, inert gas or nitrogen purging is recommended.

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11.2.2 Flow Rates

Some Important Points

- An appropriate flow rate should be maintained to minimize the possibility of burn-through or combustion. The minimum flow rate is 1.3 ft/sec. (0.4 m/sec.) for liquid and gas.
- For liquids, the maximum flow rate usually required to minimize risk of high hardness weld zone due to fast cooling rate.
- There is no restriction on maximum velocity for gas lines, subject to maintaining preheat temperatures.

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11.2.3 Other Considerations

To avoid overheating and burn through, the welding procedure specification should be based on experience in performing welding operations on similar piping or equipment, and/or be based on heat transfer analysis.

Many users establish procedures detailing the minimum wall thickness that can be hot tapped or welded in-service for a given set of conditions like pressure, temperature, and flow rate.

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11.2.3 Other Considerations

To minimize burn through, the first weld pass to equipment or piping less than 1/4 in. (6.35 mm) thick should be made with 3/32 in. (4.76 mm) or smaller diameter welding electrode to limit heat input.

For equipment and piping wall thicknesses where burn through is not a primary concern, a larger diameter electrode can be used. Weaving the bead should also be avoided as this increases the heat input.

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11.2.3 Other Considerations

Adverse effects can also occur from the heat on the process fluid. In addition, welds associated with hot taps or in-service welding often cannot be stress relieved and may be susceptible to cracking in certain environments.

Any hot tapping or in-service welding on systems containing those listed in Table 13 should be carefully reviewed.

Table 13- Hot Tapping/In-Service Welding Hazards

Substance	Hot Tapping/ In-Service Welding Hazard
Acetylene	Explosion or unstable reaction with the addition of localized heat.
Acetonitrile	Explosion or unstable reaction with the addition of localized heat.
Amines and caustic	Stress corrosion cracking due to high thermal stress upon the addition of localized heat and high hardness of non-PWHT's Weld. Hydrogen embrittlement
Butadiene	Explosion or unstable reaction
Chlorine	Carbon Steel will burn in the presence of chlorine and high heat
Compressed Air	Combustion /metal burning
Ethylene	Exothermic decomposition or explosion
Ethylene Oxide	Exothermic decomposition or explosion
Hydrogen	High temperature hydrogen attack Hydrogen assisted cracking
Hydrogen Sulfide (wet H ₂ S)	Stress corrosion cracking due to high hardness of non-PWHT's weld. Hydrogen embrittlement. Pyrophoric scale.
Hydrofluoric Acid	Hazardous substance.
Oxygen	Combustion/metal burning
Propylene	Explosion or unstable reaction
Propylene Oxide	Explosion or unstable reaction
Steam	High pressure steam can blow out.

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11.2.4 Inspection

Some Important Points

Inspection tasks typically associated with hot tapping or welding on in-service equipment should include:

- a. Verifying adequate wall thickness along the lengths of the proposed welds typically using UT or RT.
- b. Verifying the welding procedure. Often, plants have welding procedures qualified specifically for hot taps and inservice welding.
- c. Verifying flow conditions.

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11.2.4 Inspection

Some Important Points

- d. Specifying the sequence of welding full encirclement sleeves and fittings (circumferential and longitudinal welds).
- e. Verifying fit-up of the hot tap fitting.
- f. Auditing welding to assure the welding procedure is being followed.
- g. Perform NDE of completed welds. Typically this includes VT, UT shear wave using special procedures for the joint configuration, MT or PT as applicable for material and temperature.
- h. Witness leak testing of fitting, if specified.

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11.3

Lack of Fusion With GMAW-S Welding Process

A large quantity of ASTM A 106, Grade B Pipe, 4 in. through 10 in. was found to have lack of fusion (LOF) after being fabricated using the GMAW-S welding process. This piping was in normal fluid service and required 5% radiographic examination. Initially the radiographic film was read acceptable, but LOF it is not easily interpreted by most radiographers.

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Lack of Fusion With GMAW-S Welding Process

During this piping project, a weld was found to have lack of fusion while modifying a spool piece. The cut through the weld revealed the defect. Follow-up investigation and further examination indicated the root pass was acceptable in all cases, but subsequent weld passes exhibited LOF when a radiographer experienced in this particular discontinuity, read the film. ASME B31.3 considers LOF a defect.

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Lack of Fusion With GMAW-S Welding Process

The gas metal arc welding (GMAW) process can utilize various metal transfer modes. When using the low voltage, short circuiting mode (designated by the -S extension), the molten weld puddle is able to freeze more quickly. This allows the unique ability to weld out of position, to weld thin base metals, and to weld open butt root passes.

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Lack of Fusion With GMAW-S Welding Process

Due to this inherent nature of the welding process the BPV Code Section IX, restricts this process by:

- a. Requiring welders qualify with mechanical testing rather than by radiographic examination.
- b. Limiting the base metal thickness qualified by the procedure to 1.1 times the test coupon thickness for coupons less than 1/2 in. thick (12.7 mm) per variable QW-403.10.
- c. Limiting the deposited weld metal thickness qualified by the procedure to 1.1 times the deposited thickness for coupons less than 1/2 in. thick (12.7 mm) per variable QW-404-32.
- d. Making variable QW-409.2 an essential variable when qualifying a welder for the GMAW-S process.