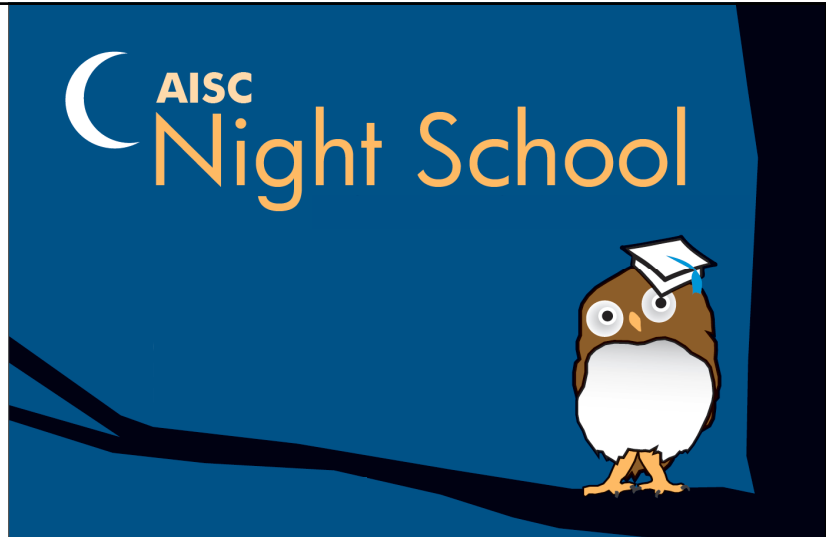


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## Welded Connections

A Primer for Engineers



Smarter.  
Stronger.  
Steel.



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## Course Description

### 21.1 Introduction and Welding Processes October 8, 2019

This session will consist of a review of applicable welding codes, the basics of welded joints and weld types, and required weld metal strength levels. Details for welded connection details will be discussed, including the basic criteria to be used to determine weld throat dimensions.



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## Learning Objectives

- Identify standards related to welding.
- Compare and contrast various arc welding processes.
- Define various welding and thermal cutting processes.
- Compare and contrast various joints and weld types.



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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 1: Introduction and Welding Processes  
October 8, 2019



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



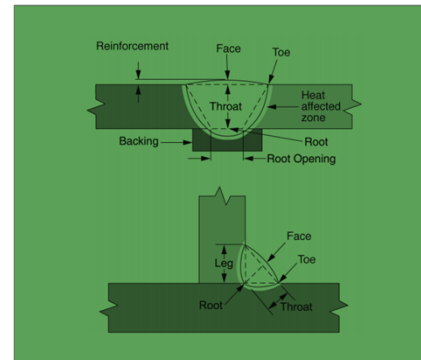
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AISC Design Guide 21, 2<sup>nd</sup> Edition

## Welded Connections— A Primer for Engineers



Design Guide 21  
Welded Connections—  
A Primer for  
Engineers

Second Edition



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## WELDED CONNECTIONS—A PRIMER FOR ENGINEERS



### Chapter 1: Introduction

- 1.1 Importance of Welding
- 1.2 Scope of Welding
- 1.3 Welding-Related Codes and Specifications



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## WELDED CONNECTIONS—A PRIMER FOR ENGINEERS



### Chapter 2: Welding and Thermal Cutting Processes

- 2.1 Introduction
- 2.2 SMAW
- 2.3 FCAW
- 2.4 SAW
- 2.5 GMAW
- 2.6 ESW/EGW
- 2.7 GTAW



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## WELDED CONNECTIONS—A PRIMER FOR ENGINEERS



### Chapter 2: Welding and Thermal Cutting Processes

- 2.8 Arc Stud Welding
- 2.9 Thermal Cutting Processes
- 2.10 Water Jet Cutting



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## WELDED CONNECTIONS—A PRIMER FOR ENGINEERS



### Chapter 3: Welded Connection Basics

- 3.1 Joints
- 3.2 Weld Types—General
- 3.3 Complete-Joint-Penetration Groove Welds
- 3.4 Partial-Joint-Penetration Groove Welds
- 3.5 Fillet Welds
- 3.6 Plug/Slot Welds
- 3.7 Puddle Welds



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## WELDED CONNECTIONS—A PRIMER FOR ENGINEERS



### Chapter 3: Welded Connection Basics

- 3.8 Interaction of Joint Types and Weld Types
- 3.9 Selection of Weld Types
- 3.10 Required Filler Metal Strength
- 3.11 Determining Weld Strength
- 3.12 Specific Requirements for Various Joints
- 3.13 Weld Symbols



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## WELDED CONNECTION BASICS

### Outline

- Applicable Codes
- Arc Welding Processes – Overview
- Welding and Thermal Cutting Processes
- Joints and Weld Types



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## WELDED CONNECTION BASICS

### Outline

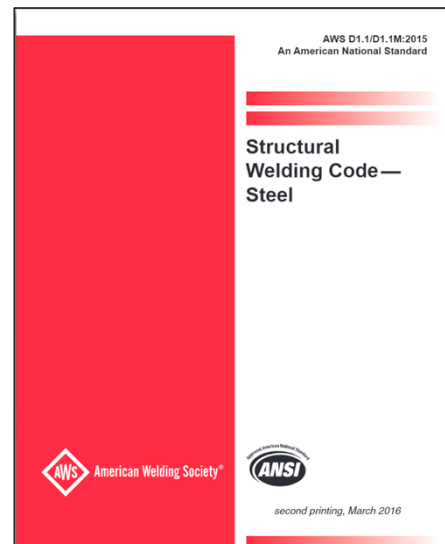
- ➔ • Applicable Codes
  - Arc Welding Processes – Overview
  - Welding and Thermal Cutting Processes
  - Joints and Weld Types



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### AWS D1.1

Structural Welding Code –  
Steel



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## AWS D1.1: 2015 Structural Welding Code – Steel



### Major sections of AWS D1.1 include the following:

- Clause 1 – General Requirements
- Clause 2 – Design of Welded Connections
- Clause 3 – Prequalification of welding procedure specifications (WPS)
- Clause 4 – Qualification
- Clause 5 – Fabrication
- Clause 6 – Inspection



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## AWS D1.1: 2015 Structural Welding Code – Steel



### Major sections of AWS D1.1 include the following:

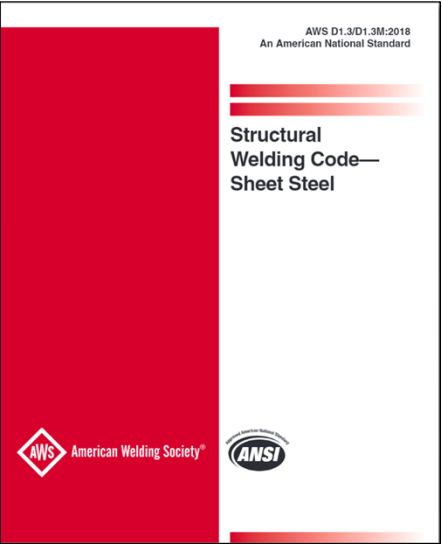
- Clause 7 – Stud Welding
- Clause 8 – Strengthening and Repair of Existing Structures
- Clause 9 – Tubular Structures
- AWS D1.1 also contains a series of Annexes and a helpful commentary that assists the user in correctly applying the code.



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**AWS D1.3**


Structural Welding Code –  
Sheet Steel



AWS D1.3/D1.3M:2018  
An American National Standard


Structural  
Welding Code—  
Sheet Steel

American Welding Society®  
ANSI




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**AWS D1.3: 2018 Structural Welding Code – Sheet Steel**



**AWS D1.3 covers:**

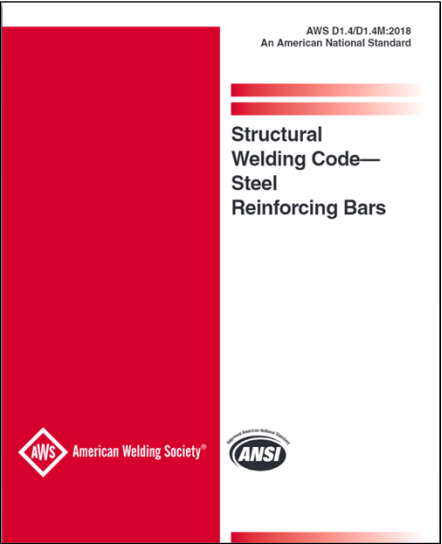
- Welding of structural sheet and strip steels, including cold-formed members equal to or less than 3/16 in. [5mm] thick.
- The primary purpose for structural steel applications: welding sheet steel decking to supporting members with puddle welds.



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**AWS D1.4**

Structural Welding Code –  
Steel Reinforcing Bars



AWS D1.4D1.4M:2018  
An American National Standard

**Structural  
Welding Code—  
Steel  
Reinforcing Bars**





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**AWS D1.4: 2018 Structural Welding Code – Steel Reinforcing Bars**

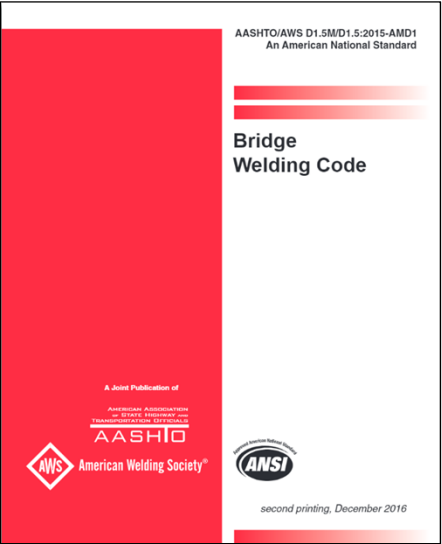
**AWS D1.4 covers:**


- Welding of reinforcing steel (rebar) to itself
- Welding of rebar to plate or shapes, including embed plates and steel used in composite construction




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**AASHTO/AWS D1.5**  
Bridge Welding Code




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**AASHTO/AWS D1.5: 2015 Bridge Welding Code**



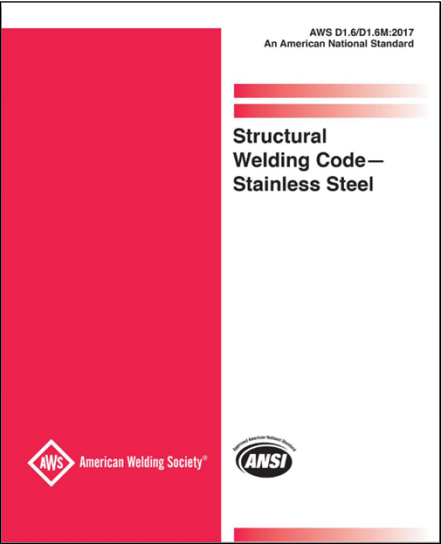
**AASHTO/AWS D1.5:**

- Joint standard of the AWS and the American Association of State Highway Transportation Officials (AASHTO)
- Generally requires that WPS be qualified by test, with a few exceptions
- Qualification testing involves Charpy V-notch (CVN) specimens and all weld metal tensile specimens
- Nondestructive testing (NDT) requirements


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**AWS D1.6**

Structural Welding Code –  
Stainless Steel




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**AWS D1.6: 2017 Structural Welding Code – Stainless Steel**

**AWS D1.6 covers:**

- Requirements for welding various grades of stainless to stainless, as well as stainless to carbon steel




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**AWS D1.7**


Guide for Strengthening and Repairing  
Existing Structures



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**AWS D1.7: 2010 Guide for Strengthening and  
Repairing Existing Structures**



**AWS D1.7:**

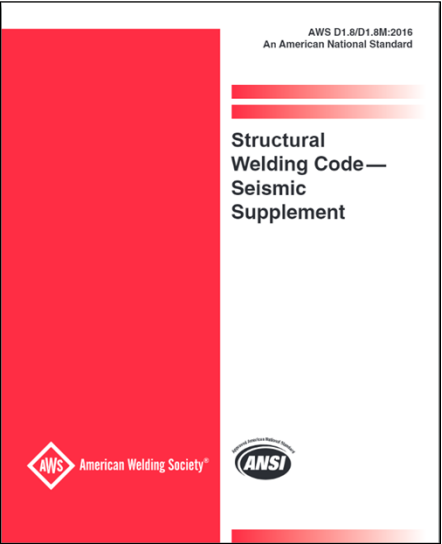
- D1.1 requires the Engineer to “establish a comprehensive plan for the work”: D1.7 can provide guidance
- Not a code, but a guide
- Provides guidance on: weldability, evaluation of existing welds, testing and sampling, heat strengthening, strengthening and damage repair

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**AWS D1.8**

Structural Welding Code –  
Seismic Supplement




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**AWS D1.8: 2016 Structural Welding Code – Seismic Supplement**

**AWS D1.8:**

- Supplements AWS D1.1
- When AWS D1.8 is specified, all the provisions of AWS D1.1 still apply, unless modified or superseded by AWS D1.8
- Assumes that the structure is designed with AISC *Seismic Provisions*

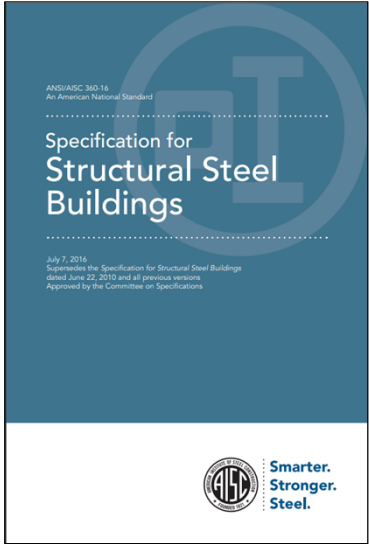


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**AISC 360-16**

Specification for Structural Steel  
Buildings




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**AISC 360-16 Specification for Structural Steel Buildings**

**AISC 360 addresses the following major welding-related items:**

- Acceptable steel designations (Section A3.1)
- Acceptable filler metals (Section A3.5)
- Requirements for splices in heavy sections (Section J1.5)
- Beam copes and weld access holes (Section J1.6)
- Welds in combination with bolts (Section J1.8)
- Details of groove welds (Section J2.2)
- Details of fillet welds (Section J2.2)



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## AISC 360-16 Specification for Structural Steel Buildings



### AISC 360 addresses the following major welding-related items:

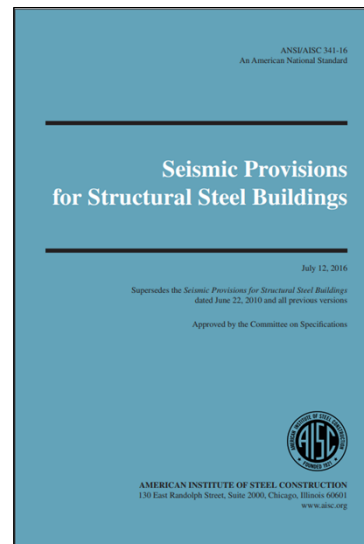
- Available strength of welded joints (Table J2.5)
- Shop fabrication/welding issues (Section M2)
- Field erection/welding issues (Section M4)
- Weld quality control and quality assurance issues (Chapter N)
- Weld details for fatigue (Appendix 3)
- Welding issues associated with existing structures (Appendix 5)



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## AISC 341-16

### Seismic Provisions for Structural Steel Buildings



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## AISC 341-16 Seismic Provisions for Structural Steel Buildings



### AISC 341:

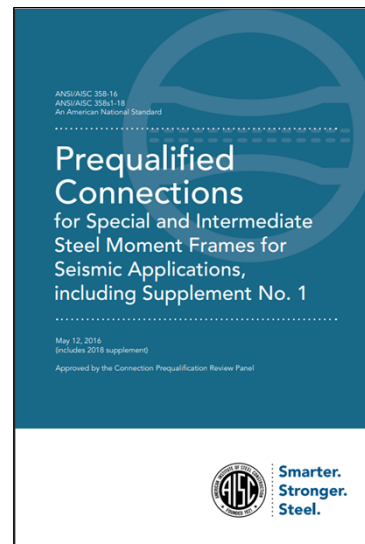
- Developed to augment the AISC *Specification*
- Adds provisions deemed necessary for high-seismic applications, where steel members are required to dissipate energy through controlled inelastic deformations in major seismic events
- For welding-related issues, primarily refers to D1.8
- Contains “grocery list” of items to be specified in contract documents, including many welding-related issues



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## AISC 358-16

Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications



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## AISC 358-16 Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications



### AISC 358:

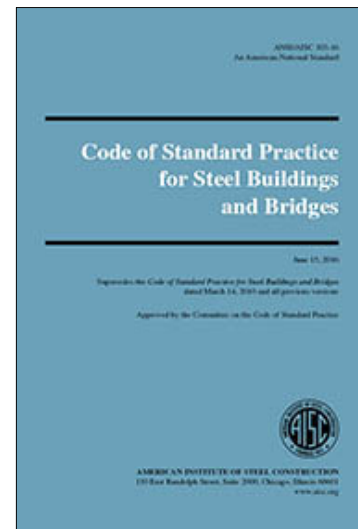
- Specifies design, detailing, fabrication, and quality criteria for connections that are prequalified in accordance with AISC *Seismic Provisions*
- For use with special moment frames (SMF) and intermediate moment frames (IMF)
- For welding-related issues, primarily refers to AISC 341
- Some prequalified connections have unique welded detail requirements (WUF-W, Endplate)



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## AISC 303-16

### Code of Standard Practice for Steel Buildings and Bridges



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## AISC 341-16 Seismic Provisions for Structural Steel Buildings



### AISC 303 addresses these major welding-related issues:

- Overall tolerances of fabricated members and erected assemblies
- Basic tolerances for architecturally exposed structural steel (AESS)



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## Welding-Related Codes and Specifications



### Other AWS D1 Codes:

- AWS D1.2/D1.2M *Structural Welding Code — Aluminum*
- AWS D1.9/D1.9M *Structural Welding Code — Titanium*



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## Welding-Related Codes and Specifications



### Other AWS Standards:

- AWS A5 *Filler Metal Specifications*
- AWS A2.4 *Standard Symbols for Welding, Bracing, and Nondestructive Examination*
- AWS A3.0/A3.0M *Standard Welding Terms and Definitions*



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## WELDED CONNECTION BASICS


### Outline

- Applicable Codes
- ➔ • Arc Welding Processes – Overview
- Welding and Thermal Cutting Processes
- Joints and Weld Types




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




**weld.**

A localized coalescence of metals or nonmetals produced by heating the materials to the welding temperature, with or without the application of pressure, or by the application of pressure alone and with or without the use of filler metal.




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### Arc Welding Processes

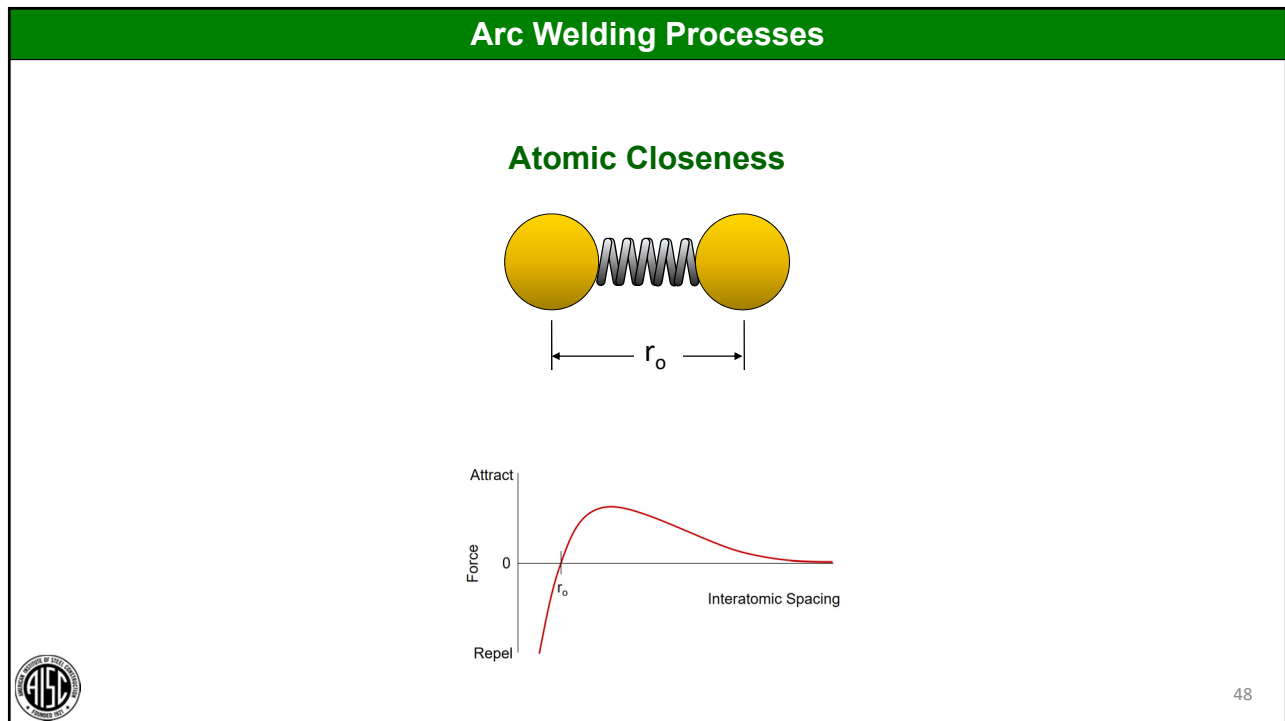
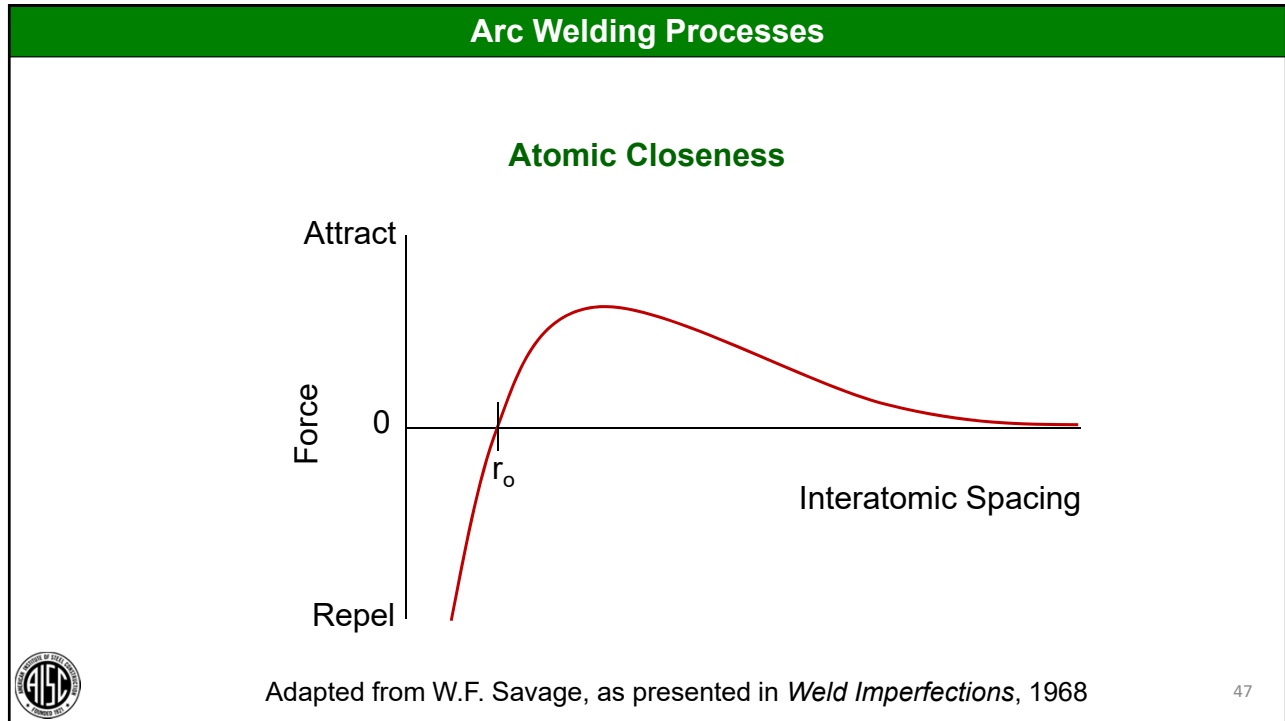


**Requirements for fusion:**

- Atomic closeness
- Atomic cleanliness



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### Arc Welding Processes

#### Atomic Closeness

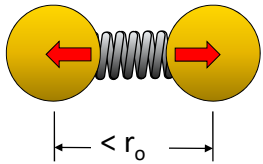
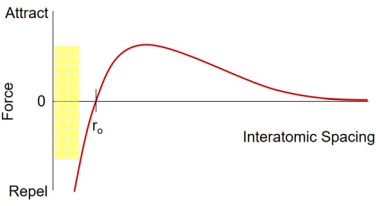



Diagram showing two yellow spheres representing atoms connected by a compressed spring. Red arrows point inward from each sphere towards the spring. Below the spheres, a horizontal line with arrows at both ends is labeled  $< r_o$ , indicating the interatomic spacing is less than the equilibrium distance.



