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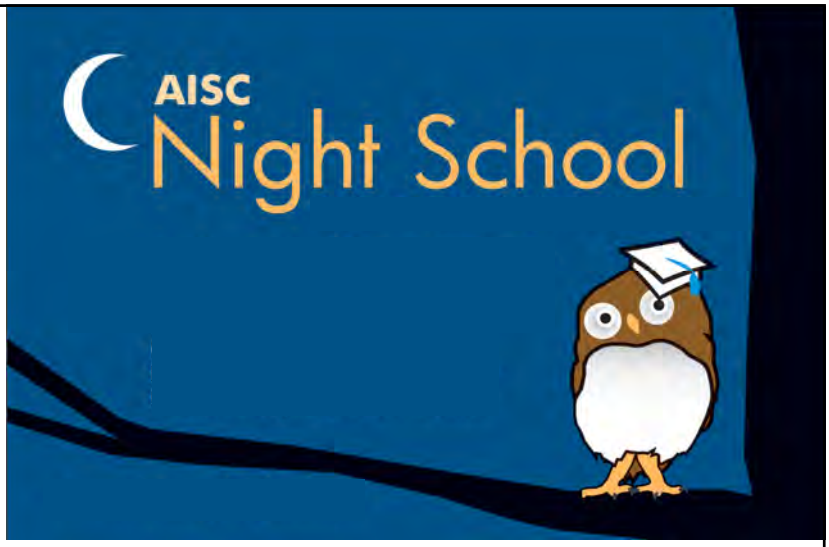

Welded Connections

A Primer for Engineers

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Course Description

21.4 Metallurgy and Cracking
November 5, 2019

This session will focus on two topics: metallurgy and cracking. Many metallurgical issues are associated with steel construction and the first part of the session will focus on the welding-related issues associated with the various steels that are commonly used in structural applications. The second half of the session will review the issue of cracking. Cracking rarely occurs when fabrication is properly done in accordance.

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Learning Objectives

- Identify the three major weld crack types.
- Identify AISC and AWS provisions that address metallurgy.
- List the elements that affect weldability.
- Explain the role of notch toughness.

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Night School 21 Course Schedule

10/8/2019 1. Introduction and Weld Processes
10/15/2019 2. Principles of Welded Connections
10/29/2019 3. Welded Connection Details
11/5/2019 4. Metallurgy and Cracking
11/19/2019 5. Fatigue of Welded Connections
11/26/2019 6. Seismic Welding Issues
12/3/2019 7. Special Welding Applications
12/10/2019 8. Problems and Fixes

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Night School 21
Welded Connections -- A Primer for Engineers

Session 4: Metallurgy and Cracking
November 5, 2019

Duane K. Miller, PE, ScD
Manager of Engineering Services and Welding Design Consultant

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METALLURGICAL ISSUES

Chapter 5: Metallurgical Issues

5.1 Introduction

5.2 Steel—Properties of Interest

5.3 Descriptions of Steel Groups

5.4 Welding Requirements for Specific Steels

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WELD CRACKING

Chapter 6: Weld Cracking

6.1 Introduction

6.2 Shrinkage and Restraint

6.3 Types of Weld Cracks

6.4 Lamellar Tearing

6.5 Reducing Shrinkage Stresses

6.6 Reducing Restraint

6.7 Post-Welding Stress Reduction Measures

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METALLURGY AND CRACKING

Outline

- Welding and Metallurgy
- Steel Categories
- Cracking
- Special Steels

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METALLURGY AND CRACKING

Metallurgy in a nutshell….

- Composition (alloys and carbon)
- Cooling Rate

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WELDING AND METALLURGY

Properties of Interest:

- Mechanical properties
- Chemical composition

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PROPERTIES OF INTEREST

Mechanical Properties:

- **Strength** (yield, tensile)
- **Ductility** (elongation, reduction in area)
- **Toughness** (CVN, CTOD)
- **Stiffness** (modulus of elasticity)

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TENSILE TEST

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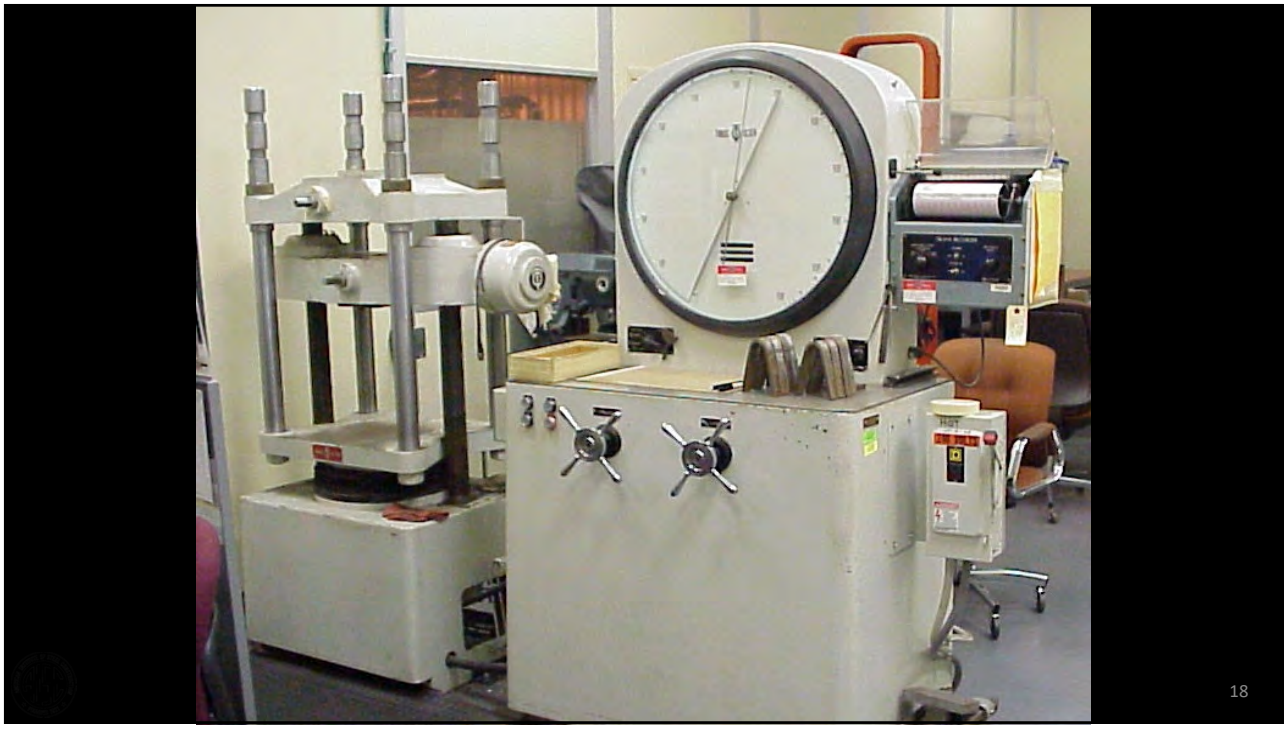

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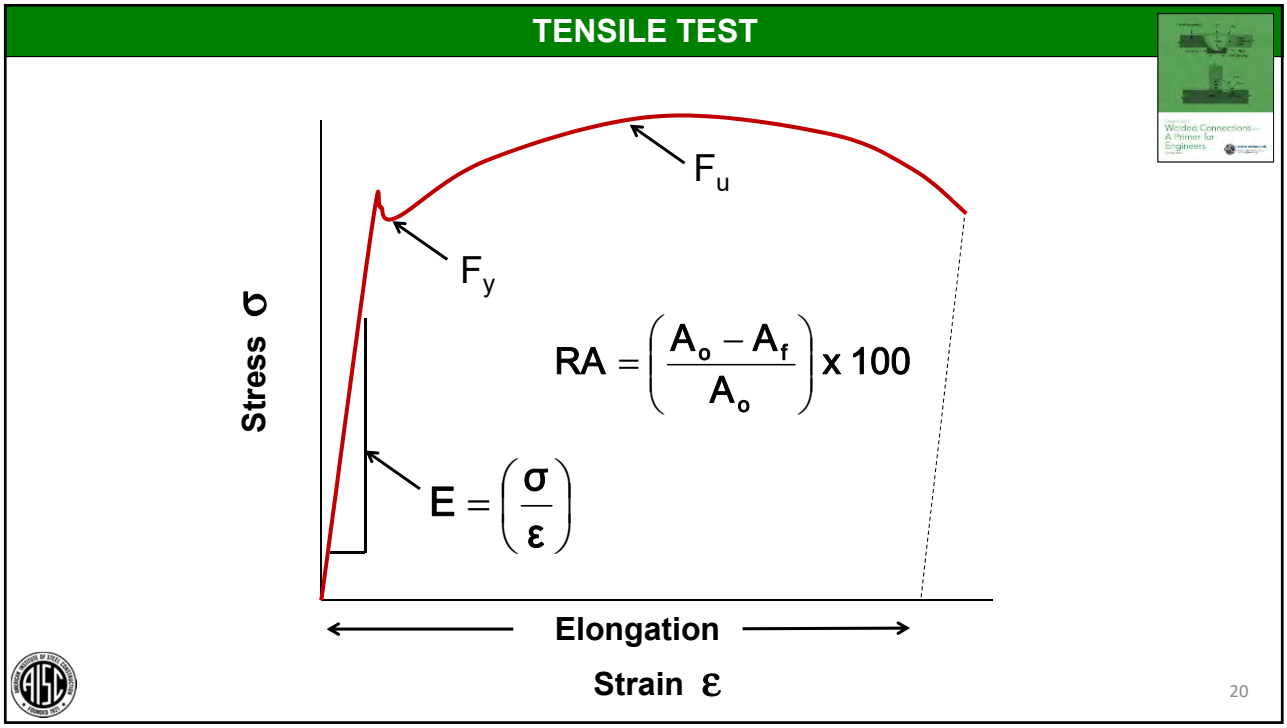

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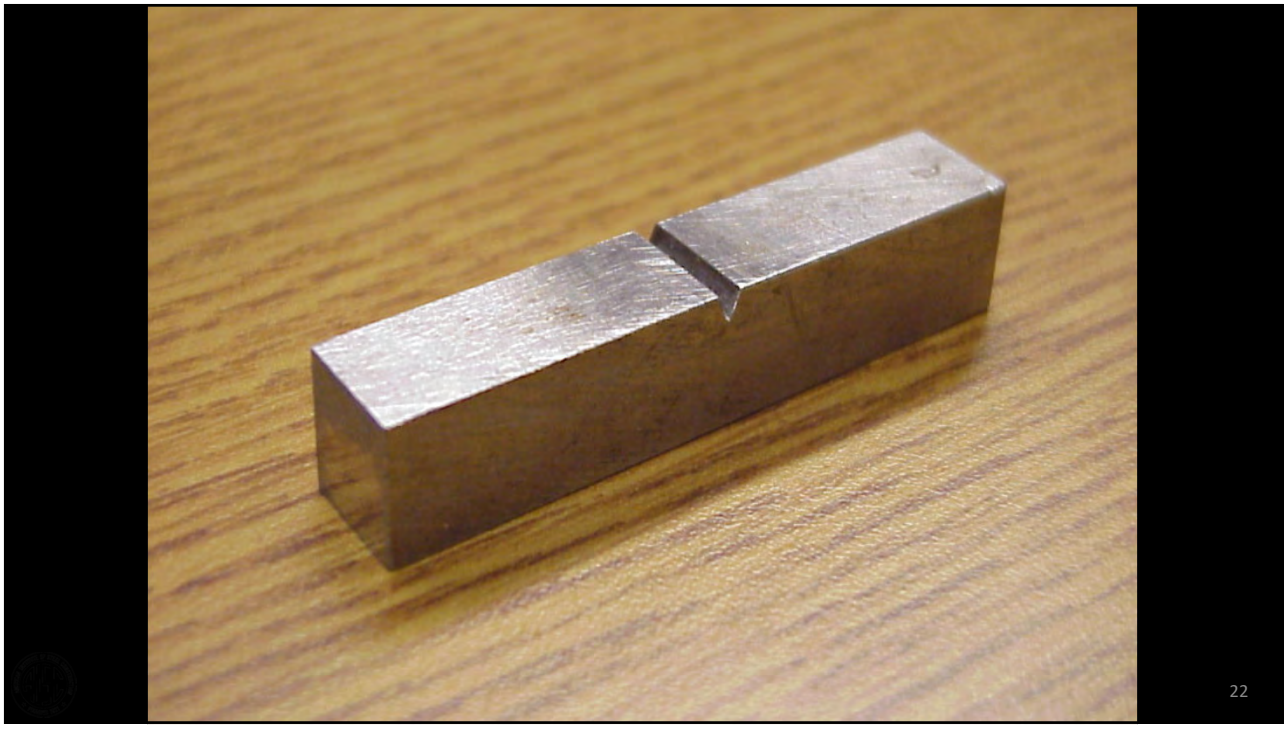

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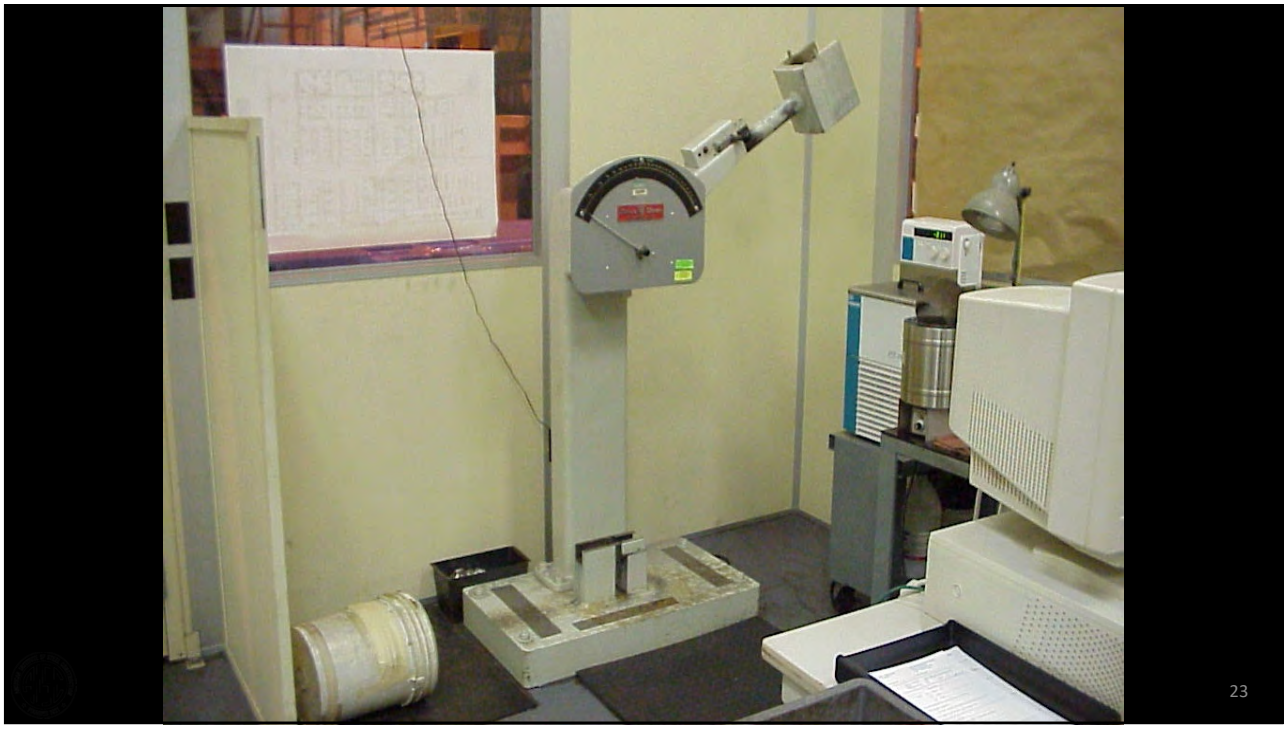

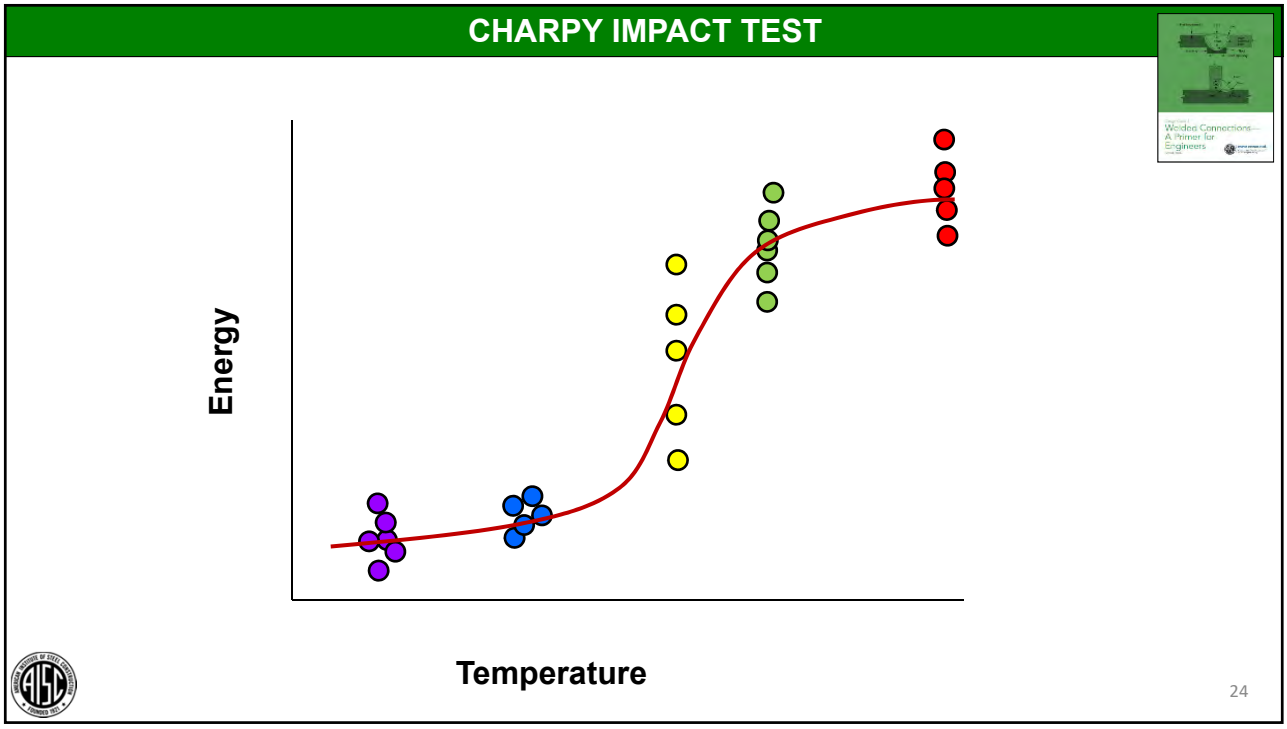

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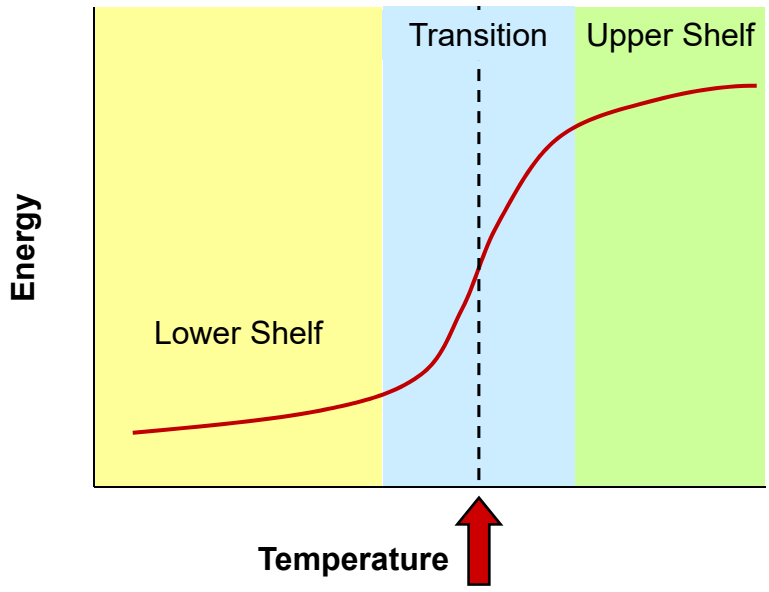

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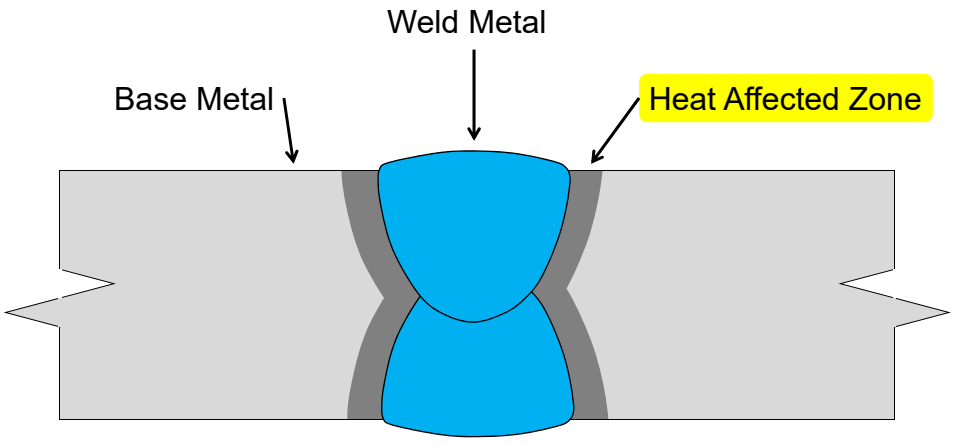
ELEMENTS OF A WELDED CONNECTION



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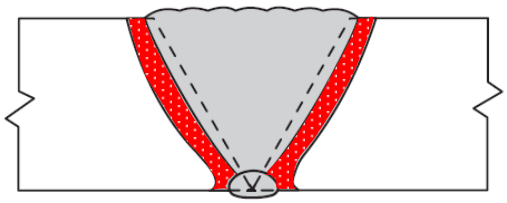
AWS STANDARD WELDING TERMS & DEFINITIONS (A3.0:2010)

heat-affected zone (HAZ).

The portion of base metal whose mechanical properties or microstructure have been altered by the heat of welding, brazing, soldering or thermal cutting.



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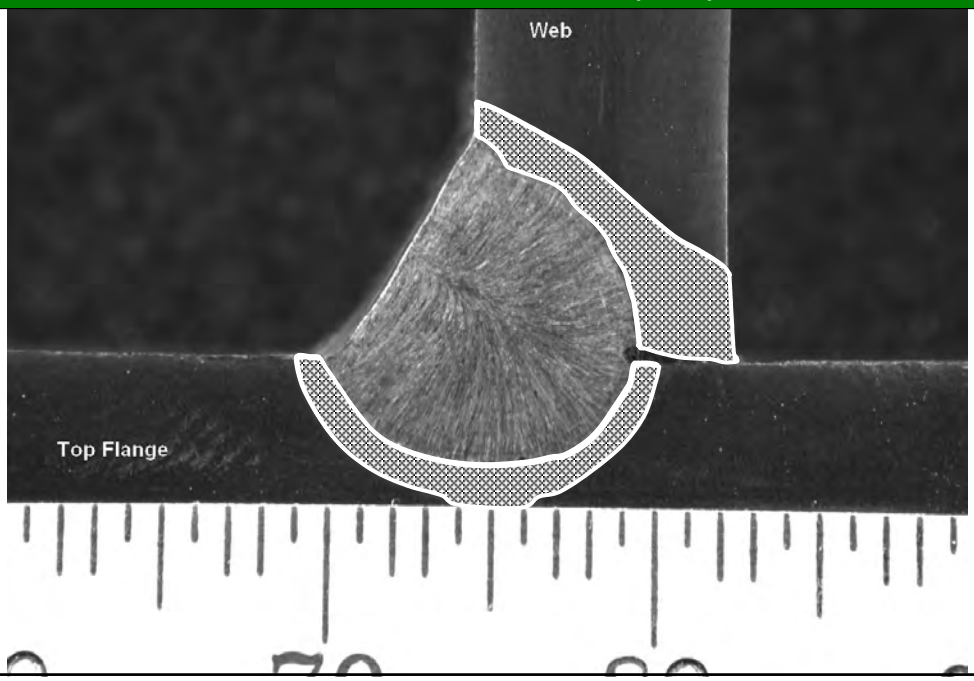
HEAT AFFECTED ZONE (HAZ)



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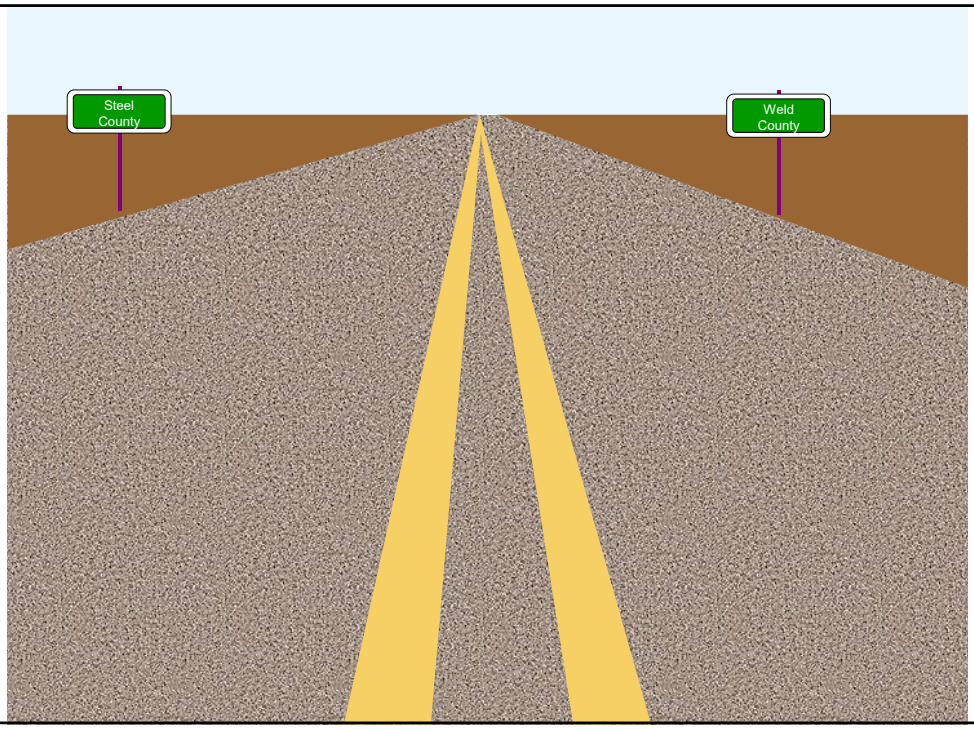

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HEAT AFFECTED ZONES

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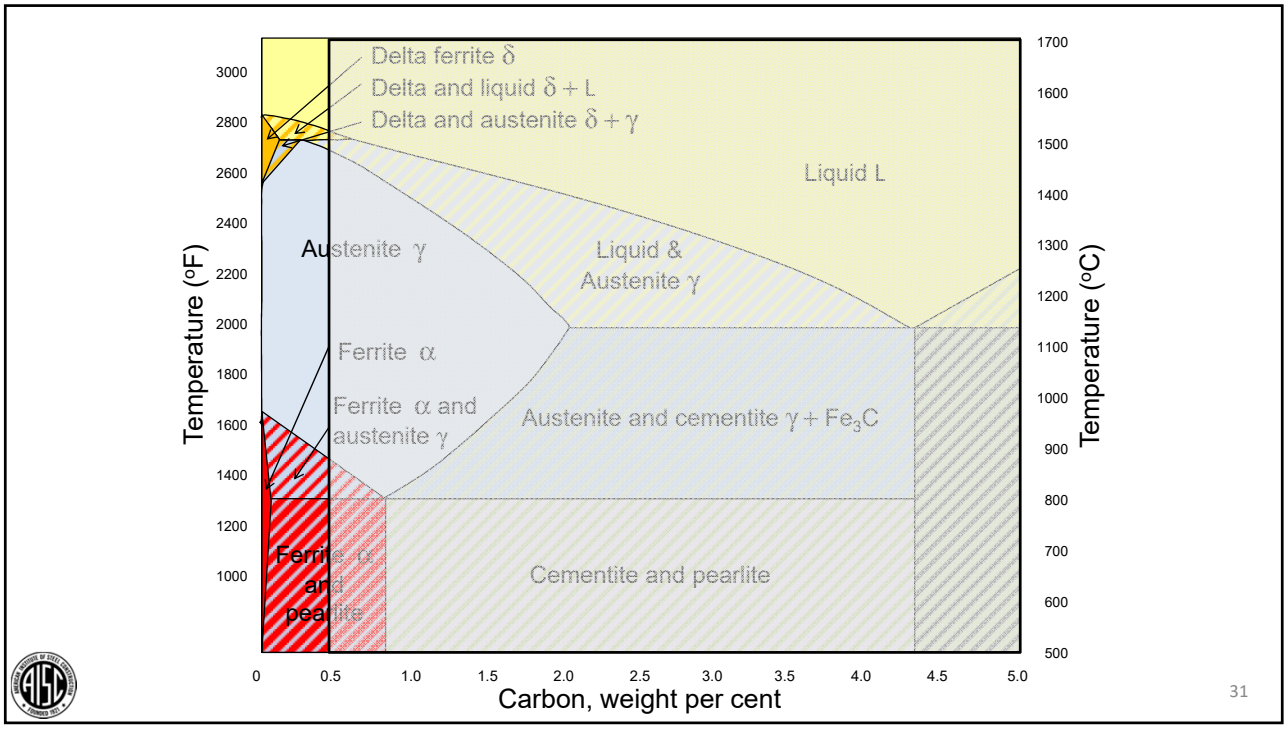

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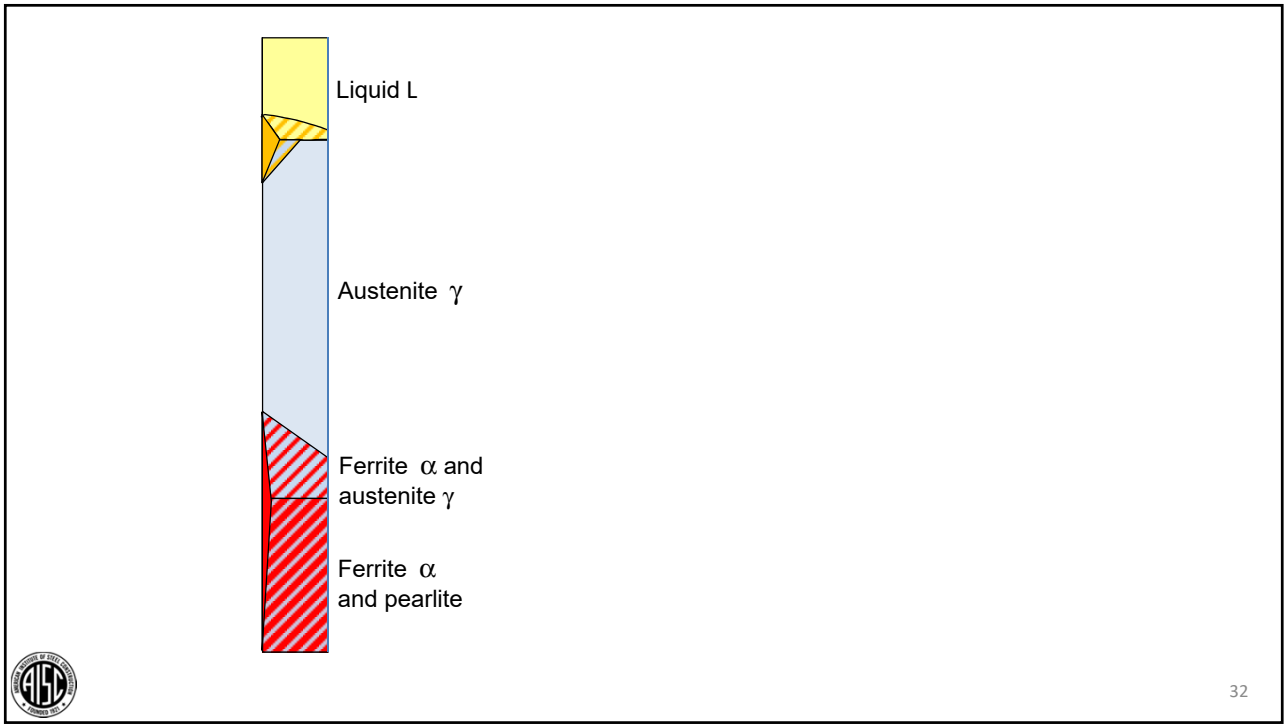

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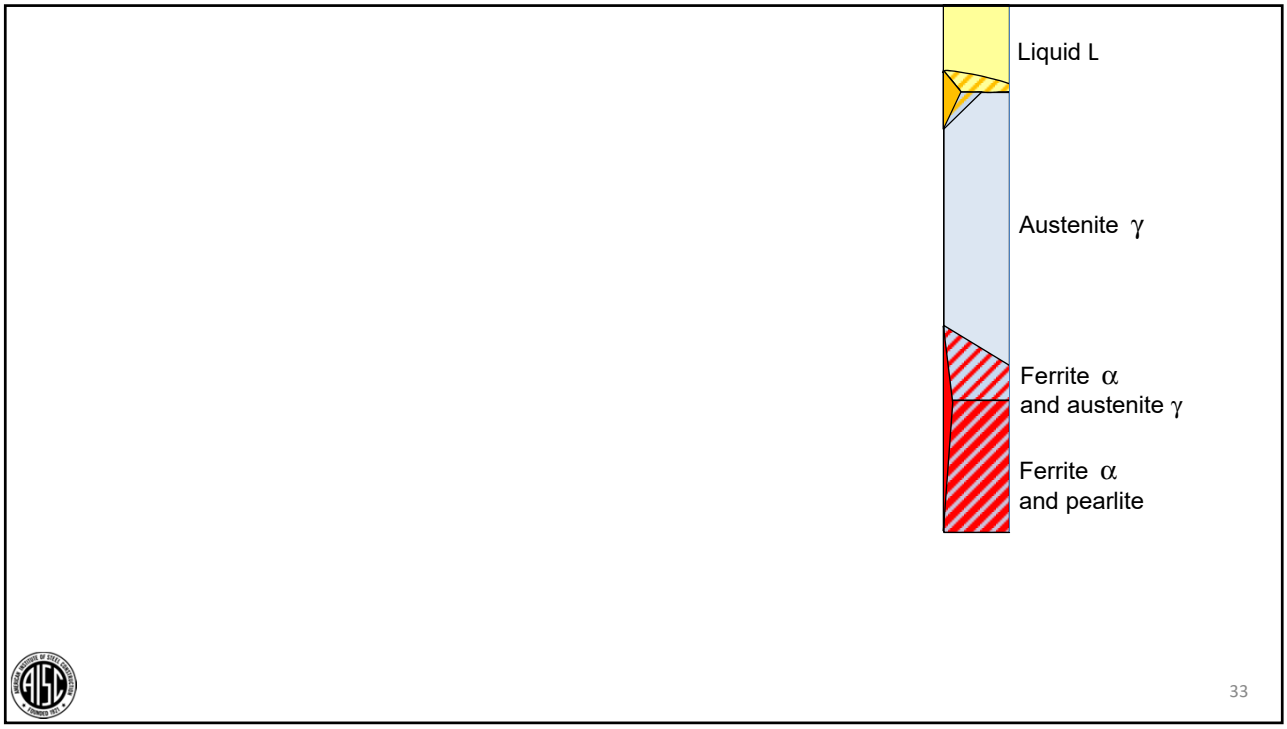

