Arc Welding Capabilities at EWI

November 29, 2012

Nick Kapustka

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Overview

- **Arc welding team**
- **Capabilities list**
- **Arc welding basic overview**
- **Arc welding processes**
  - Core processes
  - Process variations / other processes
- **Capability demonstrations**

Arc Welding Team

Harvey Castner
Program Manager
Shipbuilding, Heavy Manf., Aerospace
Former VP of Government Programs
Former Director of NJC
35+ Technical Papers
State of Ohio PE
IIW International Welding Engineer
American Welding Society Fellow

Randy Dull
Principal Engineer
Auto & Heavy Manf. Teams
AWS Committee Member (4)
AWS Senior CWI
AWS Certified Welding Engineer
ASNT ACCP Level II (VT)
State of Ohio PE
IIW International Welding Engineer
GTAW, PAW, GMAW, FCAW, SAW
SS, CS, Ni, Cu, Ti, Al, etc.
Distortion Control
Codes & Standards

Arc Welding Team

Dr. Ian Harris
Technology Leader
Director of AMC
Aerospace, Processes
IIW Commission Expert / Chair (3)
AWS Handbook Vol. 9 Chair
AWS D17.1 Committee
ASTM F42 Group Member
ASM Metals Handbook Vol. 6 Contributor
Non-Ferrous
GTAW, PAW, GMAW, HLAW

Nick Kapustka
Applications Engineer
Aerospace Team
GMAW, GTAW, PAW, CMT
Thermal Cutting
Non-Ferrous Alloys, AHSS
AWS CWI
Codes & Standards

Steve Massey
Engineering Manager
Automation Expert
AWS D16 Rob. & Auto. Committee
GMAW, FCAW, GTAW, PAW, SAW, T-GMAW
CS, SS, Al, Ni, Cu
AWS CWI

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Arc Welding Team

Marc Purslow
Applications Engineer
Arc Welding Invention Coach
Processes, Shipbuilding, Heavy Manf.
GMAW, SAW, FCAW, T-GMAW,
CS, SS, Al
AWS CWI

Adam Uziel
Applications Engineer
Aerospace Team
GTAW, PAW, GMAW
Orbital Welding
SS, Ni, Ti, Al, Coated Steels

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Capabilities

- **Project work**
  - CSP, GTH, GN5, CSL, GSP, GTO, IRD, etc.
  - Processes
    - GTAW, GMAW, FCAW, PAW, SMAW, SAW, CMT, CSC, T-GMAW, T-SAW, OFC, A-CAC, PAC, etc..
  - Expert witness, onsite assistance, codes & standards interpretation, automation expertise, fume generation, etc.
- **Membership**
  - Inquiries, membership sales, design reviews
- **Sales**
  - Internal sales teams, sales calls, project development
- **Technical leadership**
  - AWS, IIW, ASME, AMS, ASME committees
  - Peer reviewed publications, conference presentations

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Arc Welding Basic Theory

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Arc Welding Overview

- **All arc welding uses an electric arc to produce a weld by melting the base material and filler metal, if applicable**
- **Three main differences between arc welding processes:**
  - How the welding arc is initiated and controlled
    - Consumable electrodes
      - Melt and transfer to the weld for filling joint
      - The electrode is the filler metal
    - Non-consumable electrodes
      - Provide electrode for arc and generally **do not melt**
        - Tungsten or Carbon
      - Filler material, when used, is provided separately
  - How the molten metal weld pool is shielded
  - Whether filler metal is used and how it is supplied to the molten weld pool