Graph showing Force versus Interatomic Spacing. The vertical axis is labeled 'Force' with 'Attract' at the top, '0' in the middle, and 'Repel' at the bottom. The horizontal axis is labeled 'Interatomic Spacing'. A red curve starts in the 'Repel' region, crosses the zero line at a point marked  $r_o$ , reaches a peak in the 'Attract' region, and then gradually approaches zero. A yellow shaded vertical bar is positioned to the left of the  $r_o$  mark, corresponding to the compressed state shown in the diagram above.

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### Arc Welding Processes

#### Atomic Closeness

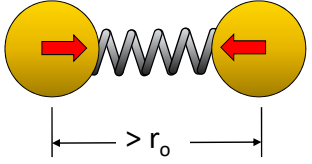
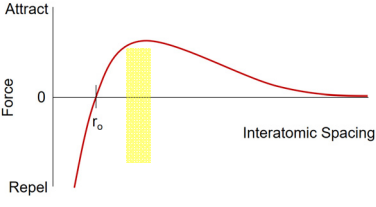



Diagram showing two yellow spheres representing atoms connected by an extended spring. Red arrows point outward from each sphere away from the spring. Below the spheres, a horizontal line with arrows at both ends is labeled  $> r_o$ , indicating the interatomic spacing is greater than the equilibrium distance.

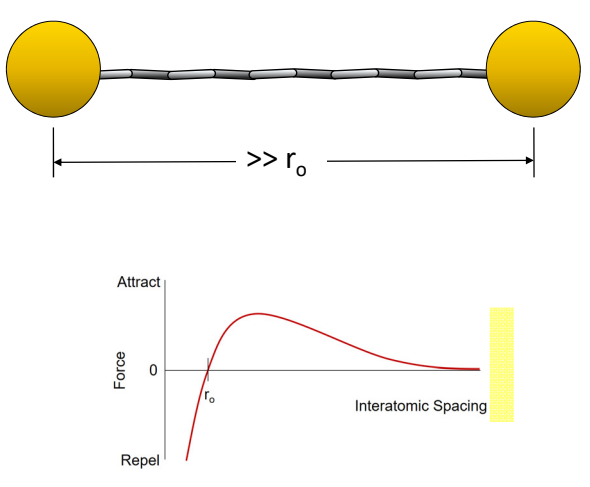


Graph showing Force versus Interatomic Spacing. The vertical axis is labeled 'Force' with 'Attract' at the top, '0' in the middle, and 'Repel' at the bottom. The horizontal axis is labeled 'Interatomic Spacing'. A red curve starts in the 'Repel' region, crosses the zero line at a point marked  $r_o$ , reaches a peak in the 'Attract' region, and then gradually approaches zero. A yellow shaded vertical bar is positioned to the right of the  $r_o$  mark, corresponding to the extended state shown in the diagram above.


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### Arc Welding Processes

### Atomic Closeness




The diagram illustrates atomic closeness. At the top, two yellow spheres represent atoms, connected by a chain of smaller spheres representing the atomic structure. A horizontal double-headed arrow below the spheres is labeled  $\gg r_o$ , indicating that the distance between the atoms is much greater than the atomic radius  $r_o$ . Below this, a graph plots Force versus Interatomic Spacing. The vertical axis is labeled 'Force' with 'Attract' at the top, '0' in the middle, and 'Repel' at the bottom. The horizontal axis is labeled 'Interatomic Spacing'. A red curve starts in the 'Repel' region, crosses the zero line at a point labeled  $r_o$ , reaches a peak in the 'Attract' region, and then gradually approaches the zero line from above. A yellow vertical bar is shown on the right side of the graph, representing a range of interatomic spacing.



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### Arc Welding Processes



Welded Connections—  
A Primer for  
Engineers

#### Atomic Closeness:

- Very, very close
- Gaps exist between materials, even carefully machined parts (typically 100-1000 atom diameters from peak to valley of carefully machined parts)



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## Arc Welding Processes



### How to Achieve Atomic Closeness:

- Melt one material (brazing, soldering)
- Melt two or more materials (arc welding, resistance welding)
- Use pressure (with or without heat) to force closeness (forge welding, friction stir welding)



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## Arc Welding Processes



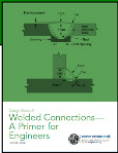
### Atomic Cleanliness:

- Oxides form very rapidly
- Oxides neutralize the attractive forces
- Other contaminants: water, oil, gasses



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## Arc Welding Processes




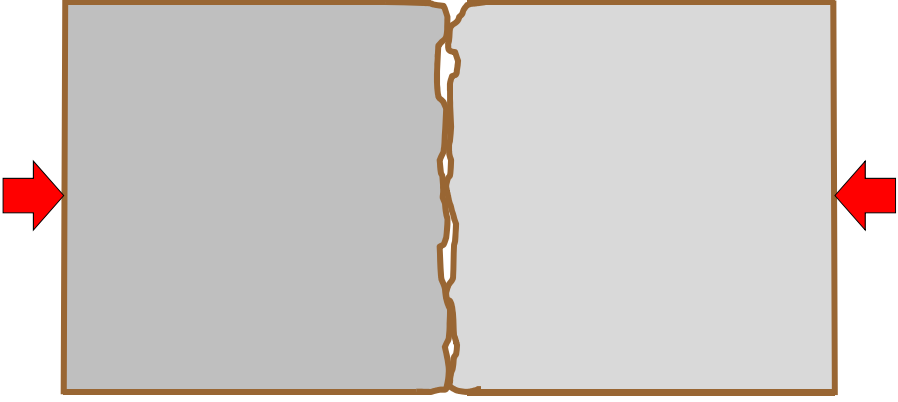
Welded Connections—  
A Primer for  
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**How to Achieve Atomic Cleanliness:**

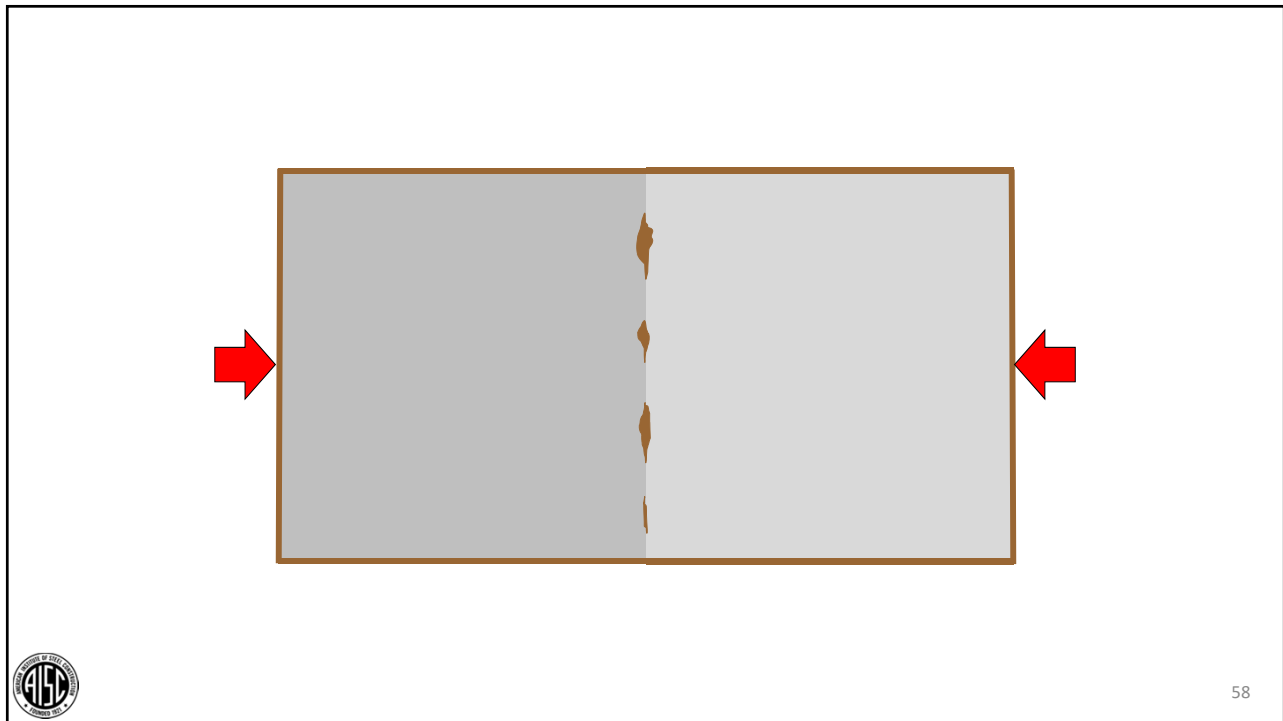
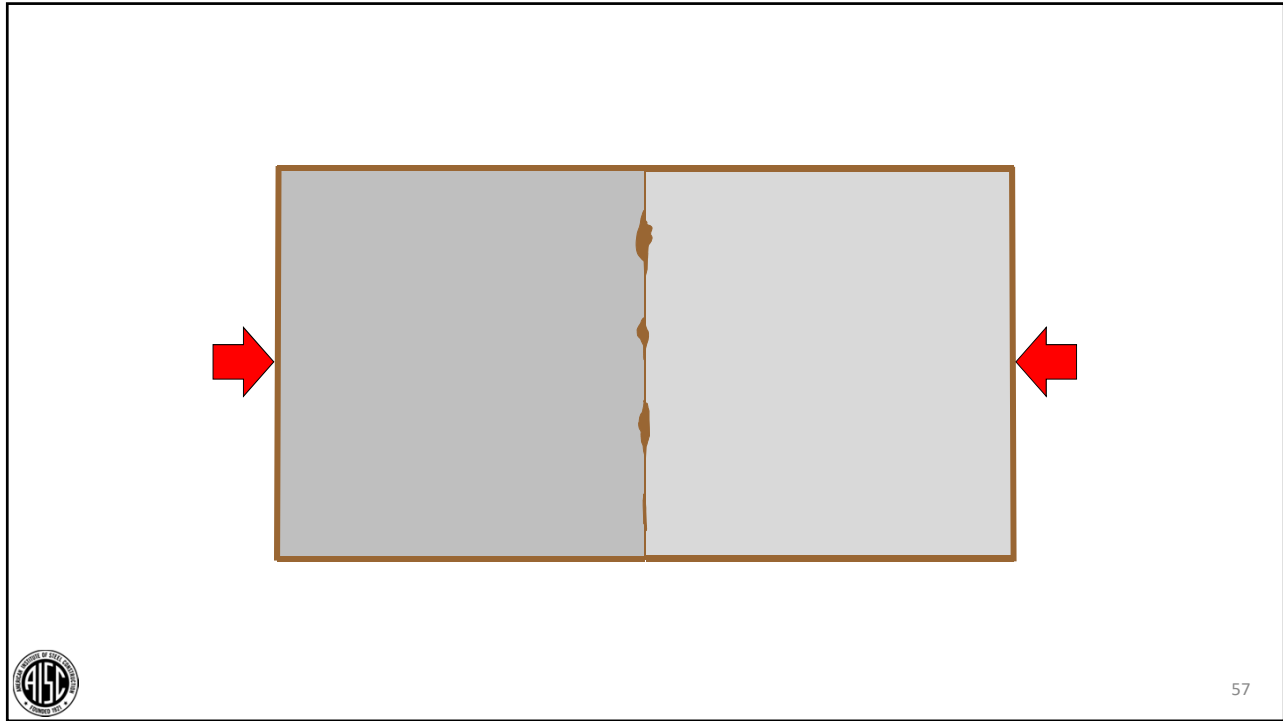
- Mechanically clean the part (scraping, machining)
- Chemically clean the part (fluxes)

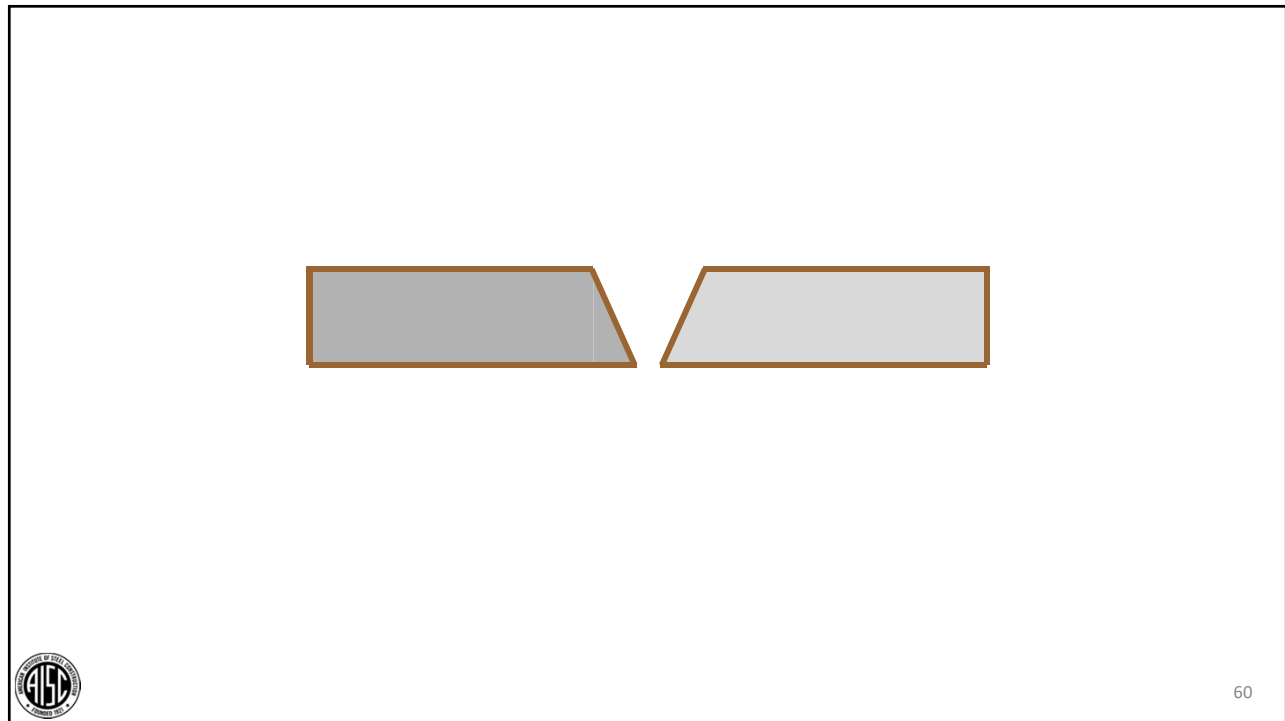
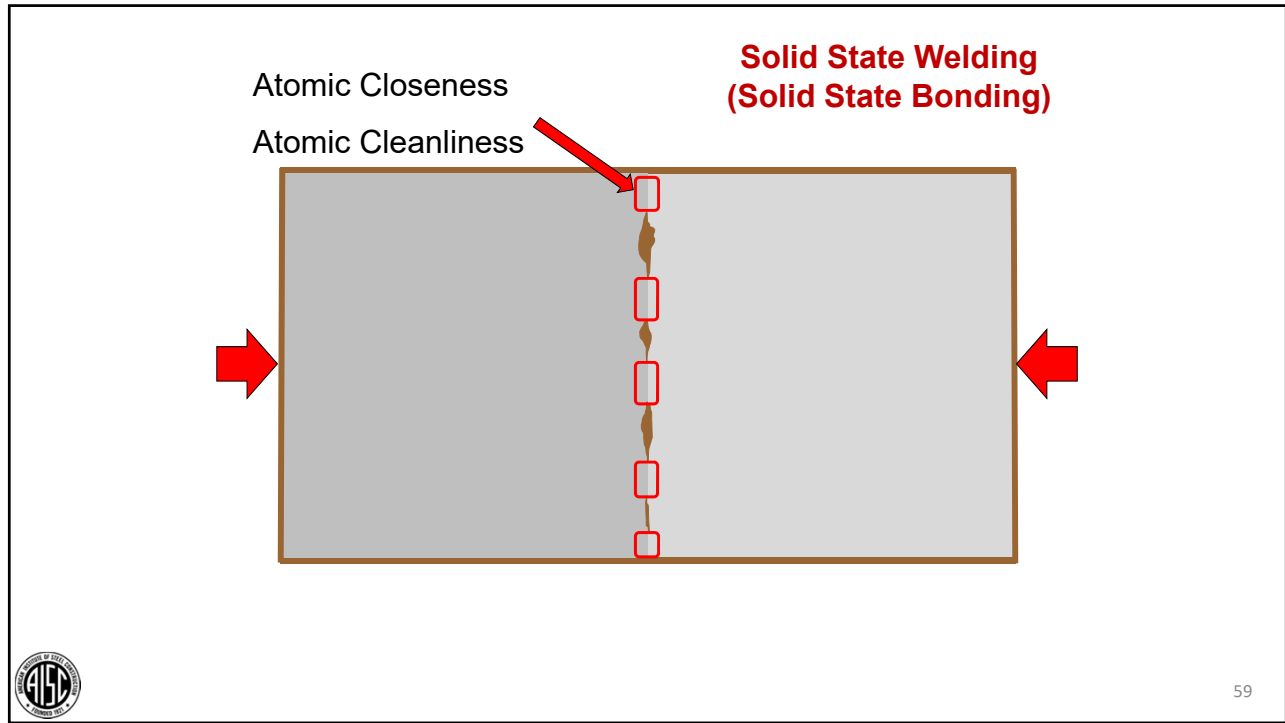


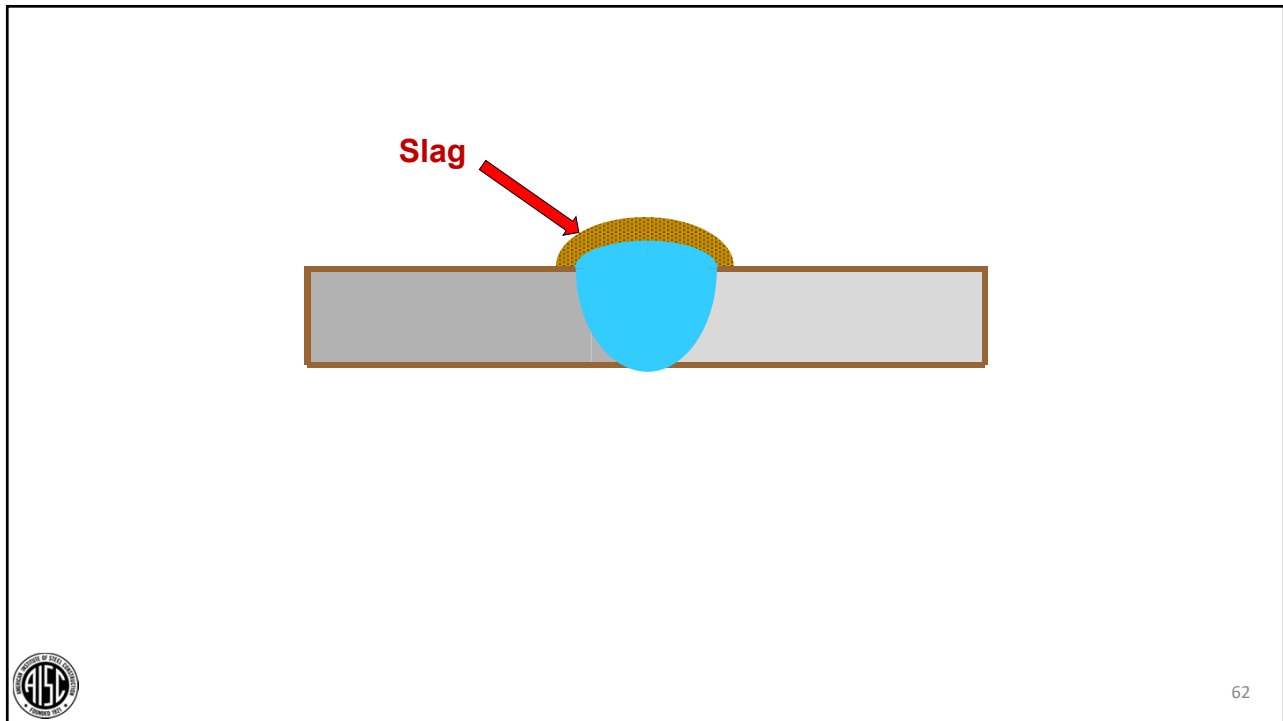
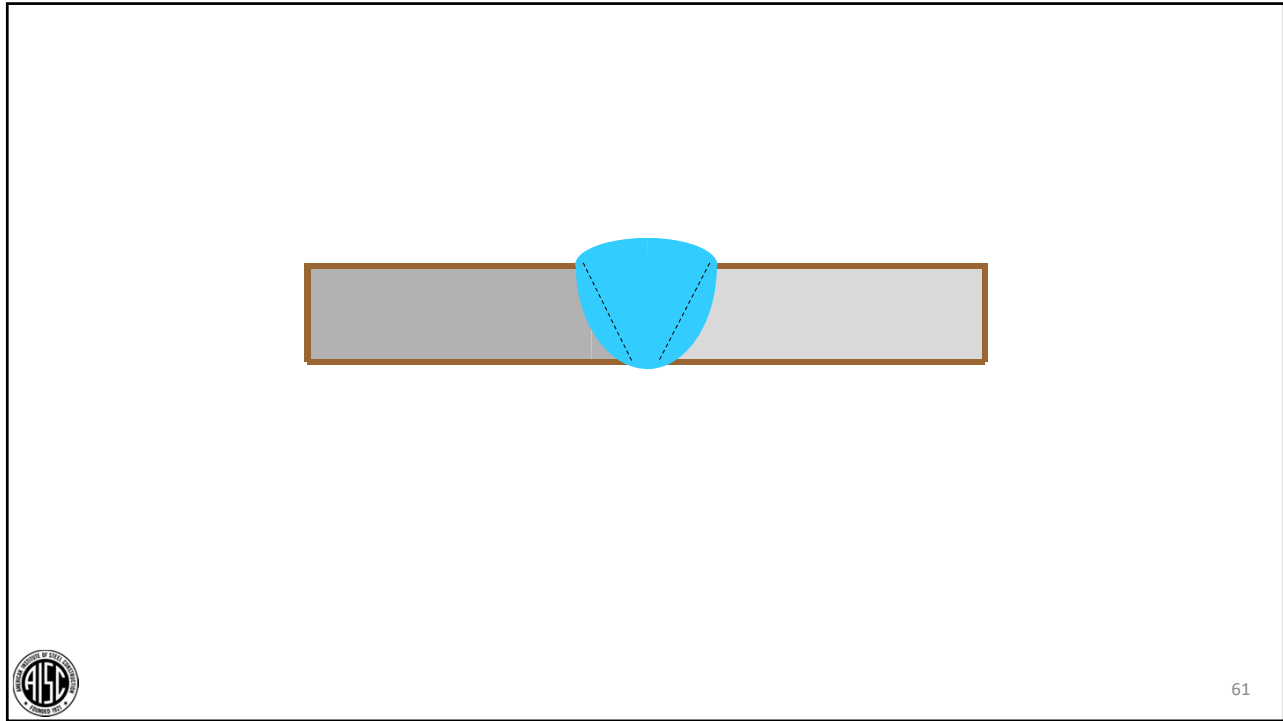
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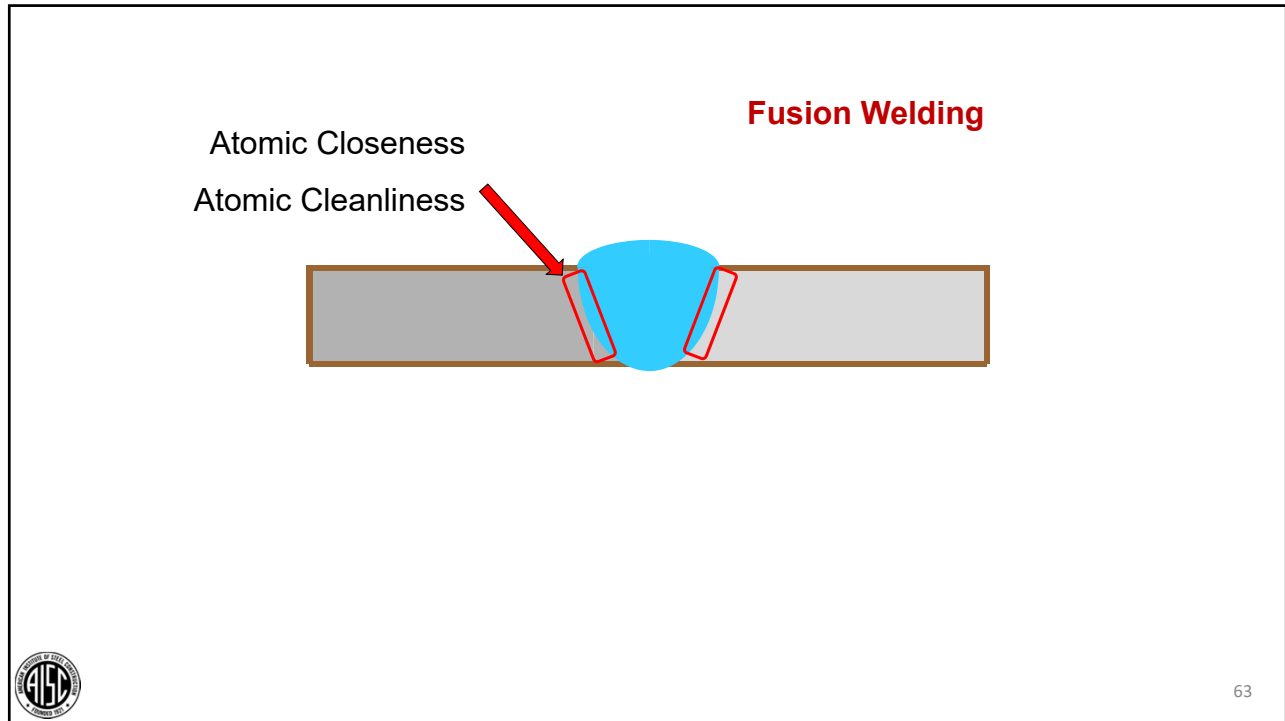


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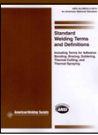









**AWS STANDARD WELDING TERMS & DEFINITIONS (A3.0:2010)**




**fusion, *fusion welding.***

The melting together of filler metal and base metal, or of base metal only, to produce a weld.