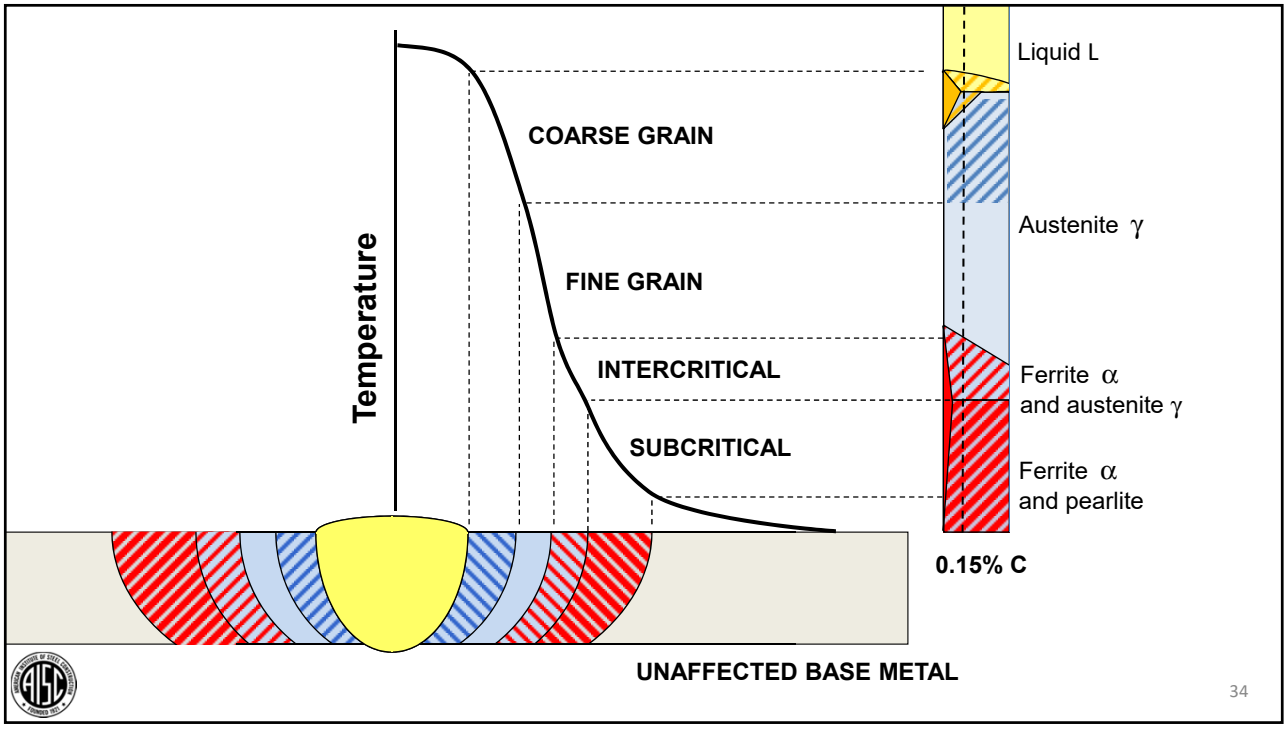

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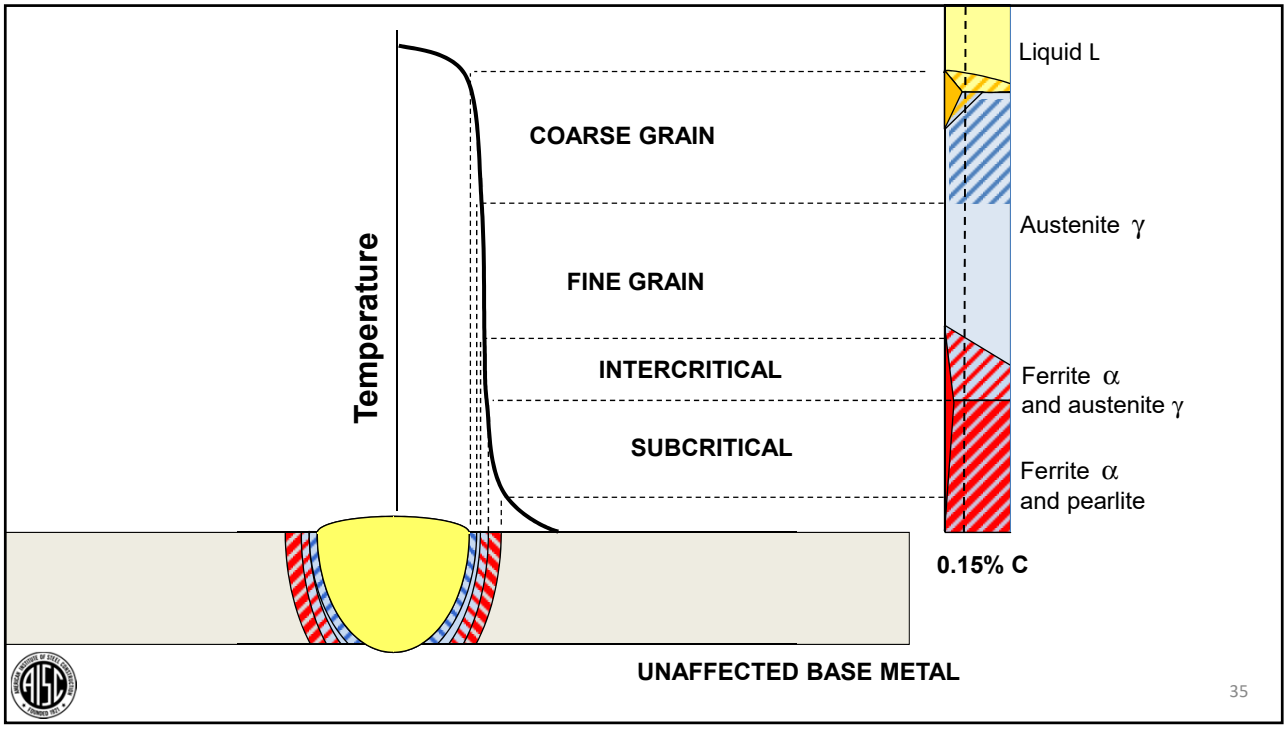

HEAT AFFECTED ZONE—IN A SINGLE PASS WELD

Coarse Grain Zone

Fine Grain Zone

Intercritical Zone

Subcritical Zone

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METALLURGY AND CRACKING

Metallurgy in a nutshell….

- Composition (alloys and carbon)
- Cooling Rate

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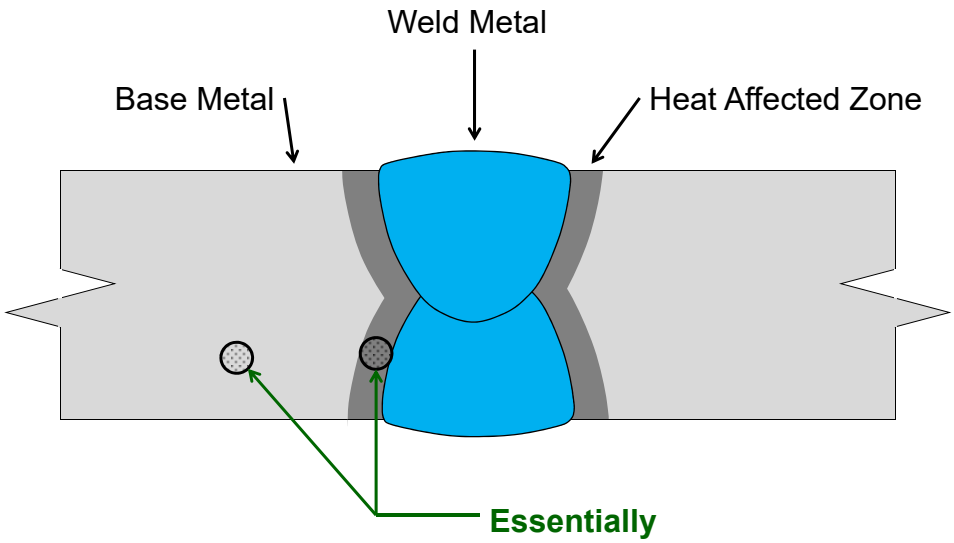
HEAT AFFECTED ZONE: CHEMISTRY

HAZ Chemistry = Base Metal Chemistry



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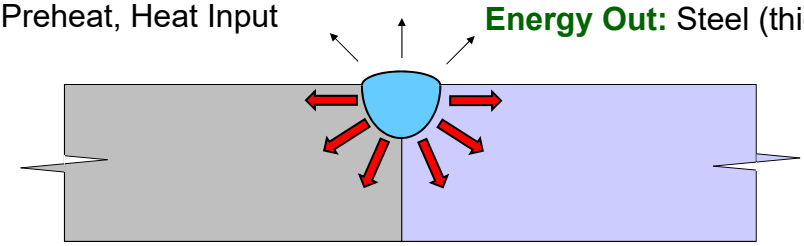
METALLURGY AND CRACKING

Metallurgy in a nutshell….

- Composition (alloys and carbon)
- Cooling Rate

Energy In: Preheat, Heat Input

Energy Out: Steel (thickness), Air



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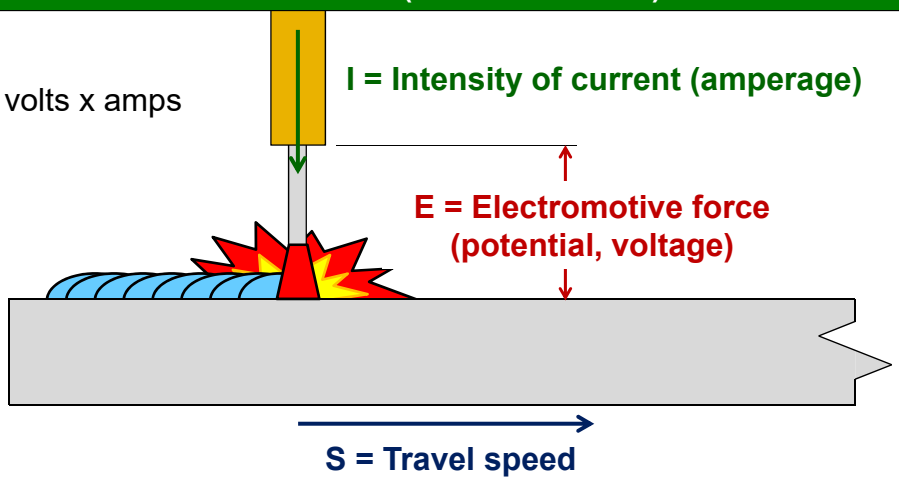
HEAT INPUT (ENERGY INPUT)

Energy = volts x amps



$$HI = \frac{60\ E\ I}{1000\ S}\ \text{KJ/in [KJ/mm]}$$

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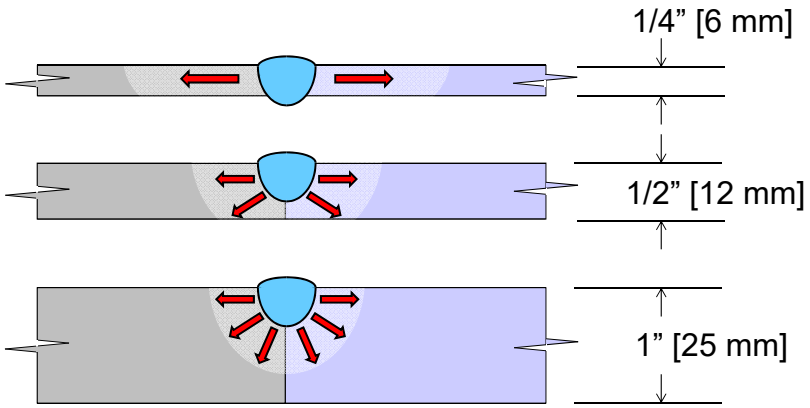
EFFECT OF PLATE THICKNESS

SMAW
HI = 50 KJ/in [2 KJ/mm]
80°F [27°C] preheat



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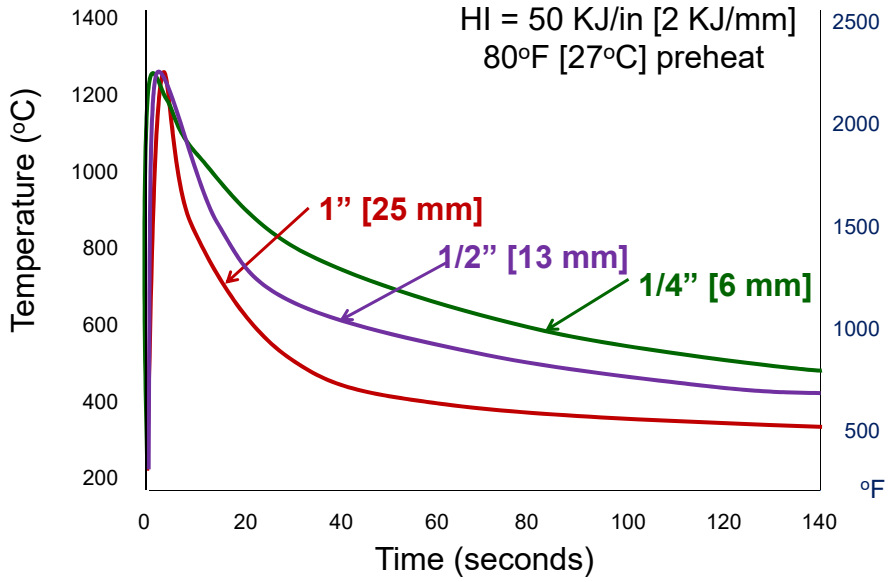
EFFECT OF PLATE THICKNESS

SMAW
HI = 50 KJ/in [2 KJ/mm]
80°F [27°C] preheat



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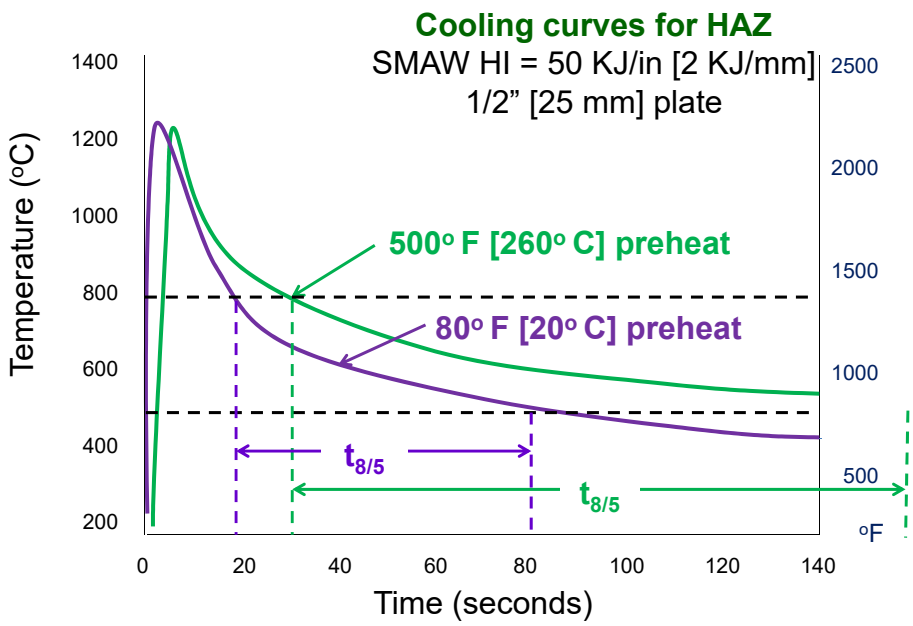
EFFECT OF PREHEAT



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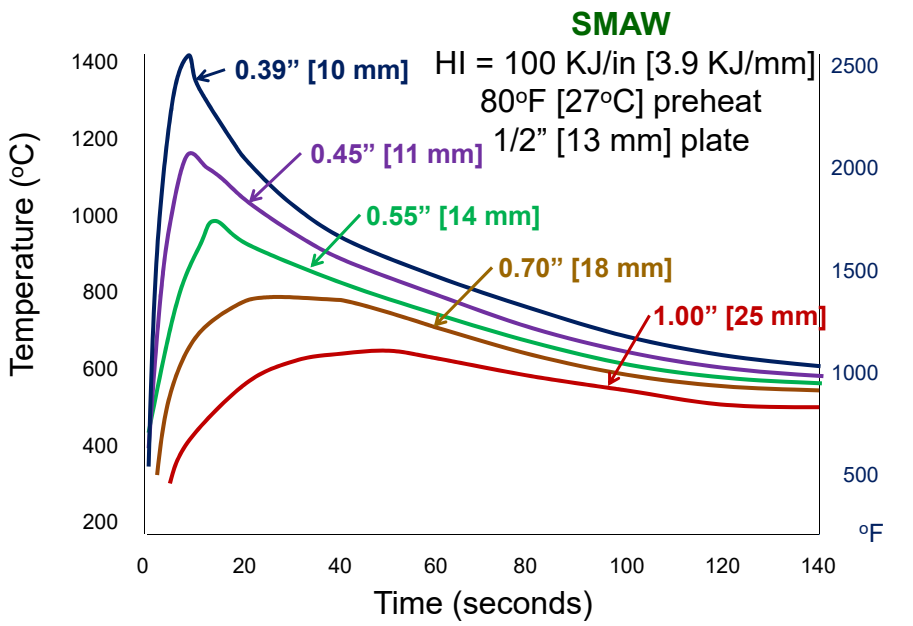
EFFECT OF DISTANCE FROM WELD CENTERLINE



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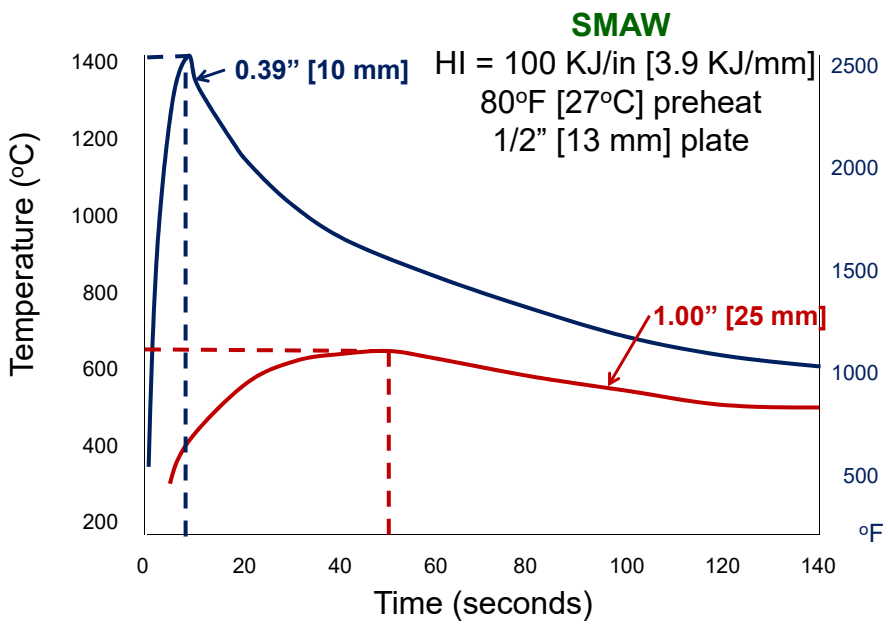
EFFECT OF DISTANCE FROM WELD CENTERLINE



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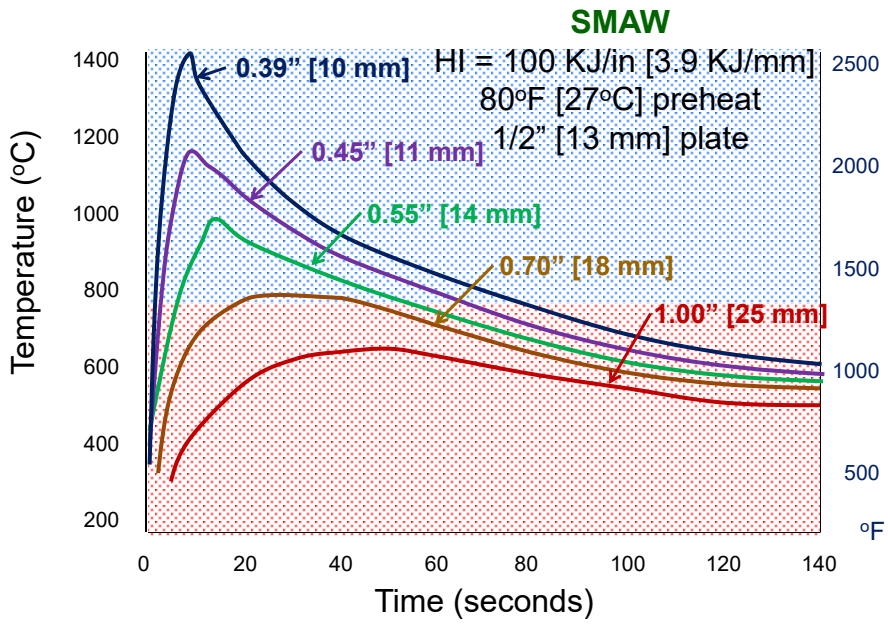
EFFECT OF DISTANCE FROM WELD CENTERLINE



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HEAT INPUT (ENERGY INPUT)

D1.1 does not directly deal with heat input, except:

- For quenched and tempered steels
- For WPSs required to deliver minimum CVN properties

D1.5 and D1.8 both address heat input directly.

D1.1 does deal with heat input indirectly.

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AISC 360-16 Specification for Structural Steel Buildings

Table J2.4: Minimum Fillet Weld Sizes

Material Thickness of Thinner Part Joined	Minimum Size of Fillet Weld
To 1/4”, inclusive	1/8”
Over 1/4” to 1/2”	3/16”
Over 1/2” to 3/4”	1/4”
Over 3/4”	5/16”

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AWS D1.1: 2015 Structural Welding Code – Steel

Table 5.7: Minimum Fillet Weld Sizes

Base-Metal Thickness (T)[a]	Minimum Size of Fillet Weld[b]	Approximate Minimum Heat Input
T ≤ 1/4”	1/8”	7 kJ/in.
1/4” < T ≤ 1/2”	3/16”	16 kJ/in.
1/2” < T ≤ 3/4”	1/4”	30 kJ/in.
3/4” < T	5/16”	43 kJ/in.

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METALLURGY AND CRACKING

Metallurgy in a nutshell….

- Composition (alloys and carbon)
- Cooling Rate

In the HAZ…

- The composition is that of the base metal
- Heating and cooling rates vary, depending on welding conditions
- Codes and practical welding limits extremes on high and low cooling rates
- Preheat is the primary means by which cooling rates are controlled

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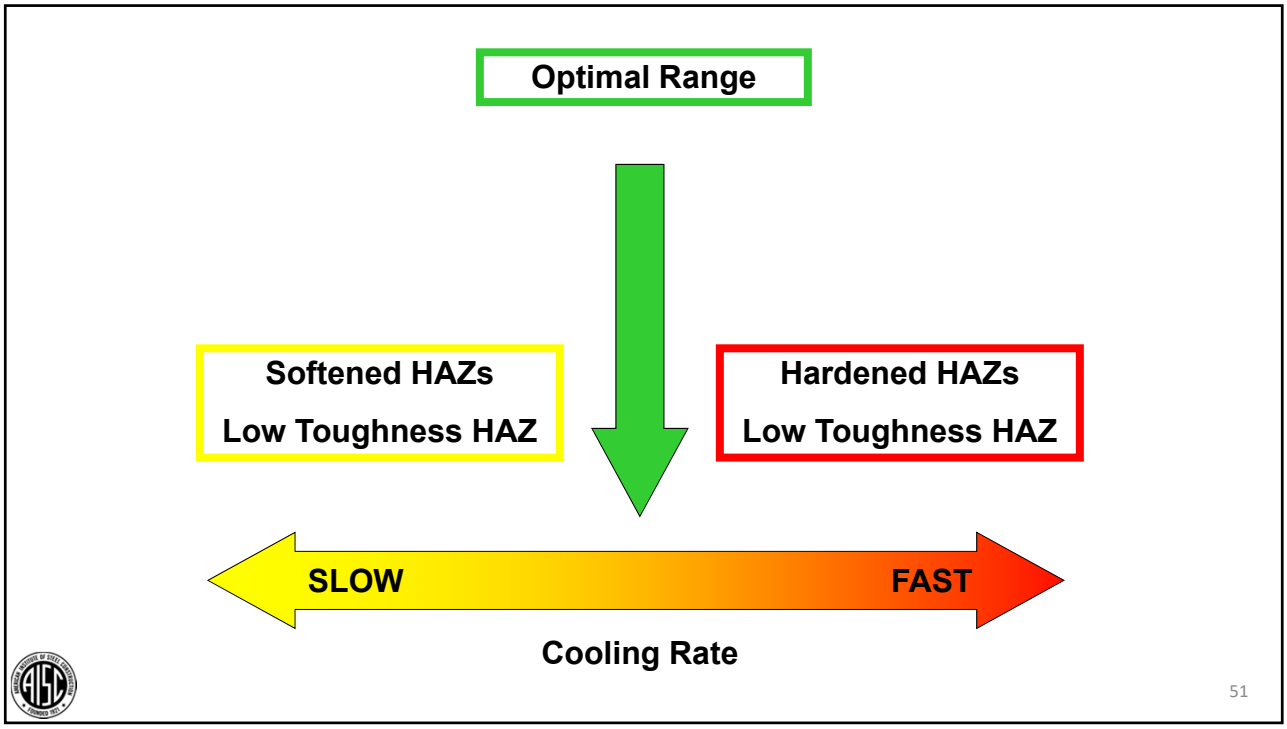

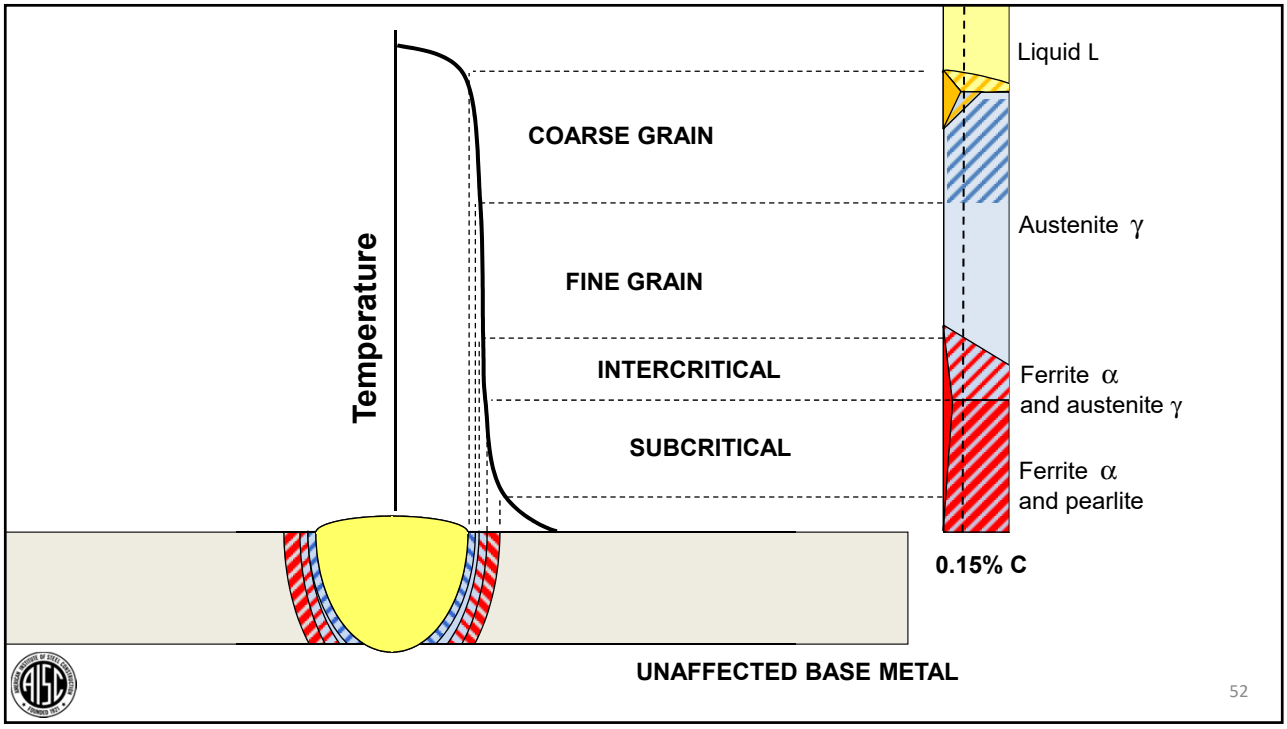

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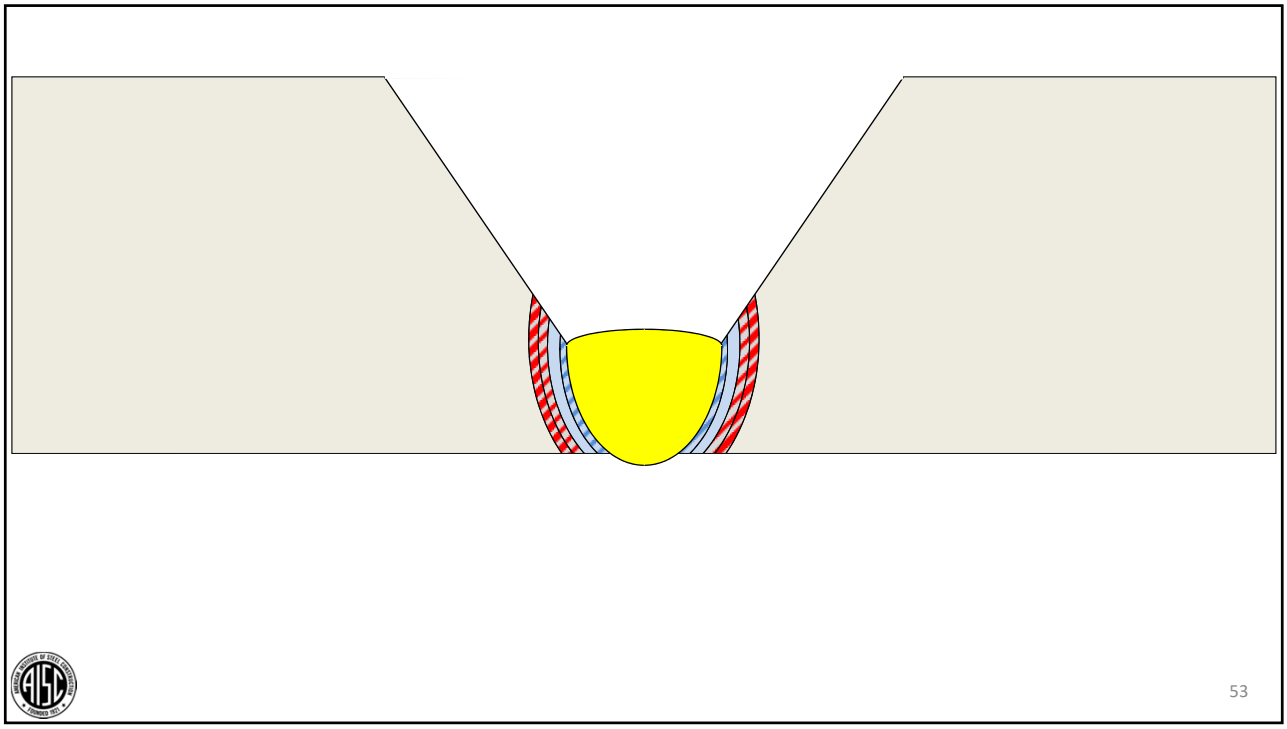

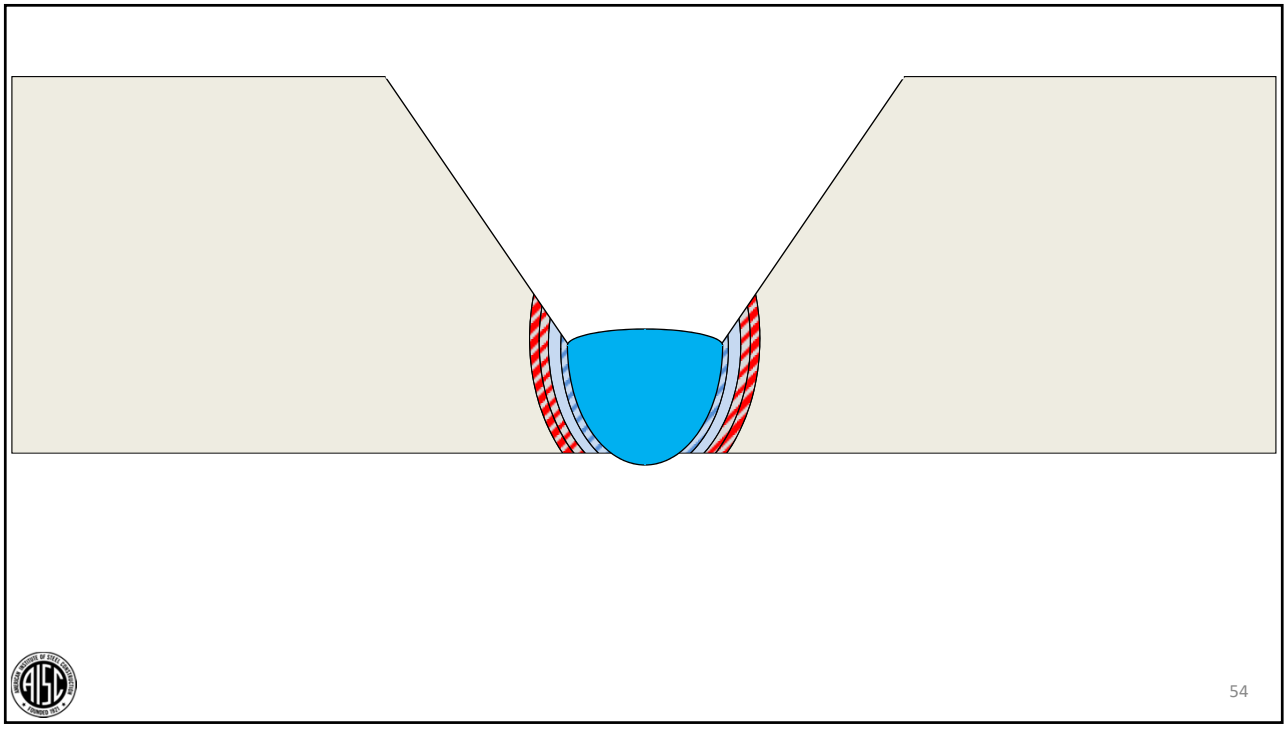

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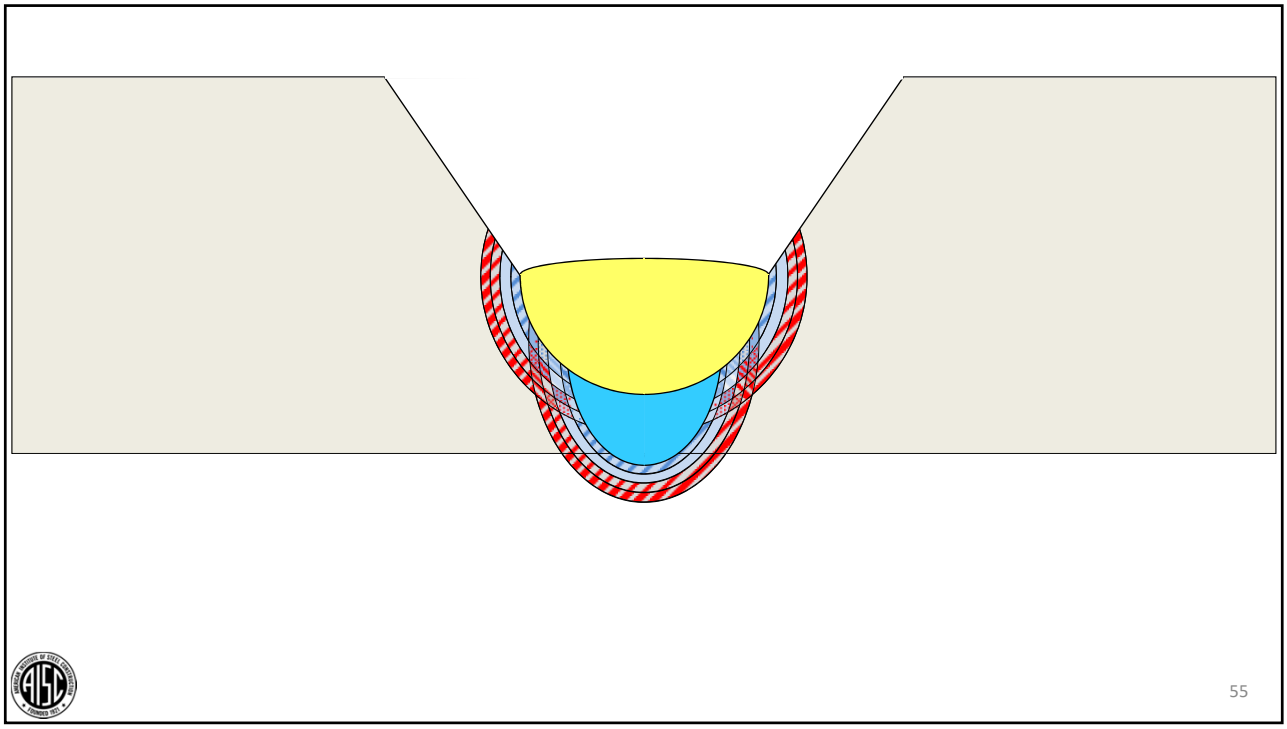