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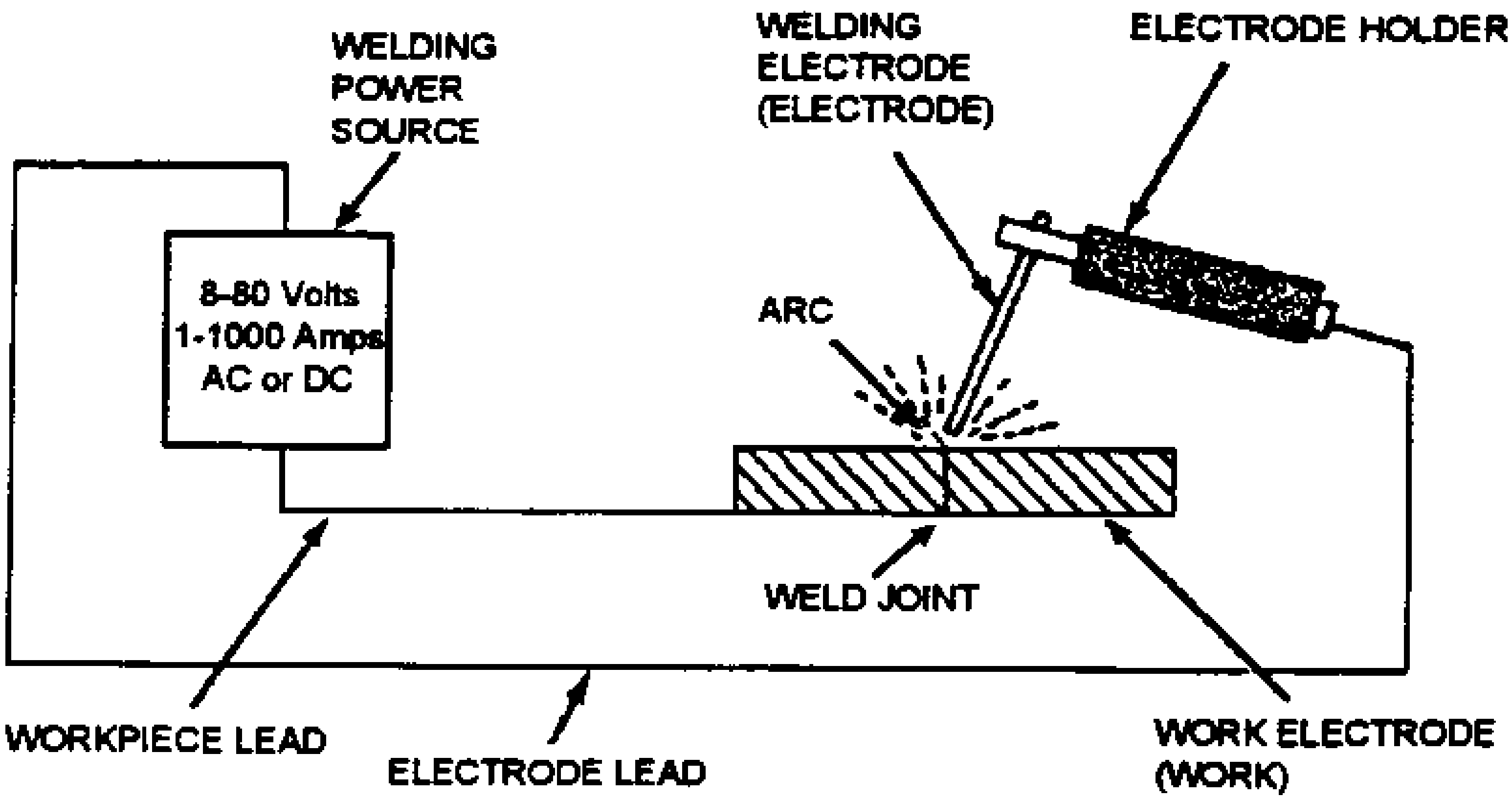
Basic Arc Welding Circuit