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


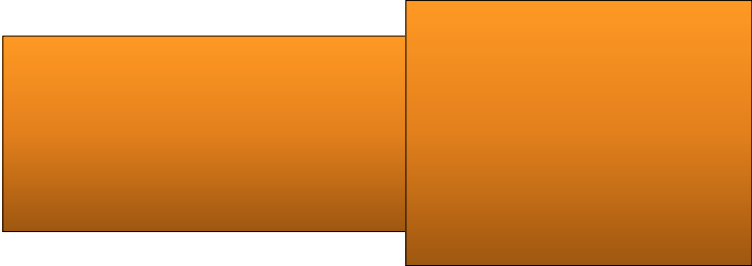


**arc welding.**

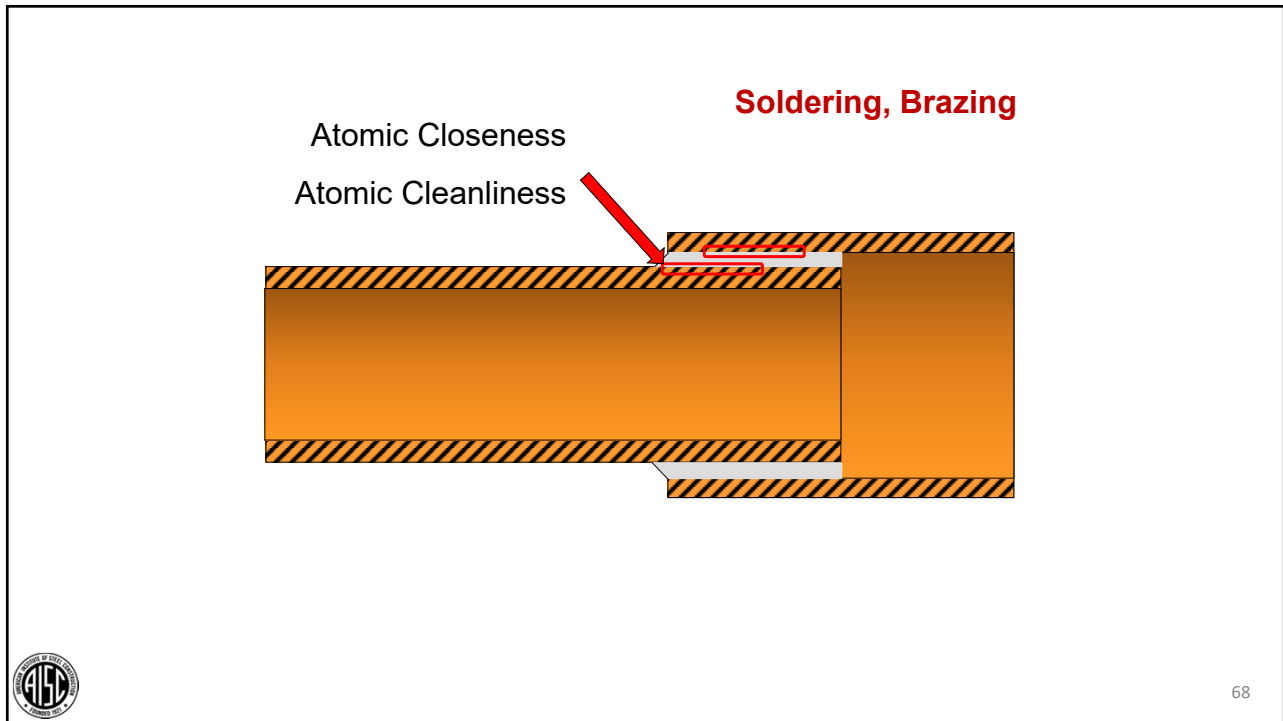
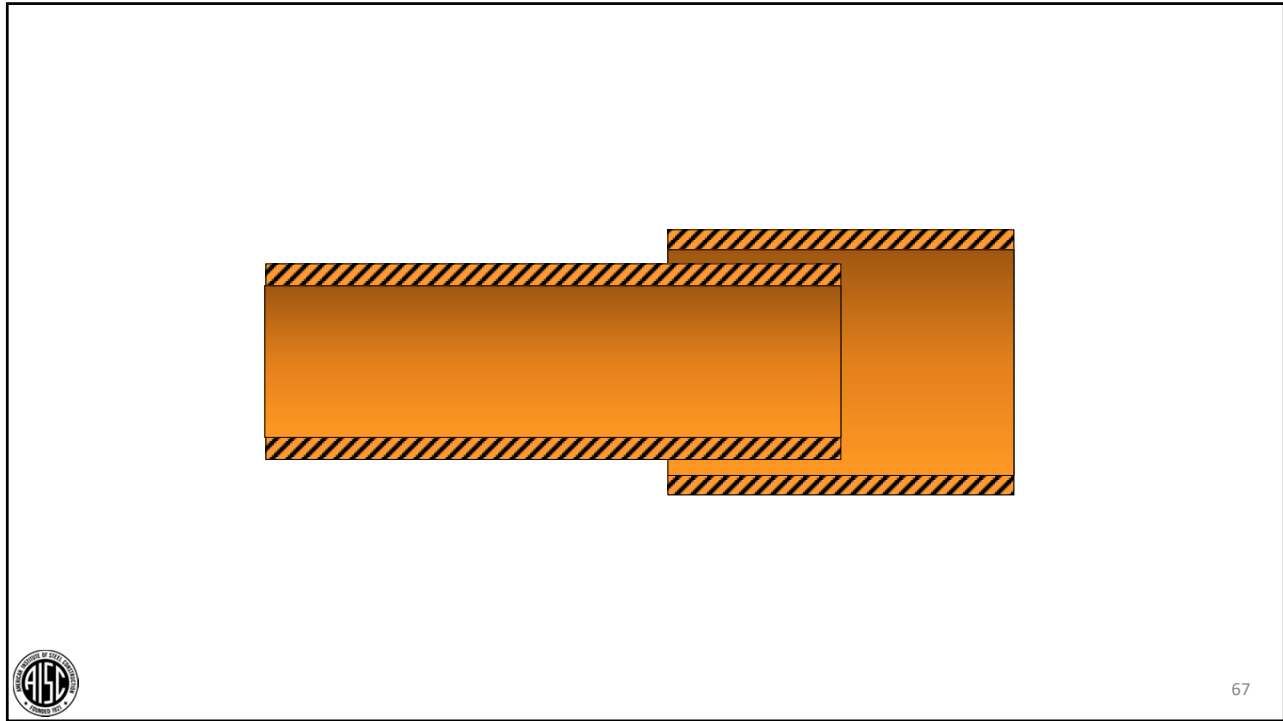
A group of welding processes producing coalescence of workpieces by melting them with an arc. The processes are used with or without the application of pressure and with or without filler metal.



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



### Soldering

A group of welding processes that produce coalescence of materials by heating them to the soldering temperature in the presence of a filler metal having a liquidus not exceeding 450 degrees C, 840 degrees F.



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



### Brazing

A group of welding processes that produce coalescence of materials by heating them to the brazing temperature in the presence of a filler metal having a liquidus above 450 degrees C, 840 degrees F.



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## Arc Welding Processes



### How to protect the metal puddle from the atmosphere:

- Inert gasses that displace the atmosphere
- Slags that form a mechanical barrier
- Both slags and gasses



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## Arc Welding Processes



**Once a puddle is formed...  
...the puddle must be protected from the atmosphere.**

- 80% Nitrogen
- 19% Oxygen

(Also, need to protect the metal droplets in the arc)



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## Arc Welding Processes



**Once a puddle is formed...**

**...need to control the shape of the puddle.**

- Shielding gasses affect weld puddle surface tension (and the wetting of the puddle to the base metal)
- Slags can be used to support and shape weld puddles



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## Arc Welding Processes



**Major arc welding processes:**

- Shielded Metal Arc Welding (SMAW)
- Flux Core Arc Welding (FCAW)
- Gas Metal Arc Welding (GMAW)
- Submerged Arc Welding (SAW)
- Gas Tungsten Arc Welding (GTAW)
- Electroslag Welding (ESW)
- Electrogas Welding (EGW)
- Arc Stud Welding (ASW)



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## Arc Welding Processes



### Major thermal cutting processes:

- Oxy-fuel Cutting (OFC)
- Plasma Arc Cutting (PAC)
- Air Arc Gouging (AAG)



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## WELDED CONNECTION BASICS

### Outline

- Applicable Codes
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- ➔ • Welding and Thermal Cutting Processes
- Joints and Weld Types





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

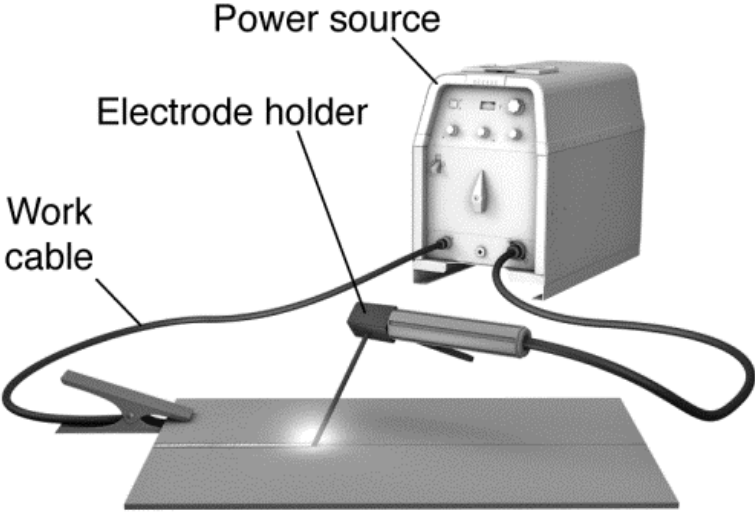
**shielded metal arc welding (SMAW).**

An arc welding process with an arc between a covered electrode and the weld pool. The process is used with shielding from the decomposition of the electrode covering, without the application of pressure, and with filler metal from the electrode.



77

**Arc Welding Processes: SMAW**





Power source

Electrode holder

Work cable

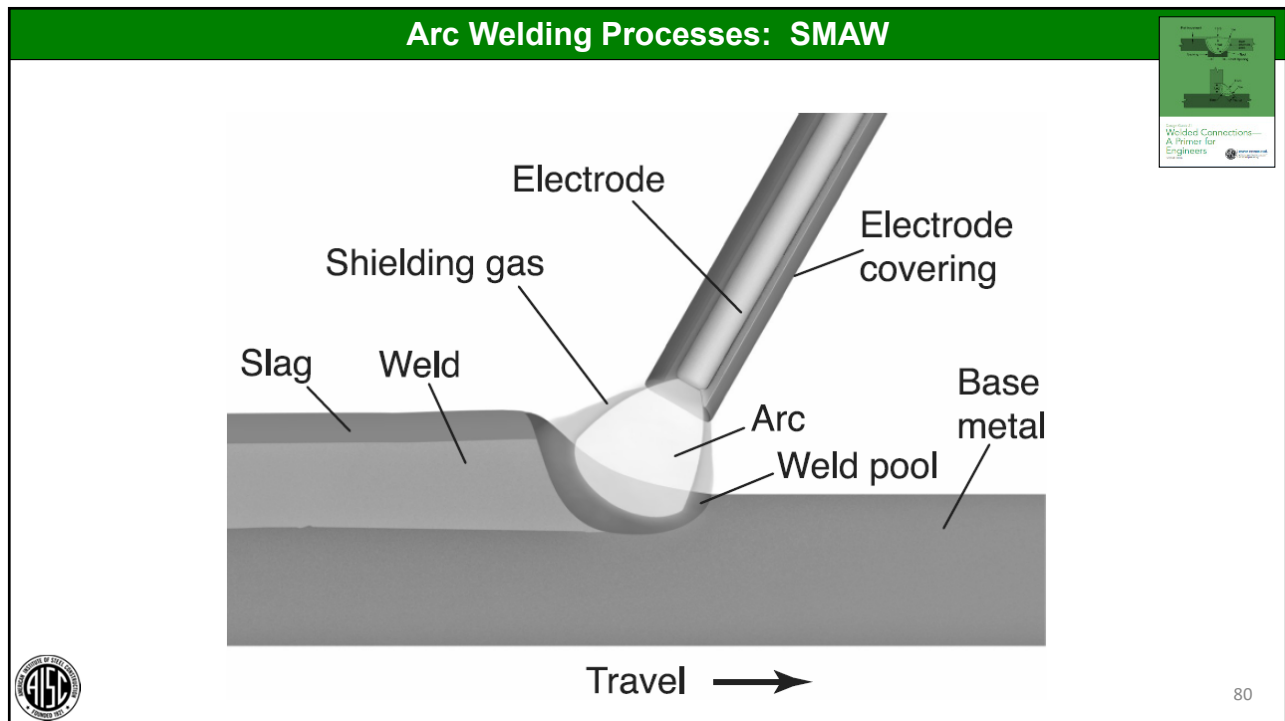
Work



78



79





81

## Arc Welding Processes: SMAW

### Advantages:

- Simplicity
- Flexibility
- Familiarity



82

## Arc Welding Processes: SMAW



### Limitations:

- Variable resistor
- Electrodes are of finite length
- Stub loss
- Operator skill required



83

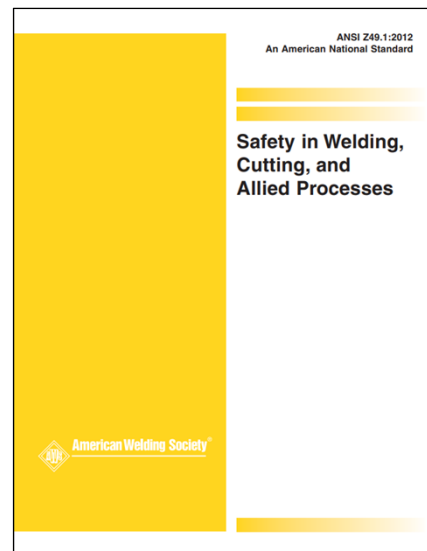
## ANSI Z49.1

### Safety in Welding, Cutting, and Allied Processes

Available by free download from AWS

[aws.org](http://aws.org)

[www.aws.org/technical/facts](http://www.aws.org/technical/facts)

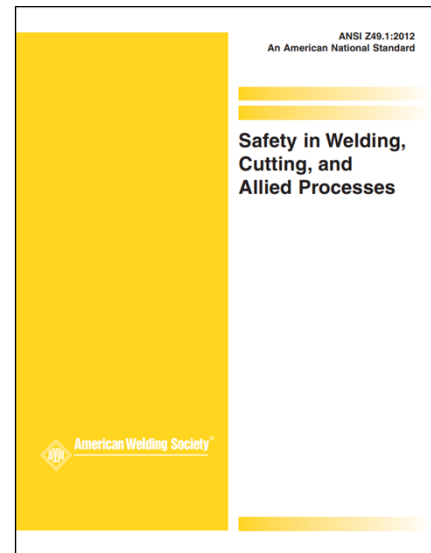


84

**The big four:**

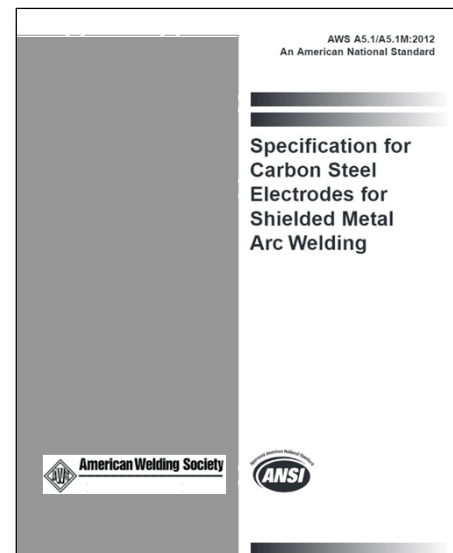
- Arc
- Fire
- Electrical
- Fume

Not comprehensive.  
See Z49.1 for a complete listing




**AWS A5.1**

Specification for Carbon Steel Electrodes  
for Shielded Metal Arc Welding



### AWS 5 Filler Metal Specifications




**E7018**

**E**lectrode \_\_\_\_\_

**70** ksi minimum specified tensile strength \_\_\_\_\_


**1** = Position of welding \_\_\_\_\_

**8** = Coating type, mechanical properties \_\_\_\_\_



87

### AWS 5 Filler Metal Specifications




**E4918**

**E**lectrode \_\_\_\_\_

**490** MPa min. specified tensile strength \_\_\_\_\_

**1** = Position of welding \_\_\_\_\_

**8** = Coating type, mechanical properties \_\_\_\_\_





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

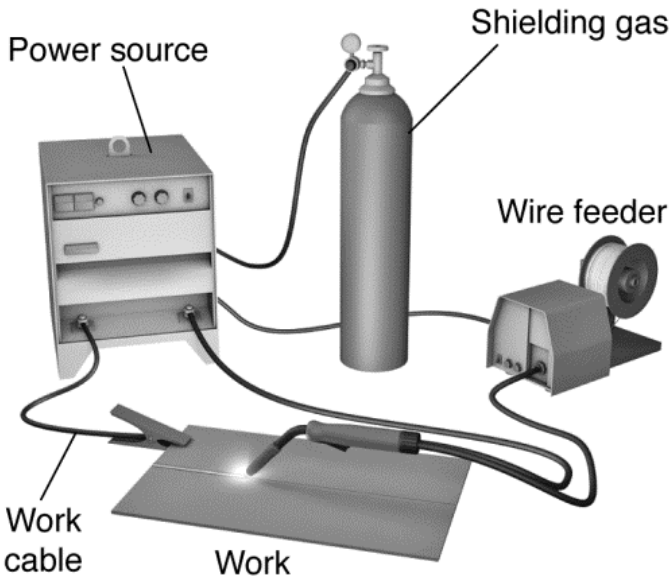
**flux cored arc welding (FCAW).**

An arc welding process using an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding from a flux contained within the tubular electrode, with or without additional shielding gas, and without the application of pressure.





89

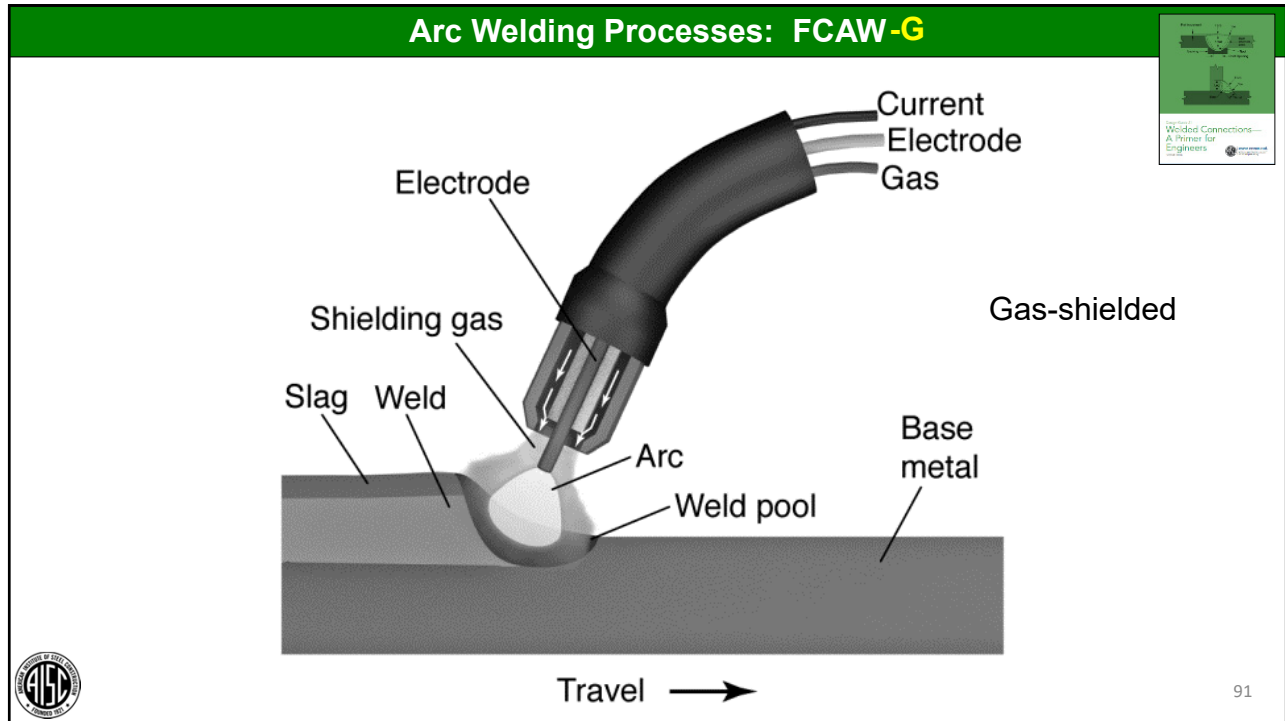
### Arc Welding Processes: FCAW

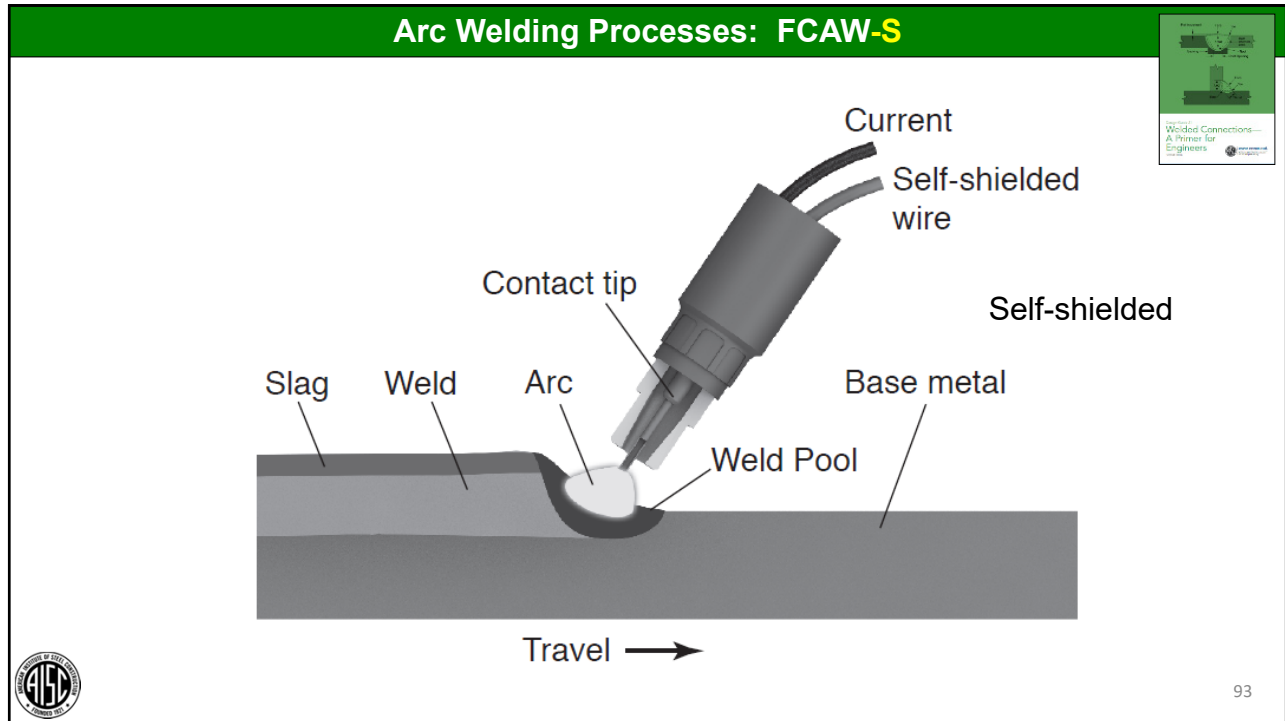


The diagram illustrates the components of a Flux Cored Arc Welding (FCAW) system. A power source is connected to a wire feeder and a work cable. The wire feeder is connected to a shielding gas cylinder and a work piece. The work piece is labeled 'Work' and has a bright spot indicating the welding arc. Labels include: Power source, Shielding gas, Wire feeder, Work cable, and Work.