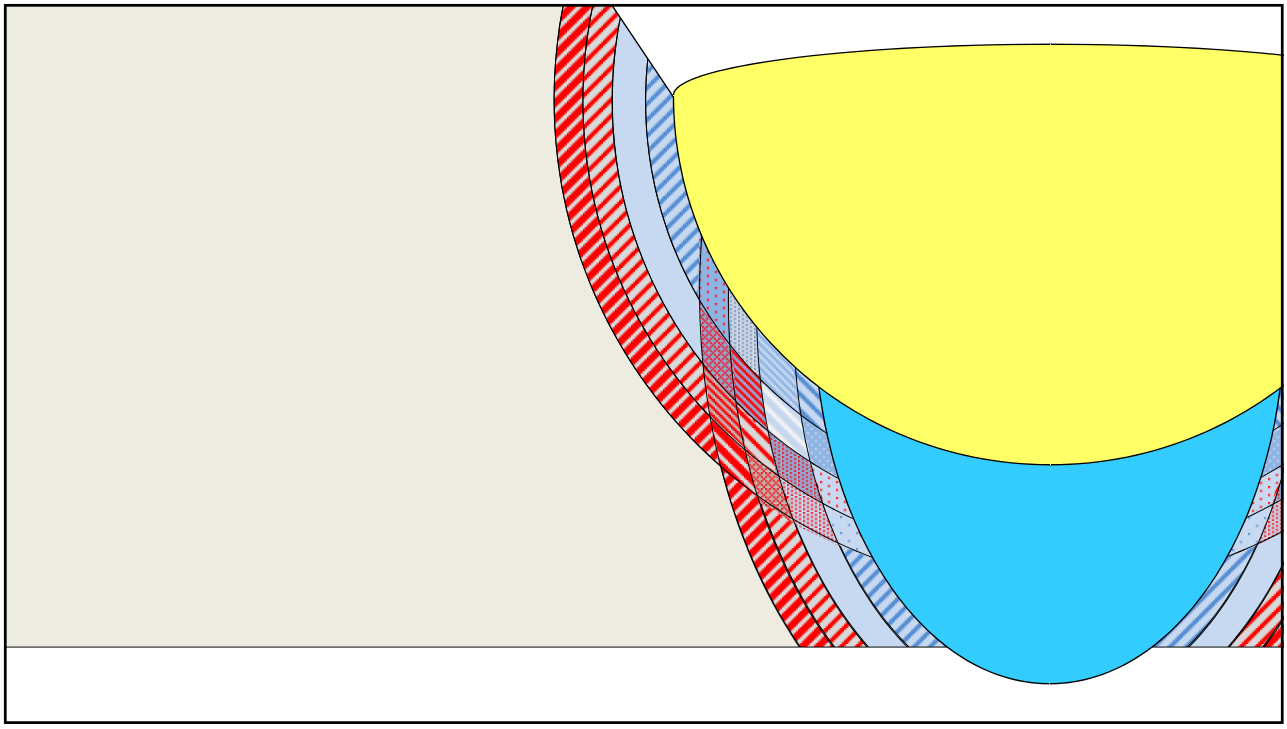

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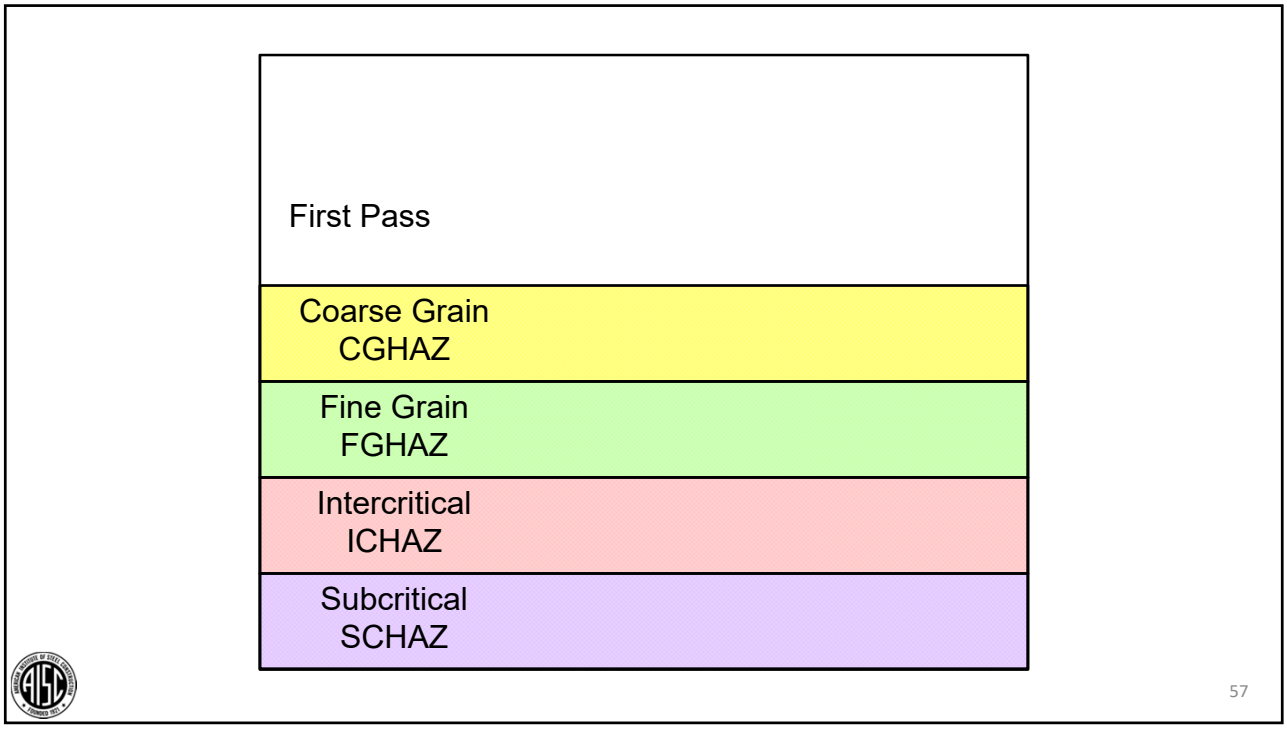

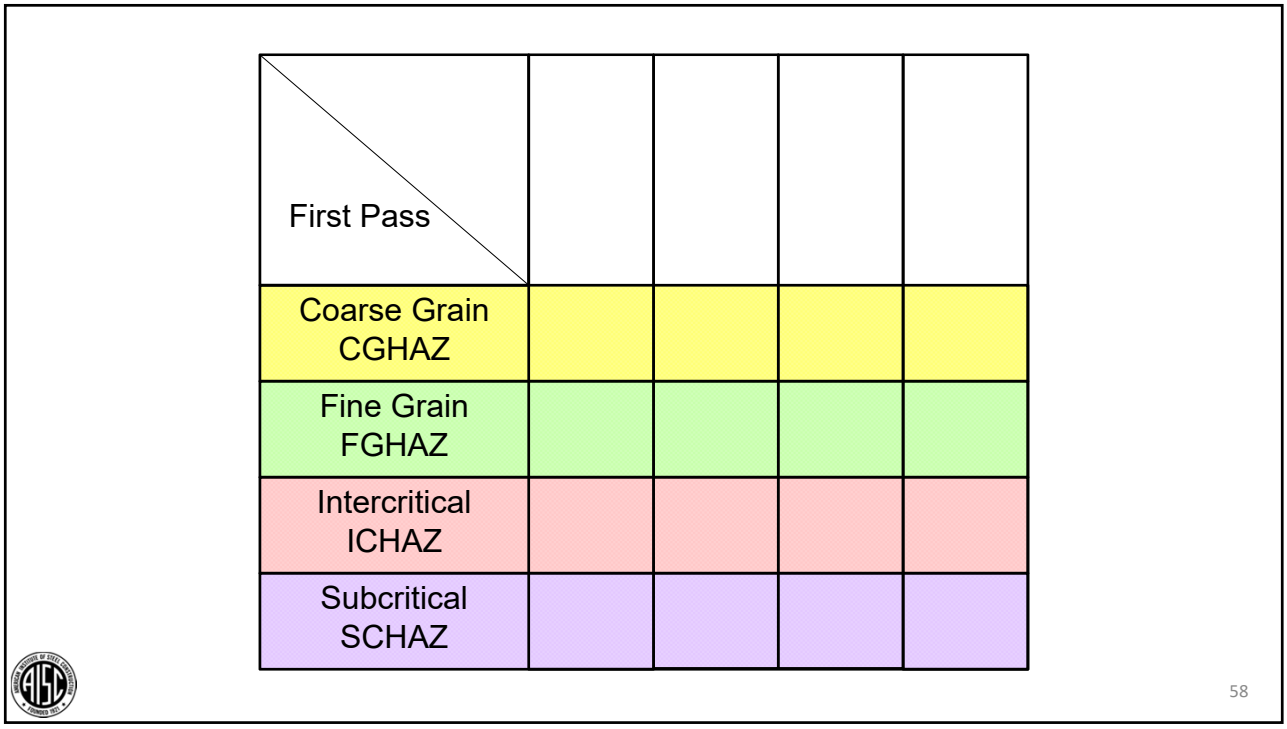

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First Pass \ Second Pass	Coarse Grain CGHAZ	Fine Grain FGHAZ	Intercritical ICHAZ	Subcritical SCHAZ
Coarse Grain CGHAZ	CGHAZ + CGHAZ	CGHAZ + FGHAZ	CGHAZ + ICHAZ	CGHAZ + SCHAZ
Fine Grain FGHAZ	FGHAZ + CGHAZ	FGHAZ + FGHAZ	FGHAZ + ICHAZ	FGHAZ + SCHAZ
Intercritical ICHAZ	ICHAZ + CGHAZ	ICHAZ + FGHAZ	ICHAZ + ICHAZ	ICHAZ + SCHAZ
Subcritical SCHAZ	SCHAZ + CGHAZ	SCHAZ + FGHAZ	SCHAZ + ICHAZ	SCHAZ + SCHAZ

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First Pass \ Second Pass	Coarse Grain CGHAZ	Fine Grain FGHAZ	Intercritical ICHAZ	Subcritical SCHAZ
Coarse Grain CGHAZ	CGHAZ + CGHAZ	CGHAZ + FGHAZ	ICCGHAZ	SCCGHAZ
Fine Grain FGHAZ	FGHAZ + CGHAZ	FGHAZ + FGHAZ	FGHAZ + ICHAZ	FGHAZ + SCHAZ
Intercritical ICHAZ	ICHAZ + CGHAZ	ICHAZ + FGHAZ	ICHAZ + ICHAZ	ICHAZ + SCHAZ
Subcritical SCHAZ	SCHAZ + CGHAZ	SCHAZ + FGHAZ	SCHAZ + ICHAZ	SCHAZ + SCHAZ

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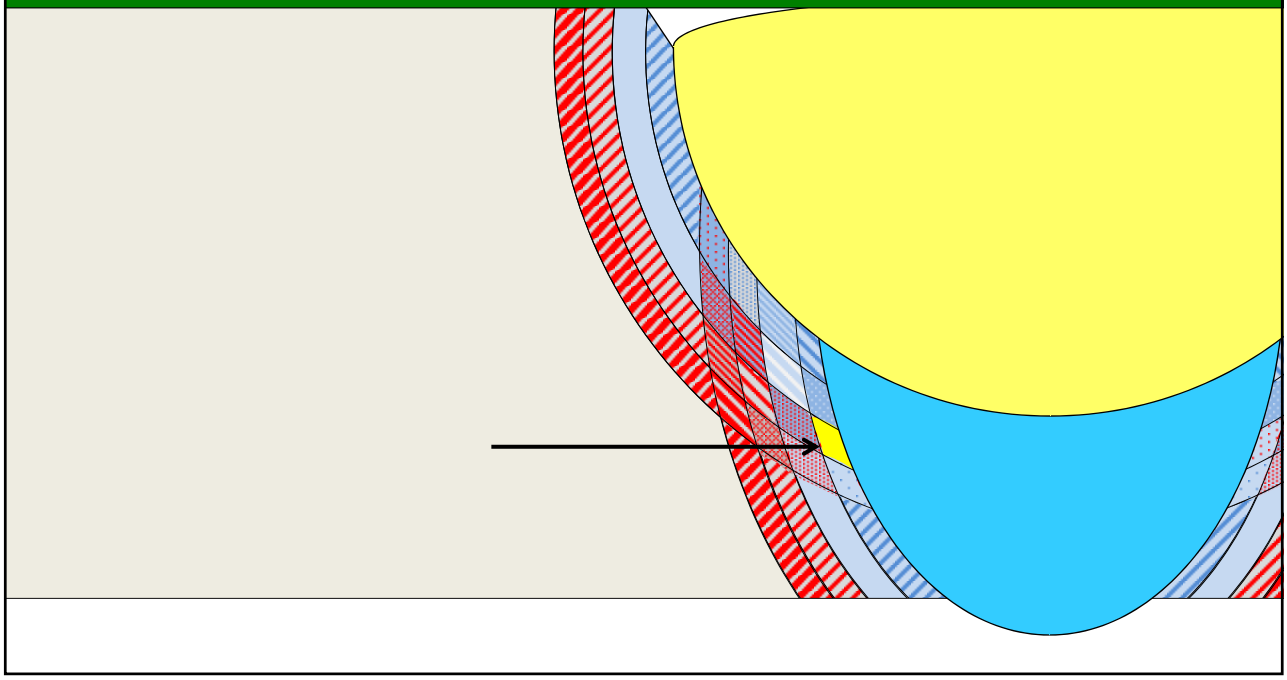
INTERCRITICAL COARSE GRAIN HEAT AFFECTED ZONE (ICCGRHAZ)



SAC PROJECT

SAC Steel Project

Report No. SAC/BD-00/13 Johnson

Preliminary Evaluation of Heat Affected Zone Toughness in Structural Shapes used in the Construction of Seismic Moment Frames

"Based on review of the available literature and the information gathered as part of the SAC program, it is expected that HAZ toughness of hot rolled and QST steel shapes is often expected to be higher than that of the as - received base metal."

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SAC PROJECT

SAC Steel Project

Report No. SAC/BD-00/13 Johnson

Preliminary Evaluation of Heat Affected Zone Toughness in Structural Shapes used in the Construction of Seismic Moment Frames

For multipass welds, the two additional regions are as follows: intercritically reheated CGHAZ (ICGCHAZ), and subcritically reheated CGHAZ (SCCGHAZ). In particular, the ICGHAZ region has been identified as a region that can often experience a substantial reduction in CTOD toughness."

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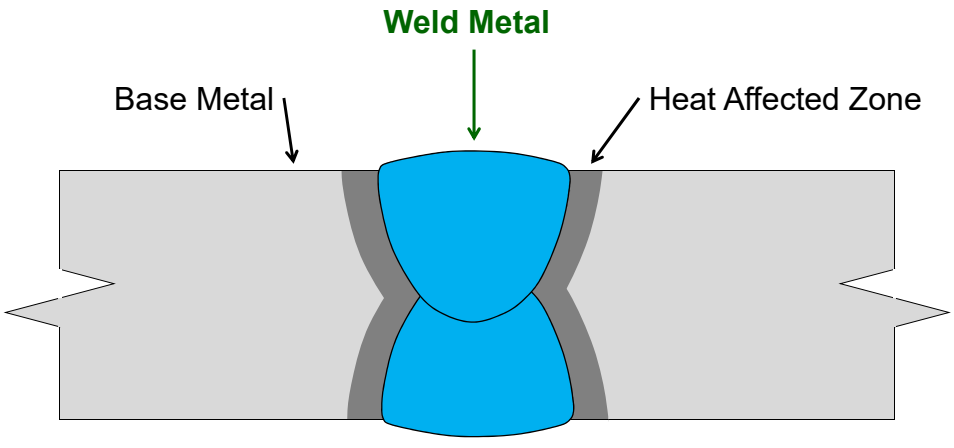
WELD METAL



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METALLURGY AND CRACKING

Metallurgy in a nutshell….

- Composition (alloys and carbon)
- Cooling Rate

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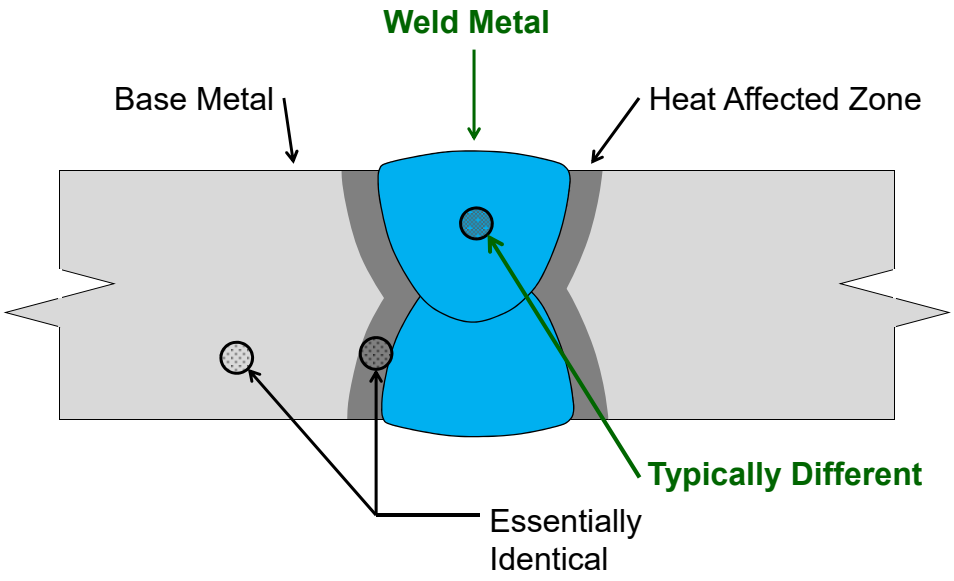
WELD METAL: CHEMISTRY



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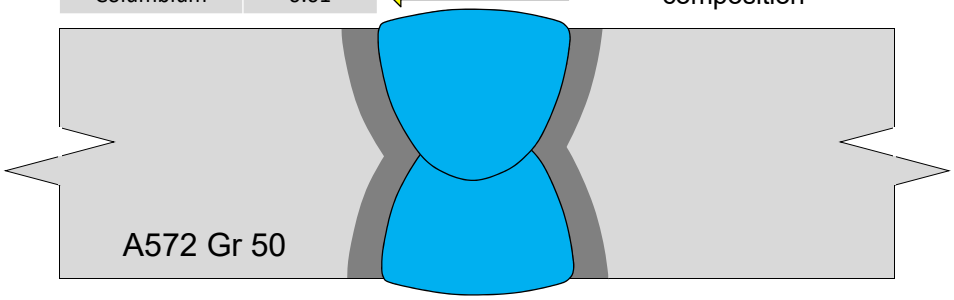
Alloy (typical)	Per Cent
Carbon	0.18
Manganese	1.15
Silicon	0.22
Copper	0.22
Vanadium	0.042
Columbium	0.01

Alloy (typical)	Per Cent
Carbon	0.04
Manganese	1.25
Silicon	0.44
Copper	0.11

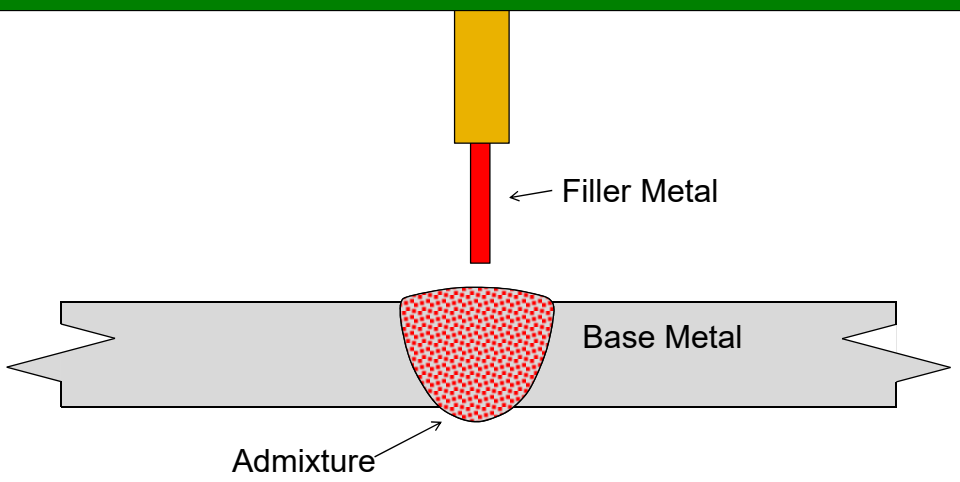
"all weld metal" composition



Typical SAW F7A2
(980/L50)

67

ADMIXTURE



Filler Metal + Base Metal = Admixture

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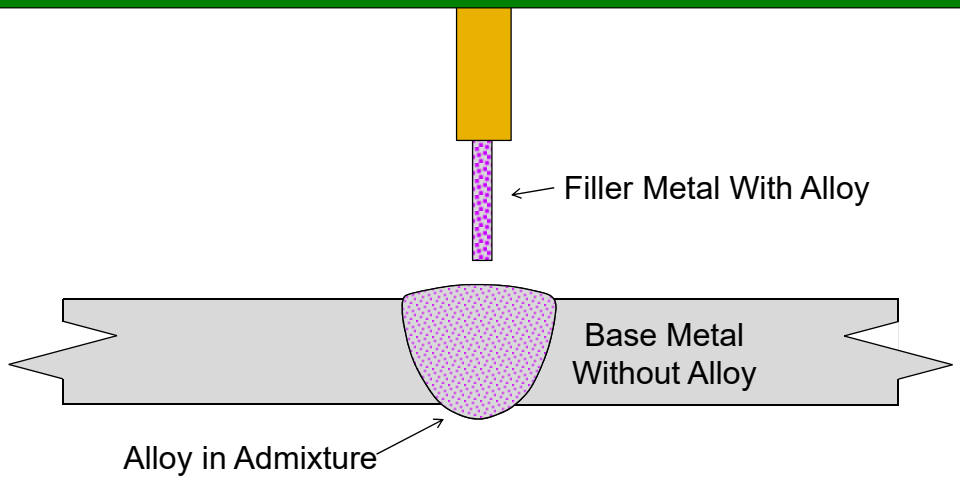
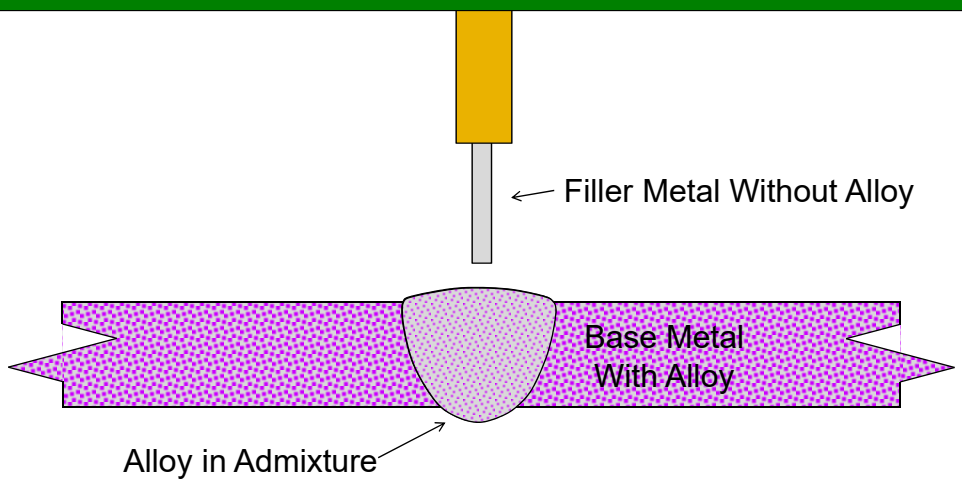
DILUTION



Alloy in Filler Metal > Alloy in Base Metal → Dilution

69

PICKUP



Alloy in Filler Metal < Alloy in Base Metal → Pickup

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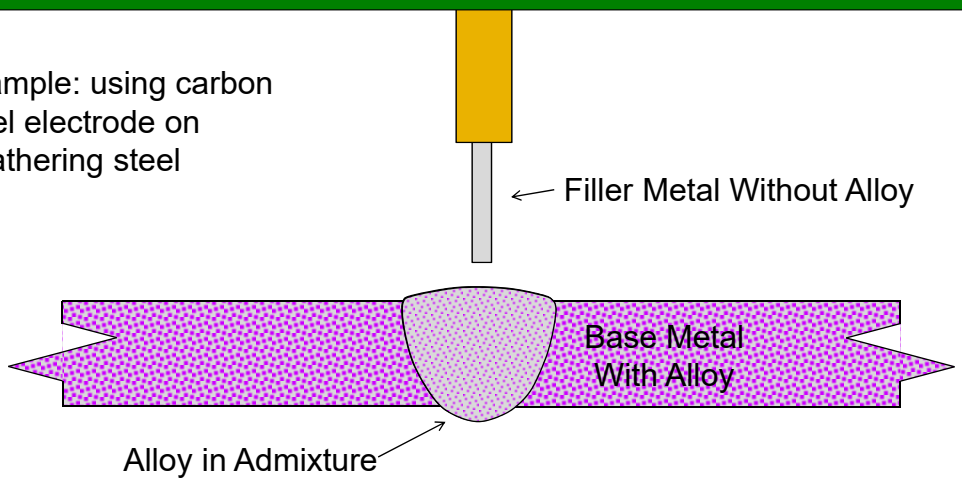
PICKUP

Example: using carbon steel electrode on weathering steel



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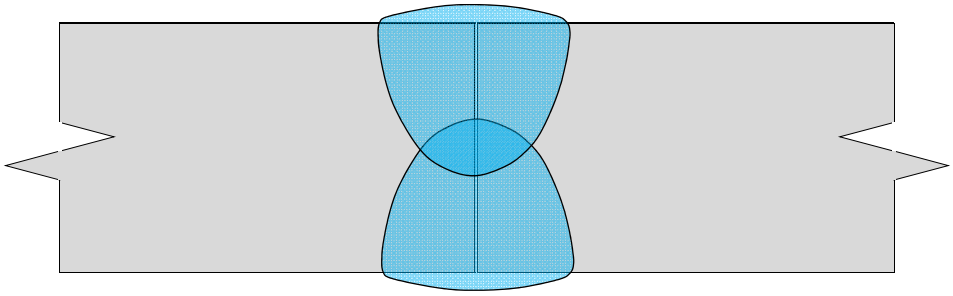

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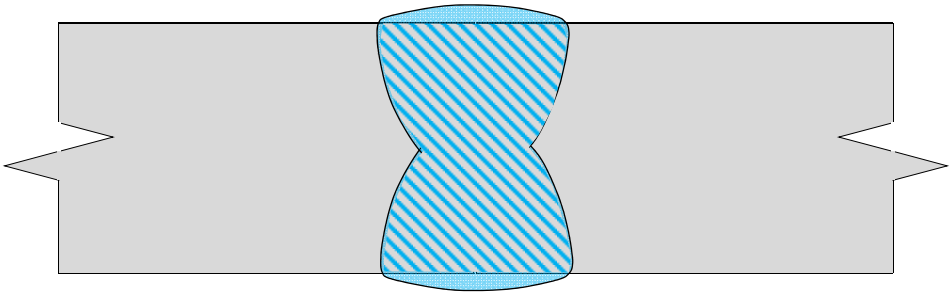

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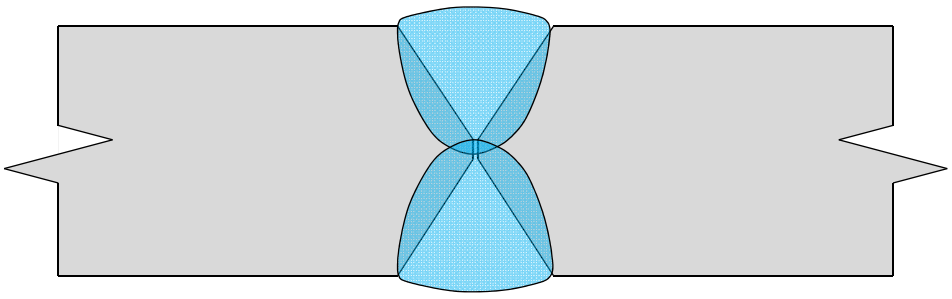

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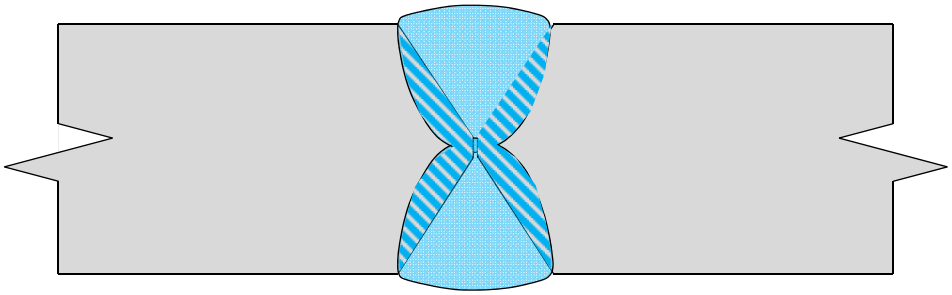
ADMIXTURE



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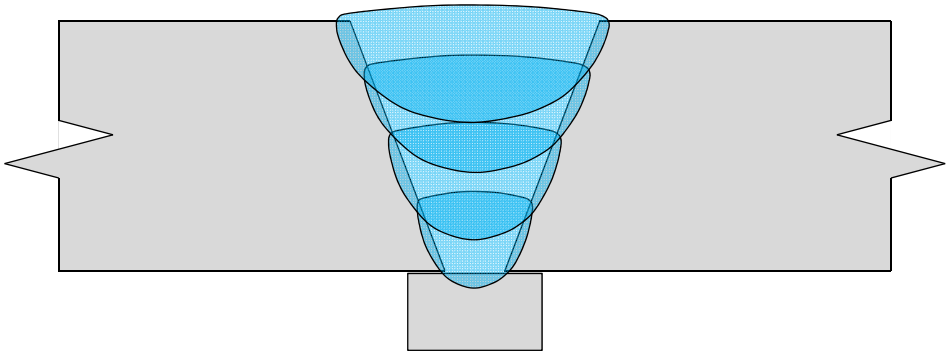

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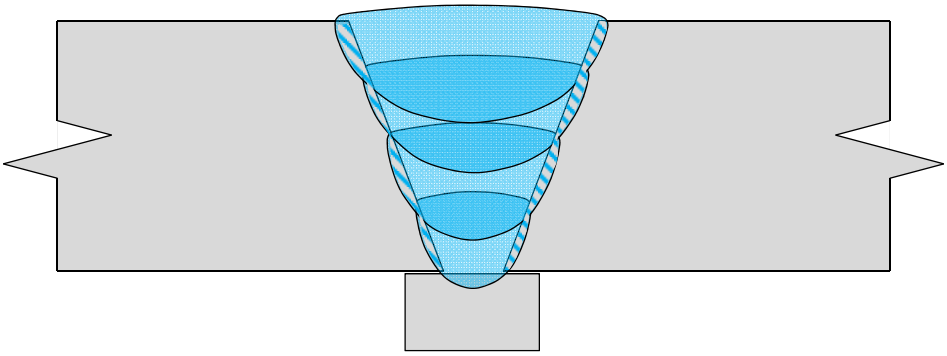
ADMIXTURE



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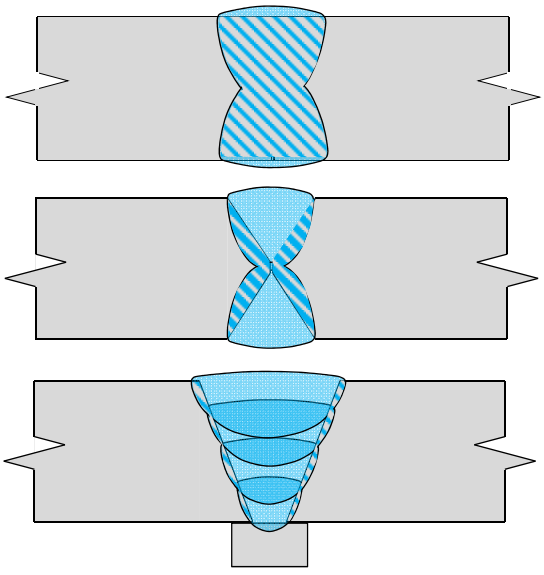

High Admixture

Medium Admixture

Low Admixture

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METALLURGY AND CRACKING

Metallurgy in a nutshell….

- Composition (alloys and carbon)
- Cooling Rate

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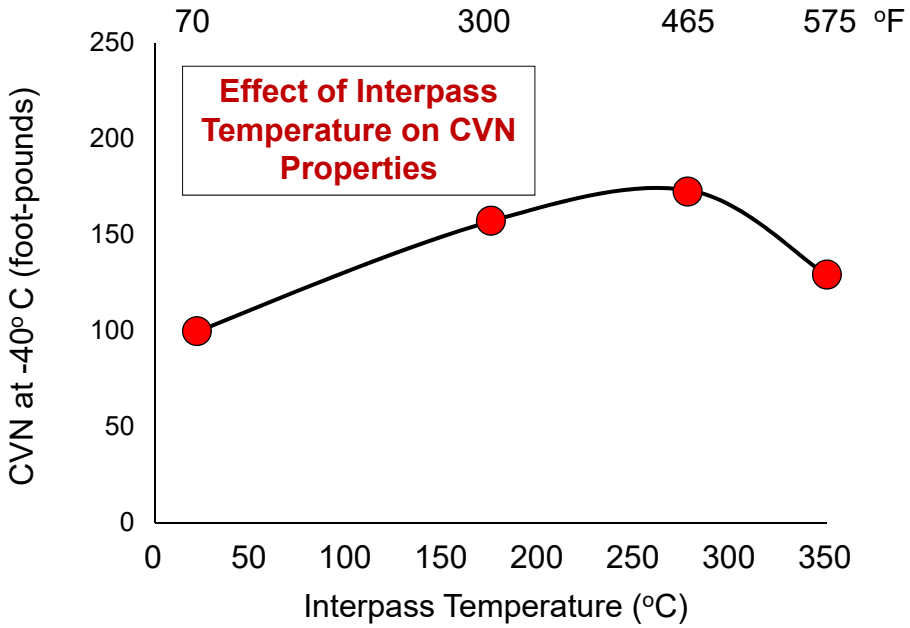

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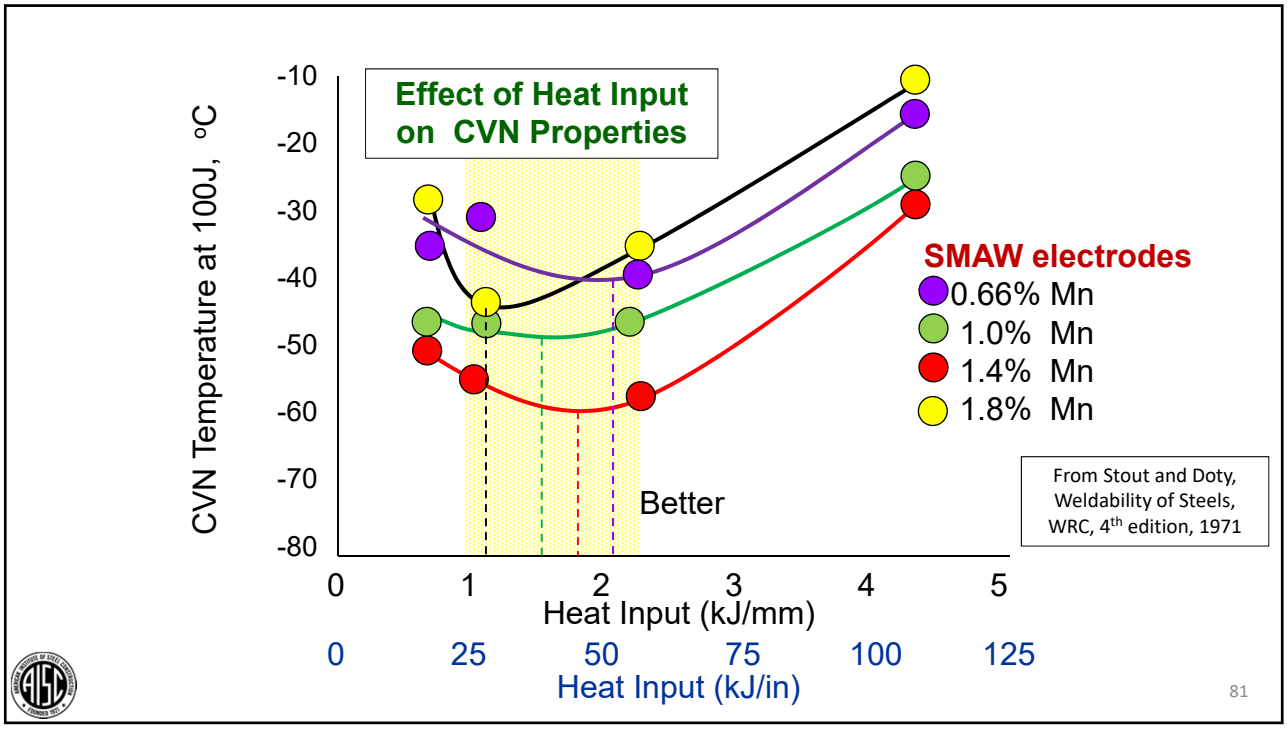

UNIFIED DESIGN OF STEEL STRUCTURES

"Most structural steel used today accept welding without the occurrences of unwanted defects."