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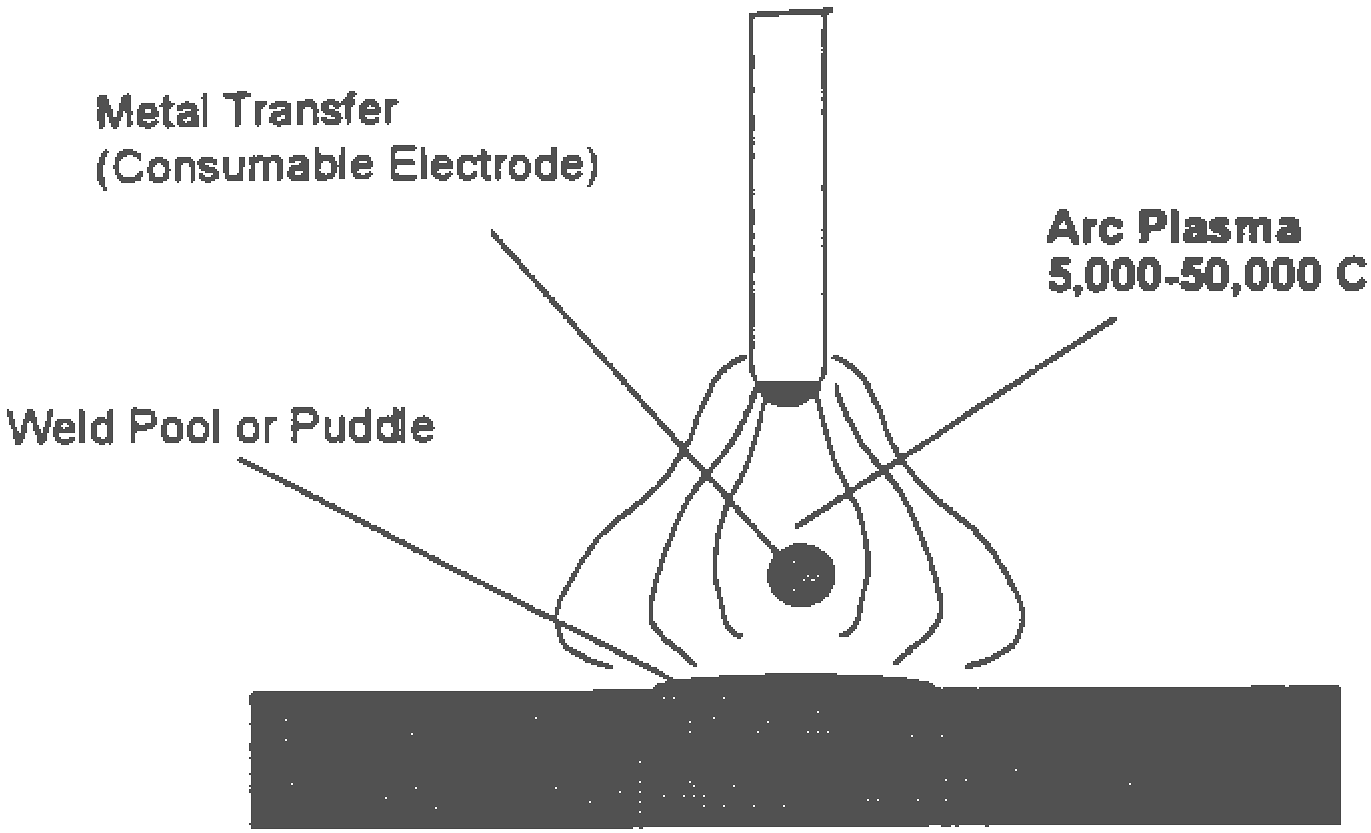
Welding Arc



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Primary Operating Parameters

- Arc voltage / arc length
- Arc current
- Electrode feed rate (consumable)
- Welding travel speed
- Electrical polarity

Need for Atmospheric Shielding

- **Molten metal reacts with the atmosphere to form oxides and nitrides**
  - Porosity will result if the weld pool is exposed to the atmosphere
  - Metallurgical changes can occur
  - Weld mechanical properties are generally reduced
- **The weld area should be free of dirt, grease, paint, scale, and other foreign objects to ensure weld quality**
  - Fluxes and shielding gasses are not designed to scavenge these components from the solidifying weld metal