90





## Arc Welding Processes: FCAW



### Advantages:

- Electrode is continuous
  - Eliminates built-in starts and stops
    - Economic advantage
    - Starts and stops are potential sources of weld discontinuities
- Increased amperages (over SMAW)
  - Increased deposition rate and productivity
- Fixed resistance for a given electrode extension
  - More uniform welding conditions are maintained



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## Arc Welding Processes: FCAW



### Advantages:

- Process is semiautomatic
  - Welders maintains the electrode extension (i.e., stickout distance) but do not need to maintain an arc length, nor do they feed the filler metal into the joint
- Process can also be mechanized or automatic



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## Arc Welding Processes: FCAW



### Limitations:

- Welding equipment costs more and is less portable than for SMAW
- Changes are more complicated than for SMAW



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## Arc Welding Processes: FCAW-G



### Advantages:

- More versatile than self-shielded flux-cored electrodes
- Provide better arc action
- High operator appeal
- Shielding from wind is not difficult in enclosed shop fabrication situations
- Weld appearance and quality are very good
- Higher-strength gas-shielded FCAW electrodes are available than for FCAW-S



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## Arc Welding Processes: FCAW-G



### Limitations:

- The need to protect the gas shield
  - AWS D1.1 limits the maximum wind velocity to 5 mph [8 km/h]
- When welding under windy conditions, porosity is likely
- Studies have shown that at wind speeds less than 5 mph, and before onset of porosity, ductility and toughness may decrease
  - AWS D1.8 has limited maximum wind velocity to 3 mph [5 km/h]



99

## Arc Welding Processes: FCAW-S



### Advantages:

- Ideal when wind may disturb the gas shield (e.g., field conditions or relatively open fabrication shops)
  - Welds have been made up to 10 mph [16 km/h] without harmful effects
- No need for gas cylinders, hoses and regulators
- No concerns about gas nozzles being plugged with weld spatter
- Gun and cable assembly is simpler than for gas-shielded
  - More suitable for welding in restricted spaces



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## Arc Welding Processes: FCAW-S



### Limitations:

- Technology is limited to 90 ksi [620 MPa] tensile strength or less
- Arc action not as good as FCAW-G



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



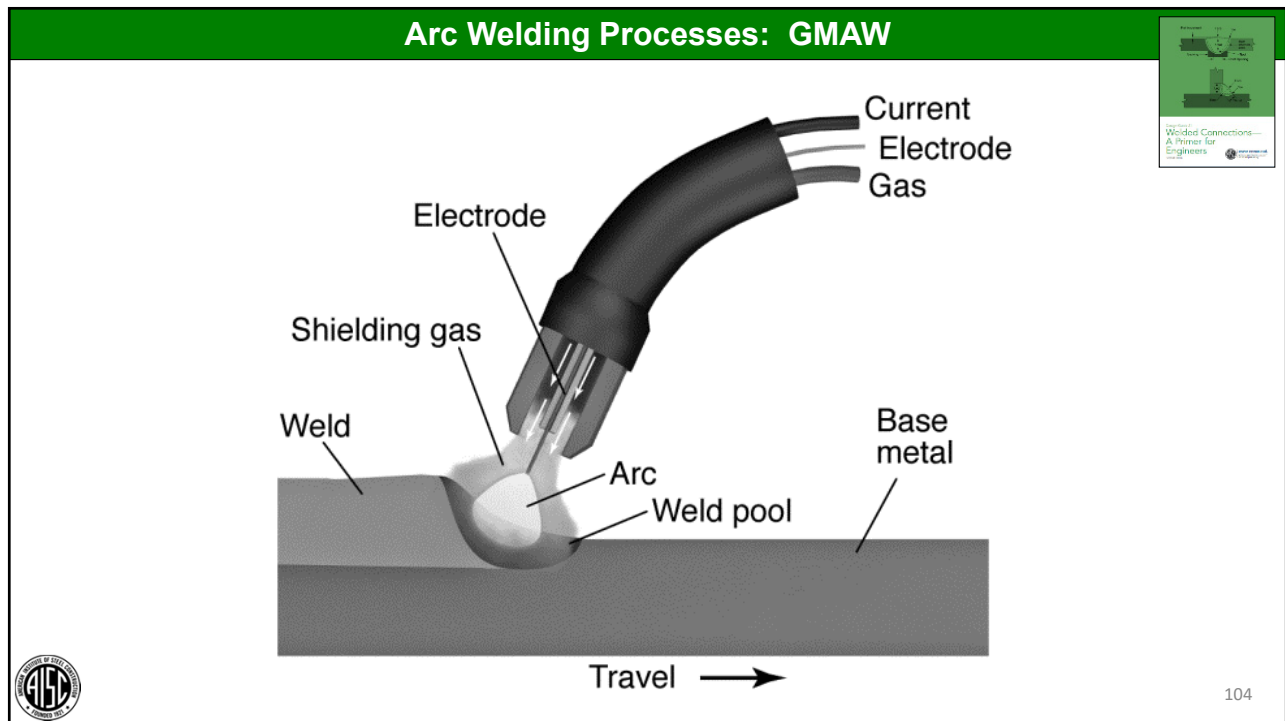
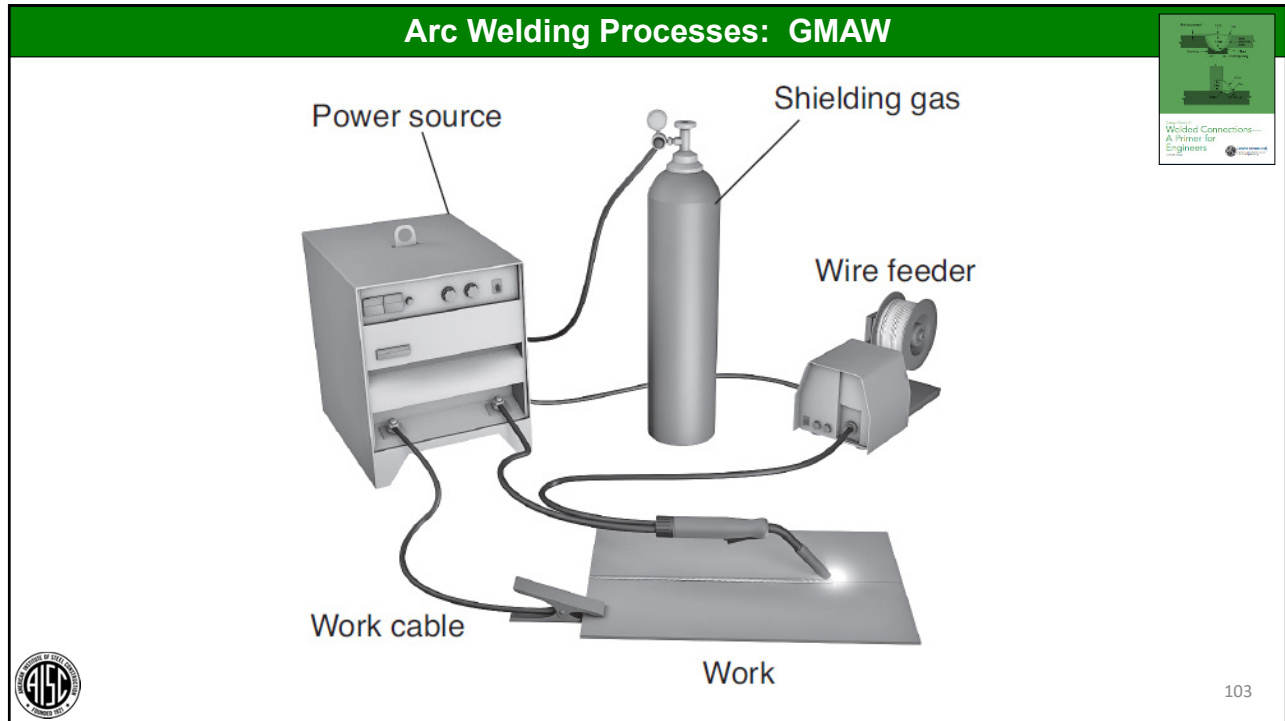
### gas metal arc welding (GMAW).

An arc welding process using an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding from an externally supplied gas and without the application of pressure.

**Note:** may use solid electrode, or metal cored electrode.



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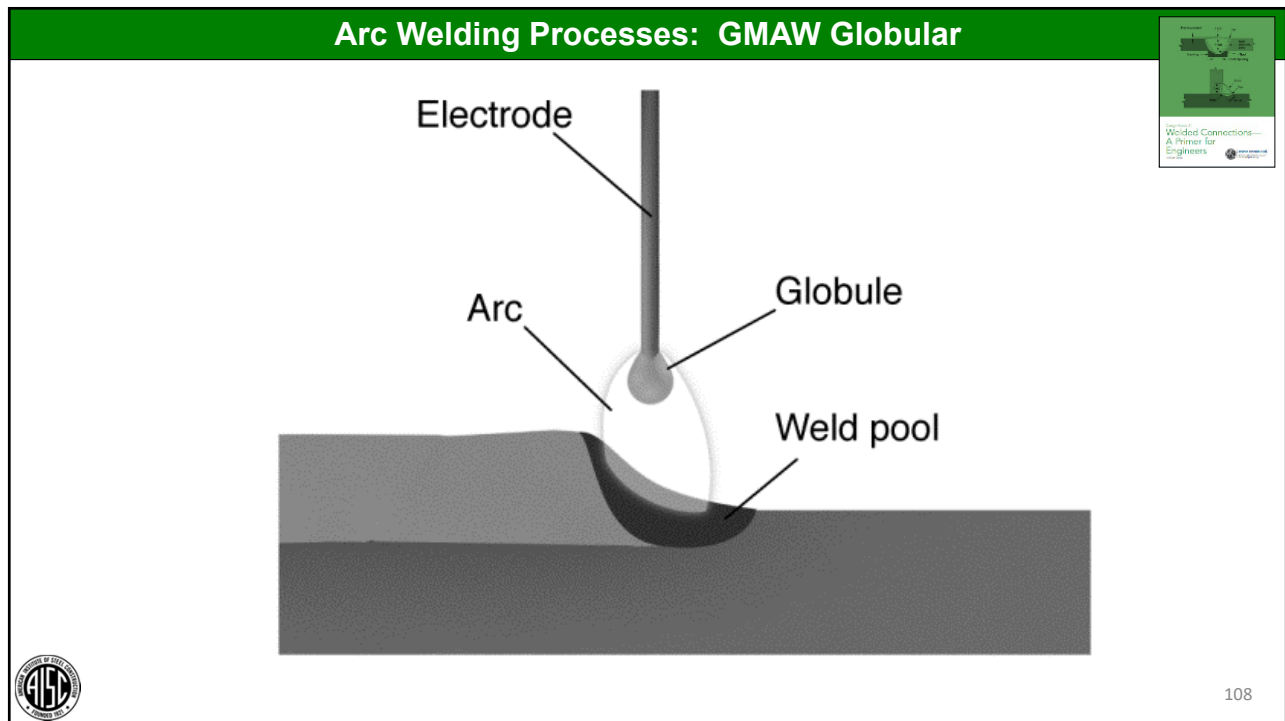
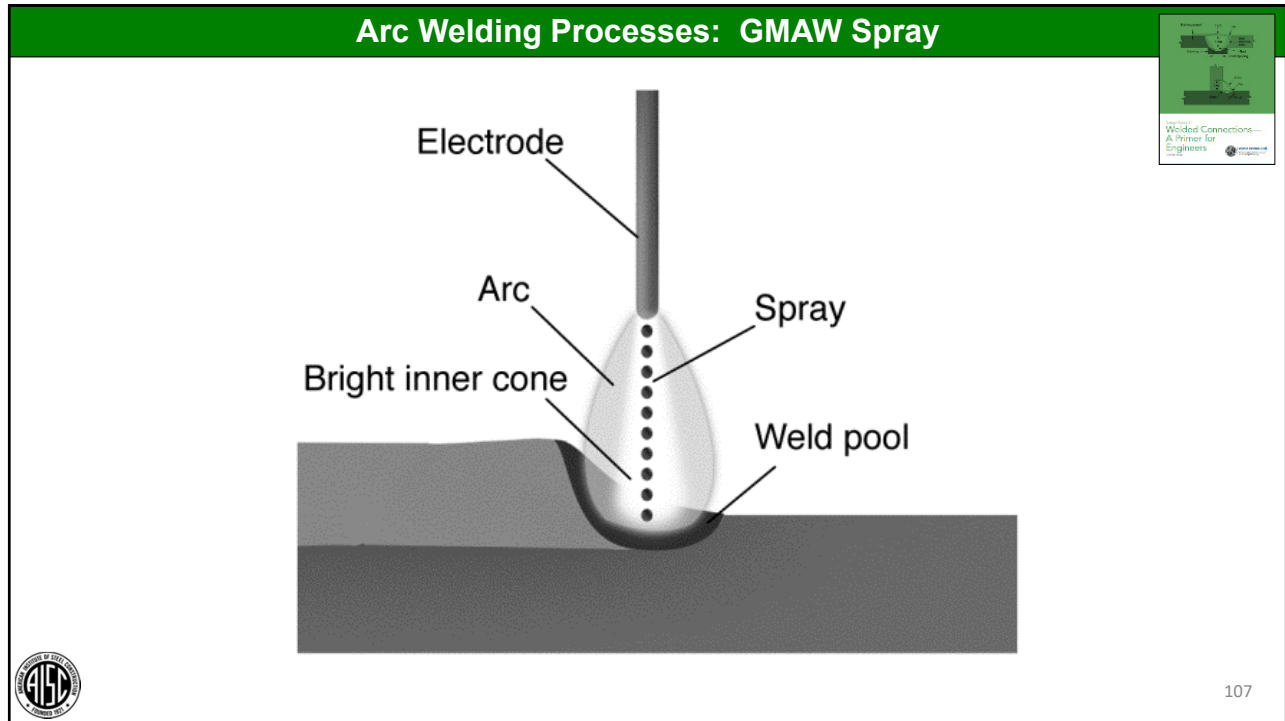
## Arc Welding Processes: GMAW

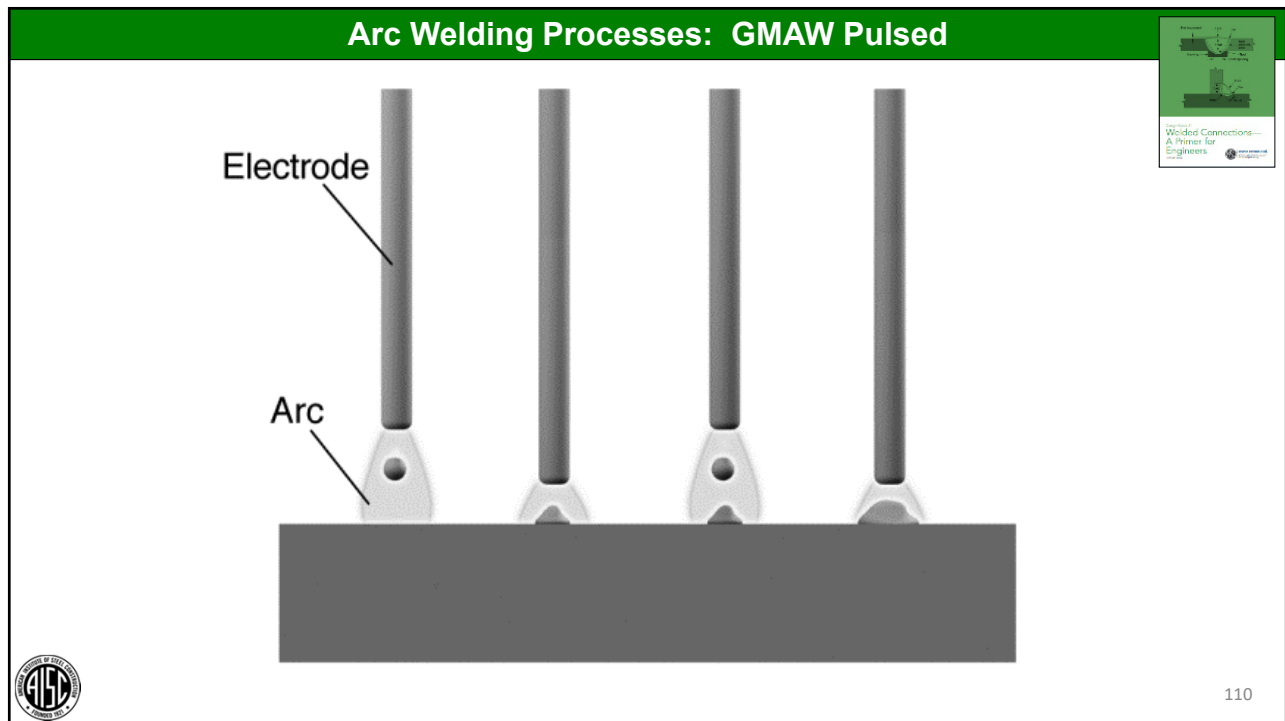
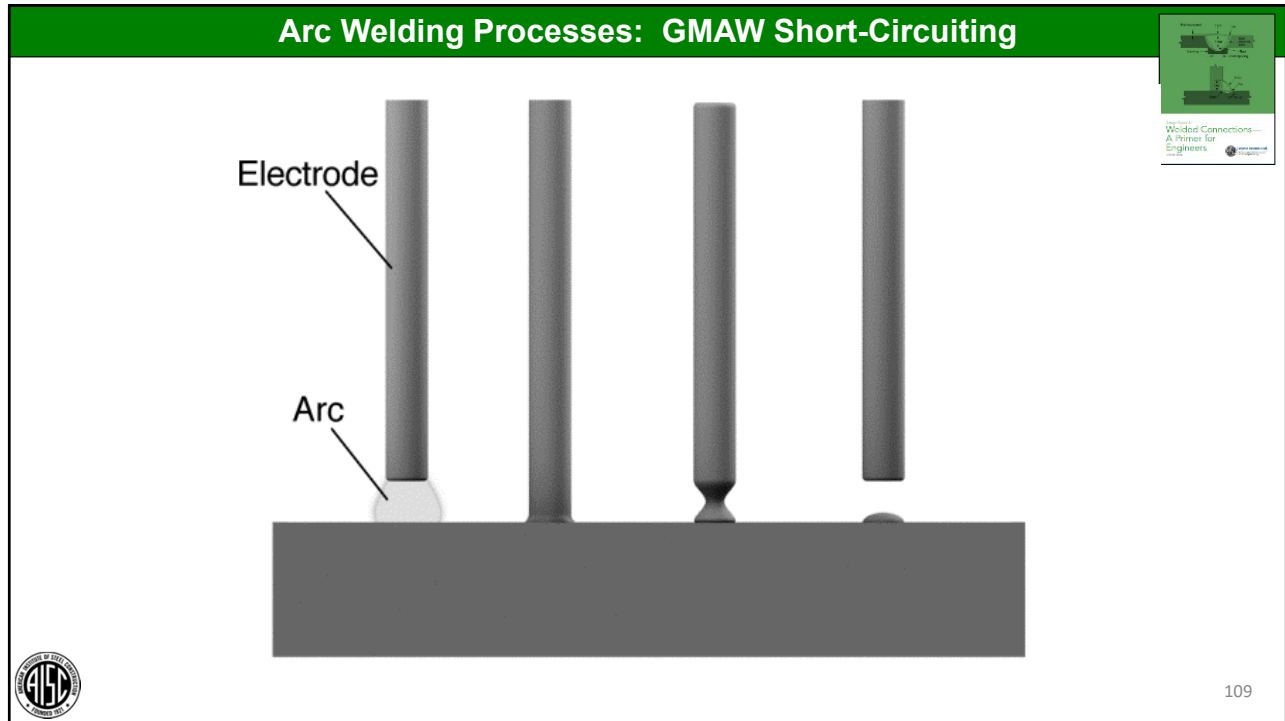
### GMAW Modes of Metal Transfer

- Spray
- Globular
- Short-Circuiting (shortarc)
- Pulsed



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## Arc Welding Processes: GMAW



### Advantages:

- No slag covers the weld; cleanup is simple and low cost
- Electrodes cost less than flux-cored electrodes
- Deposits welds with low levels of diffusible hydrogen
  - Significant advantage for welding on high strength steels
- Carries advantages of automatic and semiautomatic processes
  - Many robotic welding applications use GMAW, due to freedom from slag cleanup
  - Multiple-pass welding is easily accomplished



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## Arc Welding Processes: GMAW



### Limitations:

- Process is more sensitive to contaminants on the steel surface (such as mill scale, rust, and oil)
  - May result in porosity
  - Heavy scale may inhibit fusion
- Limited similar to FCAW-G
  - If gas shield is disturbed, porosity will result
  - Even before onset of porosity, ductility and toughness may deteriorate



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## Arc Welding Processes: GMAW



### Mode of Transfer-dependent Advantages and Limitations:

- Spray
  - Permits higher deposition rates and deposits welds with good appearance
  - Requires higher-cost, argon-based shielding gas mixtures, and can only be used in horizontal and flat positions



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## Arc Welding Processes: GMAW



### Mode of Transfer-dependent Advantages and Limitations:

- Globular
  - Uses low-cost carbon dioxide shielding and offers high deposition rates
  - Weld appearance is inferior to spray transfer; excessive weld spatter is typical; restricted to horizontal and flat positions



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## Arc Welding Processes: GMAW



### Mode of Transfer-dependent Advantages and Limitations:

- Short-circuit
  - Ideal for sheet metal; can be used for vertical and overhead positions
  - Strong tendency for fusion-type defects (incomplete fusion) makes it undesirable for most structural applications
  - Not prequalified in AWS D1.1
  - Welders must be qualified with the short-circuit mode of transfer



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## Arc Welding Processes: GMAW



### Mode of Transfer-dependent Advantages and Limitations:

- Pulsed
  - Permits all-position welding; deposits weld with good appearance
  - Requires use of more expensive, argon-based shielding gas mixtures
  - Welding equipment is more expensive and complex