Louis F. Geschwindner

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METALLURGY AND CRACKING

Outline

- Welding and Metallurgy
- Steel Categories
- Cracking
- Special Steels

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STEEL GROUPS

Steel Categories:

- AWS D1.1 Prequalified Steels
- AWS D1.1 Approved Steels
- AWS D1.1 Unlisted Steels
- Unidentified Steels

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STEEL GROUPS

AWS D1.1 Prequalified Steels:

- Steels that may be used with prequalified welding procedure specifications (WPS) without WPS qualification testing (Table 3.1)
- Includes steels with a history of satisfactory service and with known, good weldability
- Includes newer steels that have undergone testing and analysis
- All prequalified steels have Fy ≤ 90 ksi [620 MPA]
- All prequalified steels have mechanical property controls / compositional limits appropriate for welding processes / conditions within the code
- Listed in AWS D1.1, Table 3.1

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AWS D1.1: 2015 Structural Welding Code – Steel

Table 3.1
Approved Base Metals for Prequalified WPSs (see 3.3)

Group	Steel Specification Requirements					
			Minimum Yield Point/Strength		Tensile Range	
	Steel Specification		ksi	MPa	ksi	MPa
	ASTM A36	(≤3/4 in [20 mm])	36	250	58–80	400–550
	ASTM A53	Grade B	35	240	60 min.	415 min.
	ASTM A106	Grade B	35	240	60 min.	415 min.
	ASTM A131	Grades A, B, CS, D, DS, E	34	235	58–75	400–520
	ASTM A139	Grade B	35	240	60 min.	415 min.
	ASTM A381	Grade Y35	35	240	60 min.	415 min.
	ASTM A500	Grade A	33	230	45 min.	310 min.
		Grade B	42	290	58 min.	400 min.
		Grade C	46	315	62 min.	425 min.
	ASTM A501	Grade A	36	250	58 min.	400 min.
	ASTM A516	Grade 55	30	205	55–75	380–515
		Grade 60	32	220	60–80	415–550

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STEEL GROUPS

AWS D1.1 Approved Steels:

- Code-approved base metals, which require WPS qualification testing
- Includes high-strength steels (i.e., those with Fy > 90 ksi [620 MPa])
- Includes newer steels that do not have a sufficient history of satisfactory usage to be considered prequalified
- Listed in AWS D1.1, Table 4.9, along with matching strength filler metals and preheat values

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AWS D1.1: 2015 Structural Welding Code – Steel

Table 4.9
Code-Approved Base Metals and Filler Metals Requiring Qualification per Clause 4

Base Metal					Matching Strength Filler Metal			Base Metal Thickness, T		Minimum Preheat and Interpass Temperature	
	Minimum Yield Point/Strength		Tensile Range			AWS Electrode Specification[a]					
Specification	ksi	MPa	ksi	MPa	Process		Electrode Classification	in	mm	°F	°C
ASTM A871 Grade 60	60	415	75 min.	520 min.	SMAW	A5.5	E8015-X				
Grade 65	65	450	80 min.	550 min.			E8016-X				
							E8018-X				
					SAW	A5.23	F8XX-EXXX-XX				
							F8XX-ECXXX-XX				
					GMAW	A5.28	ER80S-XXX				
							E80C-XXX				
						A5.36	E8XTX-XAX-XXX				
					FCAW	A5.29	E8XTX-X				
							E8XTX-XC	Up to 3/4	Up to 20	50	10
							E8XTX-XM	Over 3/4 thru 1-1/2	Over 20 thru 38	125	50
						A5.36	E8XTX-AX-XXX				
							E8XTX-XAX-XXX				
ASTM A514 (Over 2-1/2 in [65 mm])	90	620	100–130	690–895	SMAW	A5.5	E10015-X	Over 1-1/2 thru 2-1/2	Over 38 thru 65	175	80
							E10016-X				
							E10018-X	Over 2-1/2	Over 65	225	110
ASTM A709 Grade HPS 100W [HPS 690W] (Over 2-1/2 in to 4 in	90	620	100–130	690–895			E10018M				
					SAW	A5.23	F10XX-EXXX-XX				
							F10XX-ECXXX-XX				

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STEEL GROUPS

AWS D1.1 Unlisted Steels:

- Steels not listed in AWS D1.1, Table 3.1 or Table 4.9
- Includes steels with poor weldability, which are intentionally omitted
- Includes new steels that have good weldability, but not yet incorporated into the code
- Includes steels with mechanical properties not sufficiently defined (e.g., only chemical compositions are specified for AISI/SAE grades of steels)
- Includes steels that are not classified in U.S. standards (e.g., ASTM or API), some of which might have good weldability

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STEEL GROUPS

AWS D1.1 Unlisted Steels (continued):

- Welding on unlisted steels requires WPS qualification testing
- Only exception is given in AWS D1.1, clause 3.4; the unlisted steel must:
  - be used for an auxiliary attachment.
  - be approved by the engineer.
  - have a chemical composition that falls within the limits of a prequalified steel grade
  - follow the preheat requirements for prequalified WPS

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STEEL GROUPS

AWS D1.1 Unlisted Steels (continued):

- Passing a WPS qualification test satisfies AWS D1.1 requirements for welding on unlisted steels…
- …but it is not a weldability test per se.
  - WPS qualification test plates do not sufficiently replicate actual fabrication conditions
  - A number of weldability tests have been developed (e.g., Lehigh Restraint Test, Tekken Test, CTS Test, Gapped-Bead-on-Plate Test)
- When using unlisted steels, investigate other data, beyond WPS qualification tests, to support the decision (e.g., mill data, past projects)

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AISC 360-16 Specification for Structural Steel Buildings

A3.1 Structural Steel Materials

1b. Unidentified Steel

Unidentified steel, free of injurious defects, is permitted to be used only for members or details whose failure will not reduce the strength of the structure, either locally or overall. Such use shall be subject to the approval of the engineer of record.

User Note: Unidentified steel may be used for details where the precise mechanical properties and weldability are not of concern. These are commonly curb plates, shims and other similar pieces.

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METALLURGY AND CRACKING

Outline

- Welding and Metallurgy
- Steel Categories
- Cracking
- Special Steels

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AWS D1.1: 2015 Structural Welding Code – Steel

5.25.3 Engineer's Approval.

Prior approval of the Engineer shall be obtained for repairs to base metal (other than those required by 5.14), repair of major or delayed cracks, repairs to ESW and EGW with internal defects, or for a revised design to compensate for deficiencies. The Engineer shall be notified before welded members are cut apart.

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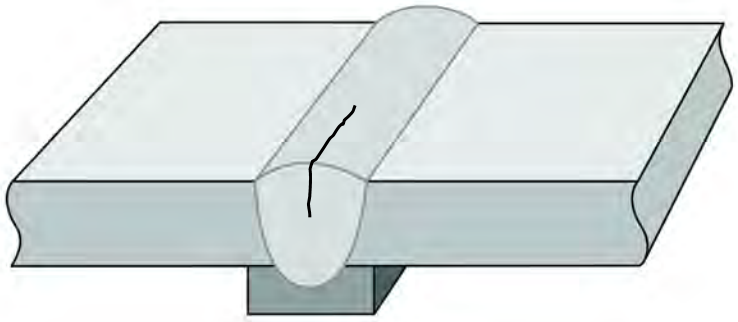
TYPES OF WELD CRACKS

Centerline Cracking



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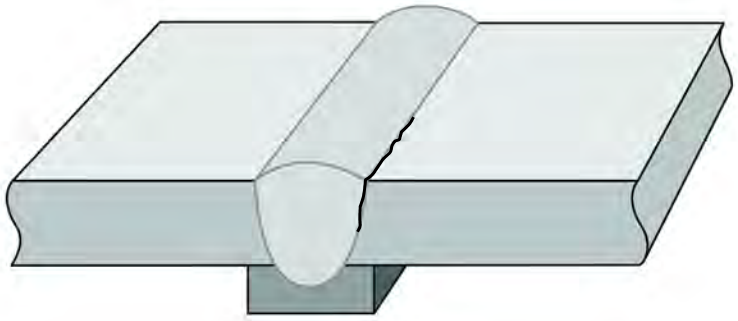
TYPES OF WELD CRACKS

Underbead Cracking



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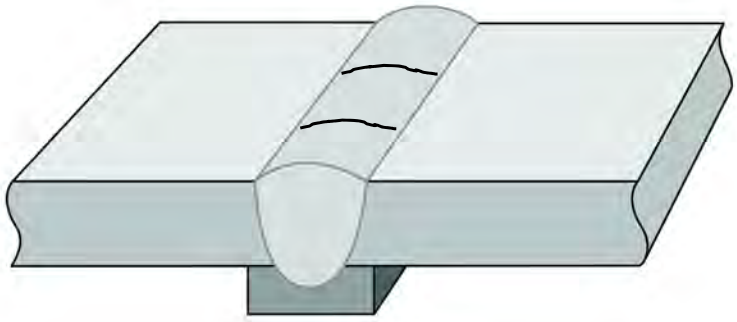
TYPES OF WELD CRACKS

Transverse Cracking



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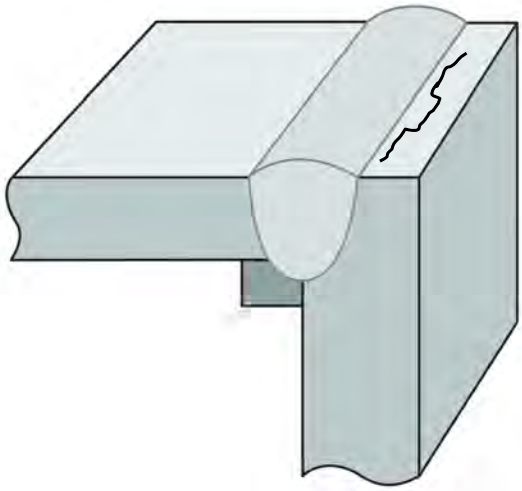
TYPES OF WELD CRACKS

Lamellar Tearing



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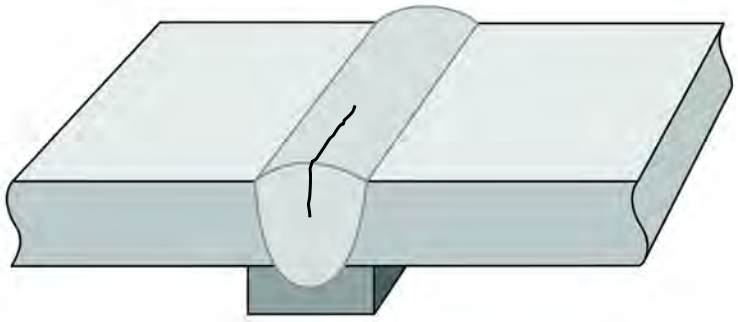
CENTERLINE CRACKING



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CENTERLINE CRACKING

Characteristics:

- Near the center of a welded bead
- Is present as weld cools — is not delayed
- Occurs at high temperatures — the crack surface may exhibit “temper colors)
- Cracks may extend from one weld layer into the next, but are more commonly isolated to one layer
- Overloaded fillet welds often fail through the weld throat and may look like centerline cracks

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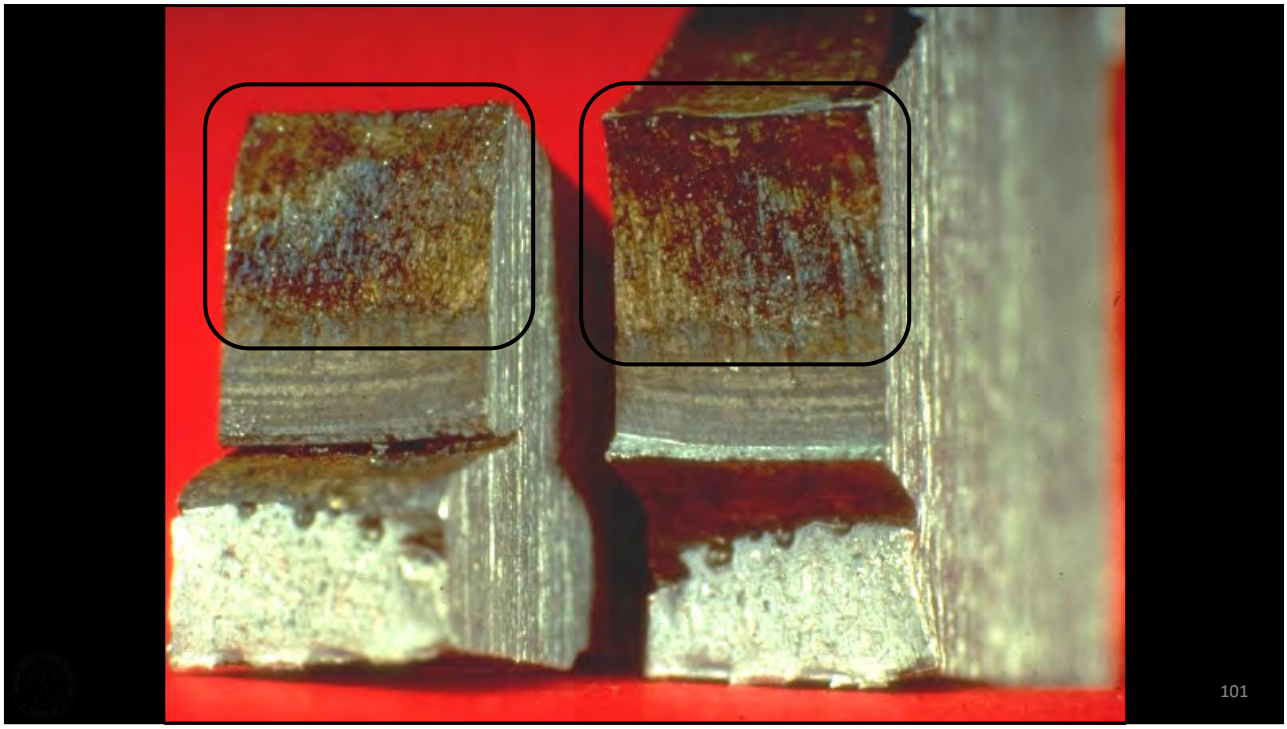

CENTERLINE CRACKING

Centerline cracks are near the weld bead centerline; may not be in the center of the joint.

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CENTERLINE CRACKING

Cause 1: Segregation Cracking

Low melting point ingredients segregate to the center during solidification

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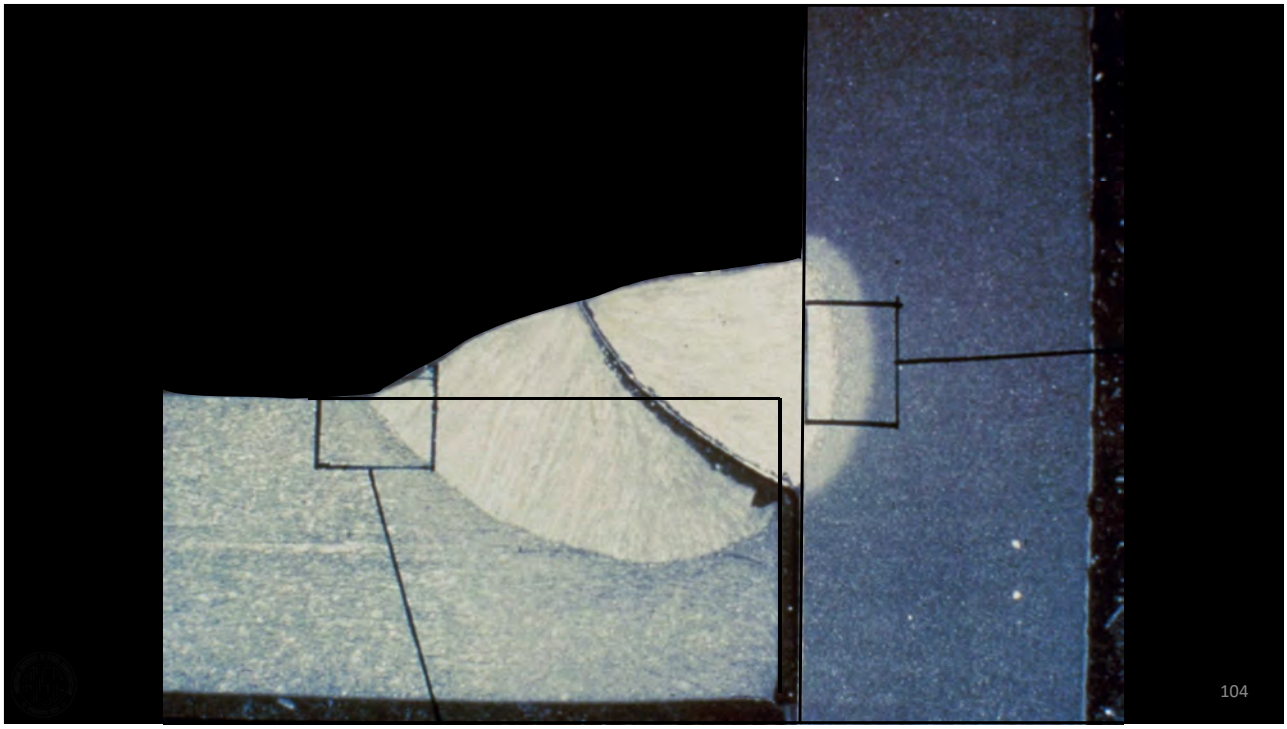

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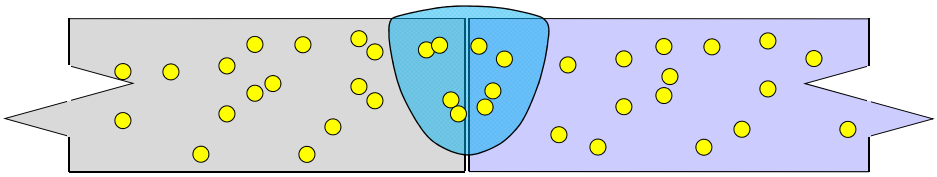
CENTERLINE CRACKING



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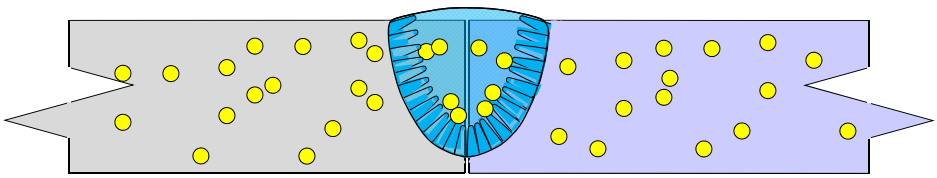
CENTERLINE CRACKING



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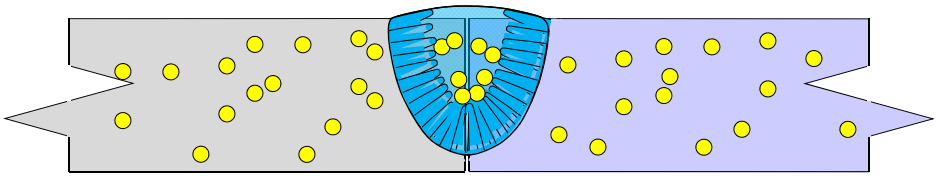
CENTERLINE CRACKING



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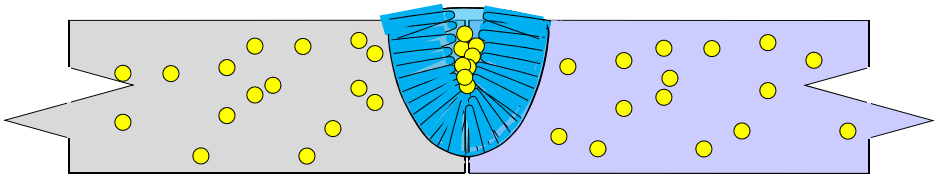
CENTERLINE CRACKING



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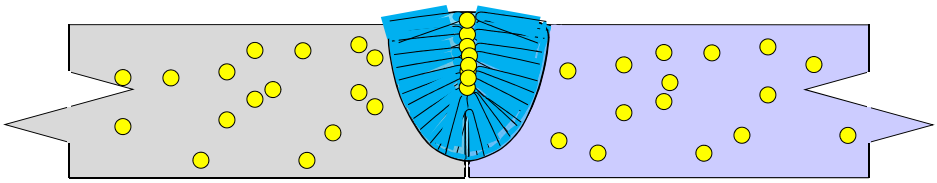
CENTERLINE CRACKING



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CENTERLINE CRACKING

Cause 1: Segregation Cracking

Low melting point ingredients segregate to the center during solidification

Solution: Minimize low melting point ingredients in the molten weld metal

- Use "good" steel

  Low levels of:

  – Phosphorous (P)
  – Sulfur (S)
  – Zinc (Zn)
  – Tin (Sn)
  – Copper (Cu)
  – Carbon (C)

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CENTERLINE CRACKING

Cause 1: Segregation Cracking

TWI Hot Cracking Susceptibility
(Universal Crack Sensitivity)

$$UCS = 230\,C + 190\,S + 75\,P + 45\,Nb - 12.3\,Si - 5.4\,Mn - 1$$

UCS $\leq$ 10 "High Resistance to Cracking"

UCS > 30 "Strong Susceptibility to Cracking"

Based on WELD METAL Composition

From Welding Metallurgy by Linnert, 4th Edition, Volume 1

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CENTERLINE CRACKING

Cause 1: Segregation Cracking

Low melting point ingredients segregate to the center during solidification

Solution: Minimize low melting point ingredients in the molten weld metal

- Use "good" steel
- Minimize admixture

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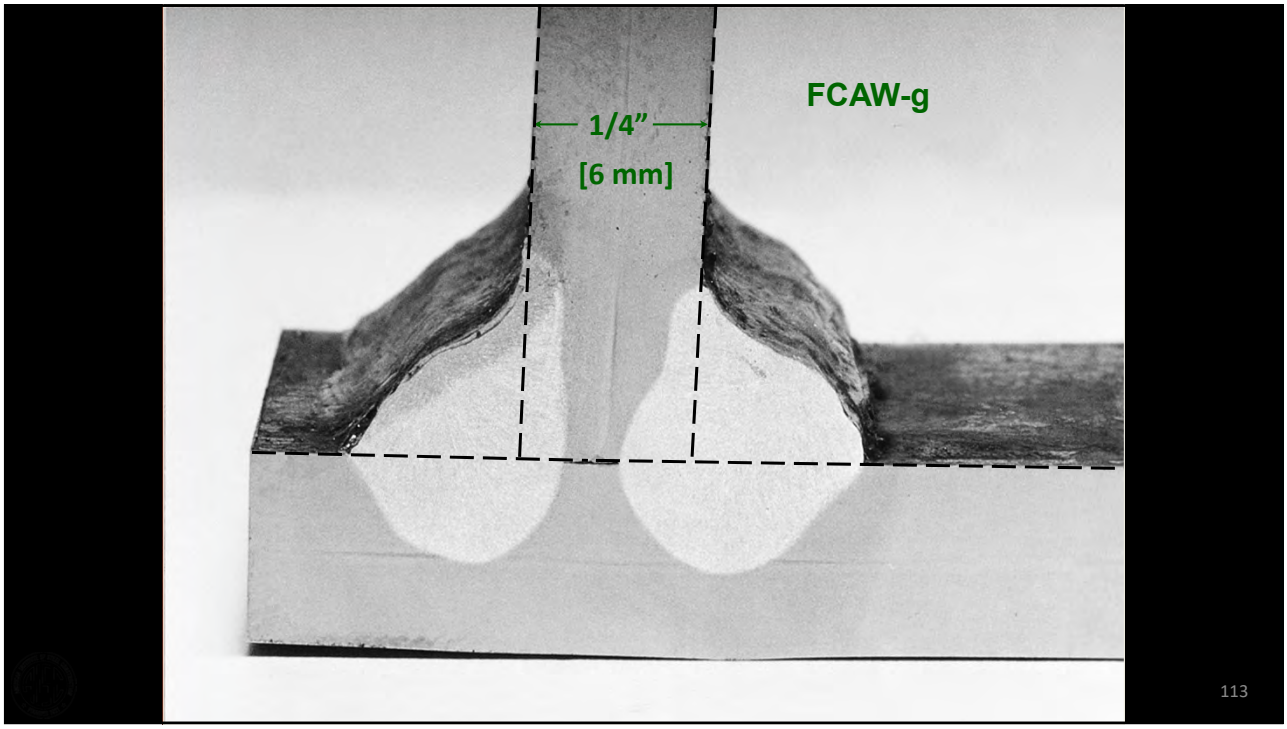

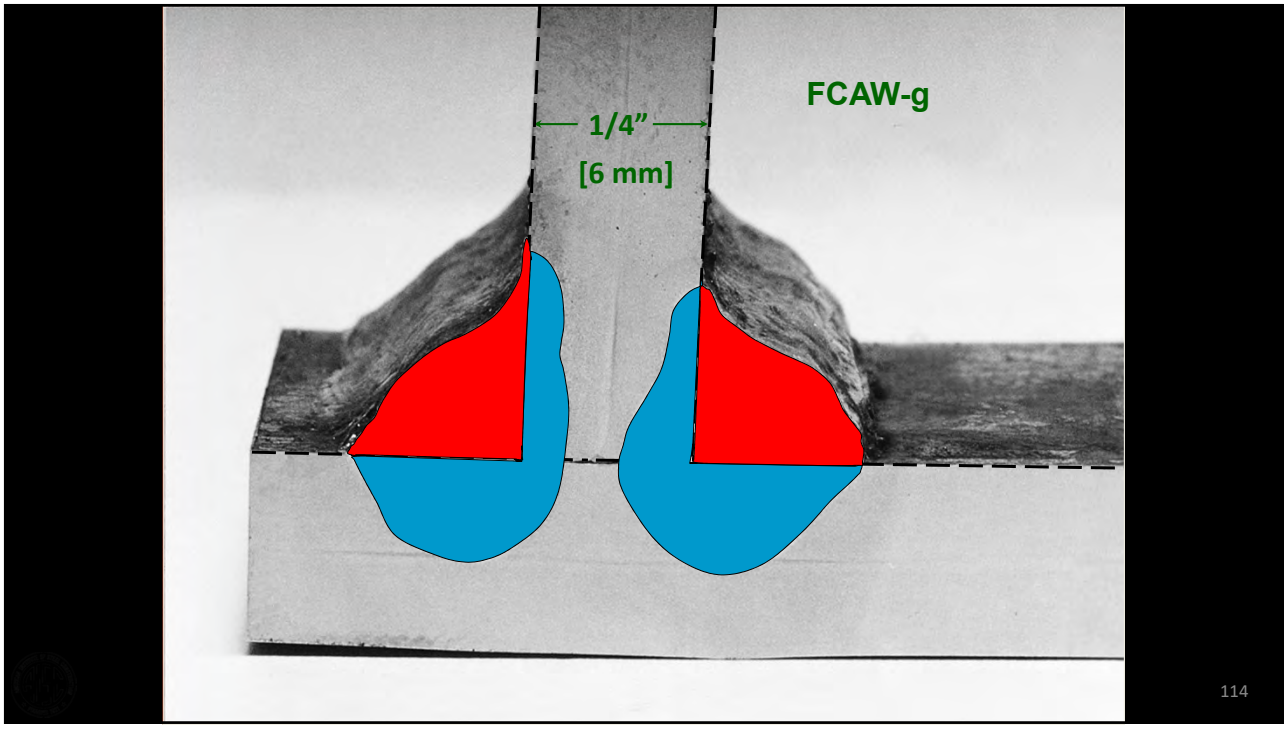

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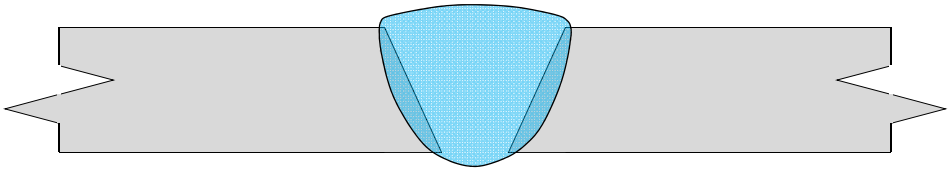
ADMIXTURE



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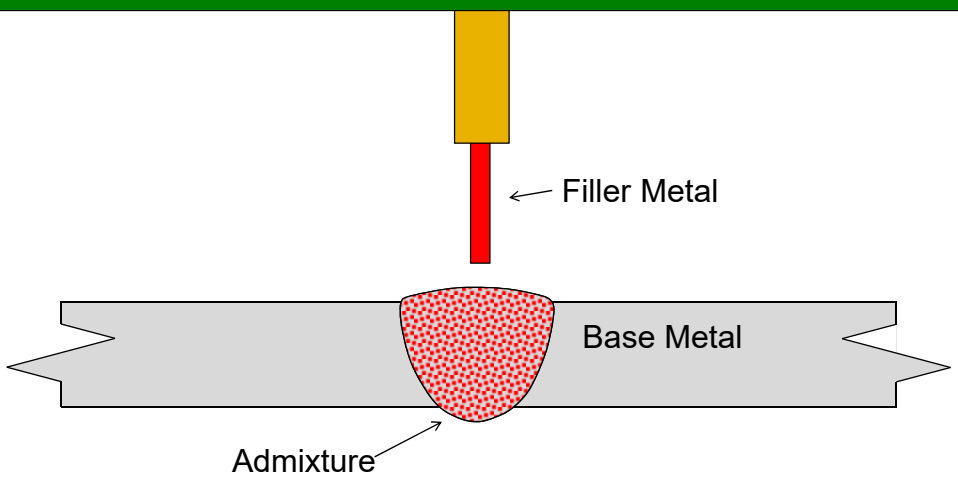

Filler Metal + Base Metal = Admixture

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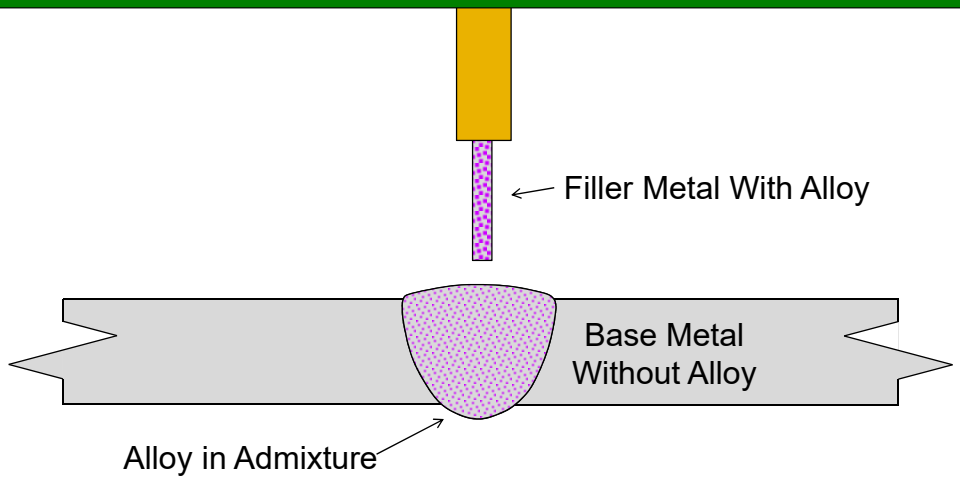
DILUTION



Alloy in Filler Metal > Alloy in Base Metal → Dilution

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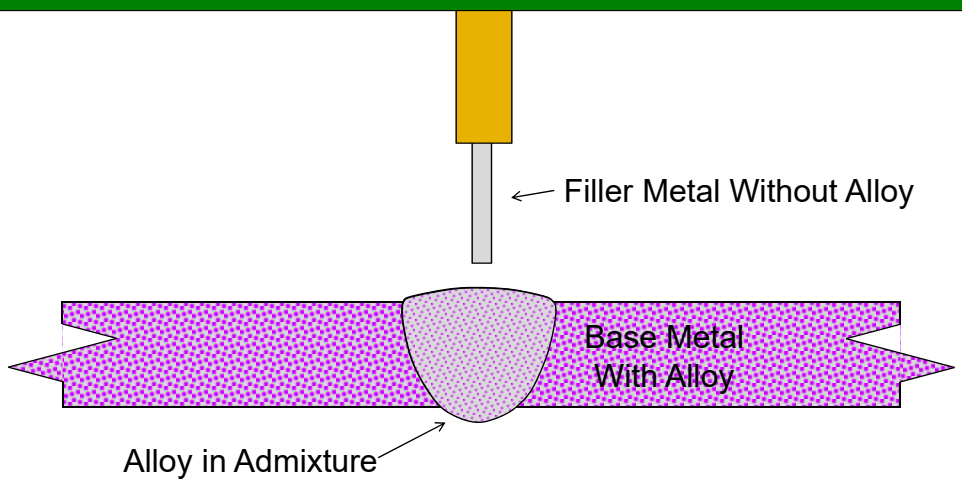
PICKUP



Alloy in Filler Metal < Alloy in Base Metal → Pickup

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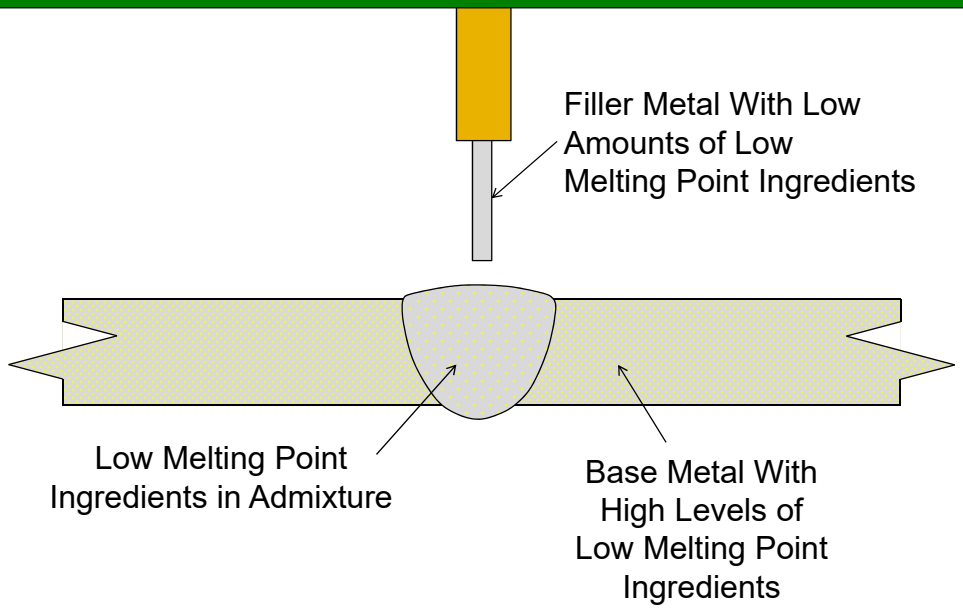
PICKUP