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

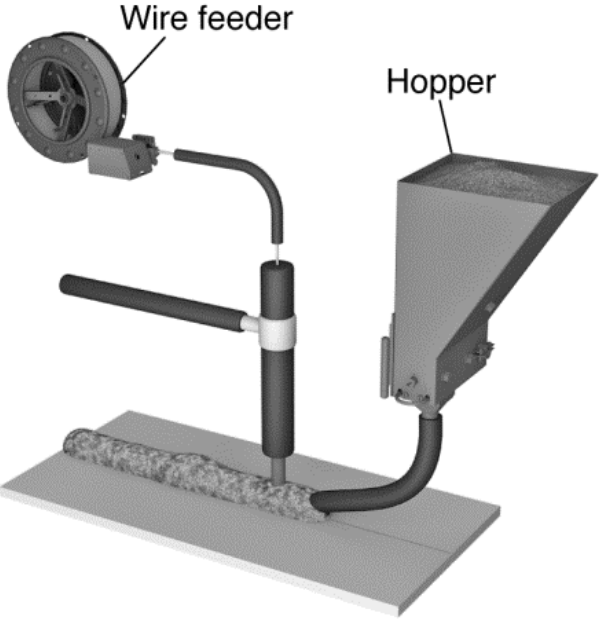


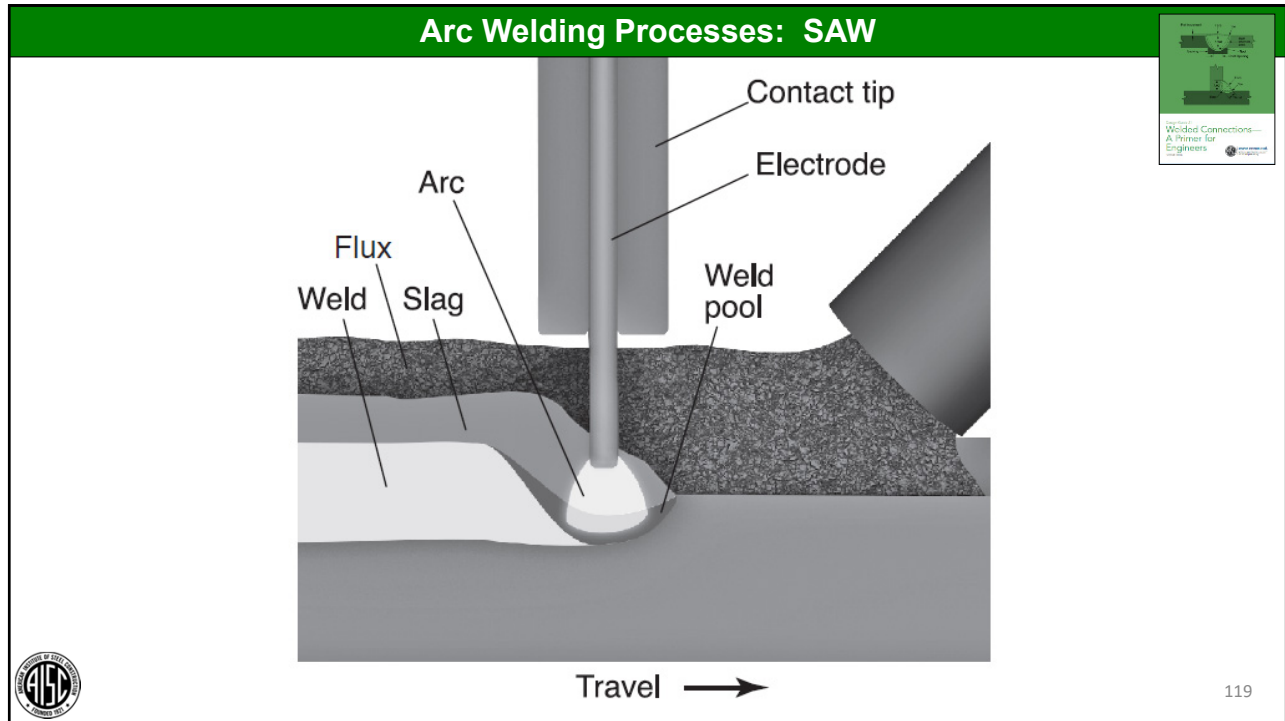
**submerged arc welding (SAW).**

An arc welding process using an arc or arcs between a bare metal electrode and the weld pool. The arc and molten metal are shielded by a blanket of granular flux on the workpieces. The process is used without pressure and with filler metal from the electrodes and sometimes from a supplemental source (welding rod, flux, or metal granules).



**Arc Welding Processes: SAW**









## Arc Welding Processes: SAW



### Advantages:

- Uses higher welding currents, leading to higher productivity and deeper penetration
  - Deeper penetration may allow fillet weld sizes to be reduced or may permit the use of groove weld details that require less weld metal
- Square wave technology may further increase deposition rate without increasing current
- For higher deposition rates, a second or third electrode can be added into the system to further increase productivity
- Process is typically mechanized or automatic
  - Welds are usually continuous for length of the joint



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## Arc Welding Processes: SAW



### Advantages:

- Welds made under protective layer of flux are excellent in appearance and spatter-free
  - Particularly significant for architecturally exposed structural steel (AESS)
- Freedom from the open arc
  - Welder does not need to use the standard protective helmet
  - Operations can be done in tight, restricted areas
  - Produces little smoke, therefore can be used in situations with restricted ventilation



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## Arc Welding Processes: SAW



### Limitations:

- Freedom from open arc does not allow the operator to observe the weld puddle
  - When done semiautomatically, operator must learn to propel gun carefully to ensure uniform bead contour
  - Degree of skill is significant for multiple-pass welds
- Better for long, uninterrupted seams rather than short, intermittent welds
- Restricted to flat and horizontal position





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

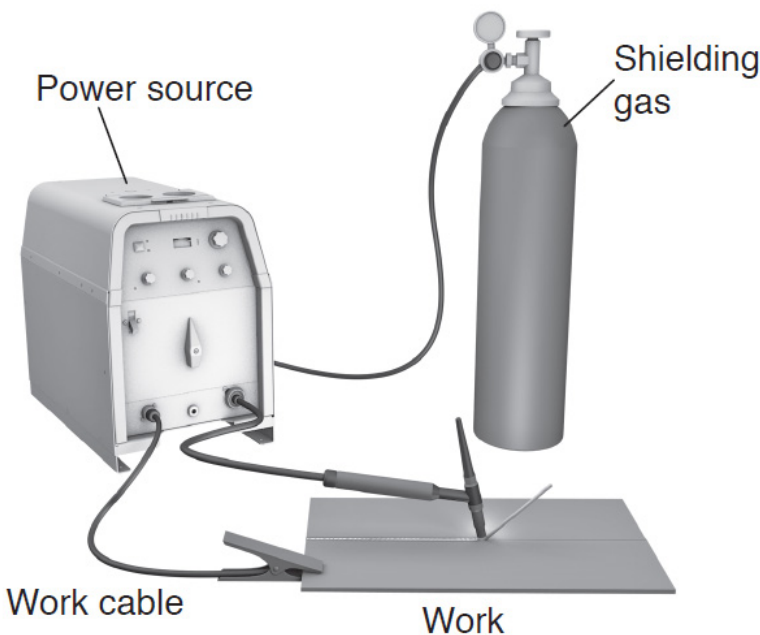
**gas tungsten arc welding (GTAW).**

An arc welding process using an arc between a tungsten electrode (nonconsumable) and the weld pool. The process is used with shielding gas and without the application of pressure.





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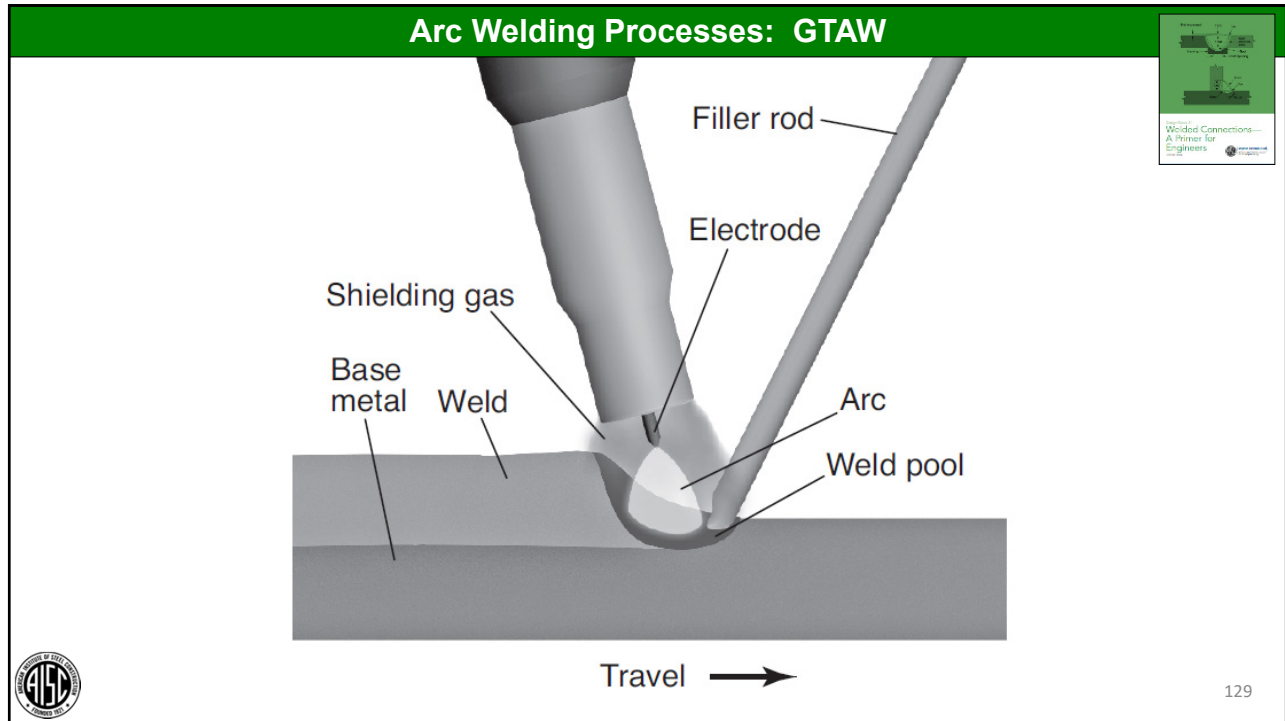
**Arc Welding Processes: GTAW**



The diagram illustrates the components of a Gas Tungsten Arc Welding (GTAW) setup. On the left is a grey power source with various control knobs and a 'Work cable' connected to it. To the right is a tall, grey 'Shielding gas' cylinder. A welding torch is connected to the power source and is shown in contact with a flat metal 'Work' piece. The torch is also connected to the shielding gas cylinder. Labels with leader lines identify the 'Power source', 'Shielding gas', 'Work cable', and 'Work'.



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

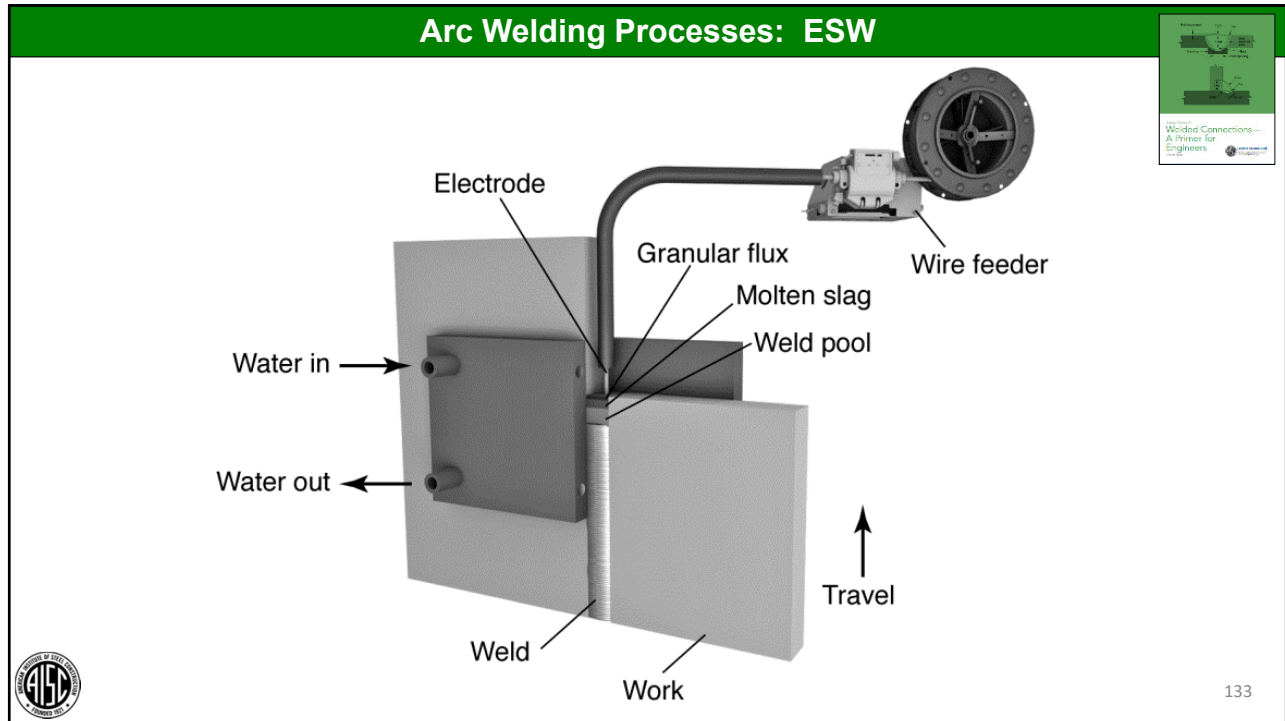


### **electroslag welding (ESW).**

A welding process producing coalescence of metals with molten slag, melting the filler metal and the surfaces of the workpieces. The weld pool is shielded by this slag, which moves along the full cross section of the joint as welding progresses. The process is initiated by an arc that heats the slag. The arc is then extinguished by the conductive slag, which is kept molten by its resistance to electric current passing between the electrode and the workpieces.




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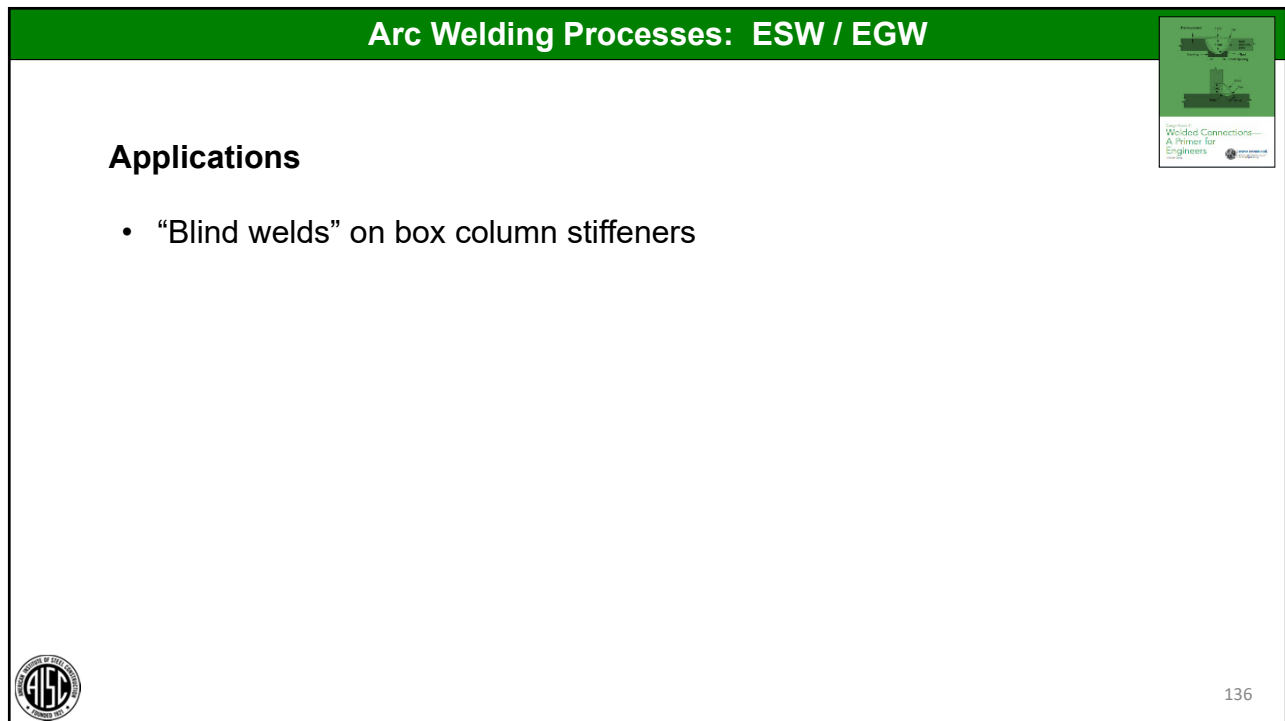
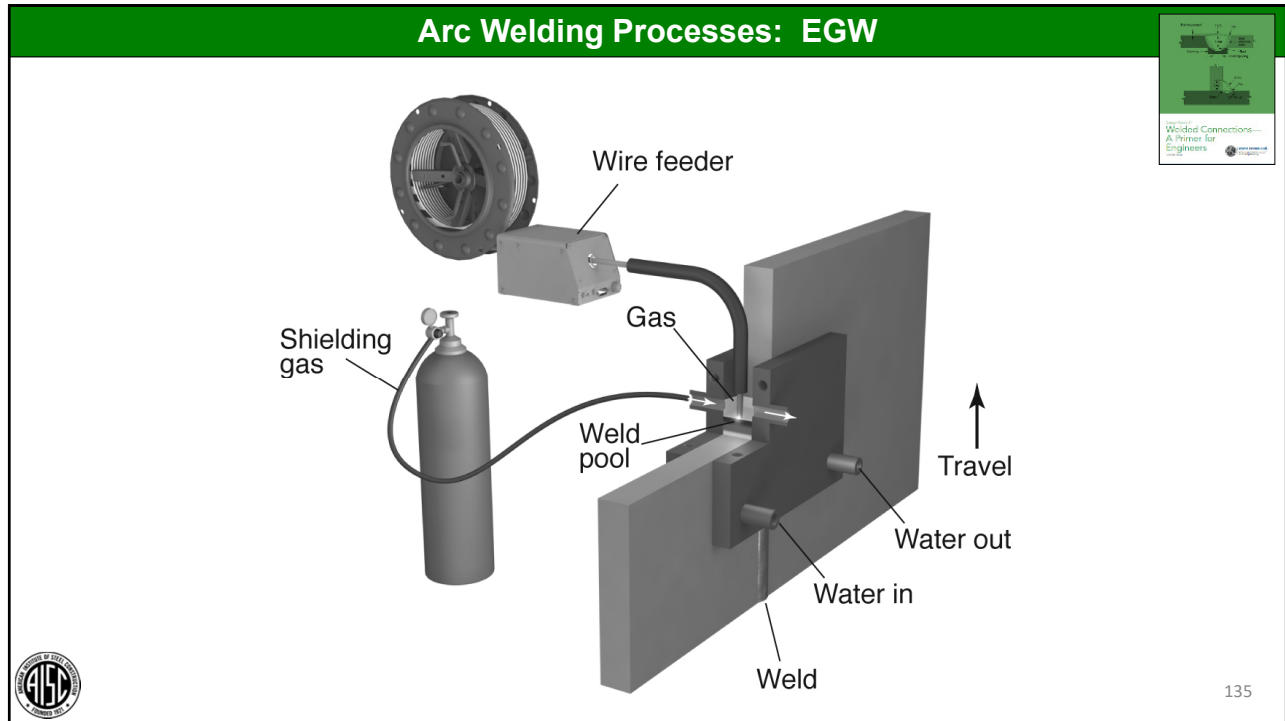
### AWS STANDARD WELDING TERMS & DEFINITIONS (A3.0:2010)

**electrogas welding (EGW).**

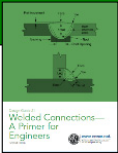
An arc welding process using an arc between a continuous filler metal electrode and the weld pool, employing approximately vertical welding progression with backing to confine the molten weld metal. The process is used with or without an externally supplied shielding gas and without the application of pressure.

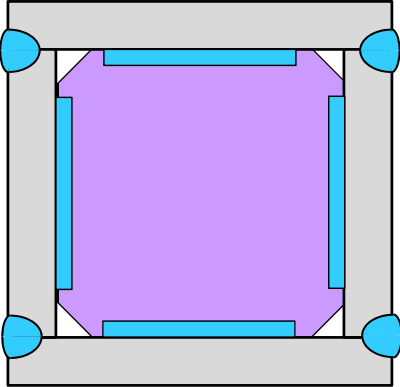



134




### Arc Welding Processes: ESW / EGW

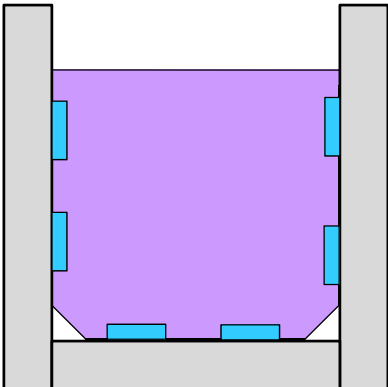





137



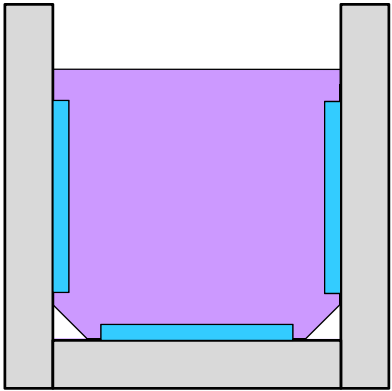
### Arc Welding Processes: ESW / EGW







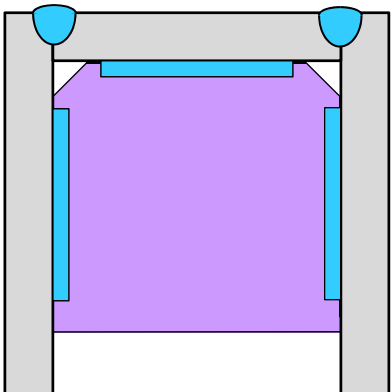
138

### Arc Welding Processes: ESW / EGW



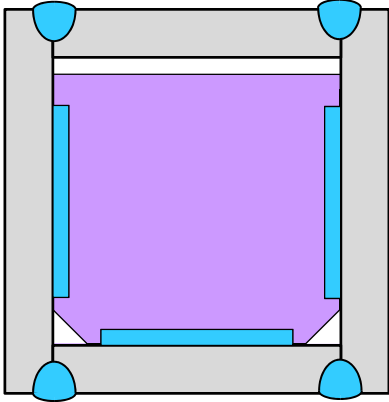
139

### Arc Welding Processes: ESW / EGW





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### Arc Welding Processes: ESW / EGW

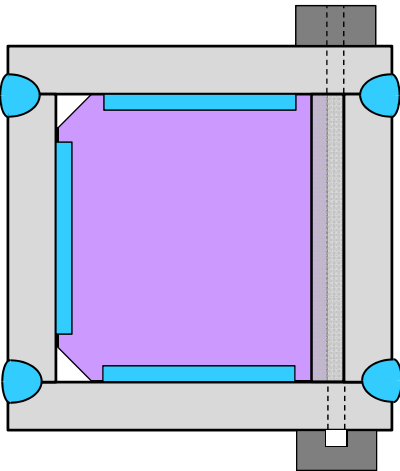


The diagram shows a square column section with a purple core. Four blue corner stiffeners are attached to the outer gray frame. The stiffeners are positioned at the corners, with one extending along the side and another along the top or bottom edge.





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### Arc Welding Processes: ESW / EGW




The diagram shows a square column section with a purple core. A vertical blue stiffener is attached to the right side of the gray frame. The stiffener is positioned vertically, extending from the top to the bottom of the column section.

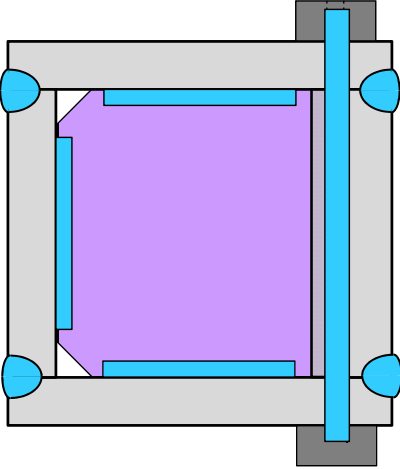



142

### Arc Welding Processes: ESW / EGW

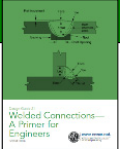


Welded Connections—  
A Primer for  
Engineers

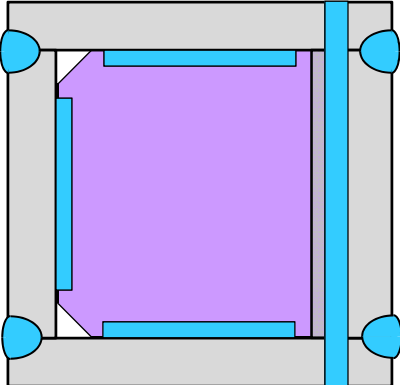



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### Arc Welding Processes: ESW / EGW



Welded Connections—  
A Primer for  
Engineers



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## Arc Welding Processes: ESW / EGW



### Applications

- “Blind welds” on box column stiffeners
- Flange splices for plate girders
- Miscellaneous applications (columns to base plates, flange plates to columns, continuity plates)



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## Arc Welding Processes: ESW / EGW



### Advantages:

- Very high deposition rates
- Normally, joint details involve square edges, eliminating beveling costs
- Material handling might be reduced because plates do not need to be flipped as is the case for double-sided welds made with SAW, for example
- Angular distortion can be reduced
- Advantageous for cyclically loaded structures
  - Center of the vertical weld is last to solidify, putting the face of the weld in compression, enabling better resistance to cyclic tensile stresses



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## Arc Welding Processes: ESW / EGW



### Advantages:

- Ability to weld in blind joints (e.g., diaphragm plates in box columns)
  - Can weld through a hole in the box
- Ideal for welding on thicker materials (1 in. [25 mm] or greater)



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## Arc Welding Processes: ESW / EGW




### Limitations:

- Not well-suited for thinner materials
- Equipment and fixturing are more expensive and less flexible
- Sensitive process with many variables
  - Specific operator training is required
  - AWS D1.1 requires all ESW and EGW welding procedure specifications be qualified by test
  - Different variables: fit of copper shoes to the work, temperature of the shoes, thickness of the slag layer
- Large heat affected zone and potentially low fracture toughness of welds




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




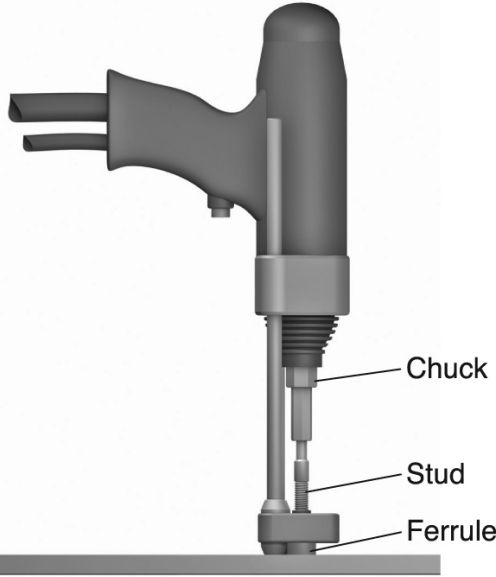
**arc stud welding (SW).**

An arc welding process using an arc between a metal stud, or similar part, and the other workpiece. The process is used without filler metal, with or without shielding gas or flux, with or without partial shielding from a ceramic or graphite ferrule surrounding the stud, and with the application of pressure after the faying surfaces are sufficiently heated.


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### Arc Welding Processes: SW

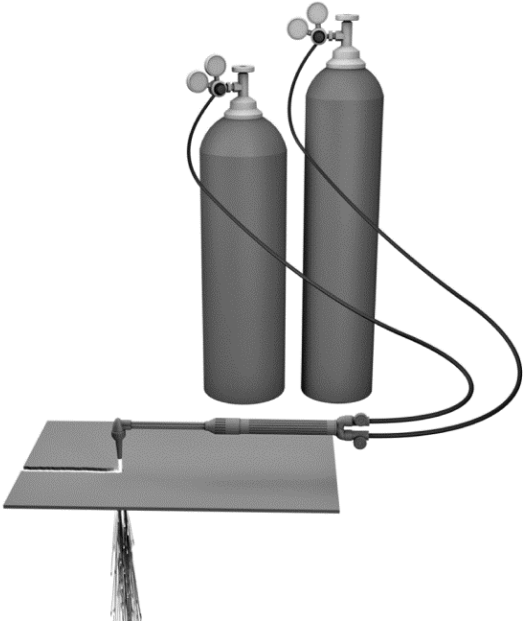




Work


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### Thermal Cutting Processes: Oxyfuel Cutting

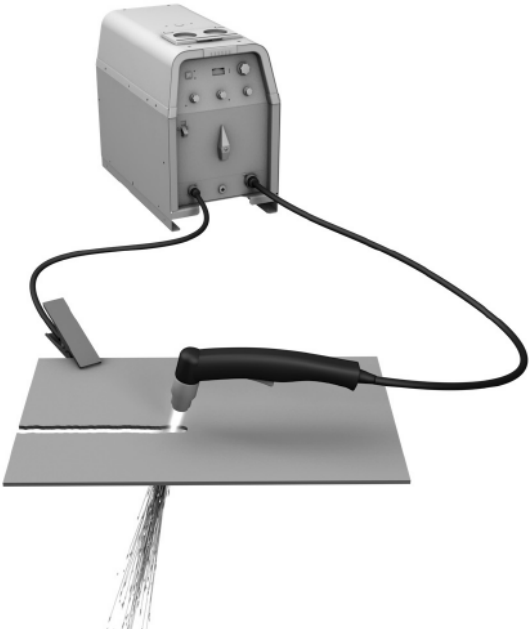


The diagram illustrates the oxyfuel cutting process. Two vertical gas cylinders are connected via hoses to a cutting torch. The torch is positioned on a metal plate, and a cut is shown in progress, with a stream of molten metal falling from the bottom. A small inset in the top right corner shows a thumbnail of the presentation slide.

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### Thermal Cutting Processes: Plasma Cutting

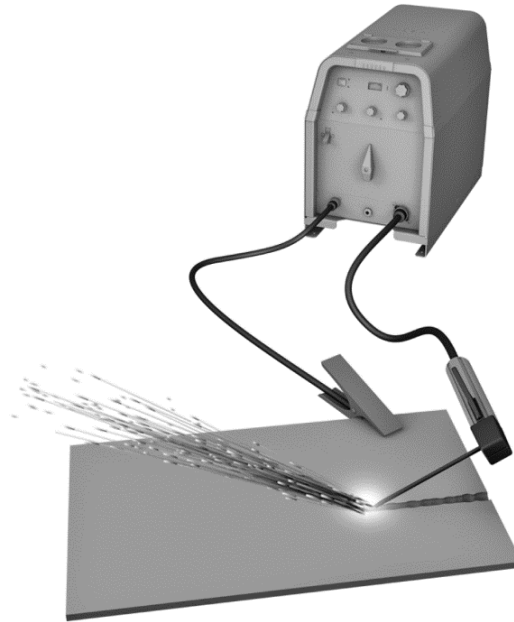


The diagram illustrates the plasma cutting process. A plasma cutting power source is connected to a plasma torch. The torch is positioned on a metal plate, and a cut is shown in progress, with a stream of molten metal falling from the bottom. A small inset in the top right corner shows a thumbnail of the presentation slide.

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## Thermal Cutting Processes: Air Arc Gouging



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## Cutting Process: Water jet cutting

- Used pressurized stream of water to cut material
- Automated and accurate
- No oxidized surface and no heat affected zone (HAZ)
- More costly and not normally used in steel fabrication
- Permitted by AISC 360 (for cutting holes)



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## Arc Welding Processes



**The selection of which process to use is typically best left up to those doing the welding.**

- Properly applied, all processes are capable of delivering quality welds
- Improperly applied, all processes may not deliver quality welds
- Mode of welding (manual, semiautomatic, automatic, robotic) will impact process selection
- Typically viewed as part of the Contractor's means and methods



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## Arc Welding Processes



**Typical welding process applications:**

- **GMAW:** for shop welding on clean parts; often the choice for robotic applications
- **FCAW-G:** for shop welding on steel with mill scale, rust
- **FCAW-S:** for field welding
- **SAW:** for big, long welds that lend themselves to automation
- **GTAW:** for special alloys, high quality welds, critical repairs
- **SMAW:** maintenance welding, field welding, tack welding, repair welding, miscellaneous fabrication



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## WELDED CONNECTION BASICS

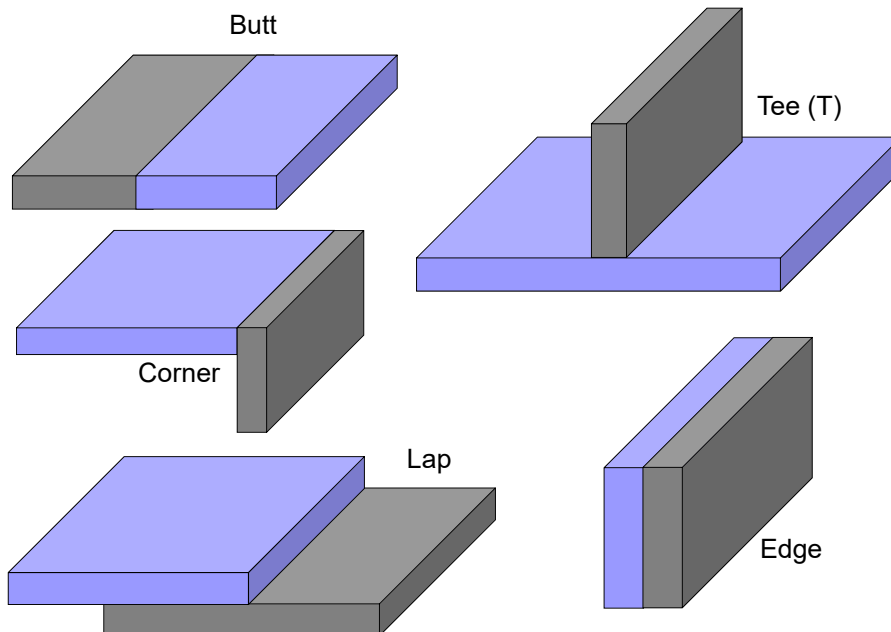
### Outline

- Applicable Codes
- Arc Welding Processes – Overview
- Welding and Thermal Cutting Processes
- ➔ • Joints and Weld Types



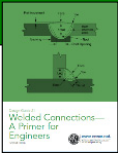
157

## Joint Types



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### Weld Types




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**Complete-Joint-Penetration Groove Welds (CJP)**  
“complete penetration welds”  
“full pen welds”  
“butt welds”


**Partial-Joint-Penetration Groove Welds (PJP)**  
“partial penetration”  
“partial pen”

**Fillet Welds**  
**Slot Welds**  
**Plug Welds**




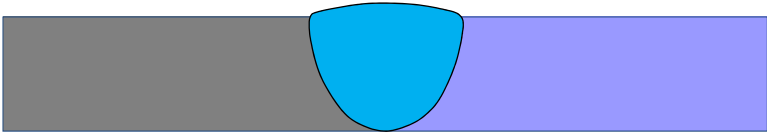
159

### Weld Types



Welded Connections—  
A Primer for  
Engineers

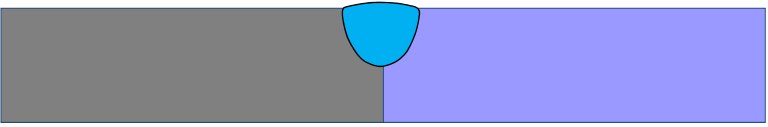
**CJP Groove Weld in Butt Joint**





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### Weld Types

#### PJP Groove Weld in Butt Joint



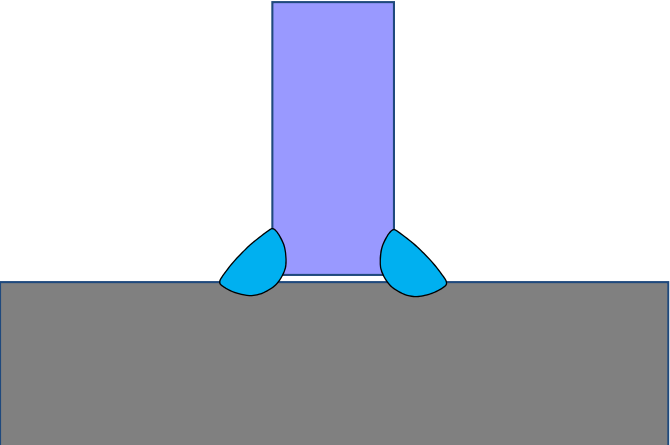
The diagram shows two rectangular steel plates, one grey and one purple, joined at their ends. A blue semi-circular weld bead is positioned at the center of the joint, representing the groove weld.





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### Weld Types

#### Fillet Weld in Tee Joint



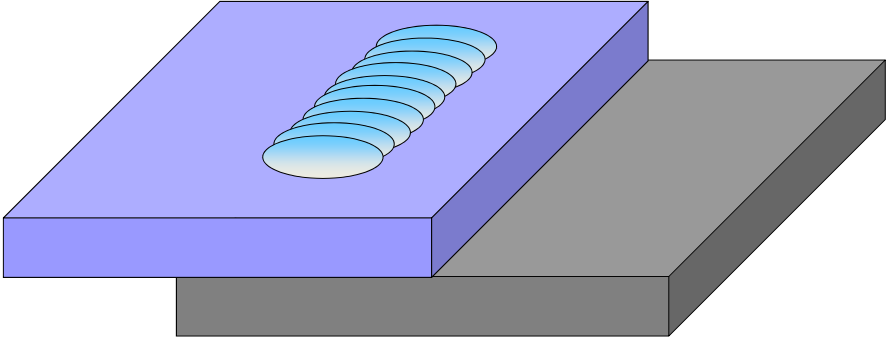
The diagram shows a vertical purple rectangular plate attached to a horizontal grey rectangular plate. Two blue teardrop-shaped weld beads are shown at the base of the vertical plate, one on each side, representing fillet welds.




162

### Weld Types

#### Slot Weld in Lap Joint



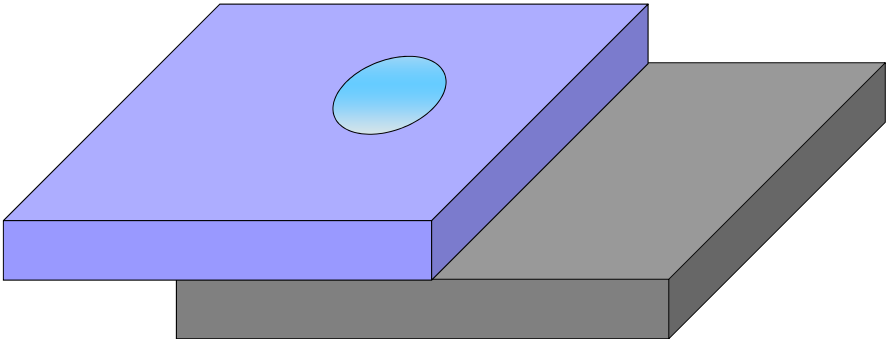
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### Weld Types

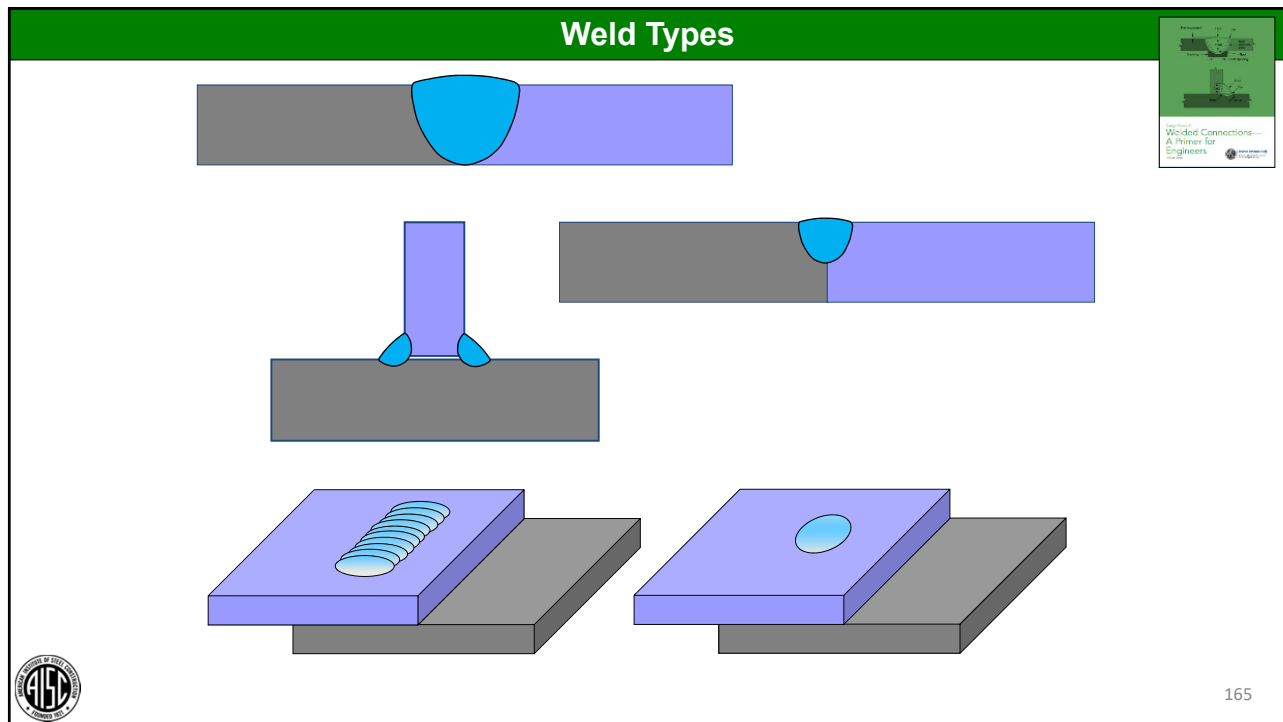
#### Plug Weld in Lap Joint



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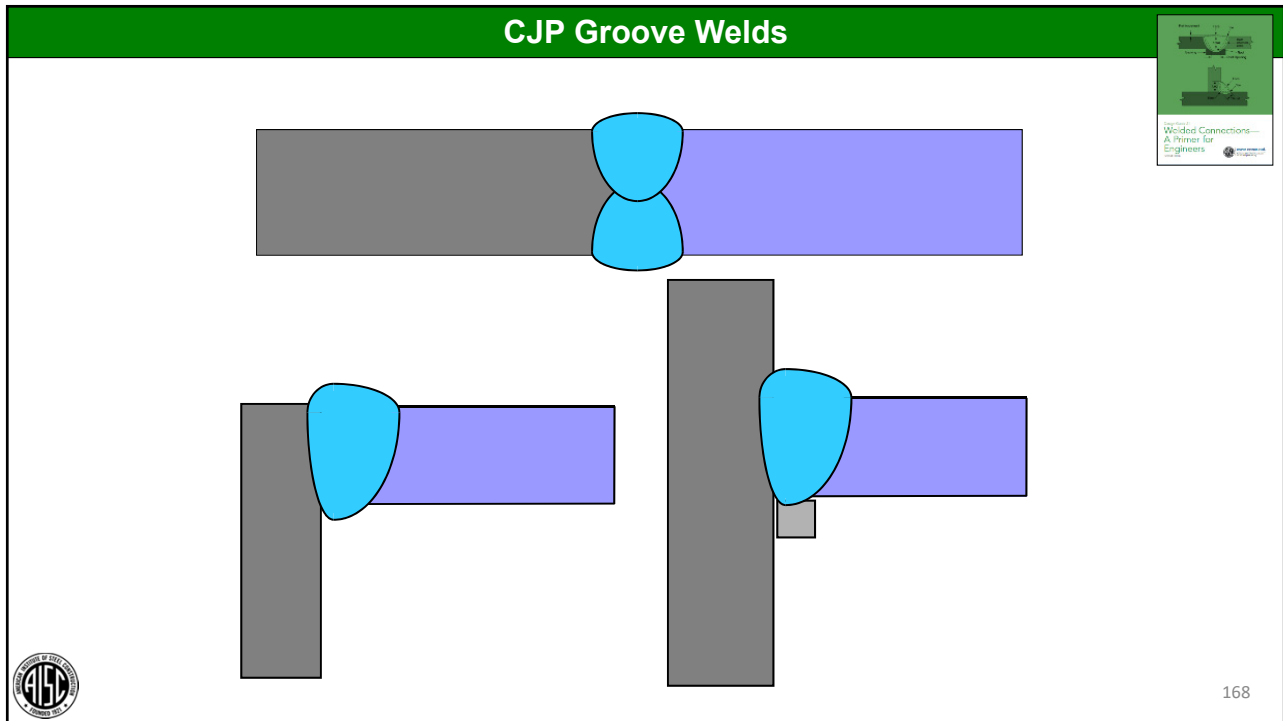
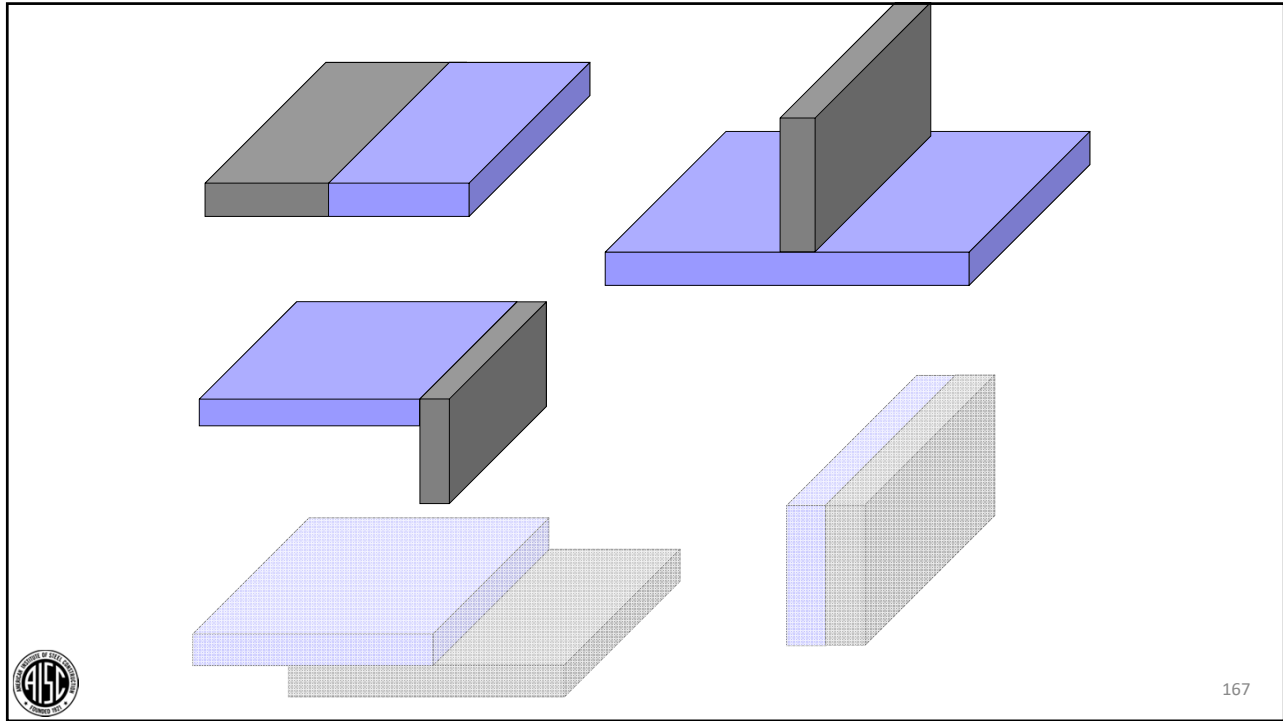
### Groove Welds

- Applied to butt, tee, corner joints
- CJP = full strength (for statically loaded connections)
- PJP = partial strength
- Tension vs. compression vs. shear

  
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### CJP Groove Welds

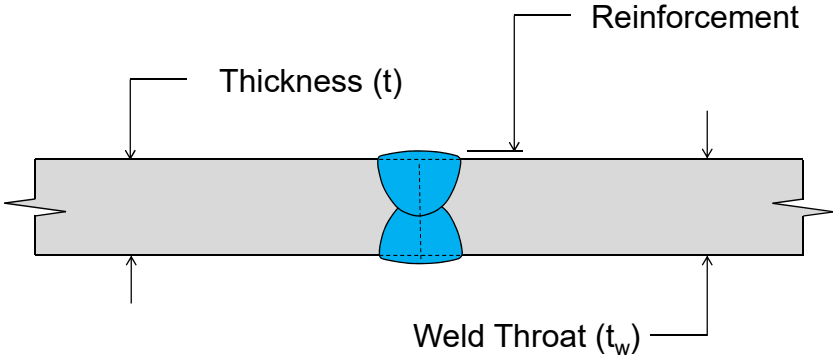
- Throat = plate thickness



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### CJP Groove Welds



#### Weld Throat Dimension ( $t_w$ )



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### CJP Groove Welds

- Throat = plate thickness
- No design calculations are required for statically loaded connections, when “matching” filler metal is used


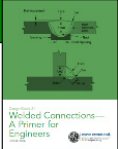
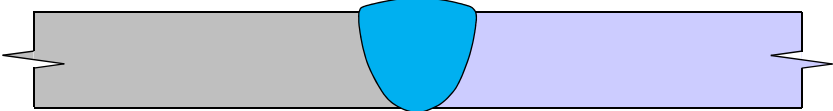


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### CJP Groove Welds

**Complete-Joint-Penetration Groove Weld (CJP)**

Single sided

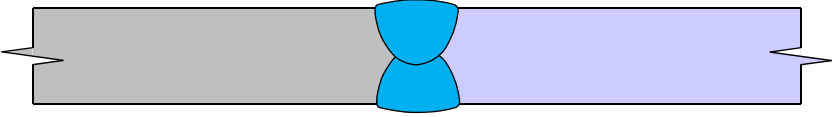


172



### CJP Groove Welds

**Complete-Joint-Penetration Groove Weld (CJP)**

Double sided



The diagram shows two horizontal bars, one grey on the left and one light blue on the right, joined at their ends. The joint is a double-sided groove weld, with two blue weld ripples meeting at the center. The welds penetrate the root of the groove from both sides. The bars have jagged ends on the far left and right, indicating they are part of a larger structure.