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CENTERLINE CRACKING

Cause 1: Segregation Cracking

Low melting point ingredients segregate to the center during solidification

Solution: Minimize low melting point ingredients in the molten weld metal

- Use "good" steel
- Minimize admixture
  - Change joint detail

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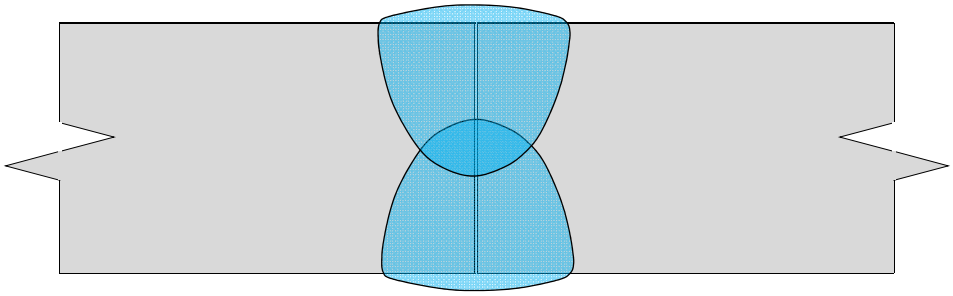
ADMIXTURE: HIGH



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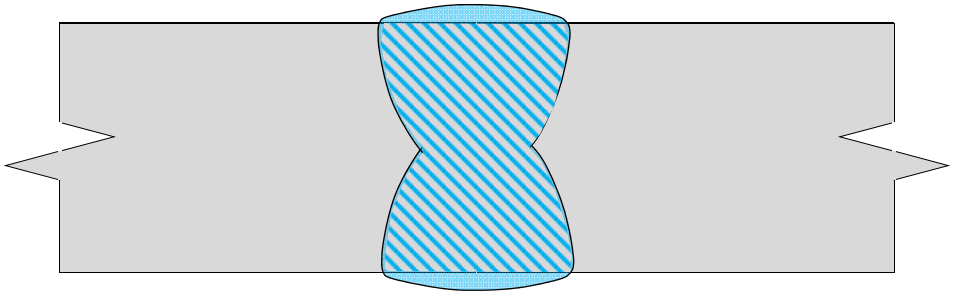
ADMIXTURE: HIGH



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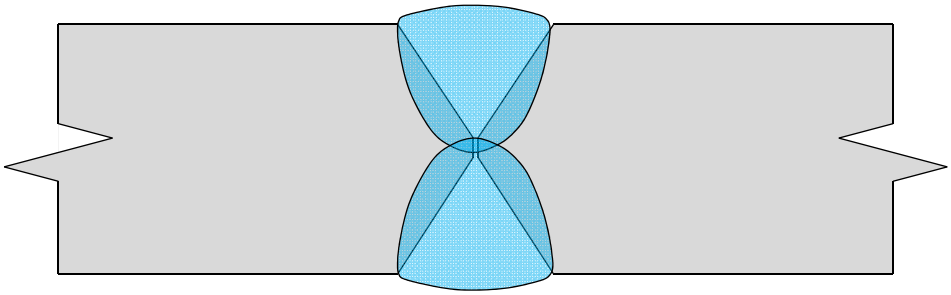
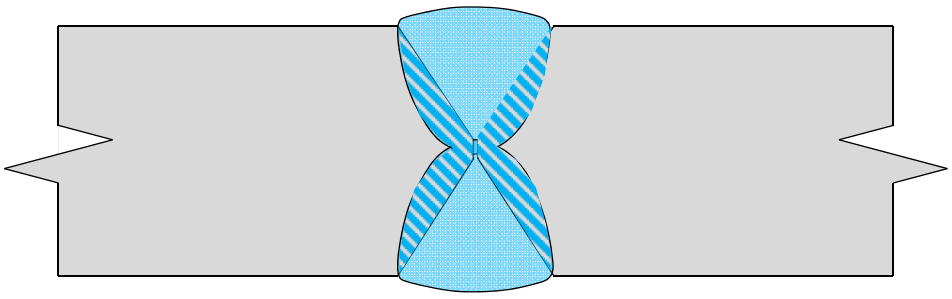
ADMIXTURE: MEDIUM



123

ADMIXTURE: MEDIUM



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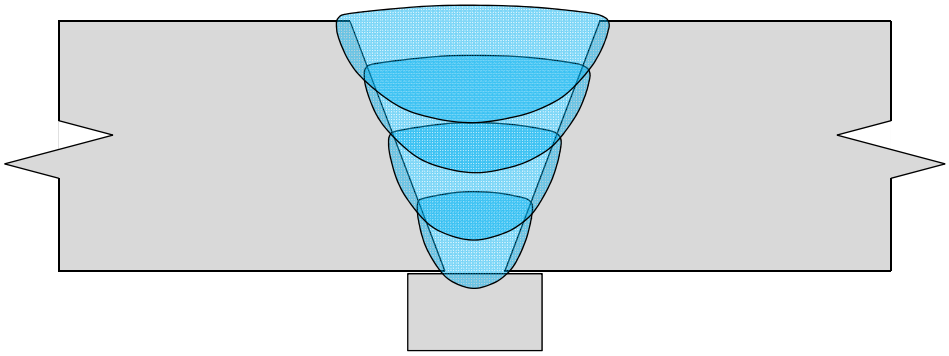
ADMIXTURE: LOW



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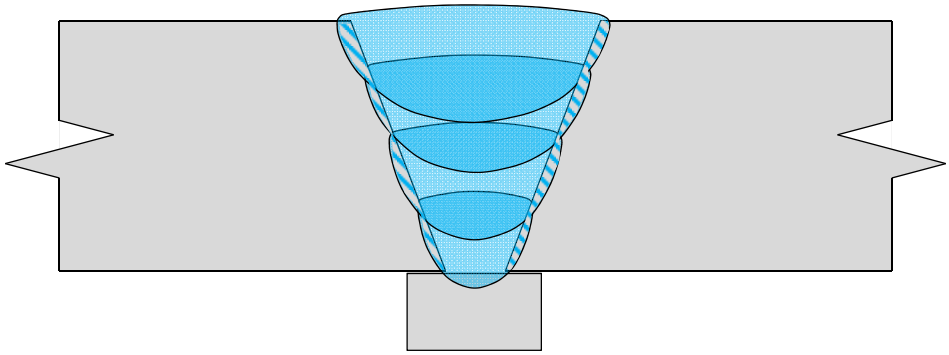
ADMIXTURE: LOW



126

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CENTERLINE CRACKING

Cause 1: Segregation Cracking

Low melting point ingredients segregate to the center during solidification

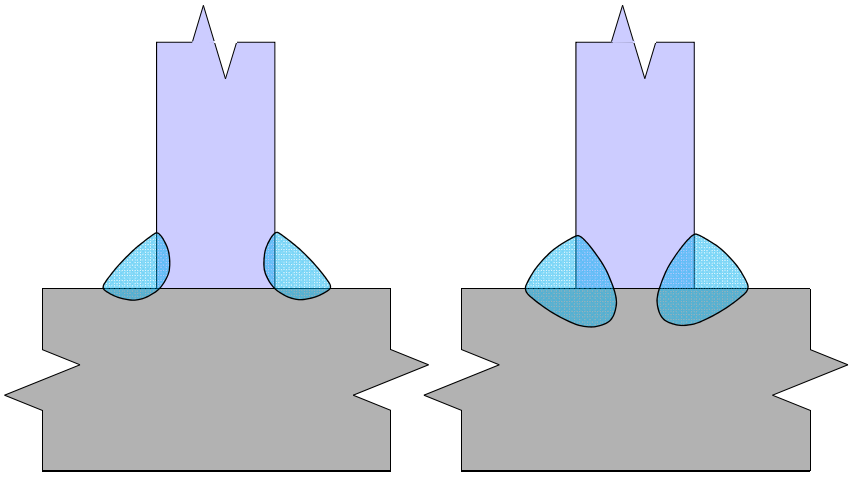
Solution: Minimize low melting point ingredients in the molten weld metal

- Use "good" steel
- Minimize admixture
  - Change joint detail
  - Minimize penetration (unless needed for joint strength)

127

ADMIXTURE

Acceptable fillet welds per AISC, AWS D1.1



Minimal Admixture **Significant Admixture**

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CENTERLINE CRACKING

Cause 1: Segregation Cracking

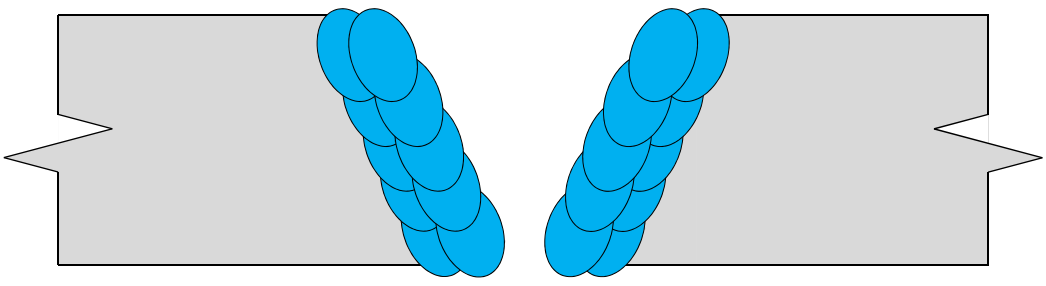
Low melting point ingredients segregate to the center during solidification

Solution: Minimize low melting point ingredients in the molten weld metal

- Use "good" steel
- Minimize admixture
  - Change joint detail
  - Minimize penetration (unless needed for joint strength)
  - Use "buttering" (overlay) technique

129

BUTTERING



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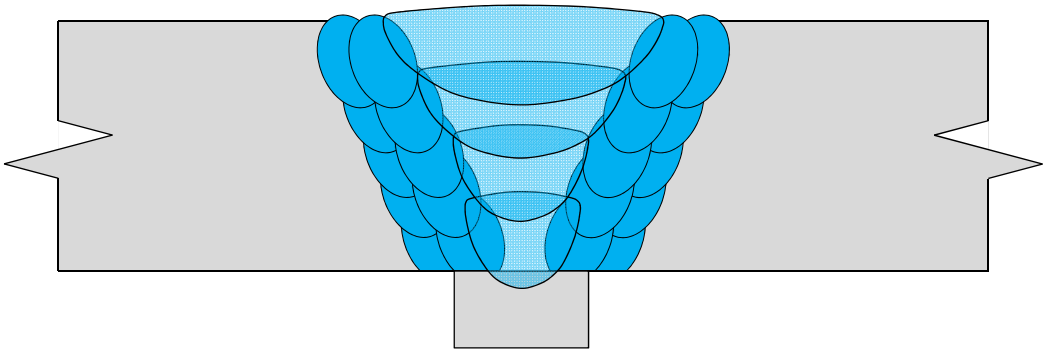
BUTTERING



131

CENTERLINE CRACKING

Cause 1: Segregation Cracking

Low melting point ingredients segregate to the center during solidification

Solution: Minimize low melting point ingredients in the molten weld metal

- Use "good" steel
- Minimize admixture

- For sulfur, use higher manganese (Mn) filler metal

Sulfur is not present as an element, but as a compound; either FeS or MnS.

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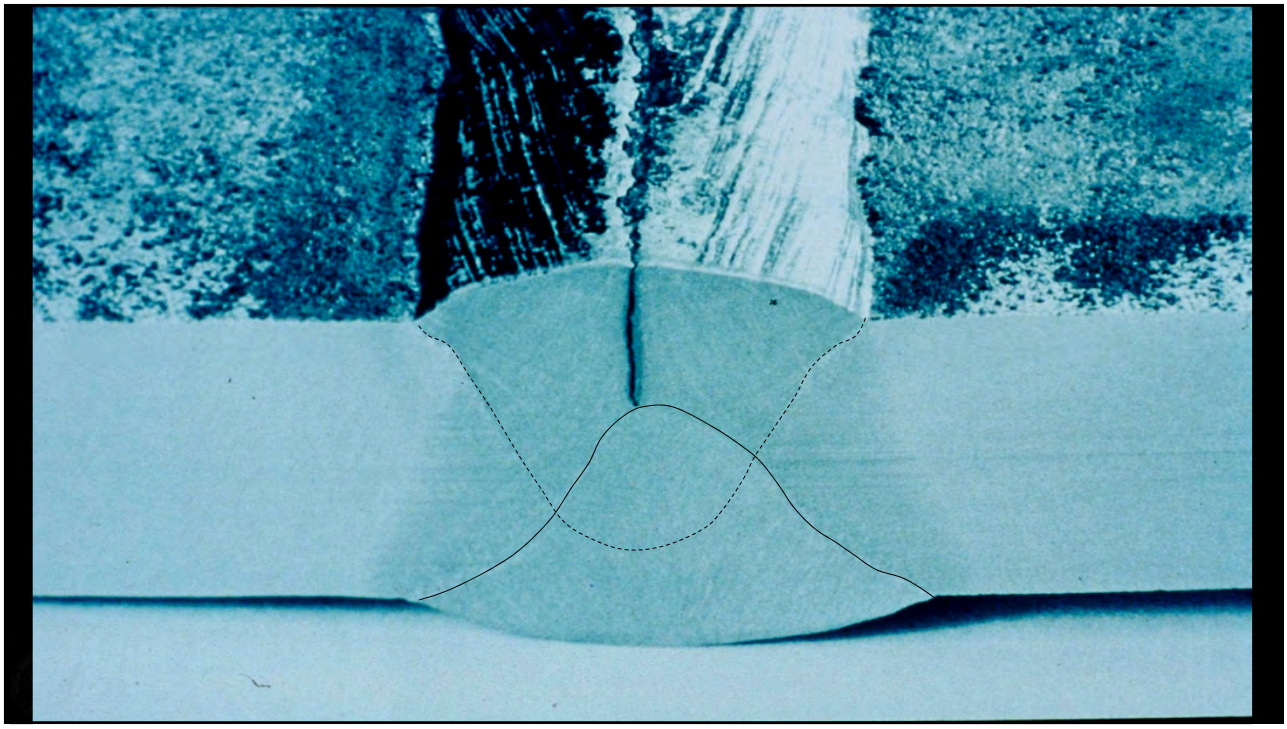
CENTERLINE CRACKING

Cause 2: Width-to-Depth Ratio Cracking

The cross-sectional width of the bead is less than the depth of the bead.

Solution: Make sure each bead is wider than it is deep.

133



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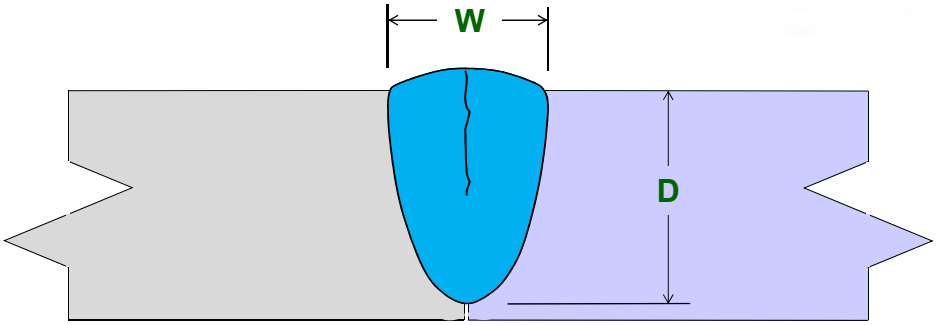
CENTERLINE CRACKING

W is the width of the weld bead
D is the depth of the weld bead



When **W < D**, the weld tends to crack

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CENTERLINE CRACKING

Cause 2: Width-to-Depth Ratio Cracking

The cross-sectional width of the bead is less than the depth of the bead.

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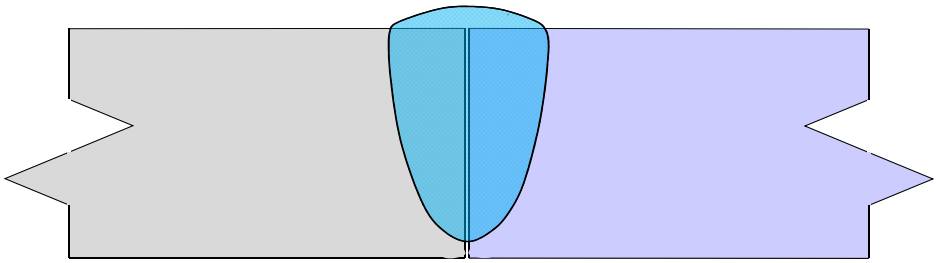
CENTERLINE CRACKING



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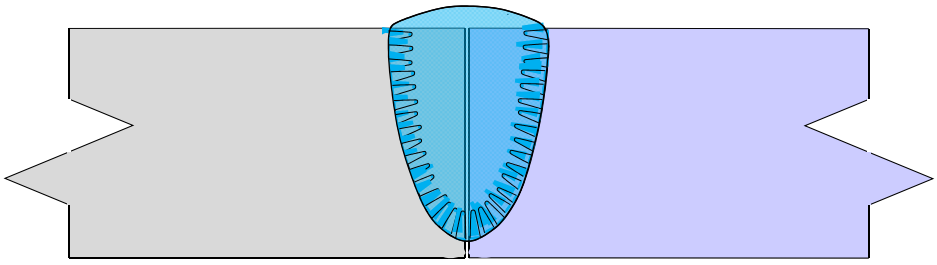
CENTERLINE CRACKING



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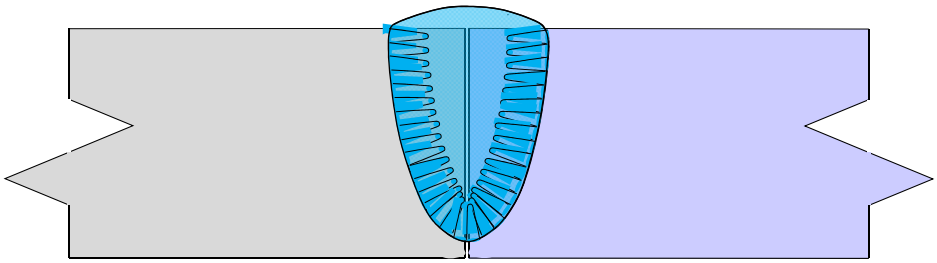
CENTERLINE CRACKING



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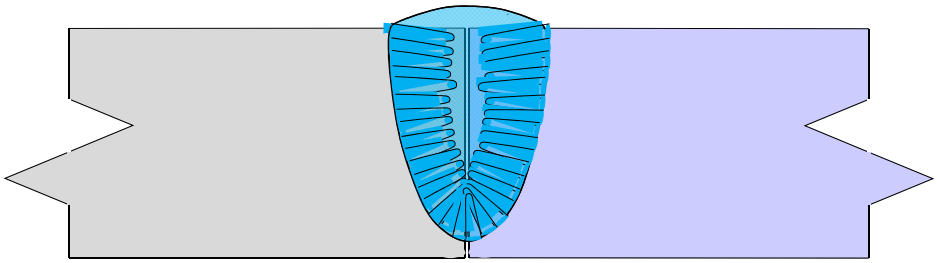
CENTERLINE CRACKING



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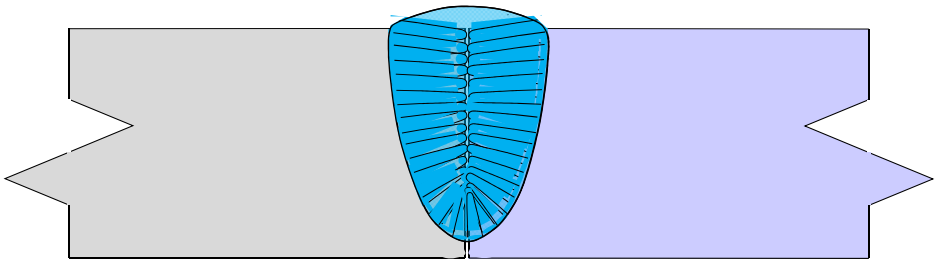
CENTERLINE CRACKING



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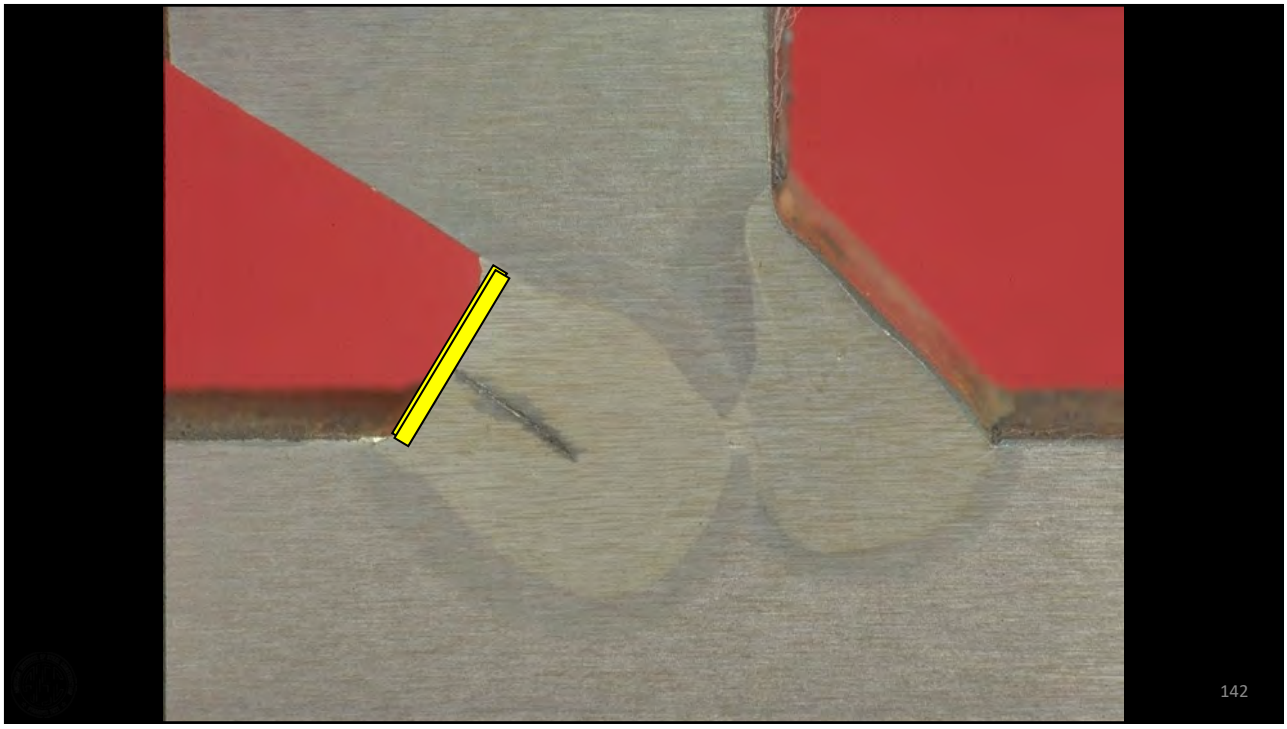

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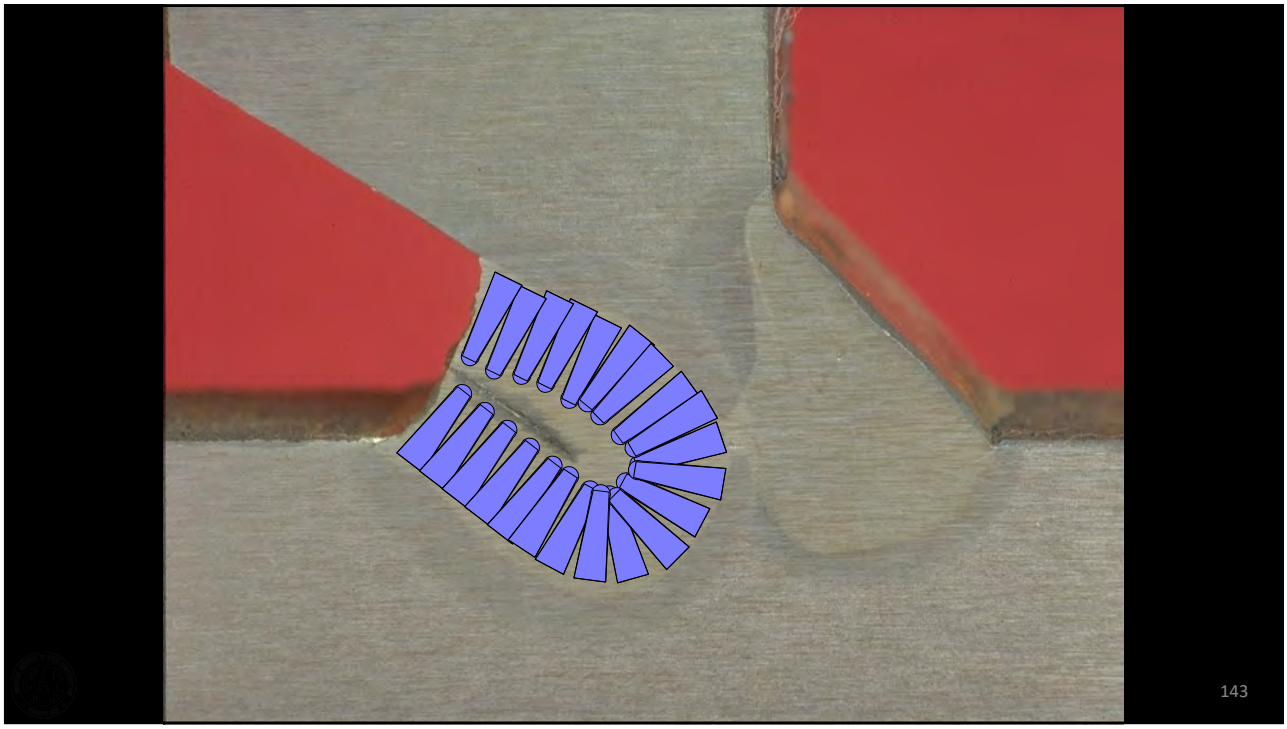

CENTERLINE CRACKING

Cause 2: Width-to-Depth Ratio Cracking

The cross-sectional width of the bead is less than the depth of the bead.

Solution: Make sure each bead is wider than it is deep.

Width-to-Depth Ratio (W/D) should be:

1:1 minimum
1.2:1 preferred
1.4:1 is ideal

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CENTERLINE CRACKING

Cause 2: Width-to-Depth Ratio Cracking

The cross-sectional width of the bead is less than the depth of the bead.

Solution: Make sure each bead is wider than it is deep.

- Use a proper joint detail

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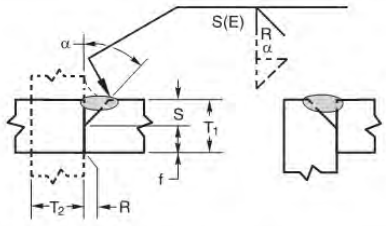
AWS D1.1: 2015 Structural Welding Code – Steel

Figure 3.2: Prequalified PJP Groove Welded Joint Details

Single-bevel-groove weld (4)
Butt joint (B)
T-joint (T)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	Base Metal Thickness (U = unlimited) T_2	Groove Preparation: Root Opening Root Face Groove Angle	Groove Preparation: Tolerances: As Detailed (see 3.12.3)	Groove Preparation: Tolerances: As Fit-Up (see 3.12.3)	Allowed Welding Positions	Weld Size (E)	Notes
SMAW	BTC-P4	U	U	R = 0 f = 1/8 min. α = 45°	+1/16, –0 +U –0 +10°, –0°	+1/8, –1/16 ±1/16 +10°, –5°	All	S–1/8	b, e, f, g, j, k
GMAW FCAW	BTC-P4-GF	1/4 min.	U	R = 0 f = 1/8 min. α = 45°	+1/16, –0 +U –0 +10°, –0°	+1/8, –1/16 ±1/16 +10°, –5°	F, H	S	a, b, f, g, j, k
							V, OH	S–1/8	
SAW	TC-P4-S	7/16 min.	U	R = 0 f = 1/4 min. α = 60°	±0 +U, –0 +10°, –0°	+1/16, –0 ±1/16 +10°, –5°	F	S	b, f, g, j, k

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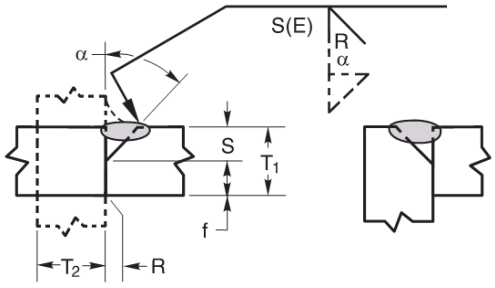
AWS D1.1: 2015 Structural Welding Code – Steel

Welding Process	Root Opening Root Face Groove Angle
SMAW	R = 0 f = 1/8" min. α = 45°
GMAW FCAW	R = 0 f = 1/8" min. α = 45°
SAW	R = 0 f = 1/4" min. α = 60°



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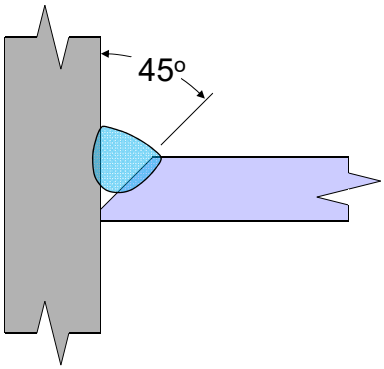
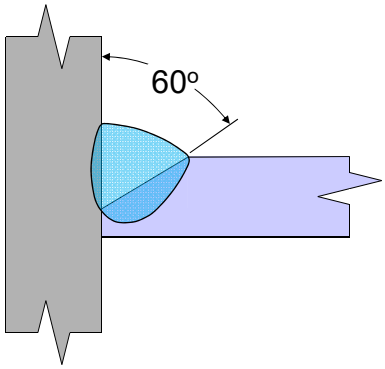
BTC-P4, BTC-P4-GF



TC-P4-S



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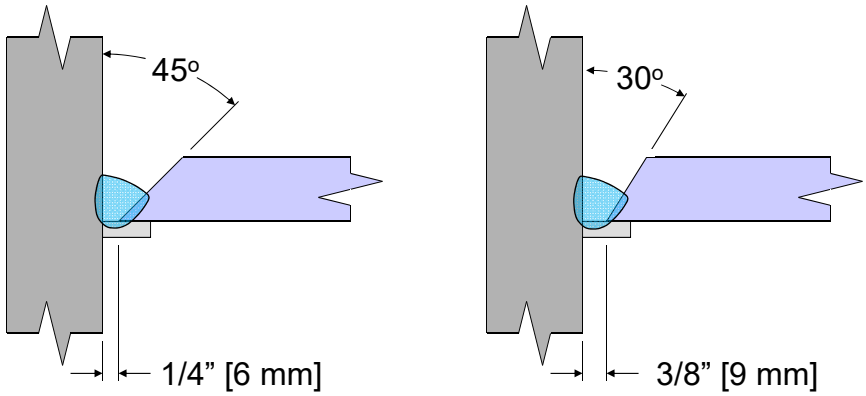
AWS D1.1: 2015 Structural Welding Code – Steel



TC-U4

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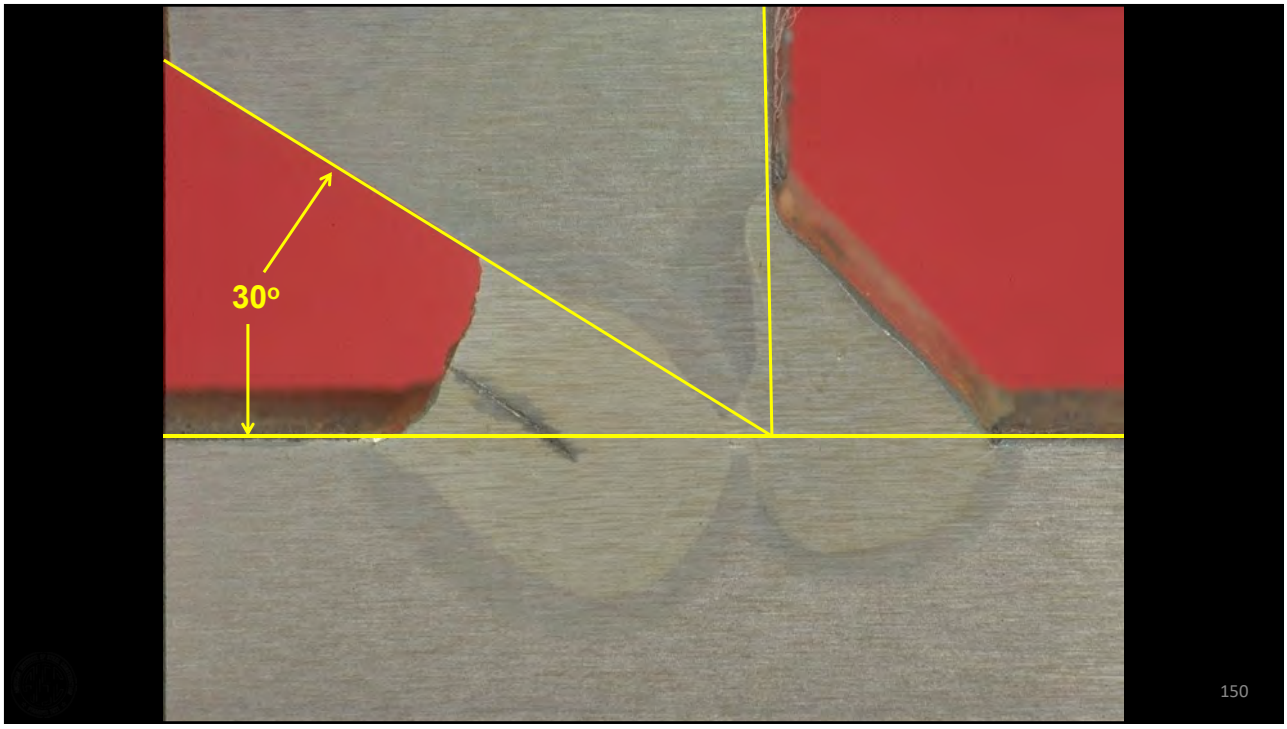

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CENTERLINE CRACKING

Cause 2: Width-to-Depth Ratio Cracking

The cross-sectional width of the bead is less than the depth of the bead.

Solution: Make sure each bead is wider than it is deep.

- Use a proper joint detail
- Control current density (δ)

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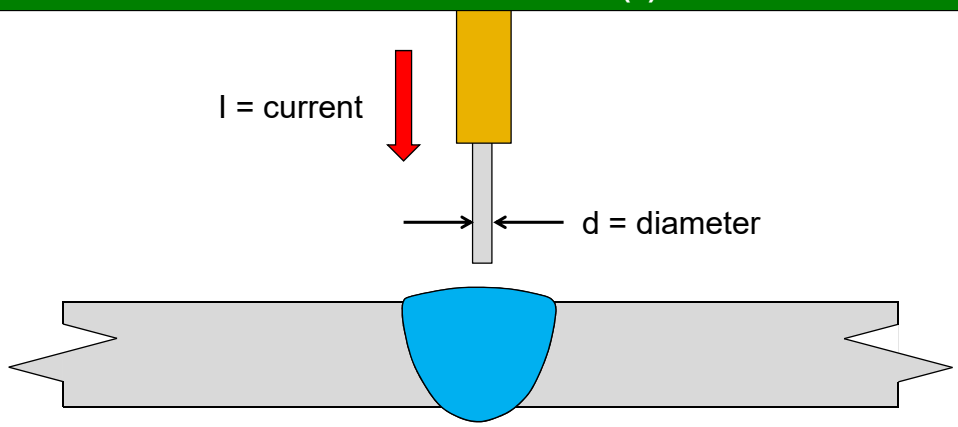
CURRENT DENSITY (δ)



$$\delta = \left(\frac{I}{A}\right) \propto \left(\frac{I}{d^2}\right)$$

where
I = current (amps)
A = cross sectional area of filler metal
d = diameter of filler metal

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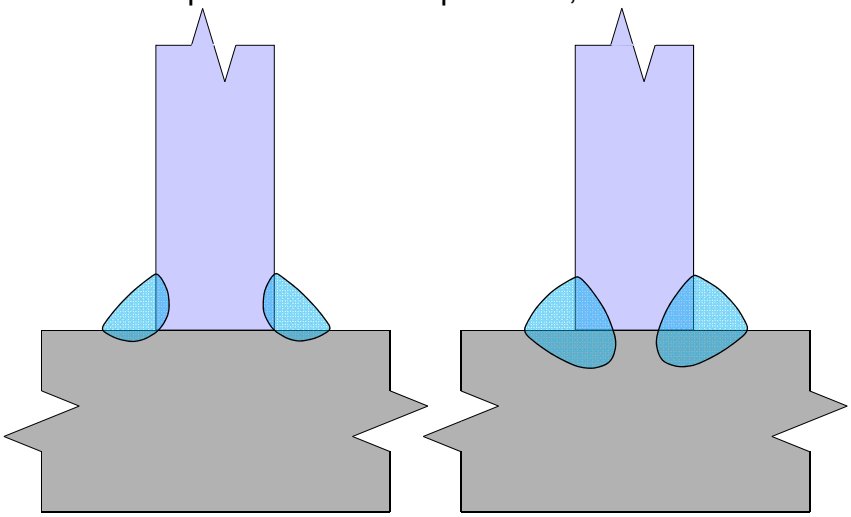
CURRENT DENSITY (δ)

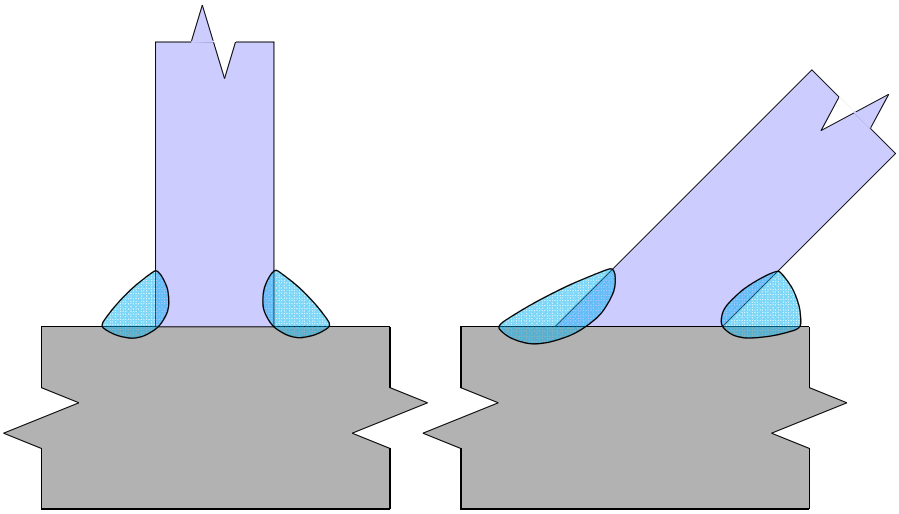
Acceptable fillet welds per AISC, AWS D1.1



Normal Current Density **Excessive Current Density**

153

CURRENT DENSITY (δ)



In 90° joint, W/D = 2:1 **In 45° joint, acute side is problematic**

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CENTERLINE CRACKING

Cause 2: Width-to-Depth Ratio Cracking

The cross-sectional width of the bead is less than the depth of the bead.

Solution: Make sure each bead is wider than it is deep.

- Use a proper joint detail
- Control current density (δ)

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CENTERLINE CRACKING

Cause 3: Surface Profile Cracking

The surface of the weld is concave

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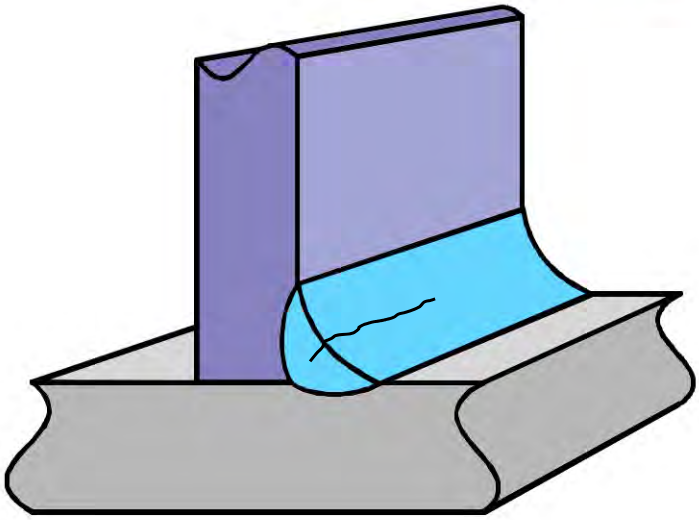
CENTERLINE CRACKING



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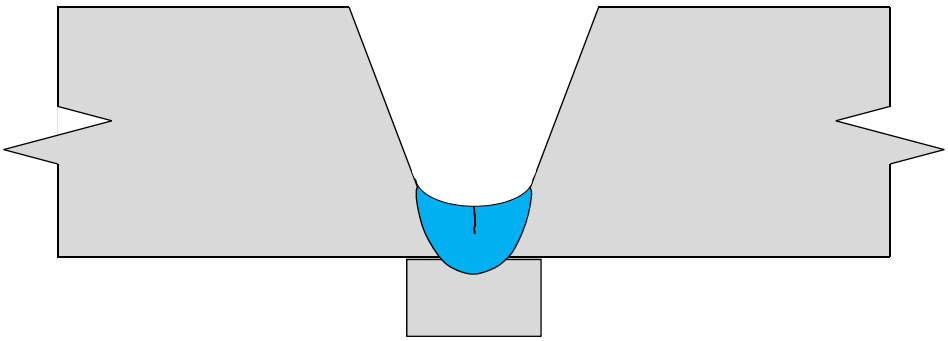
CENTERLINE CRACKING



Any concave pass, especially root passes

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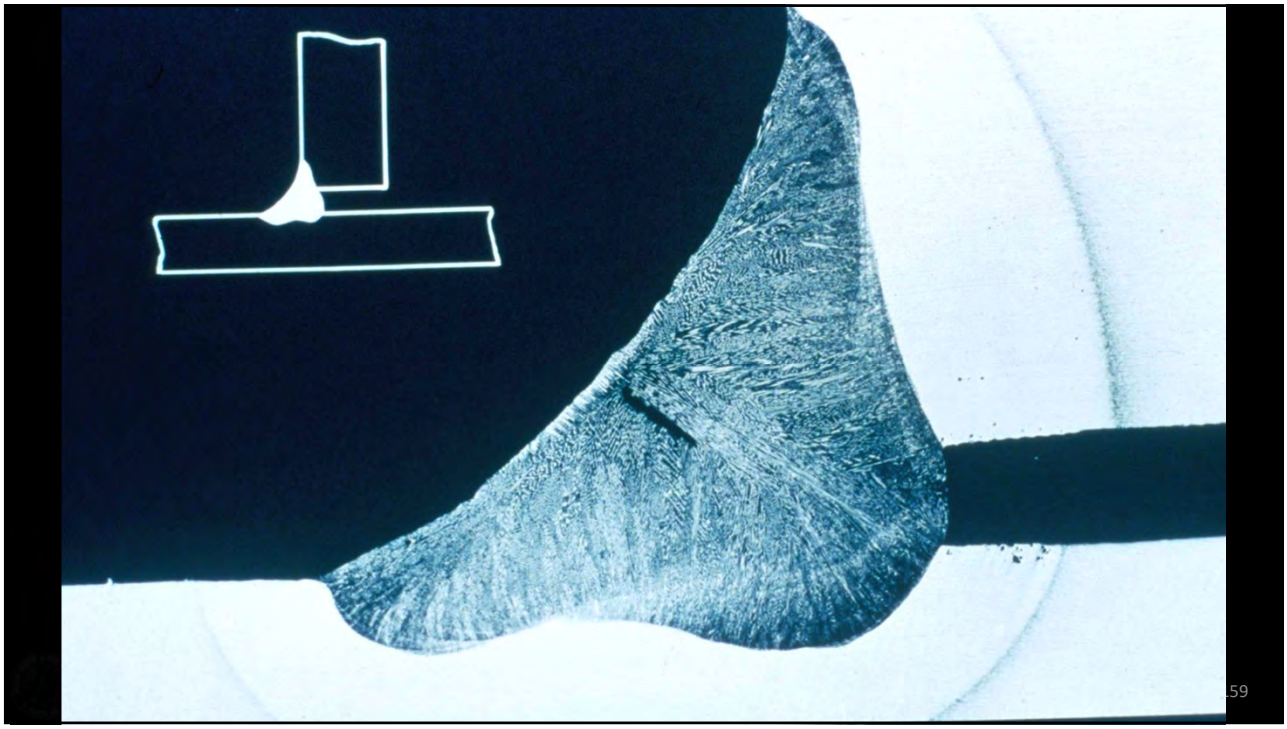

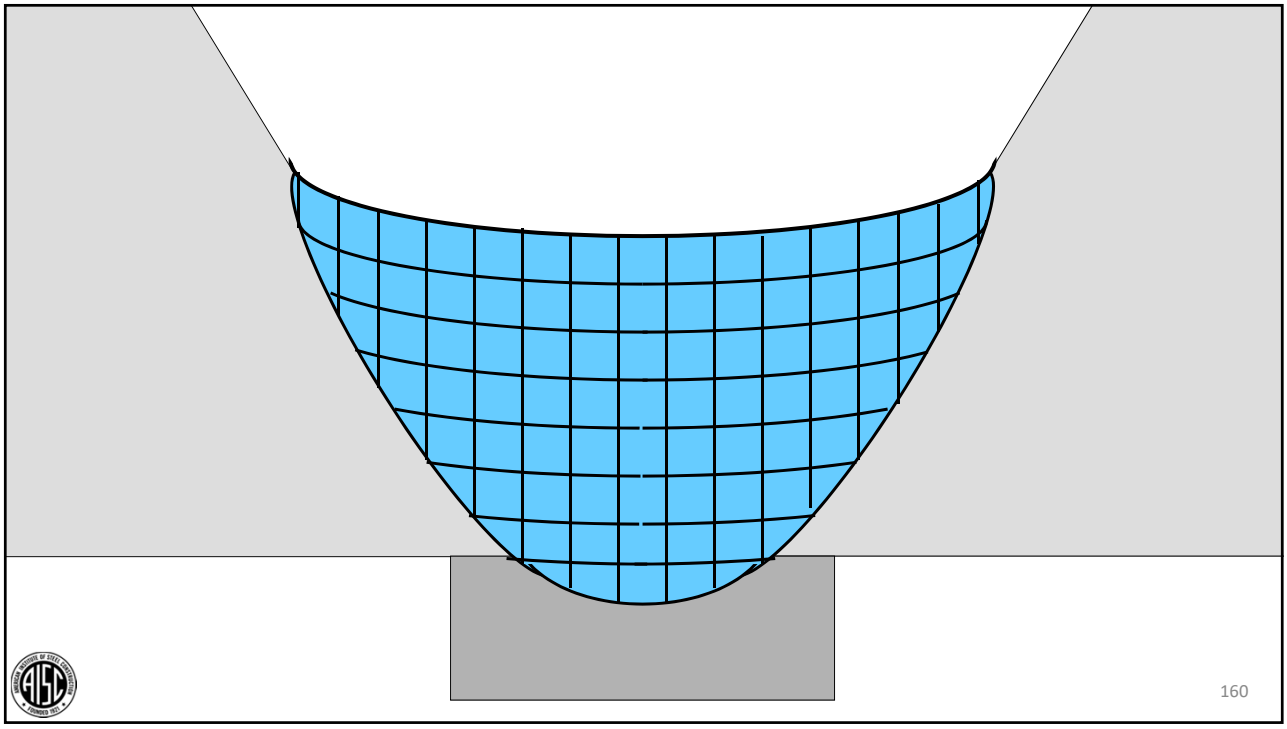

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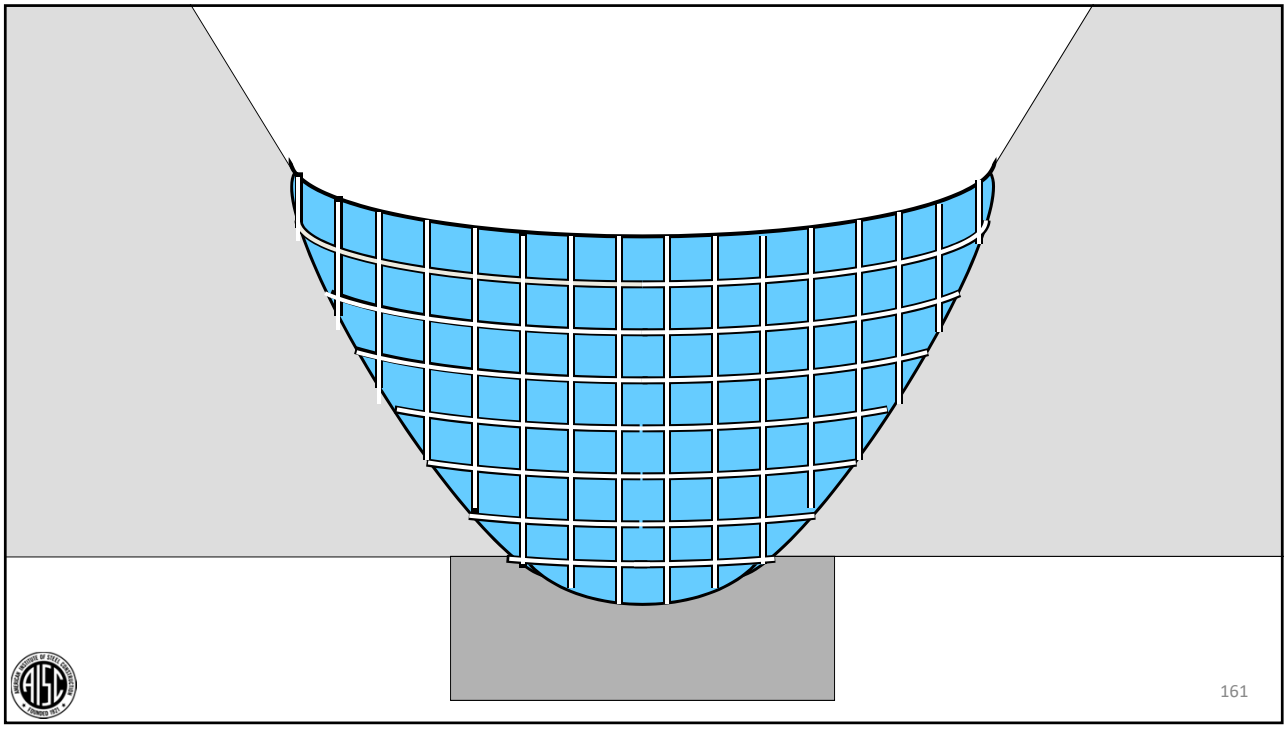

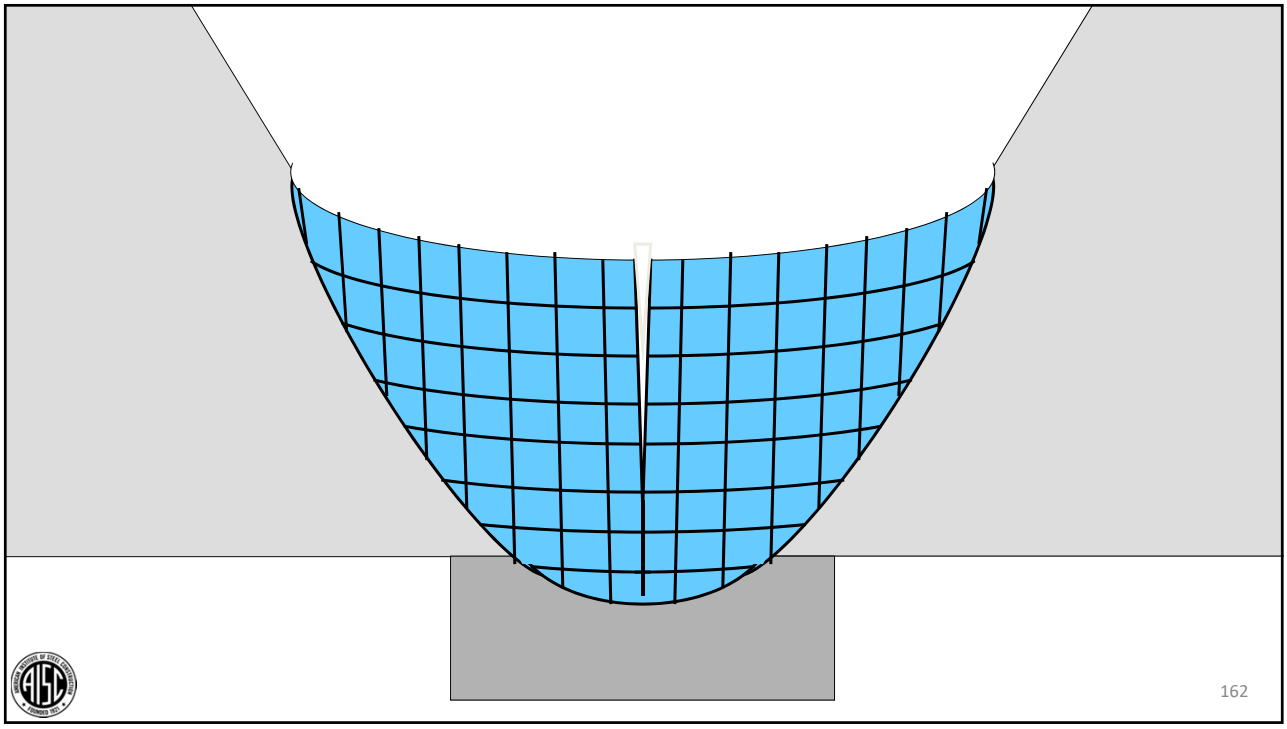

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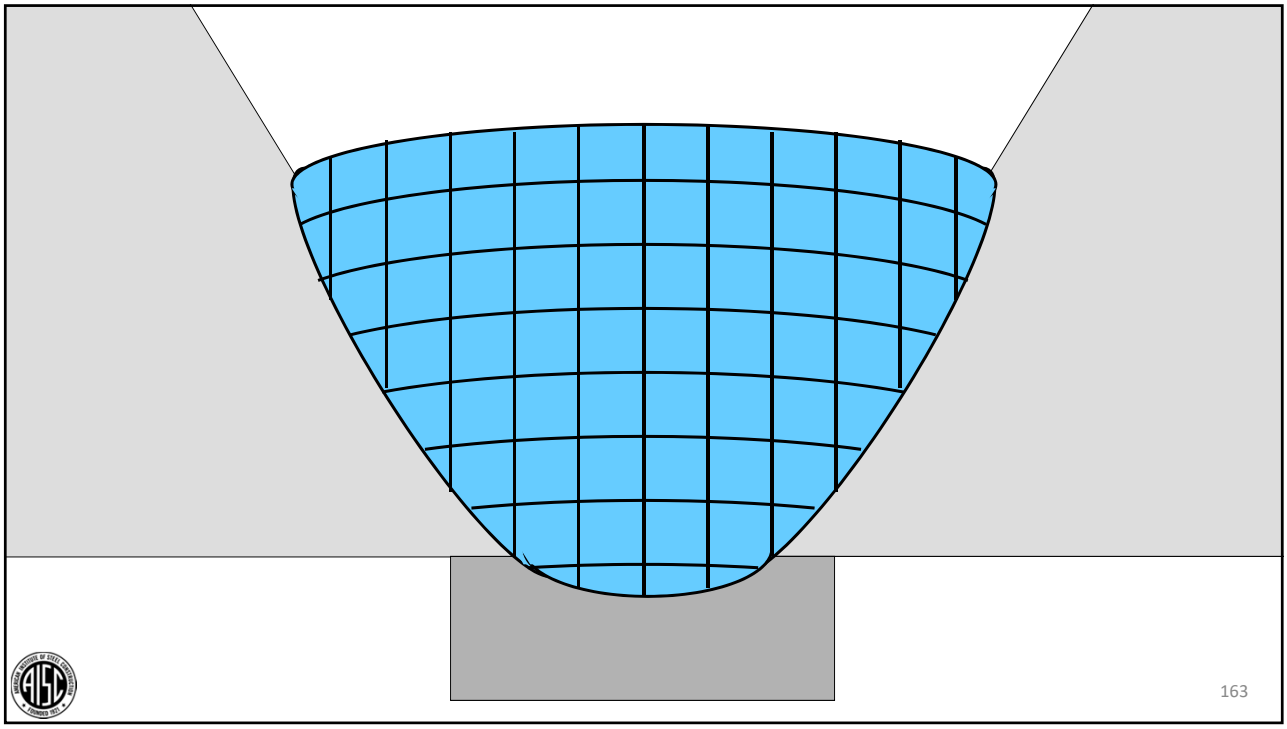

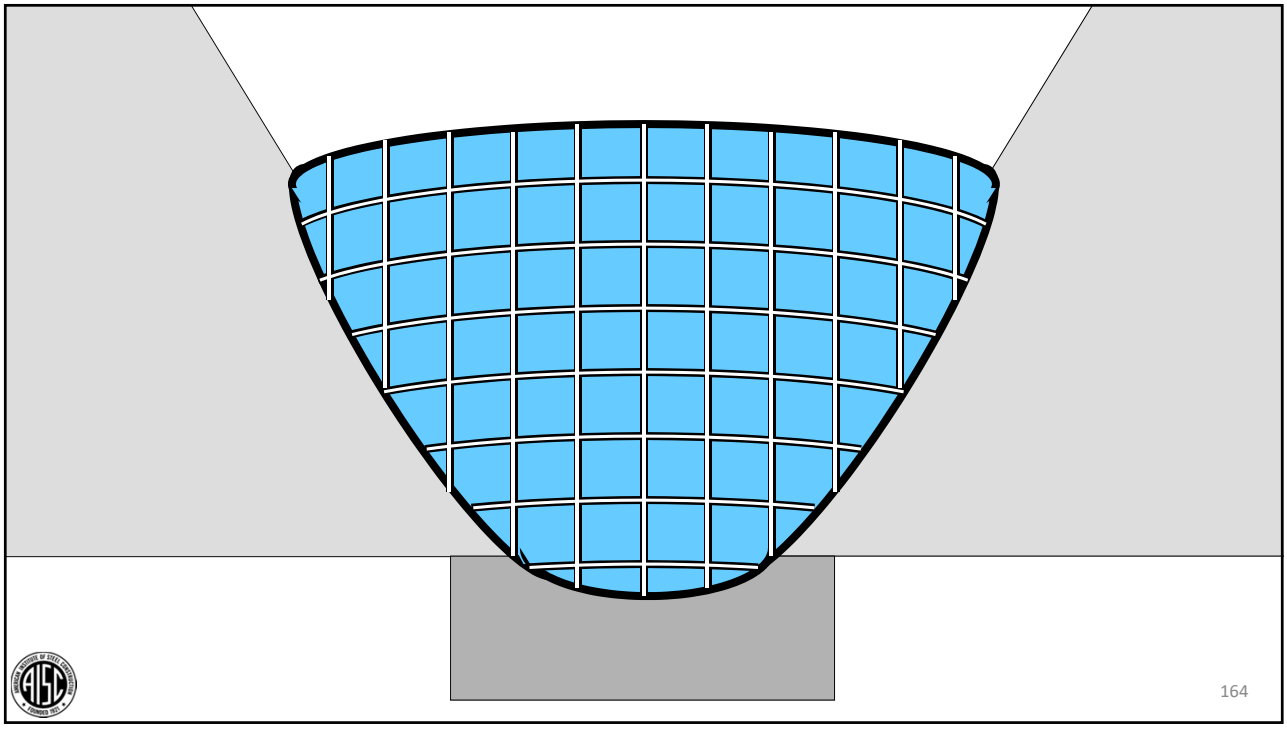

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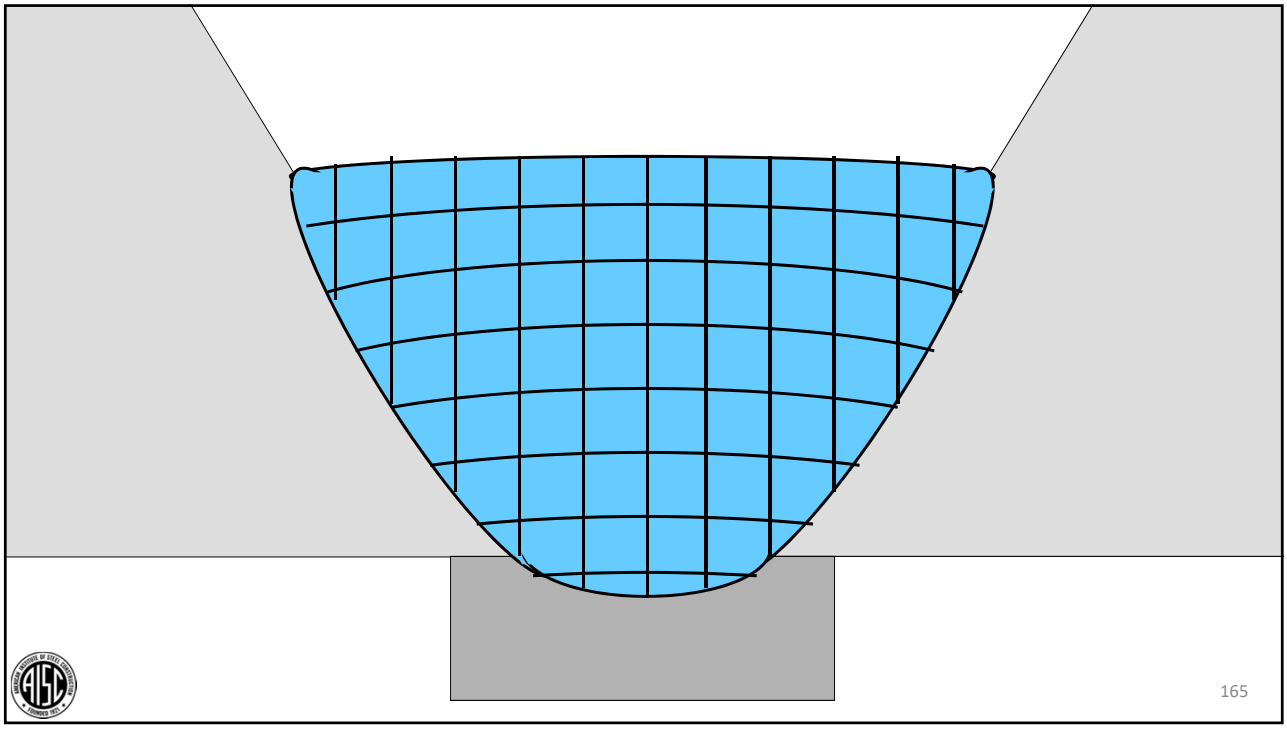

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CENTERLINE CRACKING

Cause 3: Surface Profile Cracking

The surface of the weld is concave

Solution: Make sure the bead surface is convex

- Use a proper welding procedure
  - Shielding gas
    - Argon/oxygen combinations tend to give concave beads
    - Argon/CO_2 combinations tend to give flatter/more convex beads
    - Vertical up (convex) versus vertical down (concave)
    - Lower voltage, amperage (“colder”)

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CENTERLINE CRACKING

Cause 3: Surface Profile Cracking

The surface of the weld is concave

Solution: Make sure the bead surface is convex

- Use a proper welding procedure

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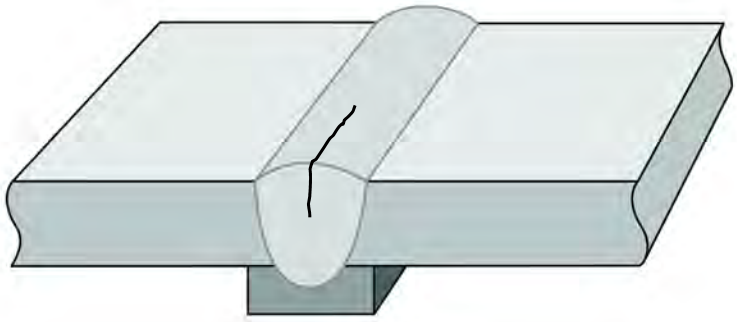
CENTERLINE CRACKING



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CENTERLINE CRACKING

Cause 1: Segregation Cracking
Cause 2: Width-to-Depth Ratio Cracking
Cause 3: Surface Profile Cracking

To troubleshoot, use a countdown.

- Surface profile: Is it concave?
- If not, check the cross section: Is the bead deeper than it is wide?
- If not, check the weld deposit chemistry.

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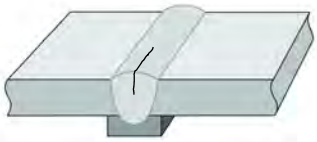
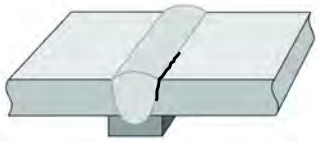
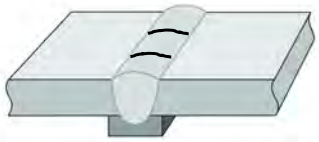
HOT CRACK



Centerline



Underbead



Transverse

COLD CRACKS

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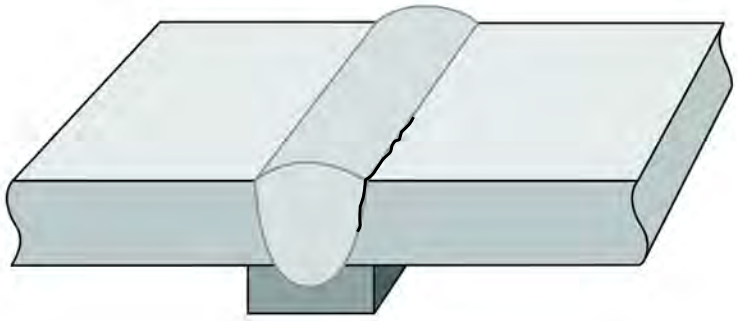
UNDERBEAD CRACKING



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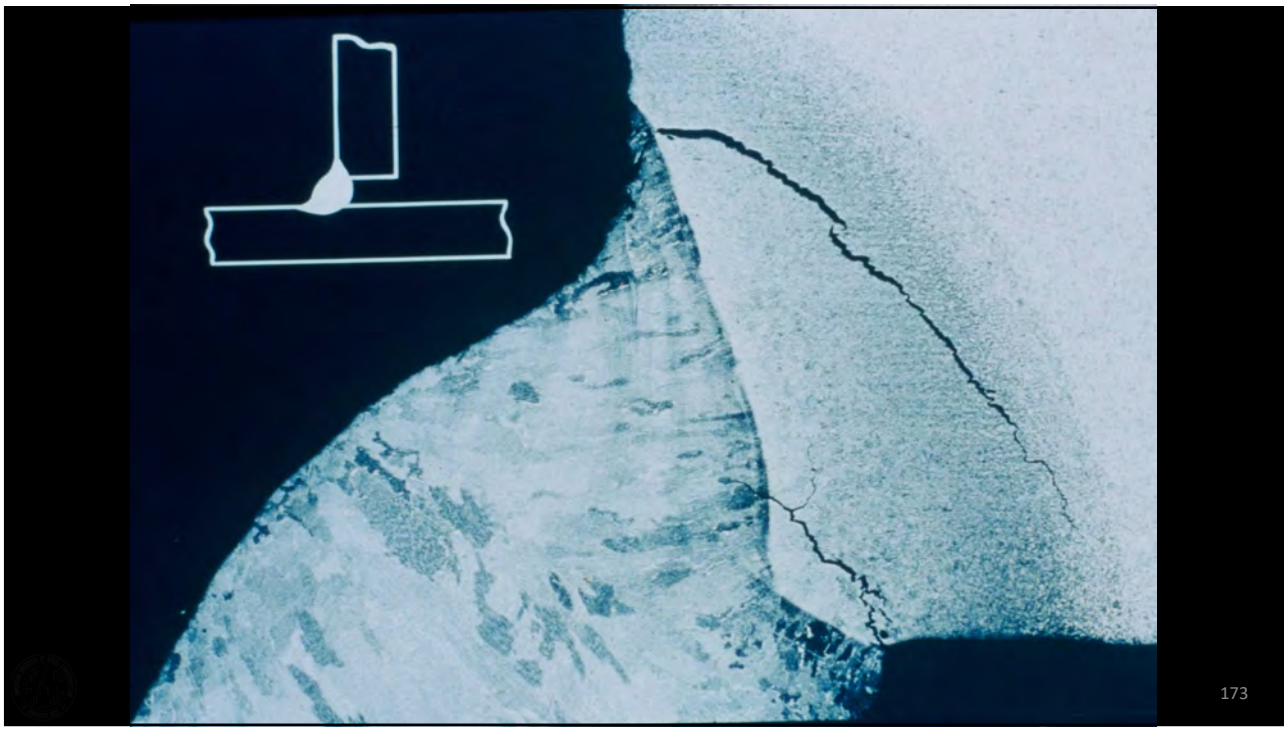

UNDERBEAD CRACKING

Characteristics:

- Located at weld toe or in heat affected zone (HAZ)
- Occurs at lower temperatures
- May be delayed—occurring up to 72 hours (or more) after welding
- May occur immediately after the weldment cools sufficiently
- Is driven by the transverse shrinkage stress
- Can be confused with in-service fatigue cracks which often occur at weld toes

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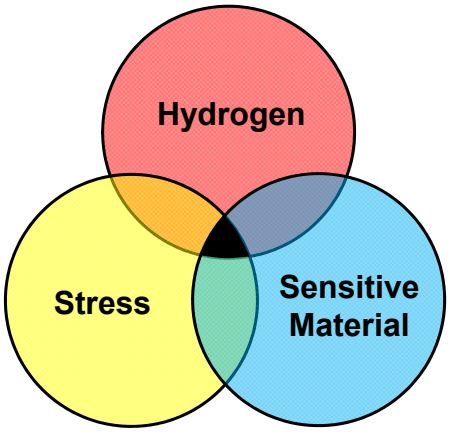
UNDERBEAD CRACKING

Cause: **Excessive hydrogen AND a sensitive material AND an applied or residual stress**



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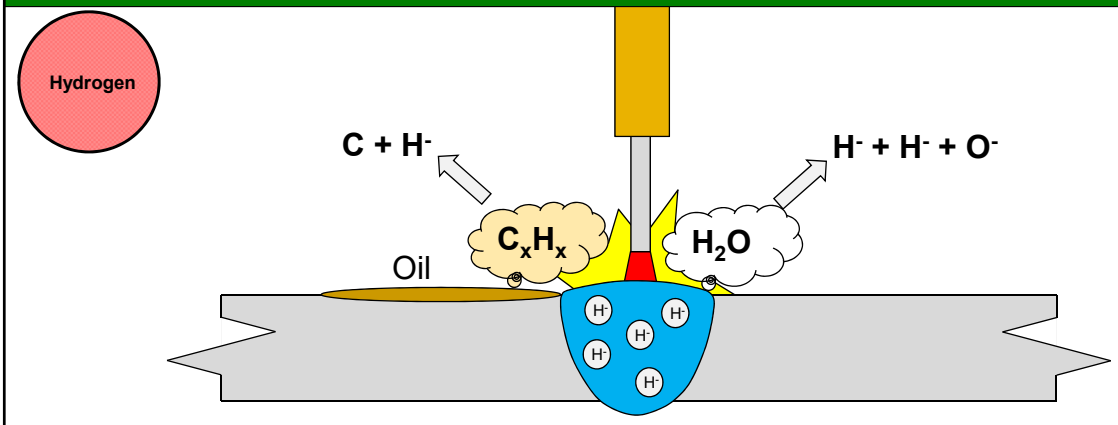
DEVELOPMENT OF ATOMIC HYDROGEN



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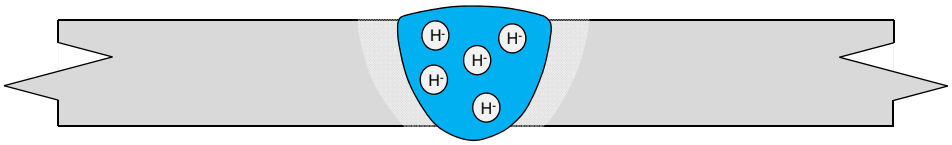
MIGRATION OF ATOMIC HYDROGEN

Hydrogen



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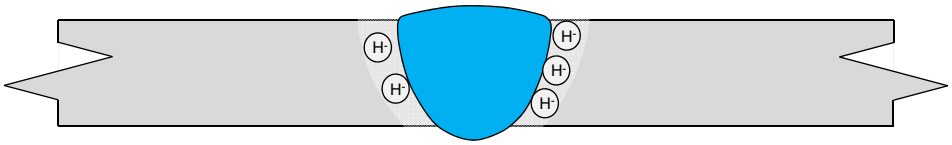
MIGRATION OF ATOMIC HYDROGEN

Hydrogen



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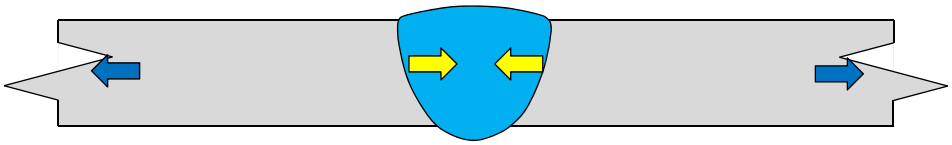
SHRINKAGE STRESSES

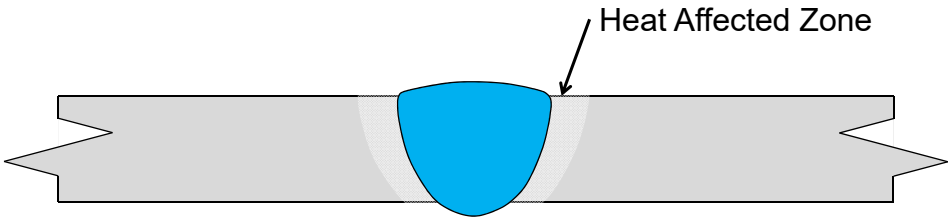
Stress



179

SENSITIVE MATERIAL

Sensitive Material



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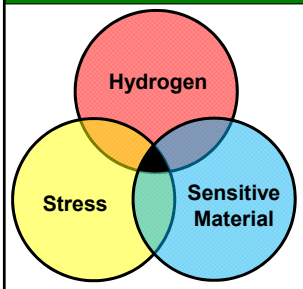
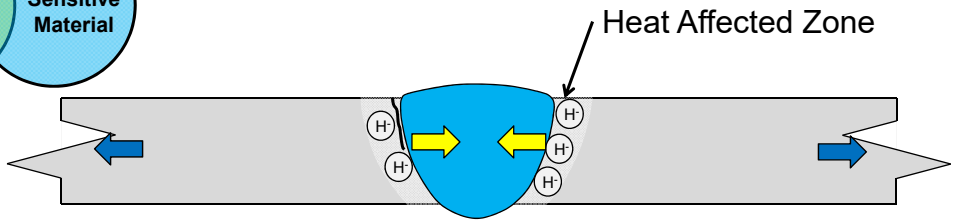
COMBINING ALL THREE

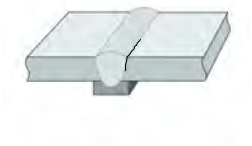




Because it takes time for hydrogen to diffuse, and because this cracking only occurs when the steel is cool (< 400°F), it may be "delayed".