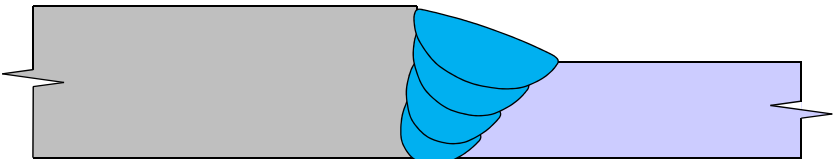


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### CJP Groove Welds

**Complete-Joint-Penetration Groove Weld (CJP)**

Two thicknesses




The diagram shows two horizontal bars, one grey on the left and one light blue on the right, joined at their ends. The joint is a two-thickness groove weld, with three blue weld ripples meeting at the center. The welds penetrate the root of the groove from both sides. The bars have jagged ends on the far left and right, indicating they are part of a larger structure.



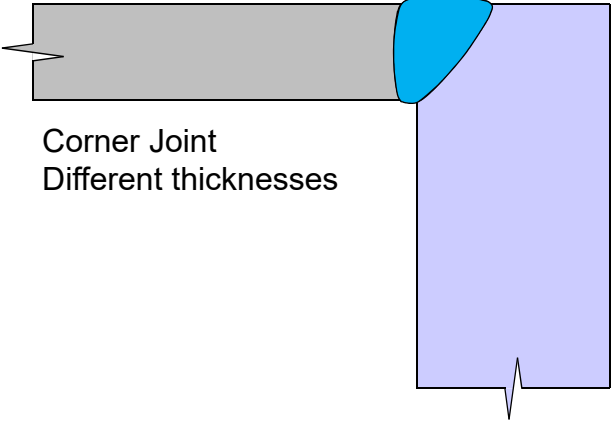
174

### CJP Groove Welds




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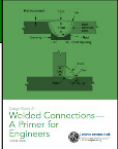
## Complete-Joint-Penetration Groove Weld (CJP)



Corner Joint  
Different thicknesses

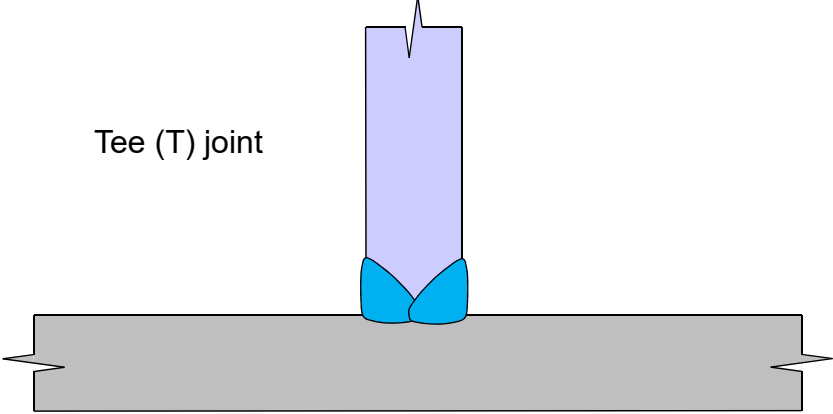
175

### CJP Groove Welds




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## Complete-Joint-Penetration Groove Weld (CJP)

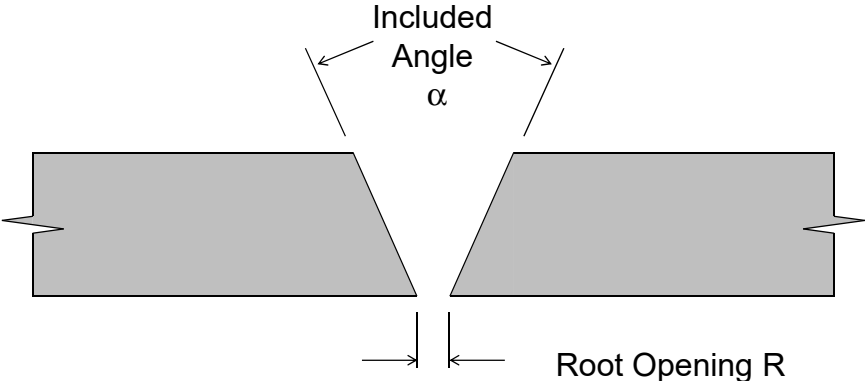


Tee (T) joint

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**CJP Groove Welds**

**Single Vee Groove Weld**



The diagram illustrates a single Vee groove weld between two steel plates. The included angle of the groove is labeled as  $\alpha$ . The root opening at the bottom of the groove is labeled as  $R$ . The plates are shown in gray with jagged ends indicating they are part of a larger assembly.


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**CJP Groove Welds**

**Square Groove**



The diagram illustrates a square groove weld between two steel plates. The groove is square-shaped, and the plates are shown in gray with jagged ends indicating they are part of a larger assembly.

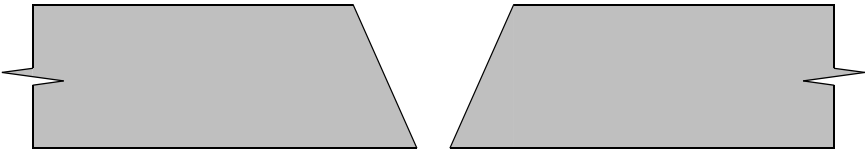
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**CJP Groove Welds**

**Single Vee Groove**



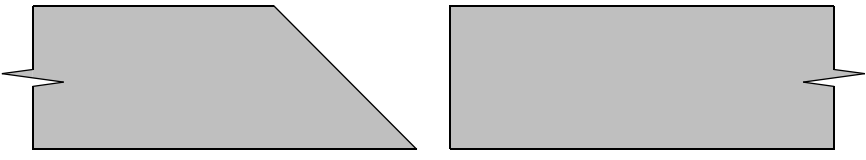
The diagram shows two gray rectangular plates positioned side-by-side. The top edges of both plates are beveled at a 45-degree angle, creating a V-shaped groove between them. A lightning bolt symbol on the left edge of the left plate and another on the right edge of the right plate indicate that the plates are to be welded together.





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**CJP Groove Welds**

**Single Bevel Groove**



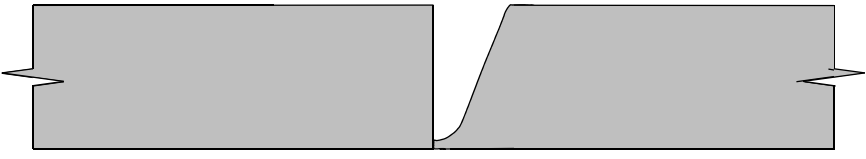
The diagram shows two gray rectangular plates positioned side-by-side. The top edge of the left plate is beveled at a 45-degree angle, while the top edge of the right plate is straight. A lightning bolt symbol on the left edge of the left plate and another on the right edge of the right plate indicate that the plates are to be welded together.





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**CJP Groove Welds**

**Single J Groove**

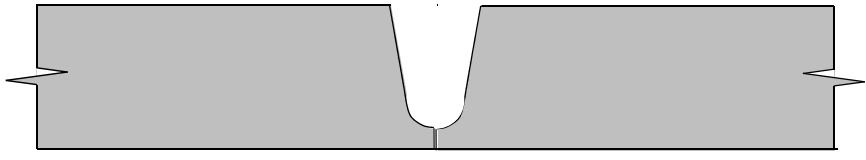




 

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**CJP Groove Welds**

**Single U Groove**

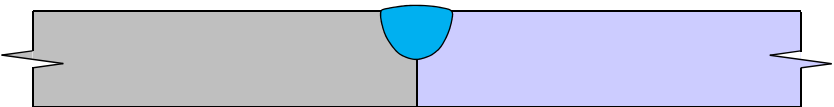



 

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**PJP Groove Welds**

**Single Sided PJP in Butt Joint**



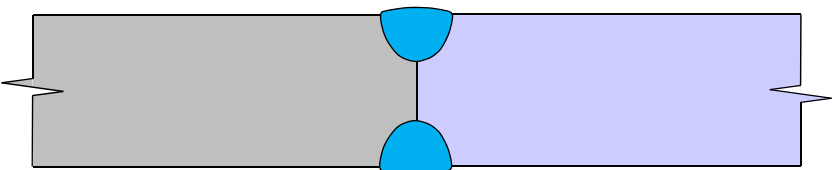
  
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**PJP Groove Welds**

**Double Sided PJP in Butt Joint**



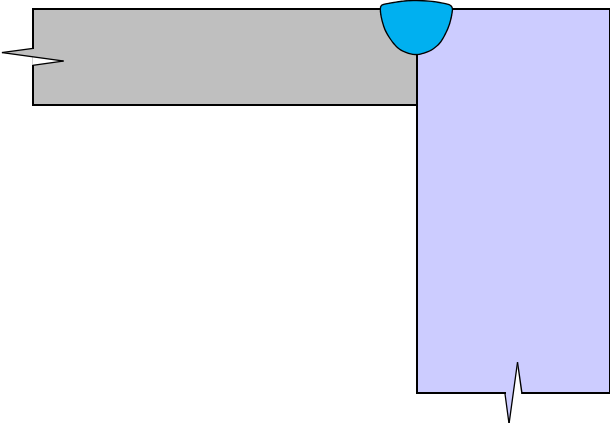
  
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### PJP Groove Welds

#### Single Sided PJP in Corner Joint



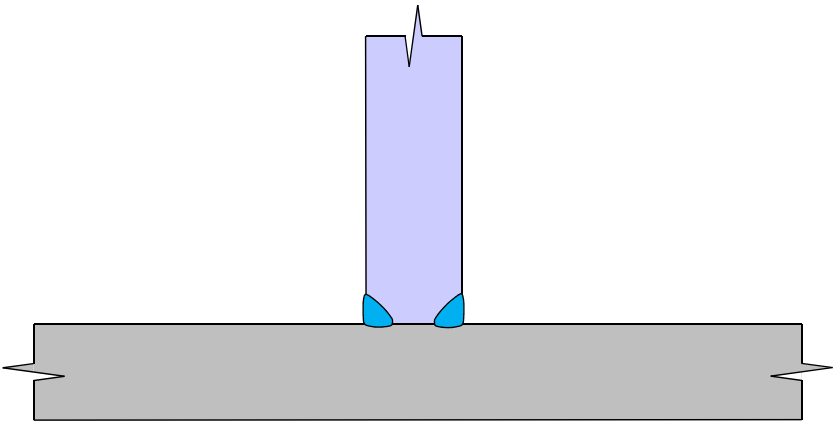
The diagram shows a corner joint where a horizontal grey member and a vertical purple member meet. A blue semi-circular weld is applied to the inner corner of the joint. Both members have jagged ends indicating they are part of a larger structure.





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### PJP Groove Welds

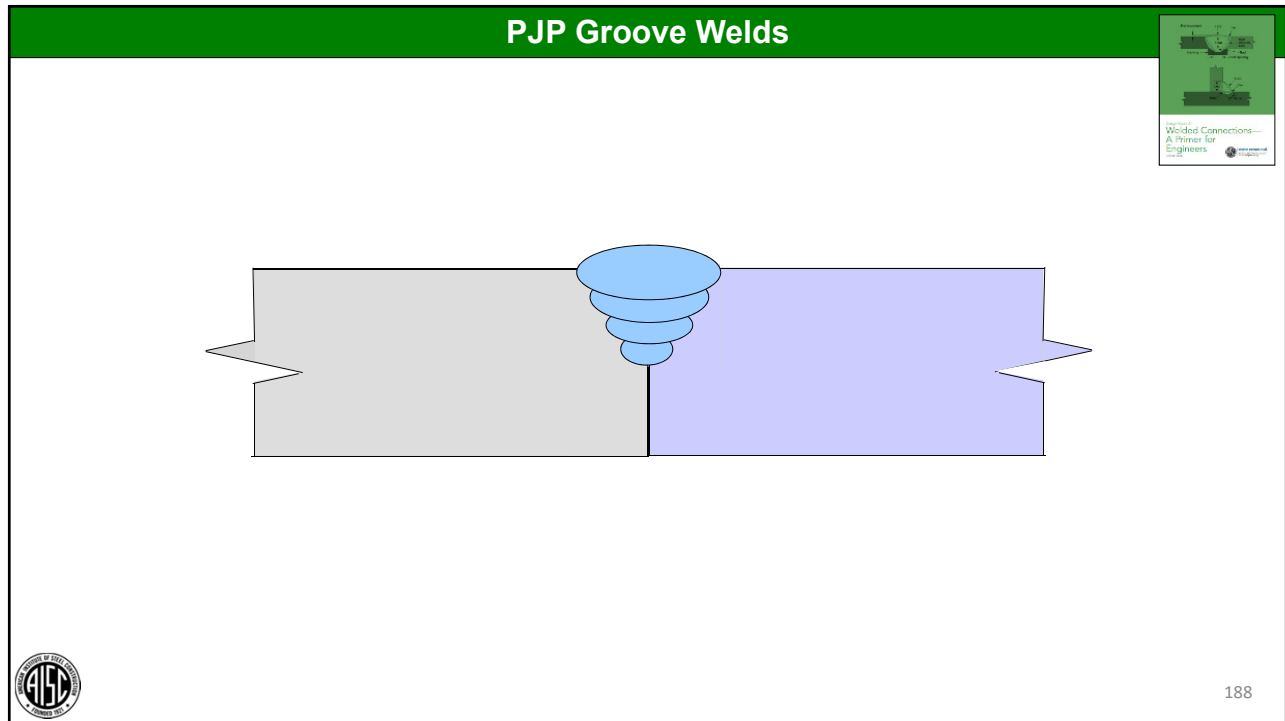
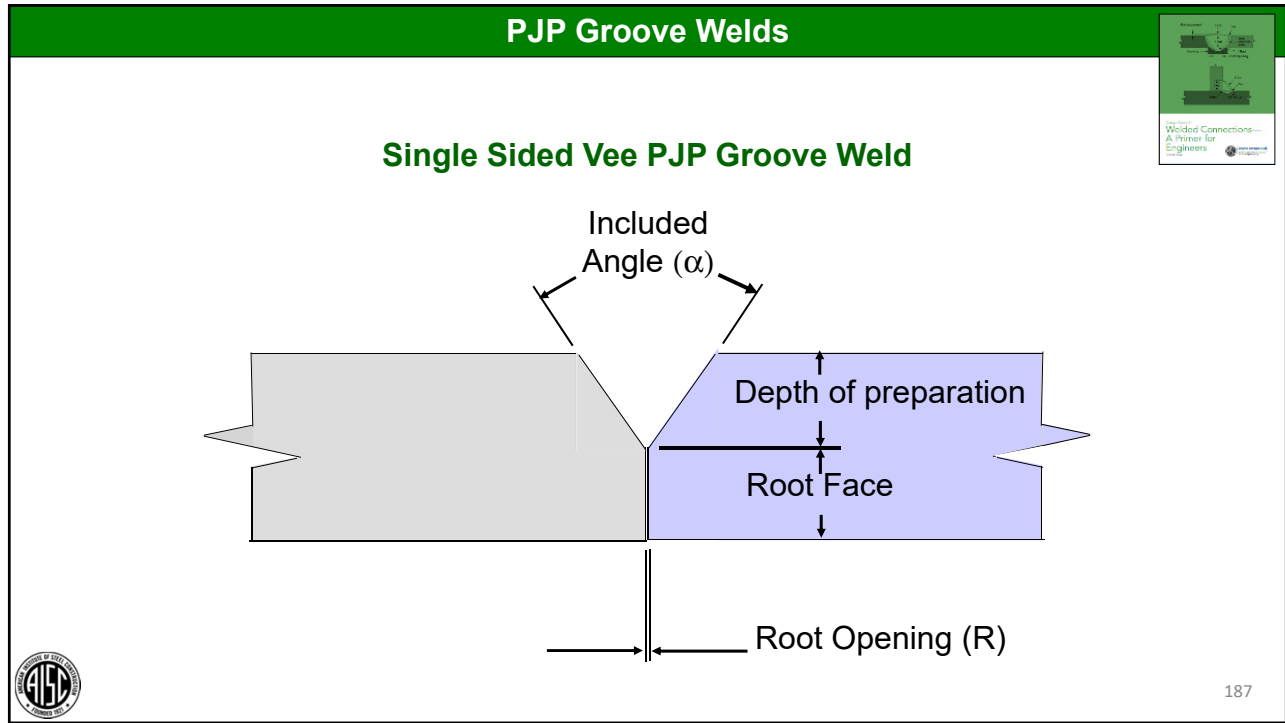
#### Double Sided PJP in Tee (T) Joint



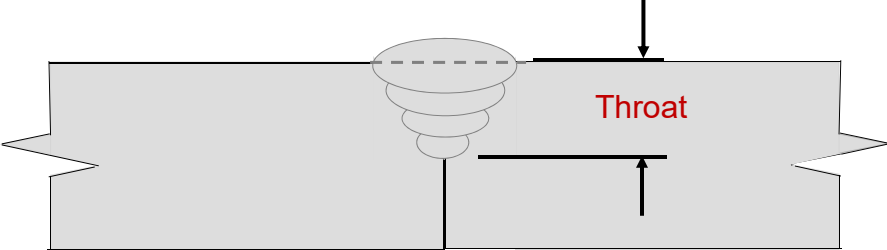
The diagram shows a Tee (T) joint where a vertical purple member is attached to the top surface of a horizontal grey member. Two blue semi-circular welds are applied, one on each side of the vertical member's stem, connecting it to the horizontal member's top flange. Both members have jagged ends indicating they are part of a larger structure.





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### PJP Groove Welds





The diagram illustrates a PJP Groove Weld. It shows two plates joined by a groove weld. The throat is the distance from the root of the groove to the face of the weld. The word "Throat" is written in red, with two horizontal arrows indicating the measurement. A vertical arrow points down to the top surface of the weld, and another vertical arrow points up to the bottom surface of the groove. The weld is shown in a cross-sectional view with a dashed line indicating the root of the groove.



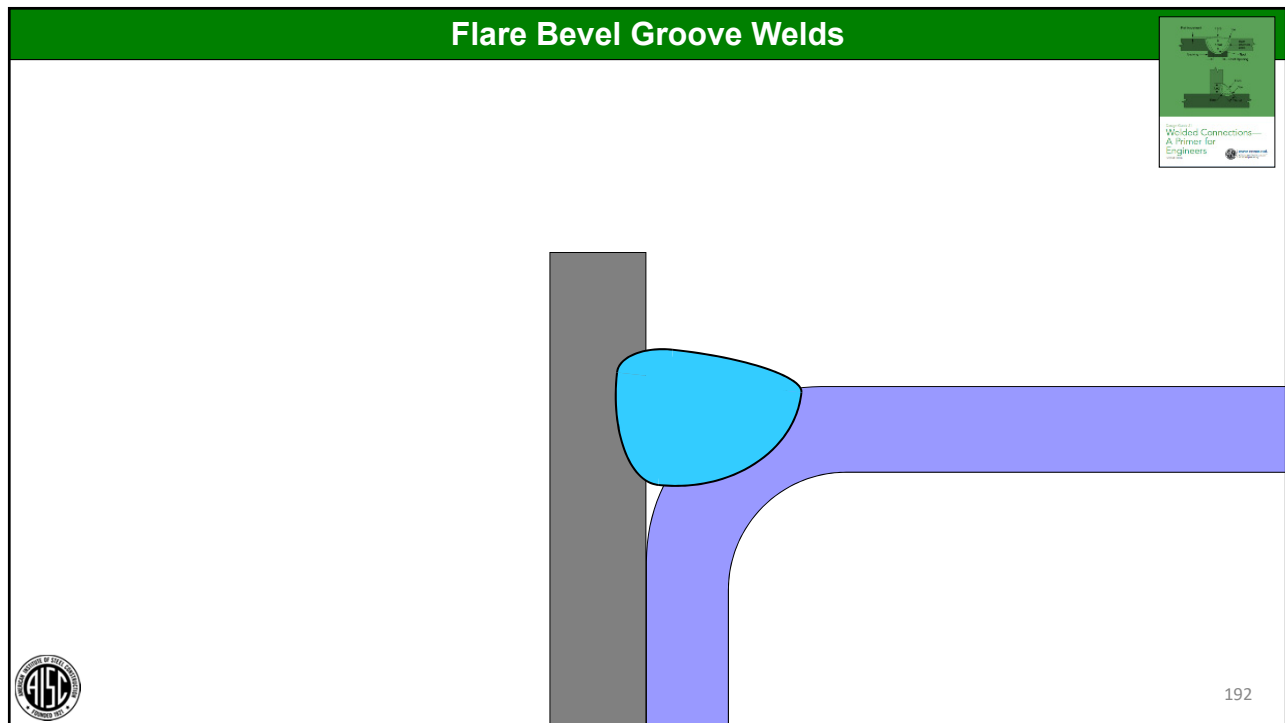
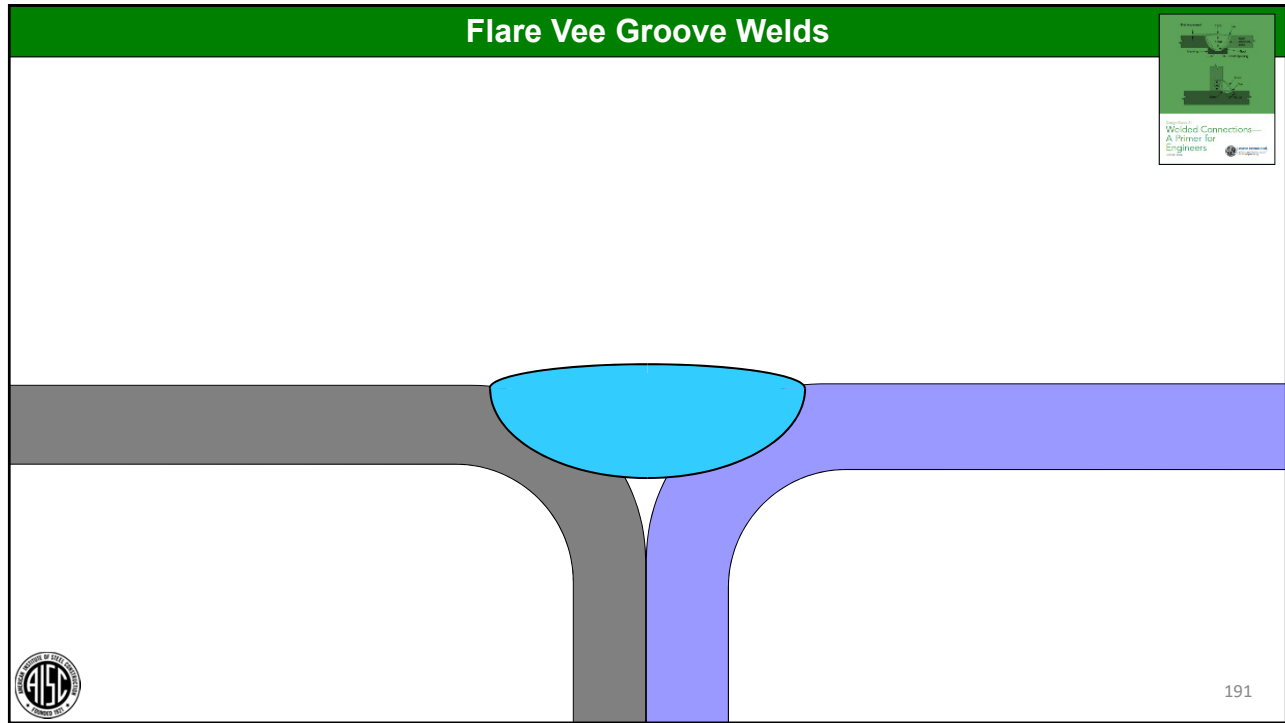
189