181

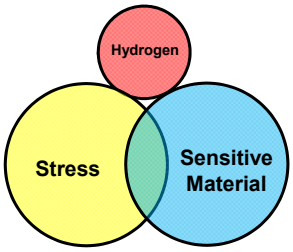
UNDERBEAD CRACKING



Cause: **Excessive hydrogen AND a sensitive material AND an applied or residual stress**

Solution:

- Reduce Hydrogen
  - Selection of filler metals
  - Storage and exposure of filler metals
  - Control base metal cleanliness
  - Maximize diffusion of hydrogen



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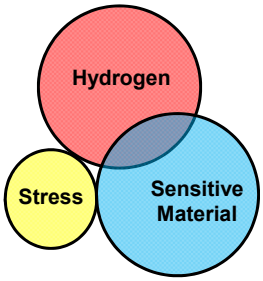
UNDERBEAD CRACKING

Cause: **Excessive hydrogen AND a sensitive material AND an applied or residual stress**

Solution:

- Reduce Residual Stress
  - Use matching or undermatching filler metal
  - Control welding sequence
  - Maintain proper preheat and interpass temperatures
  - Peen weld beads



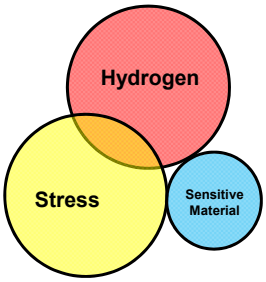
183

UNDERBEAD CRACKING

Cause: **Excessive hydrogen AND a sensitive material AND an applied or residual stress**

Solution:

- Reduce Material (HAZ) Sensitivity
  - Selection of base metal
    (low hardenability—low carbon, low alloys)
  - Increased preheat
  - Higher heat input
  - Increased interpass temperature



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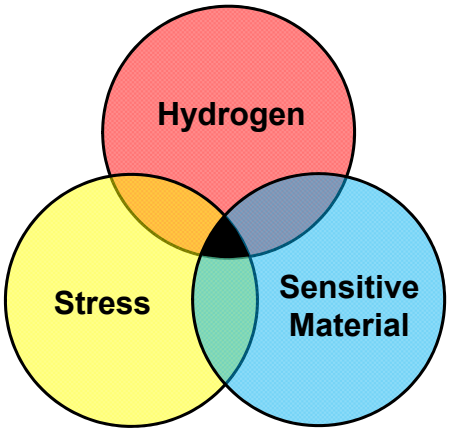
UNDERBEAD CRACKING

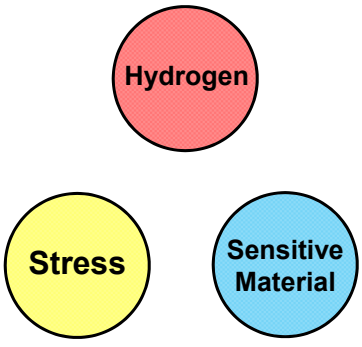
Cause: **Excessive hydrogen AND a sensitive material AND an applied or residual stress**



185

UNDERBEAD CRACKING

Cause: **Excessive hydrogen AND a sensitive material AND an applied or residual stress**



Typically, when an underbead cracking problem is encountered, all three variables are reduced.

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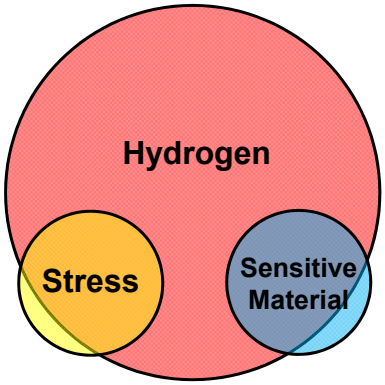
UNDERBEAD CRACKING

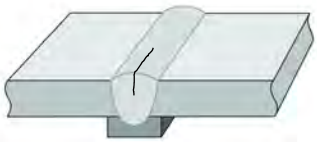
Cause: **Excessive hydrogen AND a sensitive material AND an applied or residual stress**



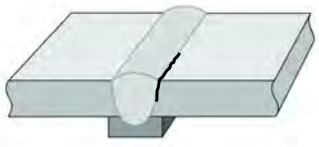
Crack-free welding is possible, even with very high hydrogen levels, if the other factors are small.

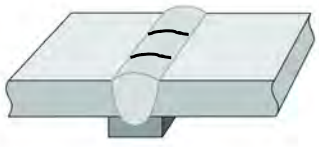
187

HOT CRACK



Centerline





Underbead Transverse

COLD CRACKS

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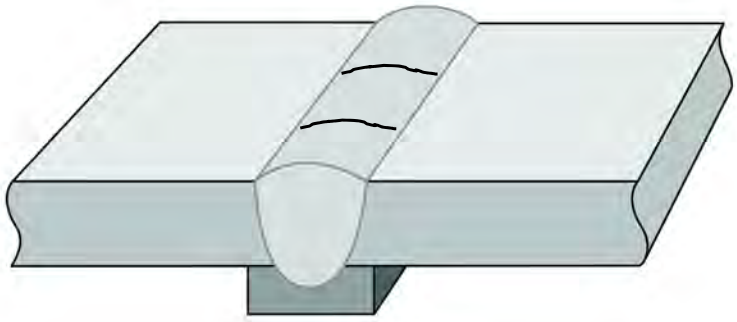
TYPES OF WELD CRACKS

Transverse Cracking



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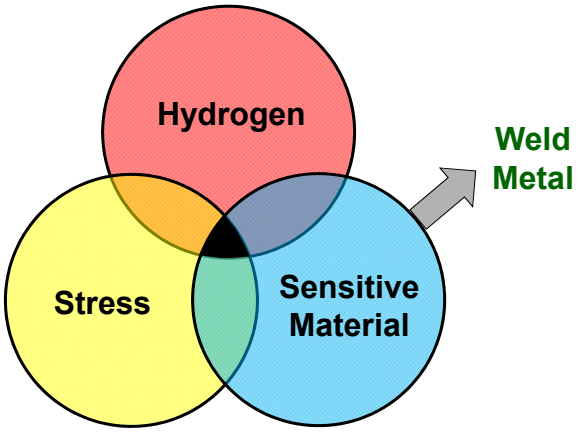
TRANSVERSE CRACKING

Cause: **Excessive hydrogen AND a sensitive material AND an applied or residual stress**



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TRANSVERSE CRACKING

Characteristics:

- May be delayed, just like underbead cracking
- Is caused by longitudinal shrinkage stress (underbead cracking is driven by transverse stress)
- Longitudinal spacing may be very regular
- Must have a sufficiently long weld (typically > 18” long)

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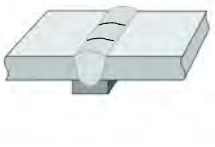
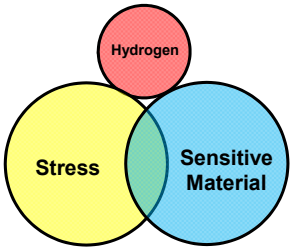
TRANSVERSE CRACKING



Cause: **Excessive hydrogen AND a sensitive material AND an applied or residual stress**

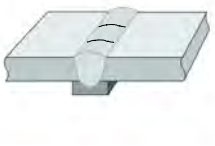
Solution:

- Reduce Hydrogen
  - Selection of filler metals
  - Storage and exposure of filler metals
  - Control base metal cleanliness
  - Maximize diffusion of hydrogen



193

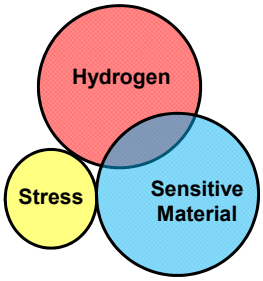
TRANSVERSE CRACKING



Cause: **Excessive hydrogen AND a sensitive material AND an applied or residual stress**

Solution:

- Reduce Residual Stress
  - Use matching or undermatching filler metal
  - Maintain proper preheat and interpass temperatures



Transverse cracking nearly always involves weld deposits that are higher in strength than the base metal.

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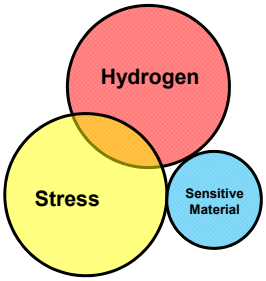
TRANSVERSE CRACKING

Cause: **Excessive hydrogen AND a sensitive material AND an applied or residual stress**

Solution:

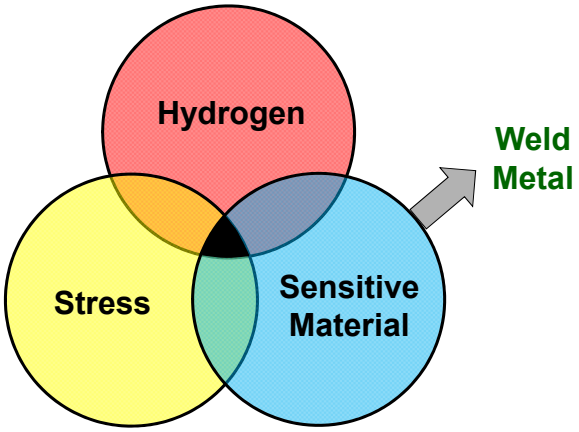
- Reduce Material (Weld Metal) Sensitivity
  - Selection of filler metal
  - Use undermatching where possible
  - Increased preheat
  - Higher heat input
  - Increased interpass temperature
  - Control admixture (pickup)



195

TRANSVERSE CRACKING

Cause: **Excessive hydrogen AND a sensitive material AND an applied or residual stress**



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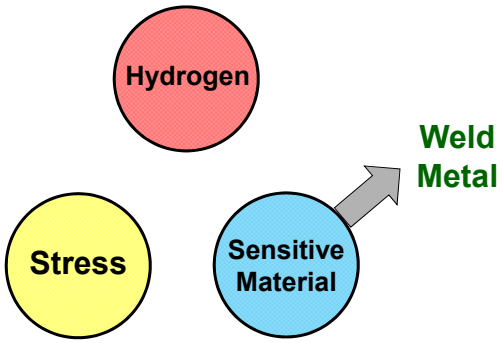
TRANSVERSE CRACKING

Cause: **Excessive hydrogen AND a sensitive material AND an applied or residual stress**



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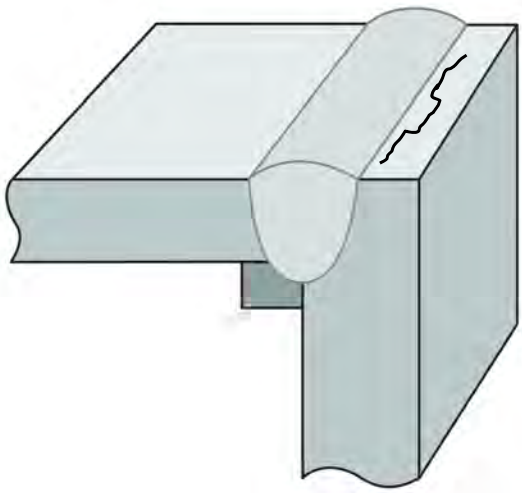
LAMELLAR TEARING



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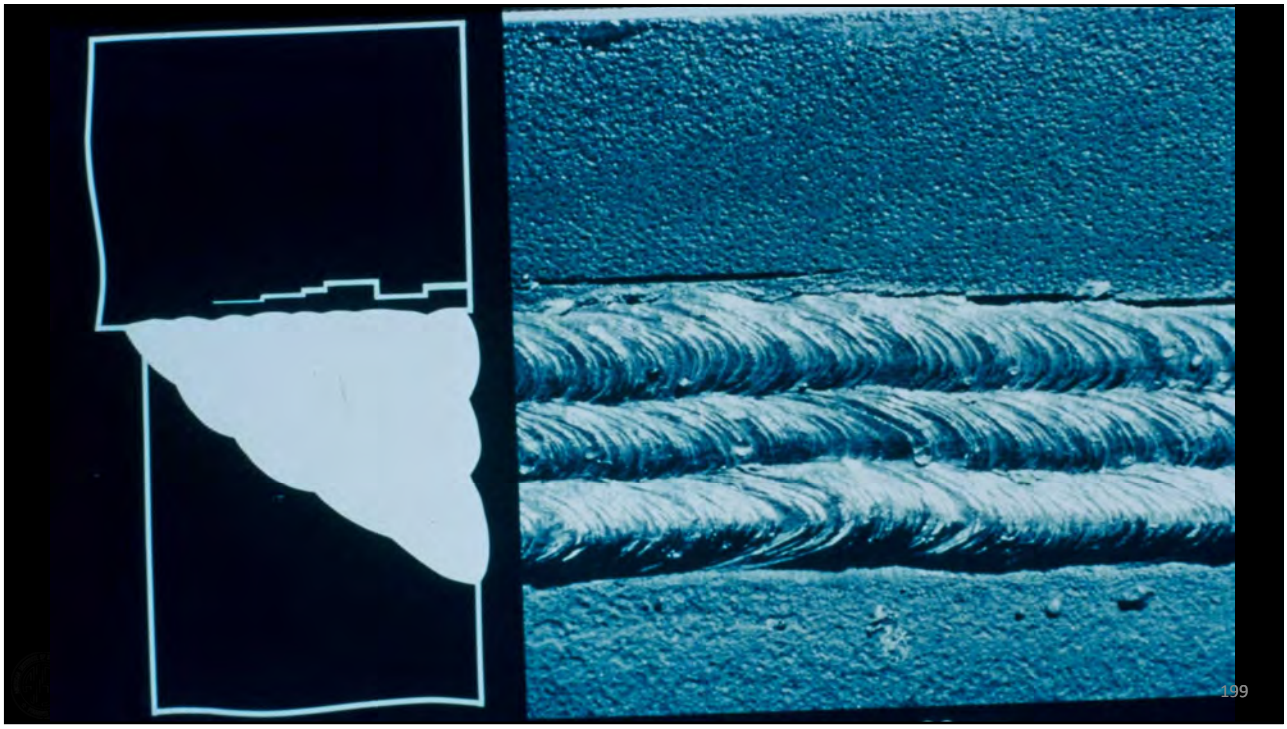

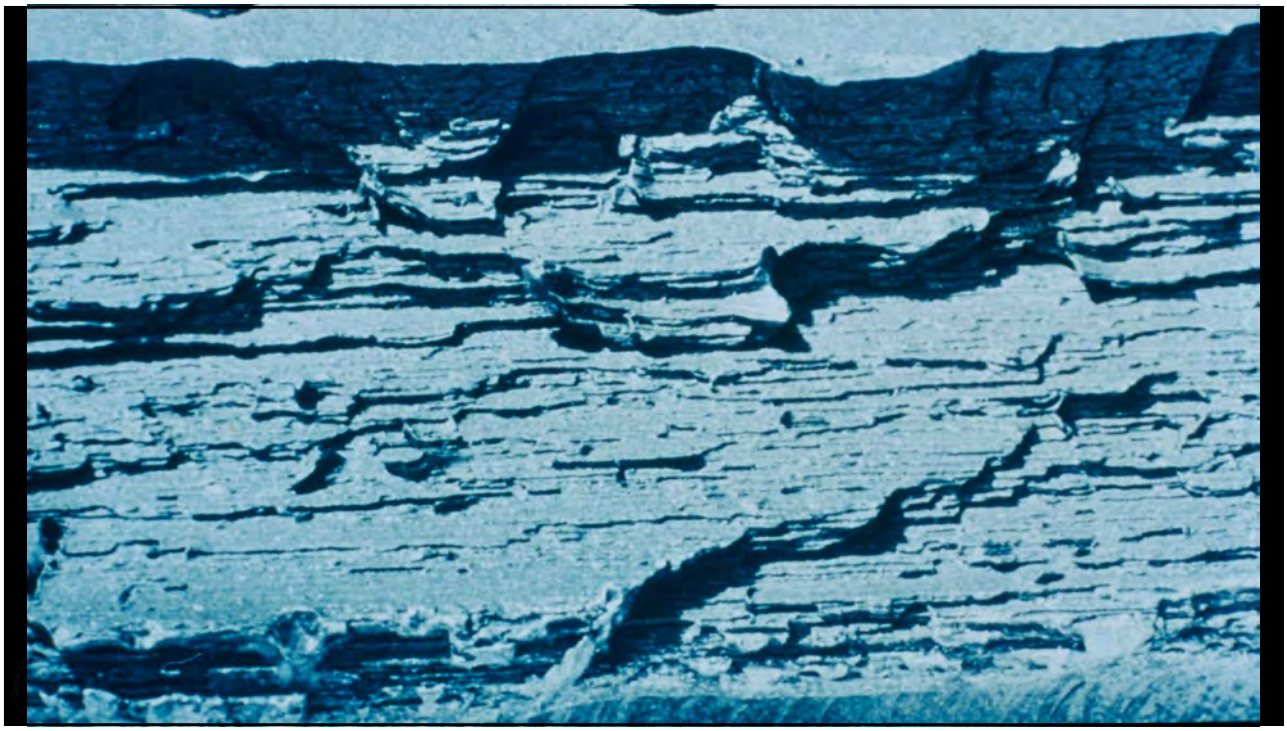

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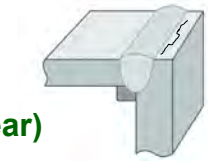
LAMELLAR TEARING

Cause: **Through thickness weld shrinkage strains cause planar inclusions to join together (tear)**



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LAMELLAR TEARING

Characteristics:

- Typically occurs immediately outside the heat affected zone
- Typically is not delayed
- Is aggravated by hydrogen (but not caused by hydrogen)
- Occurs less frequently today (2012) than it did in the past (due to improved steel making practices)
- Typically associated with steel thicknesses >3/4”
- Not to be confused with de-lamination, which typically occurs at the mid-thickness

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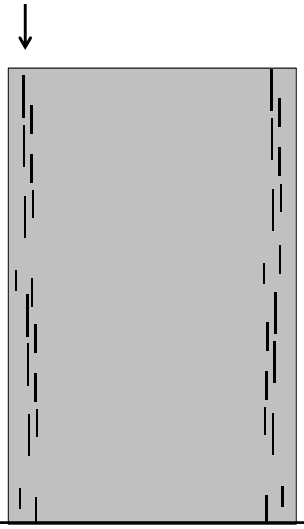
LAMELLAR TEARING

Inclusions, typically manganese sulfides



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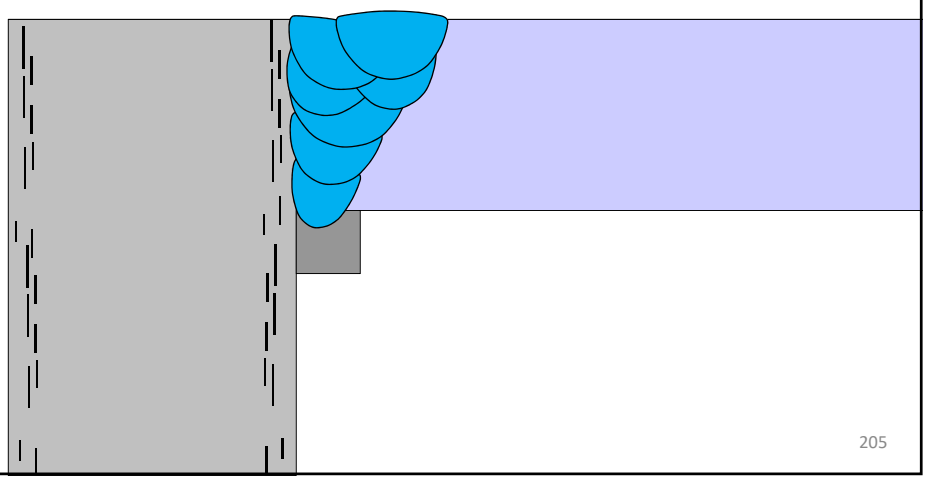
LAMELLAR TEARING



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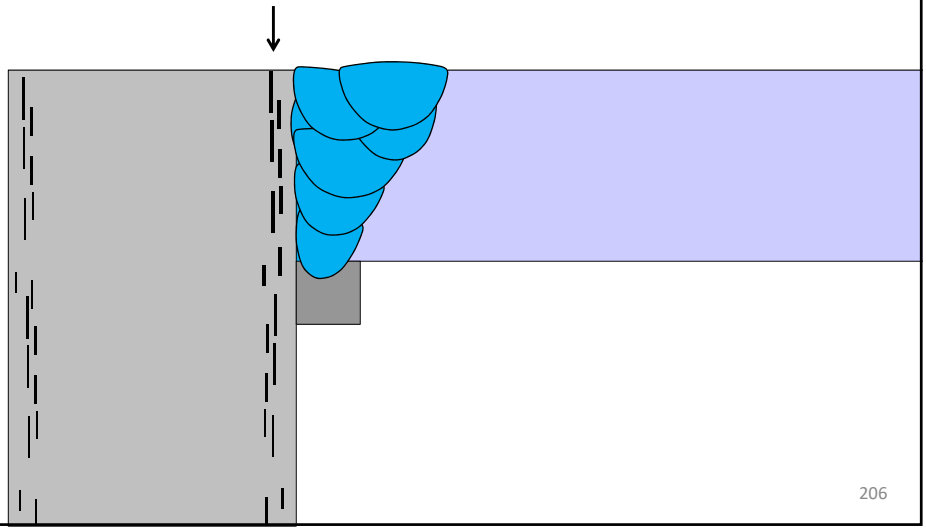
LAMELLAR TEARING

Step 1: Separation of the inclusions from the surrounding steel



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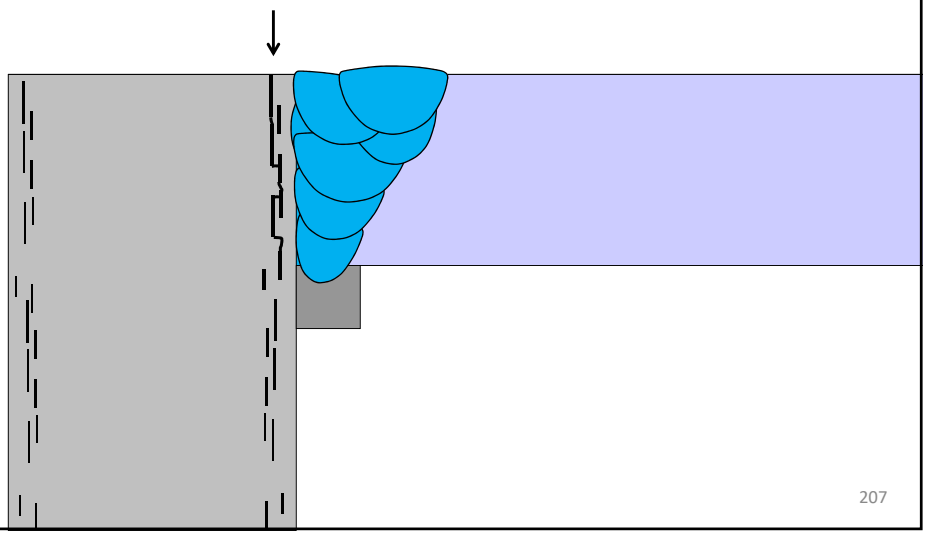
LAMELLAR TEARING

Step 2: Ductile tearing of the ligaments between the inclusions



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LAMELLAR TEARING

Cause: **Through thickness weld shrinkage strains cause planar inclusions to join together (tear)**

Solution:

- Use appropriate joint configurations

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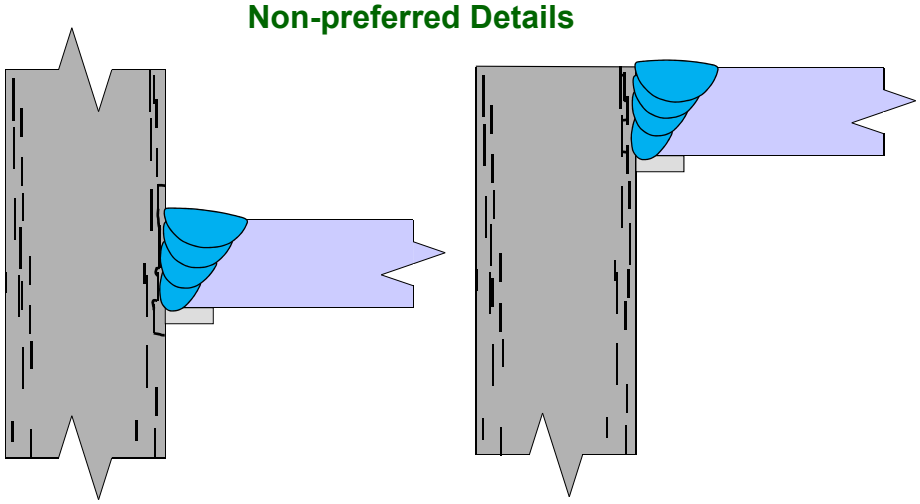
LAMELLAR TEARING

Non-preferred Details



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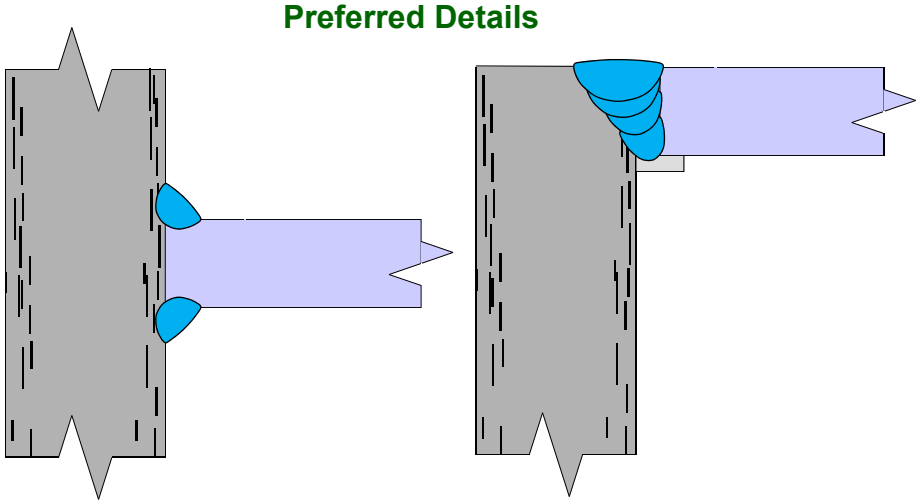
LAMELLAR TEARING

Preferred Details



Fillets instead of CJP

CJP with bevel on the problematic side

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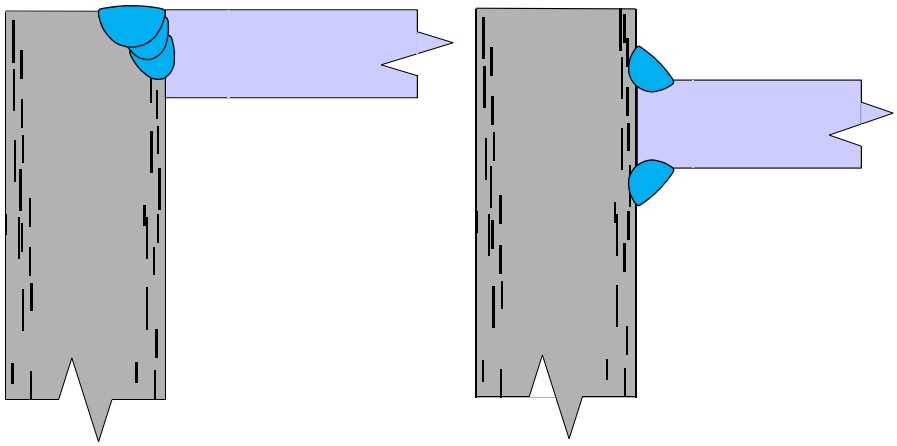
LAMELLAR TEARING

Preferred Details



PJP instead of CJP

A corner-like tee joint

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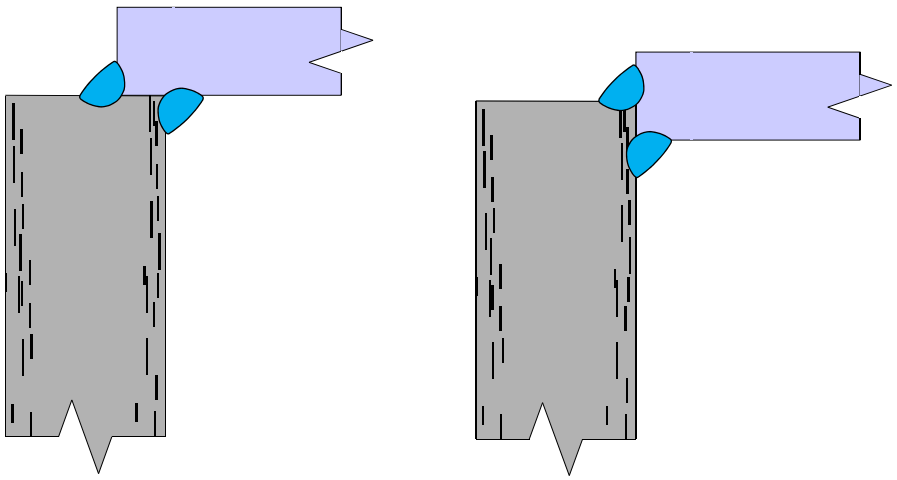
LAMELLAR TEARING

Preferred Details



Weld applied to ends of plate

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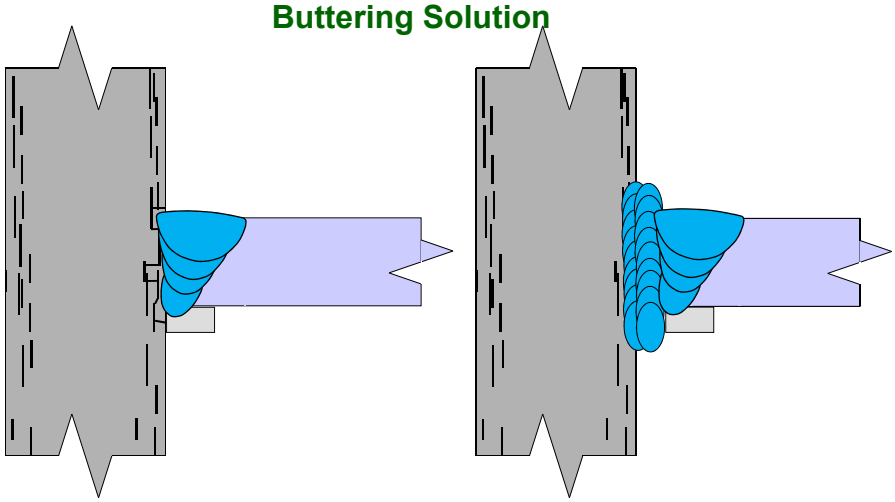
LAMELLAR TEARING

Buttering Solution



Sensitive Detail

Buttered Detail

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LAMELLAR TEARING

Cause: **Through thickness weld shrinkage strains cause planar inclusions to join together (tear)**

Solution: Better Material

- Reduce inclusions in the steel
- Control the inclusion shape in the steel

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LAMELLAR TEARING

Cause: **Through thickness weld shrinkage strains cause planar inclusions to join together (tear)**

Solution: Better Detailing

- Bevel the sensitive member
- Minimize weld volumes: PJPs vs. CJPs
- Minimize weld volumes: Optimized details
- Butter the joint

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LAMELLAR TEARING

Cause: **Through thickness weld shrinkage strains cause planar inclusions to join together (tear)**

Solution: Better Fabrication

- Minimize shrinkage strains (peening can be helpful when properly done)
- Increased preheat, lower hydrogen
- Weld only once (plan the work)

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LAMELLAR TEARING

Cause: **Through thickness weld shrinkage strains cause planar inclusions to join together (tear)**

Solution:

- Better Material
- Better Detailing
- Better Fabrication

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PREHEAT

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AWS STANDARD WELDING TERMS & DEFINITIONS (A3.0:2010)

preheat temperature.

The temperature of the base metal in the volume surrounding the point of welding immediately before welding is started. In a multiple pass weld, it is also the temperature immediately before the second and subsequent passes are started.

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AWS STANDARD WELDING TERMS & DEFINITIONS (A3.0:2010)

interpass temperature.

In a multipass weld, the temperature of the weld area between weld passes.

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AWS D1.1: 2015 Structural Welding Code – Steel

Table 3.3
Prequalified Minimum Preheat and Interpass Temperature (see 3.5)

Category	Steel Specification		Welding Process	Thickness of Thickest Part at Point of Welding		Minimum Preheat and Interpass Temperature	
				in	mm	°F	°C
	ASTM A36						
	ASTM A53	Grade B					
	ASTM A106	Grade B					
	ASTM A131	Grades A, B, CS, D, DS, E					
	ASTM A139	Grade B					
	ASTM A381	Grade Y35					
	ASTM A500	Grade A					
		Grade B					
		Grade C					
	ASTM A501	Grade A					
	ASTM A516			1/8 to 3/4 incl.	3 to 20 incl.	32[a]	0[a]
	ASTM A524	Grades I & II					
	ASTM A573	Grade 65					
	ASTM A709	Grade 36	SMAW with other	Over 3/4 thru 1-1/2	Over 20 thru 38	150	65
	ASTM A1008 SS	Grade 30					

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AWS D1.1: 2015 Structural Welding Code – Steel

	ASTM A808						
	~~ASTM A913[b]~~	Grade 50					
	ASTM A992						
	ASTM A1008 HSLAS	Grade 45 Class 1					
		Grade 45 Class 2					
		Grade 50 Class 1					
		Grade 50 Class 2		1/8 to 3/4 incl.	3 to 20 incl.	32[a]	0[a]
		Grade 55 Class 1					
		Grade 55 Class 2					
	ASTM A1008 HSLAS-F	Grade 50	SMAW with low-hydrogen electrodes, SAW, GMAW, FCAW	Over 3/4 thru 1-1/2 incl.	Over 20 thru 38 incl.	50	10
B (Cont'd)	ASTM A1011 HSLAS	Grade 45 Class 1					
		Grade 45 Class 2					
		Grade 50 Class 1					
		Grade 50 Class 2					
		Grade 55 Class 1		Over 1-1/2 thru 2-1/2 incl.	Over 38 thru 65 incl.	150	65
		Grade 55 Class 2					
	ASTM A1011 HSLAS-F	Grade 50					
	ASTM A1018 HSLAS	Grade 45 Class 1					
		Grade 45 Class 2					
		Grade 50 Class 1		Over 2-1/2	Over 65	225	110
		Grade 50 Class 2					
		Grade 55 Class 1					
		Grade 55 Class 2					

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AWS D1.1: 2015 Structural Welding Code – Steel

Annex H

Guideline on Alternative Methods for Determining Preheat

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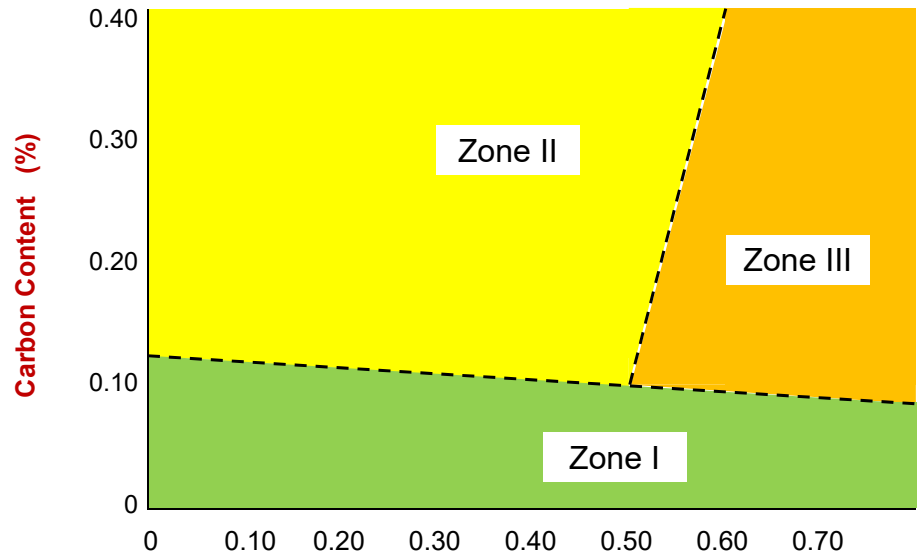

$$CE = C + \frac{(Mn + Si)}{6} + \frac{(Cr + Mo + V)}{5} + \frac{(Ni + Cu)}{15}$$

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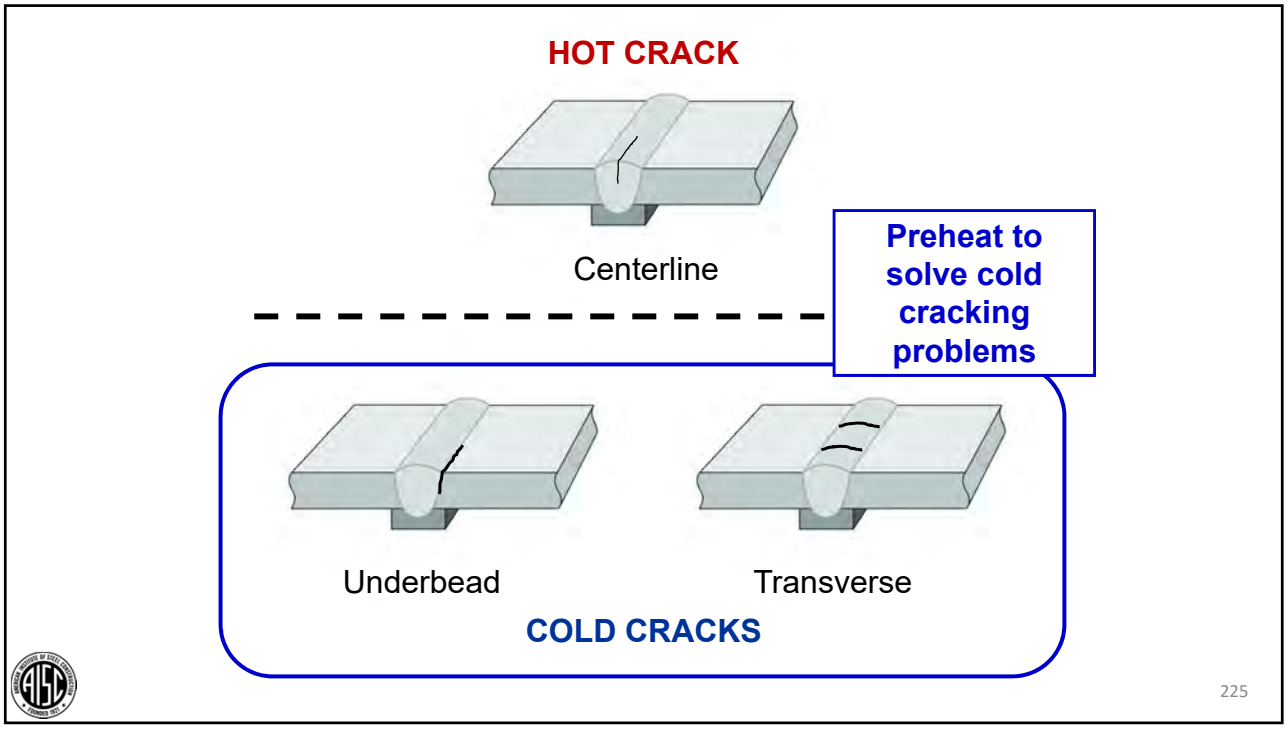

POSTHEAT

Postheat:

- Heating weldments to 400-450°F immediately after welding
- Holding at elevated temperatures for an hour per inch of thickness of weld deposit
- Significantly reduces diffusible hydrogen levels
- Effective for “cold cracking” problems

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POSTHEAT

Apply post heat before cold cracking can occur
(i.e., before the steel cools to below 400°F).

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POSTHEAT

Wrapping weldments in insulating blankets—essentially the same concept as post heat

- Caveat 1: Wrapping slows cooling rate, but weldment cools from interpass temperature which is often less than 400 °F at time weldment is wrapped.
- Caveat 2: wrapping works best when the whole weldment is at elevated temperatures

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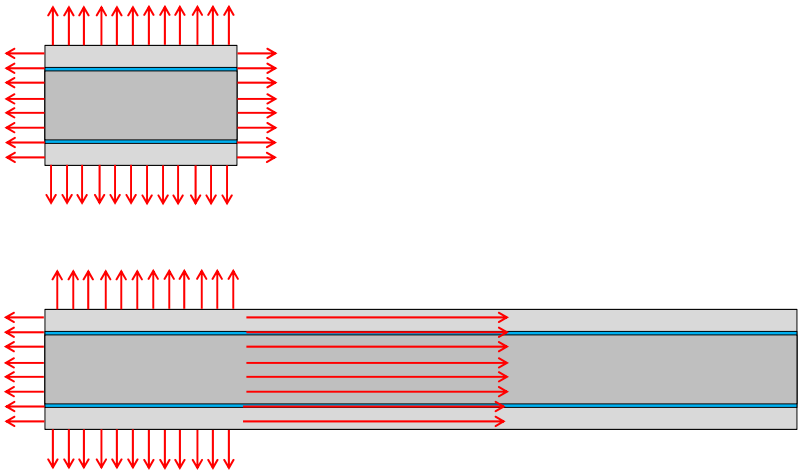
WRAPPING



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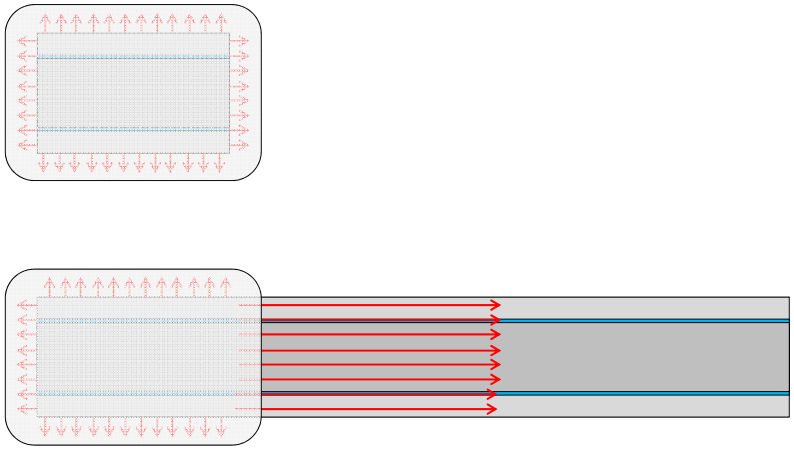
WRAPPING



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AASHTO/AWS D1.5: 2015 Bridge Welding Code

12.15.1.1 Minimum Temperature Prior to Hydrogen Diffusion Postheat.

When hydrogen diffusion postheat is required, the weld shall not be allowed to cool below the minimum preheat and interpass temperate before being raised to the postheat temperature.

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AASHTO/AWS D1.5: 2015 Bridge Welding Code

12.15.1.2 Hydrogen Diffusion Postheat Temperature Limitations.

When hydrogen diffusion postheat is required, welds and adjacent base metal shall be heated to a temperature of 230°C [450°F] minimum to 315°C [600°F] maximum for not less than one hour for each 25 mm [1 in.] of weld thickness, or two hours, whichever is less. The minimum heating time for repair welds shall be one hour for each 25 mm [1 in.] of repair weld depth from the surface, but not less than one hour. Longer heating periods maybe used.

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METALLURGY AND CRACKING

Outline

- Welding and Metallurgy
- Steel Categories
- Cracking
- Special Steels

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5.4 WELDING REQUIREMENTS FOR SPECIFIC STEELS

5.4.1 Weathering Steels
5.4.2 Quenched and Tempered Steels
5.4.3 Quenched and Self-Tempered Steels
5.4.4 Multigrade Steels
5.4.5 Historical (Obsolete) Steels
5.4.6 Cast Iron
5.4.7 Wrought Iron
5.4.8 Steel Castings
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5.4.10 Stainless Steels
5.4.11 Bolts
5.4.12 Nuts
5.4.13 Washers
5.4.14 Anchor Rods

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5.4 WELDING REQUIREMENTS FOR SPECIFIC STEELS

Weathering Steels

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5.4 WELDING REQUIREMENTS FOR SPECIFIC STEELS

Weathering Steels

A588 (A709 Grade 50W)

HPS 50W, HPS 70W, and HPS 100W

A606 (sheet steel)

A847 (cold-formed tubing)

A514

A852

A242

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5.4 WELDING REQUIREMENTS FOR SPECIFIC STEELS

Weathering Steels

- Unique welding concern: similar atmospheric corrosion resistance
- "Color match"
- If painted, no unusual welding concerns

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5.4 WELDING REQUIREMENTS FOR SPECIFIC STEELS

Weathering Steels

Three approaches:

- Use alloy filler metal
- Rely on admixture
- "Cap" the final surface with alloy filler metal

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AWS D1.1: 2015 Structural Welding Code – Steel

3.7.3 Weathering Steel Requirements. For exposed, bare, unpainted applications of weathering steel requiring weld metal with atmospheric corrosion resistance and coloring characteristics similar to that of the base metal, the electrode or electrode-flux combination shall conform to Table 3.4. The exceptions to this requirement are as follows:

3.7.3.1 Single-Pass Groove Welds. Groove welds made with a single pass or a single pass each side may be made using any of the filler metals for Group II base metals in Table 3.2.

3.7.3.2 Single-Pass Fillet Welds. Single-pass fillet welds up to the following sizes may be made using any of the filler metals for Group II base metals listed in Table 3.2:

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AWS D1.1: 2015 Structural Welding Code – Steel

Table 3.4 (see 3.7.3)
Filler Metal Requirements for Exposed Bare Applications of Weathering Steels

Process	AWS Filler Metal Specification	Approved Electrodes[a]
SMAW	A5.5	All electrodes that deposit weld metal meeting a B2L, C1, C1L, C2, C2L, C3, or WX analysis per A5.5.
SAW	A5.23	All electrode-flux combinations that deposit weld metal with a Ni1, Ni2, Ni3, Ni4, or WX analysis per A5.23.
FCAW	A5.29 and A5.36	All electrodes that deposit weld metal with a B2L, K2, Ni1, Ni2, Ni3, Ni4, or WX analysis per A5.29 or A5.36.
GMAW	A5.28 and A5.36	All electrodes that meet filler metal composition requirements of B2L, G[a], Ni1, Ni2, Ni3, analysis per A5.28 or A5.36.

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AWS D1.1: 2015 Structural Welding Code – Steel

Table 3.4 (see 3.7.3)
Filler Metal Requirements for Exposed Bare Applications of Weathering Steels

Process	AWS Filler Metal Specification	Approved Electrodes[a]
SMAW	A5.5	All electrodes that deposit weld metal meeting a B2L, C1, C1L, C2, C2L, C3, or WX analysis per A5.5.
SAW	A5.23	All electrode-flux combinations that deposit weld metal with a Ni1, Ni2, Ni3, Ni4, or WX analysis per A5.23.

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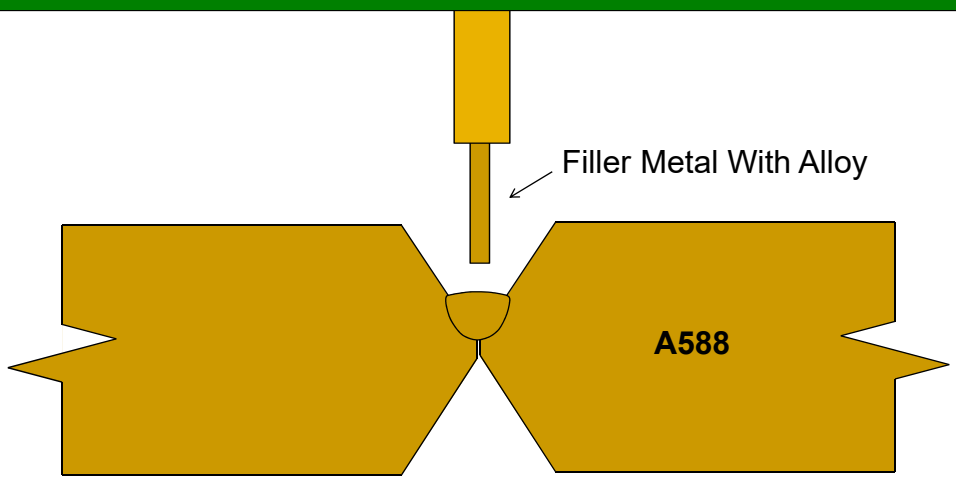
5.4 WELDING REQUIREMENTS FOR SPECIFIC STEELS



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AWS D1.1: 2015 Structural Welding Code – Steel

3.7.3 Weathering Steel Requirements (cont'd)**…..**The exceptions to this requirement are as follows:

3.7.3.1 Single-Pass Groove Welds. Groove welds made with a single pass or a single pass each side may be made using any of the filler metals for Group II base metals in Table 3.2.

3.7.3.2 Single-Pass Fillet Welds. Single-pass fillet welds up to the following sizes may be made using any of the filler metals for Group II base metals listed in Table 3.2:

SMAW	1/4 in [6 mm]
SAW	5/16 in [8 mm]
GMAW/FCAW	5/16 in [8 mm]

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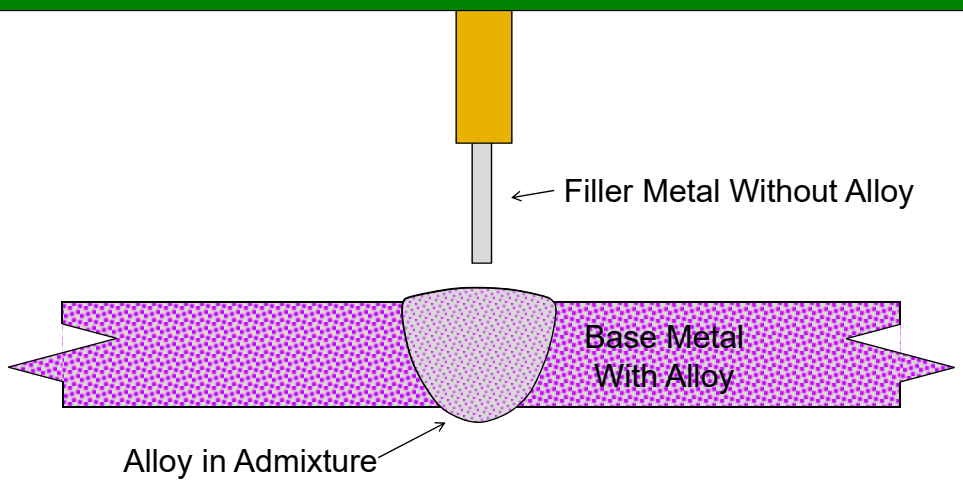
PICKUP



Alloy in Filler Metal < Alloy in Base Metal → Pickup

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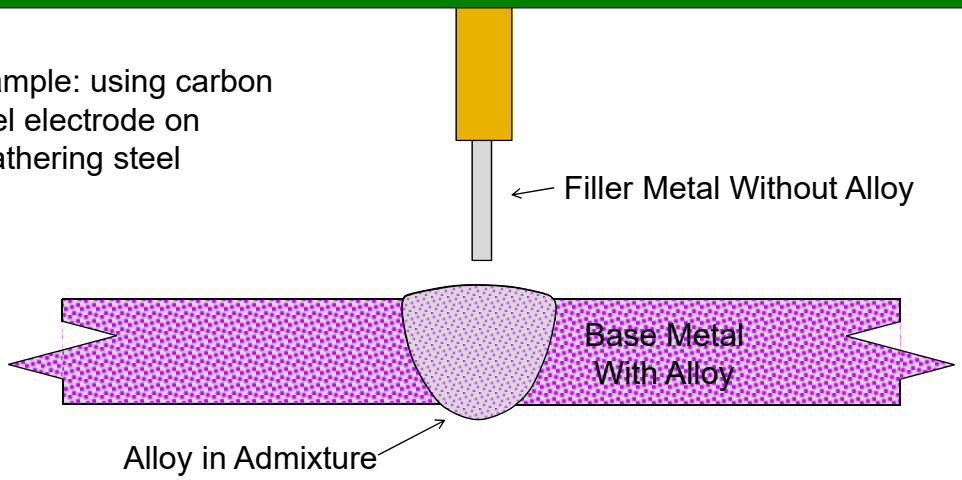
PICKUP

Example: using carbon steel electrode on weathering steel



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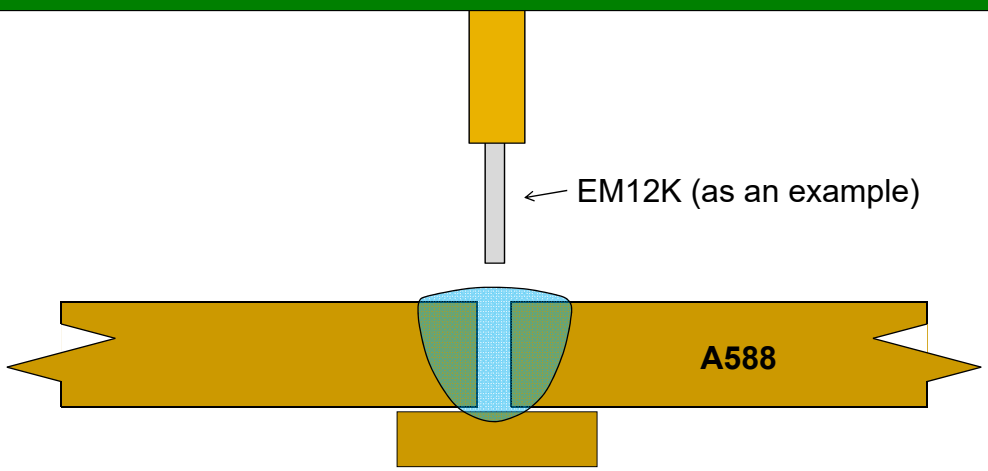
PICKUP



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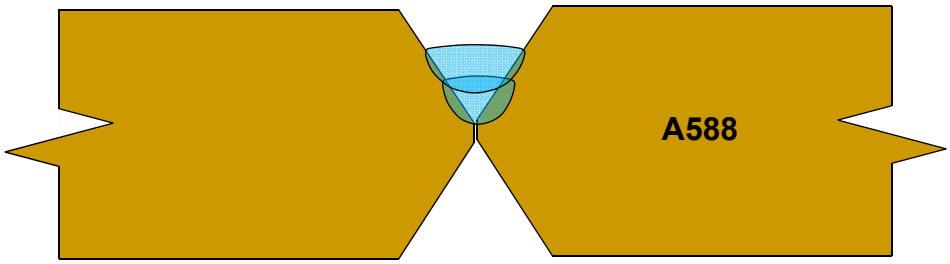
5.4 WELDING REQUIREMENTS FOR SPECIFIC STEELS

Weathering Steels



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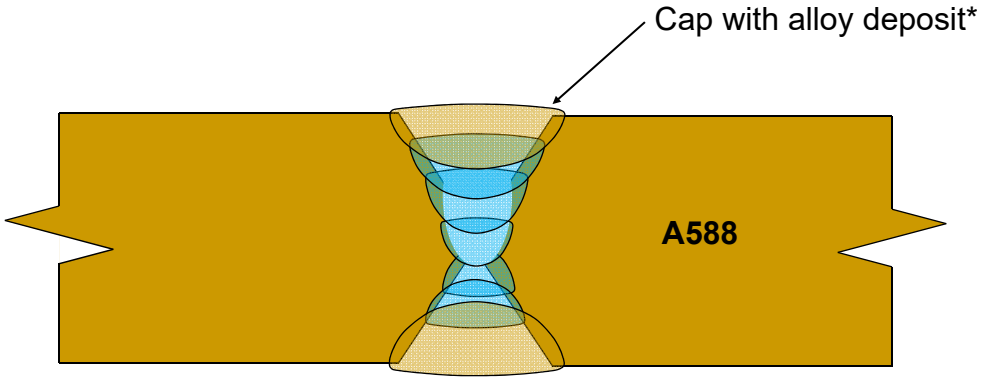
5.4 WELDING REQUIREMENTS FOR SPECIFIC STEELS

Weathering Steels



*Faces, ends of weld

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5.4 WELDING REQUIREMENTS FOR SPECIFIC STEELS

Quenched and Steels (Q&T)

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5.4 WELDING REQUIREMENTS FOR SPECIFIC STEELS

Quenched and Steels (Q&T)

Table 5-1. Quenched and Tempered Steels

Steel Specification		Specified Minimum Yield Strength, ksi (MPa)	Specified Minimum Tensile Strength, ksi (MPa)	Processing Method	D1.1 Coverage
API 2Y	Gr. 42	42–67 (290–462)	62 (427)	Q&T	Prequalified (AWS Table 3.1)
	Gr. 50	50–75 (345–517)	65 (448)		
	Gr. 60	60–90 (414–621)	75 (517)		
ASTM A709	HPS 70W	70 (485) min.	85–110 (585–760)	Q&T	
ASTM A514	> 2½ in. (65 mm)	90 (620) min.	100–130 (690–895)	Q&T	Code approved (AWS Table 4.9)
	≤ 2½ in. (65 mm)	100 (690) min.	110–130 (760–895)		

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AWS D1.1: 2015 Structural Welding Code – Steel

5.7 Heat Input Control for Quenched and Tempered Steels

When quenched and tempered steels are welded, the heat input shall be restricted in conjunction with the maximum preheat and interpass temperatures required. Such considerations shall include the additional heat input produced in simultaneous welding on the two sides of a common member. The preceding limitations shall be in conformance with the producer's recommendations.

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AASHTO/AWS D1.5: 2015 Bridge Welding Code

Table 12.5
M 270M/M 270 (A709/A709M) Grade HPS 690W [HPS 100W]
Minimum and Maximum Preheat/Interpass Temperature, °C [°F] (see 12.14)

	Heat Input (as calculated by 5.12) kJ/mm [kJ/in]				
Thickness t, mm [in]	1.2 [30] ≤ HI < 1.6 [40]	1.6 [40] ≤ HI < 2.0 [50]	2.0 [50] ≤ HI < 2.8 [70]	2.8 [70] ≤ HI < 3.6 [90]	3.6 [90] ≤ HI
6 [1/4] ≤ t ≤ 10 [3/8]	40–60 [100–150]	—	—	—	—
10 [3/8] < t ≤ 13 [1/2]	60–160 [150–300]	40–100 [100–200]	—	—	—
13 [1/2] < t ≤ 20 [3/4]	120–200 [250–400]	100–180 [200–350]	40–120 [100–250]	—	—
20 [3/4] < t ≤ 25 [1]	—	120–200 [250–400]	120–200 [250–400]	60–160 [150–300]	—
25 [1] < t ≤ 50 [2]	—	—	120–200 [250–400]	120–200 [250–400]	100–180 [200–350]
t > 50 [2]	—	—	150–240 [300–450]	140–240 [300–450]	140–240 [300–450]

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AASHTO/AWS D1.5: 2015 Bridge Welding Code

Thickness t, mm [in]	1.2 [30] ≤ HI < 1.6 [40]	1.6 [40] ≤ HI < 2.0 [50]
6 [1/4] ≤ t ≤ 10 [3/8]	40–60 [100–150]	—
10 [3/8] < t ≤ 13 [1/2]	60–160 [150–300]	40–100 [100–200]
13 [1/2] < t ≤ 20 [3/4]	120–200 [250–400]	100–180 [200–350]
20 [3/4] < t ≤ 25 [1]	—	120–200 [250–400]
25 [1] < t ≤ 50 [2]	—	—
t > 50 [2]	—	—

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5.4 WELDING REQUIREMENTS FOR SPECIFIC STEELS

Quenched and Steels (Q&T)

- Heat input limits, preheat and maximum interpass temperature limits
- Heat shrinking temperature limits
- Welding process limits (ESW, EGW)
- Plug and slot weld prohibitions
- Tack weld restrictions
- Special welder qualification requirements

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5.4 WELDING REQUIREMENTS FOR SPECIFIC STEELS

Historical (Obsolete) Steels

- ASTM A7
- ASTM A9
- ASTM A373
- ASTM A242

Discussed in terms of weldability

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5.4 WELDING REQUIREMENTS FOR SPECIFIC STEELS

Historical (Obsolete) Steels

The weldability of A7 must be evaluated on a case-by-case basis. The ASTM A7 specification was in effect for 67 years and mill practices varied over the years. However, in 1957, the 11th edition of *The Procedure Handbook of Arc Welding* (Lincoln Foundation, 1957) stated “Although specifications are not intended to control carbon content, experiences with the material, as it has been delivered, indicate that the carbon content is within the readily weldable range.” Thus, by the late 1950s the general experience with the material being delivered was that the weldability was good.

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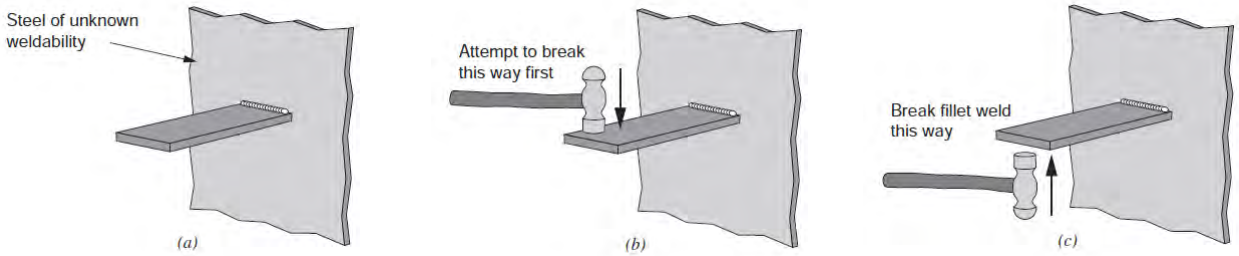
5.4 WELDING REQUIREMENTS FOR SPECIFIC STEELS

Historical (Obsolete) Steels



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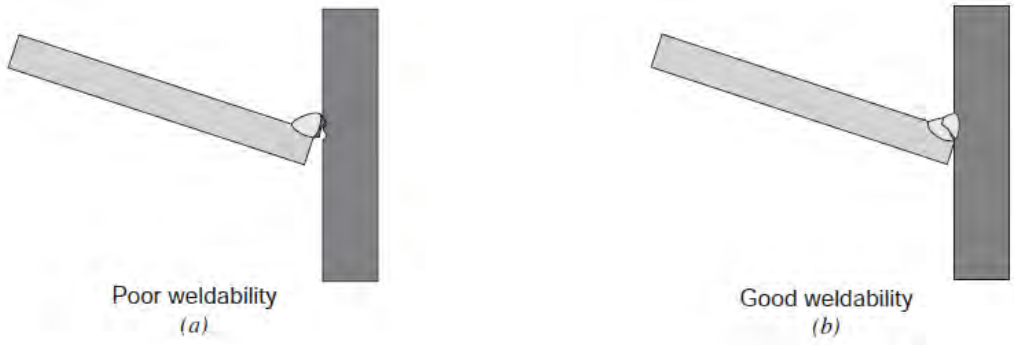
5.4 WELDING REQUIREMENTS FOR SPECIFIC STEELS

Historical (Obsolete) Steels



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METALLURGY AND CRACKING

Outline

- Welding and Metallurgy
- Steel Categories
- Cracking
- Special Steels

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Thank you!

AISC | Questions?

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- EEU – You must take all quizzes and the final exam to receive EEU.
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- REINFORCEMENT – Reinforce what you learn tonight. Get more out of the course.

Note: If you attend the live presentation, you do not have to take the quizzes to receive PDHs

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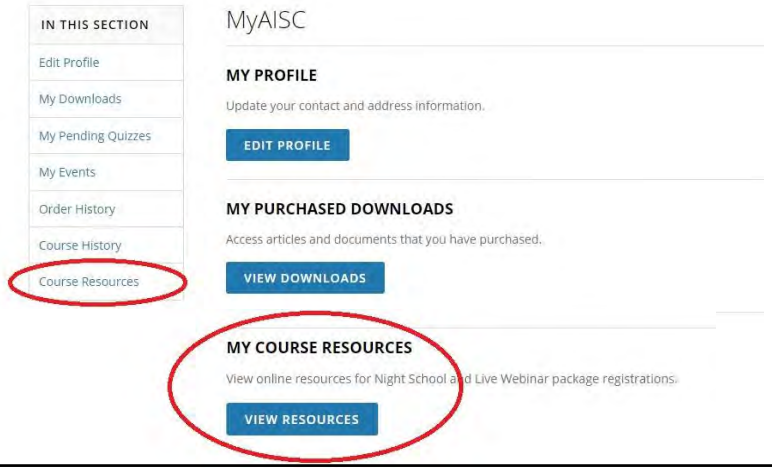

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Night School Resources

Course Resources

Event	Start Date
NS 13 8-Session Package-Night School 13 - Design of Industrial Buildings	1/30/2017 7:00:00 PM
NS 14 8-Session Package-Night School 14 - Fundamentals of Stability	6/5/2017 7:00:00 PM

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Night School Resources

Night School 13: Design of Industrial Buildings

8-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Video	Quiz	Attendance
NS13 - Design Criteria	1/30/2017 7:00:00 PM	Handouts	View Passcode: NS13DSN	Pass Score: 80	Pending
NS13 - Economic Considerations	2/6/2017 7:00:00 PM	Handouts	Available 02/08/2017 5pm EST	Available 02/08/2017 5pm EST	Pending
NS13 - Lateral Load Systems and Details	2/13/2017 7:00:00 PM	Handouts	Available 02/15/2017 5pm EST	Available 02/15/2017 5pm EST	Pending
NS13 - Preliminary Design Procedures	2/27/2017 7:00:00 PM	Handouts	Available 03/01/2017 5pm EST	Available 03/01/2017 5pm EST	Pending
NS13 - Crane Girder Design and Frame Analysis	3/6/2017 7:00:00 PM	Handouts	Available 03/08/2017 5pm EST	Available 03/08/2017 5pm EST	Pending
NS13 - Frame Member and Connection Design	3/13/2017 7:00:00 PM	Handouts	Available 03/15/2017 5pm EST	Available 03/15/2017 5pm EST	Pending
NS13 - Transfer Crane Girder & Longitudinal Bldg Bracing Dsn	3/27/2017 7:00:00 PM	Handouts	Available 03/29/2017 5pm EST	Available 03/29/2017 5pm EST	Pending

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Night School Resources

- Weekly "quiz and recording" email.
- Weekly updates of the master quiz and attendance record, found at www.aisc.org/nightschool21. Scroll down to Quiz and Attendance records.
    - Updated on Thursday mornings.

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Night School Resources

- Webinar connection information
    - Reminder email sent out Tuesday mornings
- Links to handouts also found here

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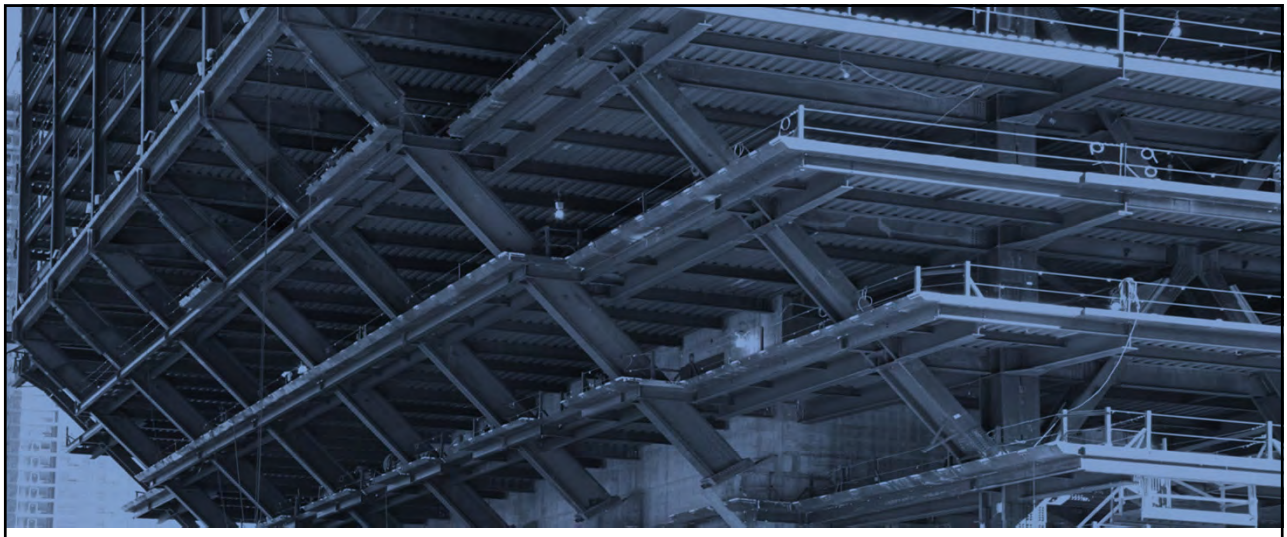

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