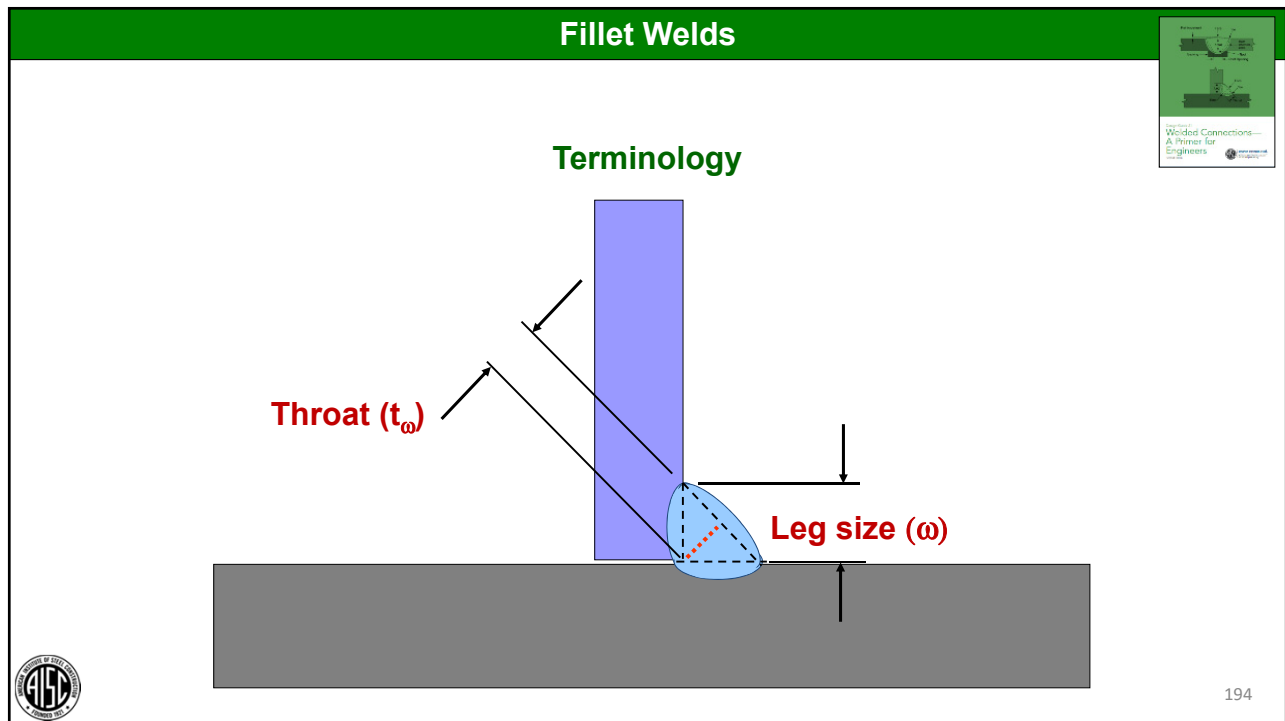
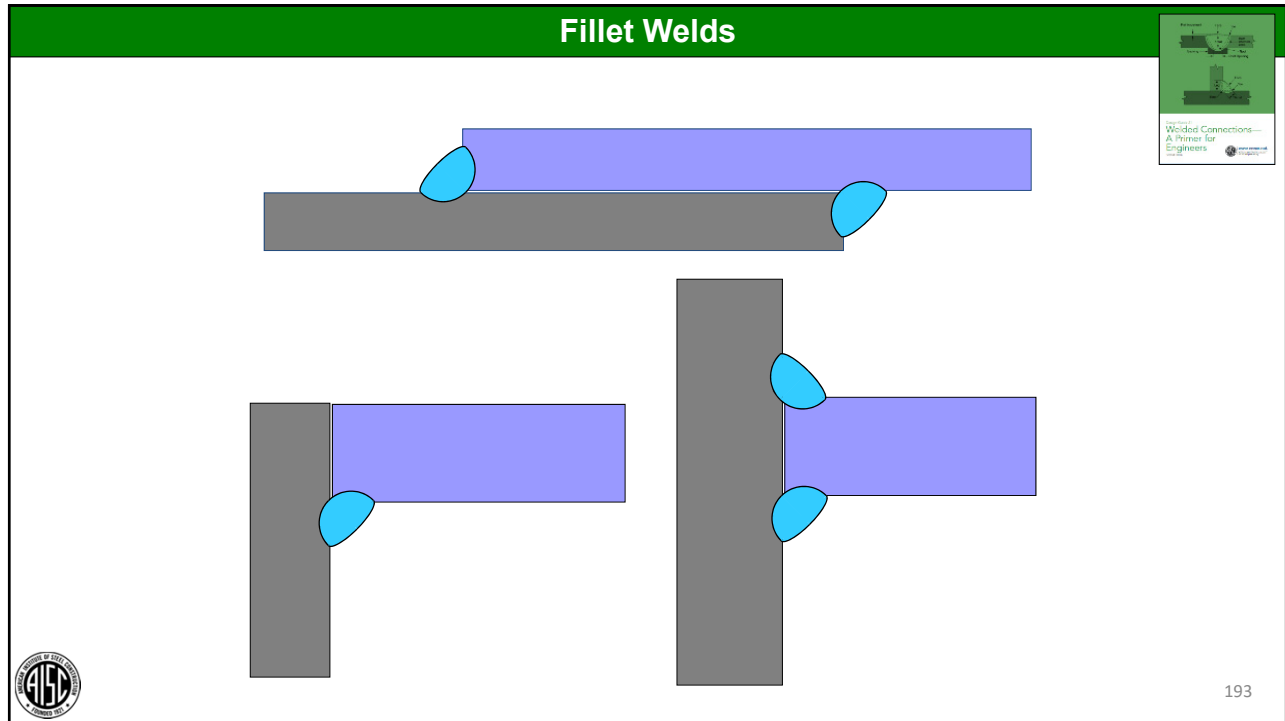
### PJP Groove Welds

- Throat < plate thickness
- Must determine throat



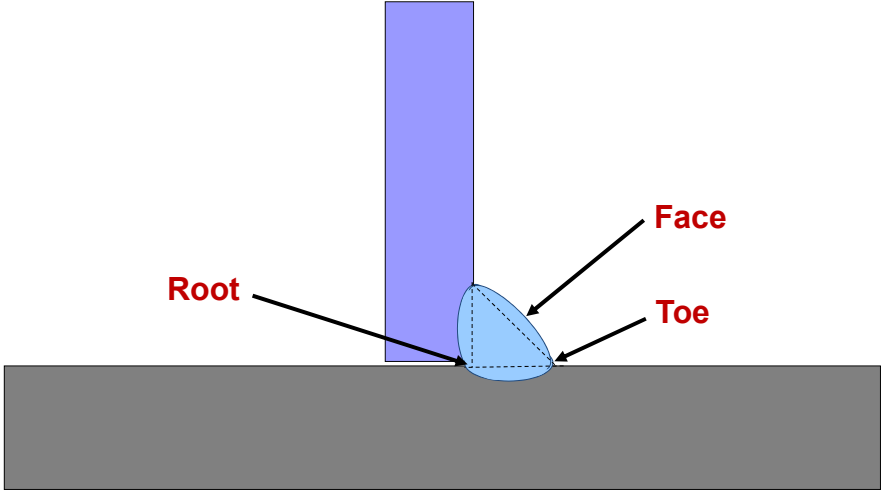
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### Fillet Welds

**Terminology**



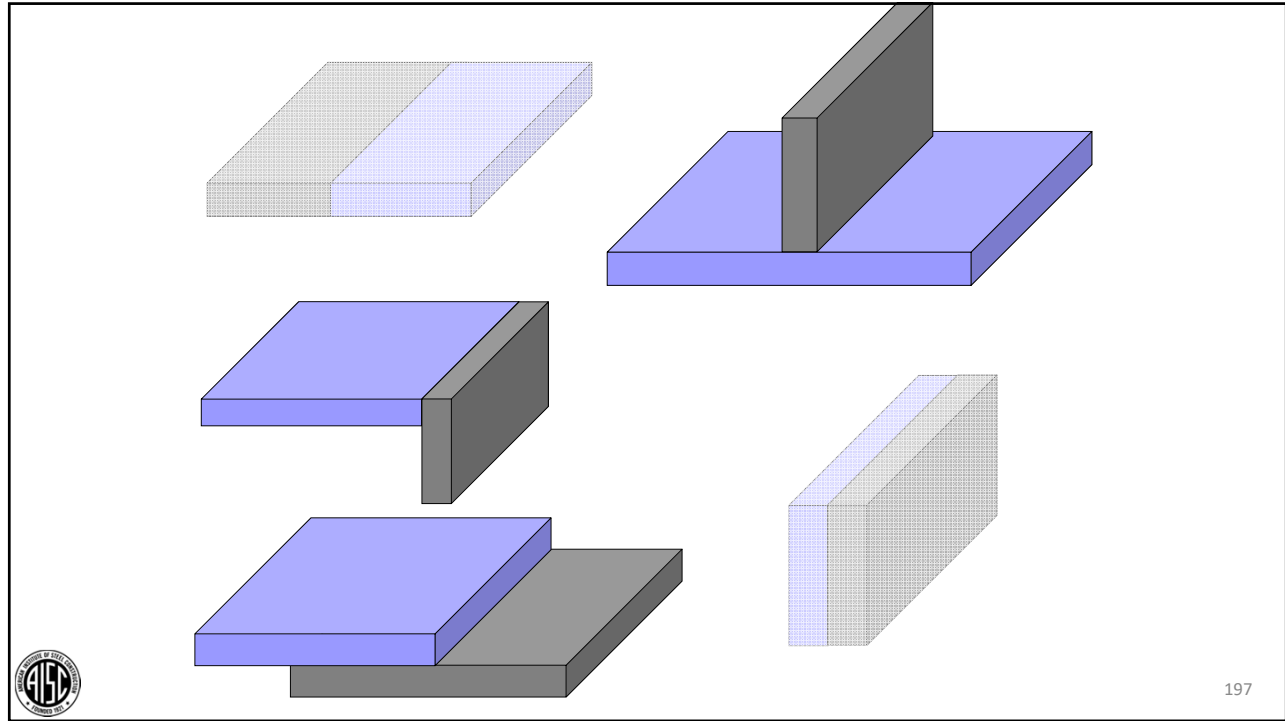
The diagram illustrates a fillet weld joint. A vertical blue bar is attached to a horizontal grey base. The weld is shown in a cross-section, with a dashed line indicating the root. The top surface of the weld is labeled 'Face', and the bottom surface is labeled 'Root'. The edges of the weld are labeled 'Toe'.

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### Fillet Welds

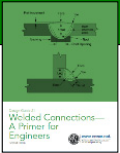
- Applied to tee, corner, lap joints

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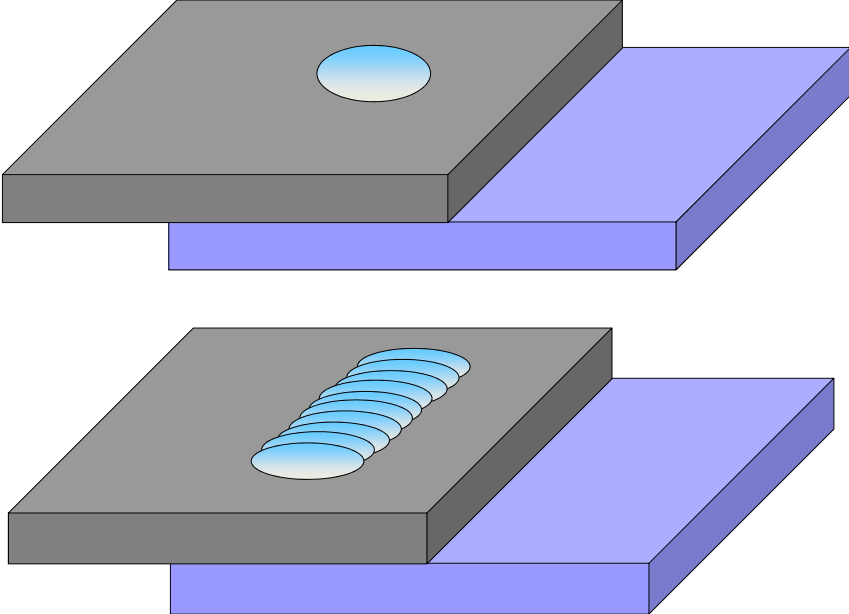
### Fillet Welds

- Applied to tee, corner, lap joints
- Specify leg (throat) dimension
- Specify length

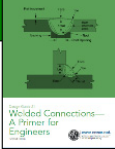



The AISC logo is in the bottom left corner, and the number 198 is in the bottom right corner.

### Plug and Slot Welds





The diagram illustrates two stages of a plug and slot weld. In the top stage, a grey plate with a circular hole is positioned above a blue plate. In the bottom stage, the hole is filled with a series of overlapping welds, creating a slot weld.



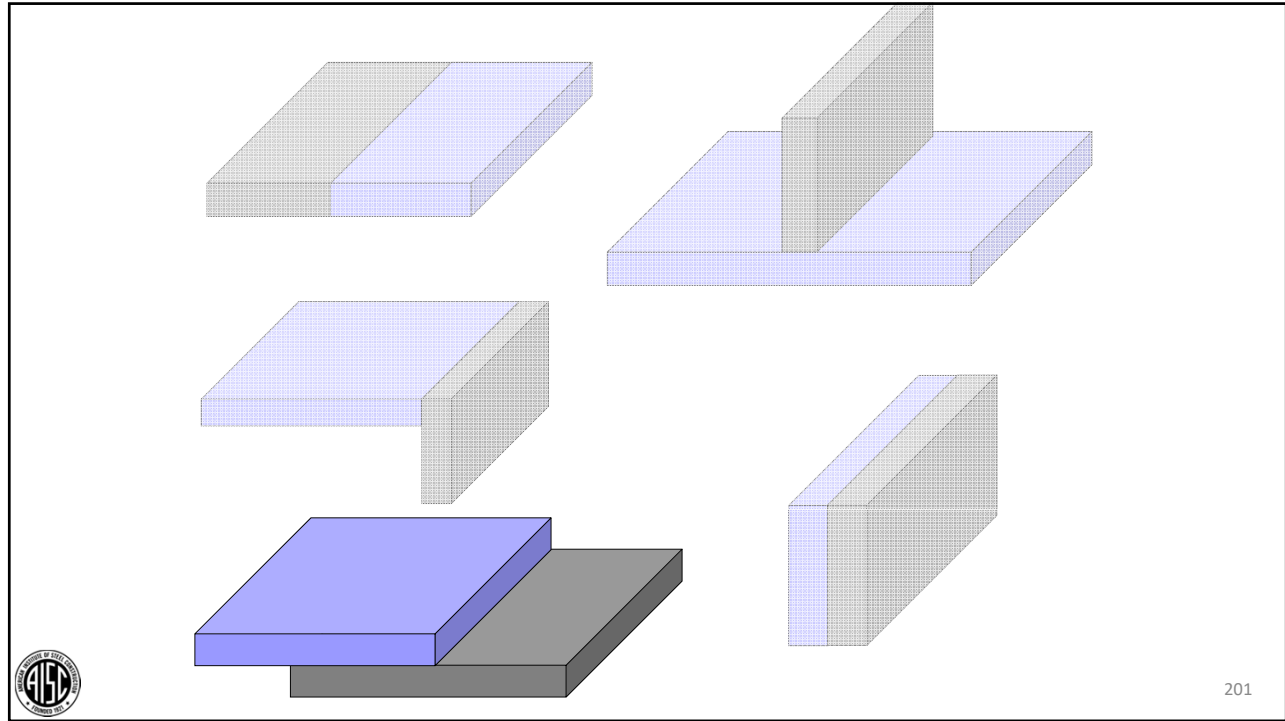
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### Plug and Slot Welds

- Applied to lap joints




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### Plug and Slot Welds

- Applied to lap joints
- Not often applied in structures
- Restricted capacity in cyclically loaded structures



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## WELDED CONNECTION BASICS

### Outline

- Applicable Codes
- Arc Welding Processes – Overview
- Welding and Thermal Cutting Processes
- Joints and Weld Types



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# Thank you!

**AISC** | Questions?



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## Individual Session Registrants

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### PDH Certificates

- You will receive an email on how to report attendance from:  
[registration@aisc.org](mailto:registration@aisc.org).
- Be on the lookout: Check your spam filter! Check your junk folder!
- Completely fill out online form. Don't forget to check the boxes next to each attendee's name!



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## Individual Session Registrants

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### PDH Certificates

- Reporting site (URL will be provided in the forthcoming email).
- Username: Same as AISC website username.
- Password: Same as AISC website password.



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## 8-Session Registrants

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### PDH Certificates

One certificate will be issued at the conclusion of all 8 sessions.



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## 8-Session Registrants

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### Access to the quiz

Information for accessing the quiz will be emailed to you by Thursday. It will contain a link to access the quiz. EMAIL COMES FROM [NIGHTSCHOOL@AISC.ORG](mailto:NIGHTSCHOOL@AISC.ORG).

### Quiz and attendance records

Posted Thursday mornings. [www.aisc.org/nightschool](http://www.aisc.org/nightschool) -- Click on Current Course Details.

### Reasons for quiz

- EEU – You must take all quizzes and the final exam to receive EEU.
- PDHs – If you watch a recorded session, you must pass quiz for PDHs.
- 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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## 8-Session Registrants

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### Access to the recording

Information for accessing the recording will be emailed to you by Thursday. The recording will be available for four weeks. (For 8-session registrants only.) EMAIL COMES FROM [NIGHTSCHOOL@AISC.ORG](mailto:NIGHTSCHOOL@AISC.ORG).

### PDHs via recording

If you watch a recorded session, you must take *and pass* the quiz for PDHs.



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## 8-Session Registrants

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### Night School Resources

Find all your handouts, quizzes and quiz scores, recording access, and attendance information all in one place!



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## 8-Session Registrants

### Night School Resources

Go to [www.aisc.org](http://www.aisc.org) and sign in.



#### Login

If you're an existing customer, please enter your username and password.

<p><b>USERNAME</b></p> <input type="text" value="Enter your username"/>	<p><b>DON'T HAVE AN ACCOUNT?</b></p> <p>My AISC allows you to access Engineering Journal articles and Design Guides you have downloaded from the bookstore.</p> <p><b>REGISTER NOW</b></p>
<p><b>PASSWORD</b></p> <input type="text" value="Enter your password"/>	
<input type="checkbox"/> Remember Me	



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## 8-Session Registrants

### Night School Resources

Go to [www.aisc.org](http://www.aisc.org) and sign in.

<p><b>IN THIS SECTION</b></p> <ul style="list-style-type: none"><li>Edit Profile</li><li>My Downloads</li><li>My Pending Quizzes</li><li>My Events</li><li>Order History</li><li>Course History</li><li><b>Course Resources</b></li></ul>	<p><b>MyAISC</b></p> <hr/> <p><b>MY PROFILE</b></p> <p>Update your contact and address information.</p> <p><b>EDIT PROFILE</b></p> <hr/> <p><b>MY PURCHASED DOWNLOADS</b></p> <p>Access articles and documents that you have purchased.</p> <p><b>VIEW DOWNLOADS</b></p> <hr/> <p><b>MY COURSE RESOURCES</b></p> <p>View online resources for Night School and Live Webinar package registrations.</p> <p><b>VIEW RESOURCES</b></p>
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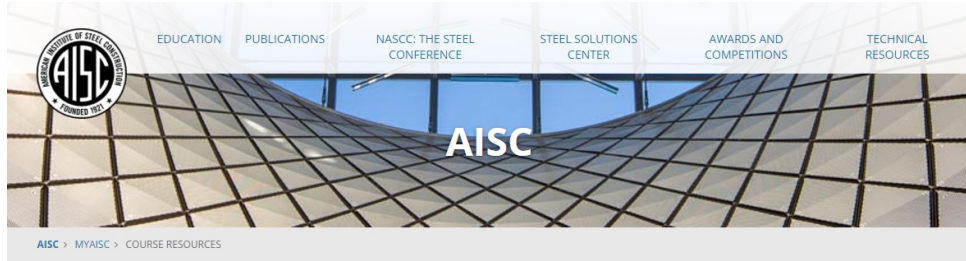


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# 8-Session Registrants

## 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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# 8-Session Registrants

## 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	<a href="#">Handouts</a>	<a href="#">View</a> Passcode: NS13DSN	Pass Score: 80	Pending
NS13 - Economic Considerations	2/6/2017 7:00:00 PM	<a href="#">Handouts</a>	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	<a href="#">Handouts</a>	Available 02/15/2017 5pm EST	Available 02/15/2017 5pm EST	Pending
NS13 - Preliminary Design Procedures	2/27/2017 7:00:00 PM	<a href="#">Handouts</a>	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	<a href="#">Handouts</a>	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	<a href="#">Handouts</a>	Available 03/15/2017 5pm EST	Available 03/15/2017 5pm EST	Pending
NS13 - Transfer Crane Girder & Longitudinal Bldg Bracing Dgn	3/27/2017 7:00:00 PM	<a href="#">Handouts</a>	Available 03/29/2017 5pm EST	Available 03/29/2017 5pm EST	Pending
NS13 - Building Envelope and Bracing Design	4/3/2017 7:00:00 PM	<a href="#">Handouts</a>	Available 04/05/2017 5pm EST	Available 04/05/2017 5pm EST	Pending



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## 8-Session Registrants

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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](http://www.aisc.org/nightschool21). Scroll down to Quiz and Attendance records.
  - Updated on Thursday mornings.



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## 8-Session Registrants

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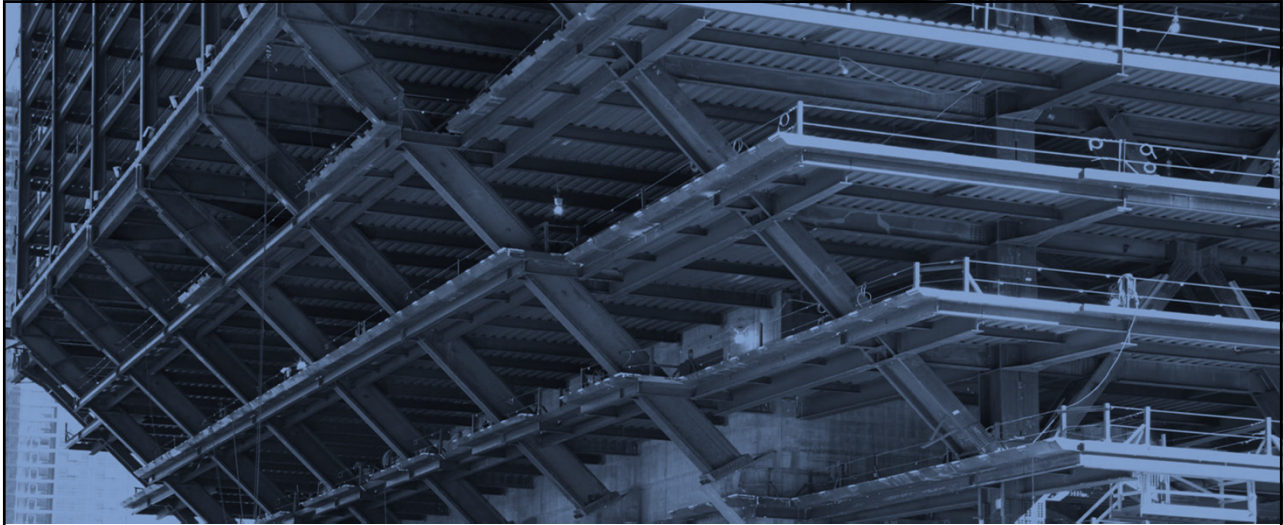
### Night School Resources

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



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