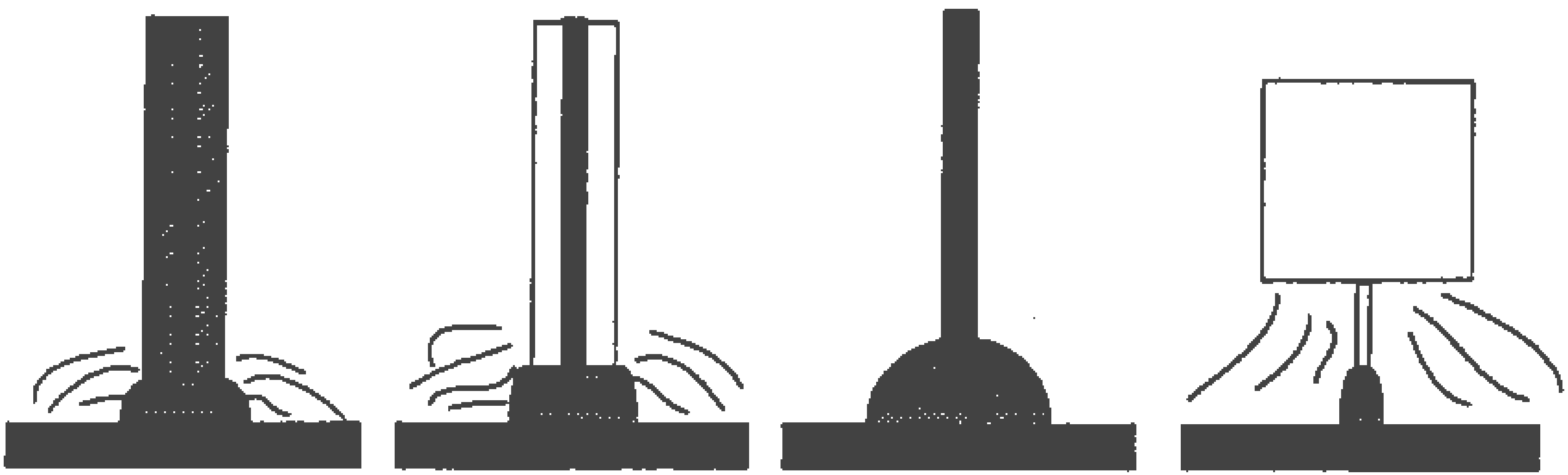
Flux Shielding

- Decomposes and provides a gas to shield the arc and prevent atmospheric contamination of the molten filler metal and weld pool
- Provides scavengers, deoxidizers, and fluxing agents to cleanse the weld and prevent excessive grain growth in the weld metal
- Establishes the electrical characteristics of the electrode
- Provides a slag blanket to protect the hot weld bead from the air and can enhance the mechanical properties, weld bead shape and surface cleanliness
- Provides a means of adding alloying elements to change the mechanical properties of the weld metal

Gas Shielding

- **Purges the weld area to shield the molten metal from the atmosphere**
- **Argon is the most common inert gas**
- **CO_2 is sometimes used**
  - Less expensive
  - Similar to gases produced from fluxes
- **CO_2 and O_2 are commonly mixed with argon**
  - Promotes oxidation to stabilize the arc and metal transfer
  - Improves weld bead wetting
- **H_2 can be added to increase arc heat in some cases**
- **Helium may also be used to increase arc heat**
- **Requires addition of deoxidizers to filler materials**

Sources of Shielding



Covered Electrode	Flux Cored	Submerged Arc	Gas Shielded
Covering forms CO_2 & slag	Core forms gasses & slag	Flux shields arc	Ar, CO_2 & mixes

Arc Welding Processes

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Arc Welding Processes

Core Processes

- **SMAW, MMAW**
  - “Stick” welding
- **GTAW**
  - “TIG” welding
- **GMAW**
  - “MIG” welding
- **FCAW**
- **SAW**
- **PAW**

Process Variations

- **T-GMAW**
  - NG-T GMAW
- **Strip cladding**
- **RWF-GMAW**
- **PAC-G**
- **CAG**
- **Hybrid welding**
  - Hybrid laser arc welding
  - Hybrid GMAW / PAW welding

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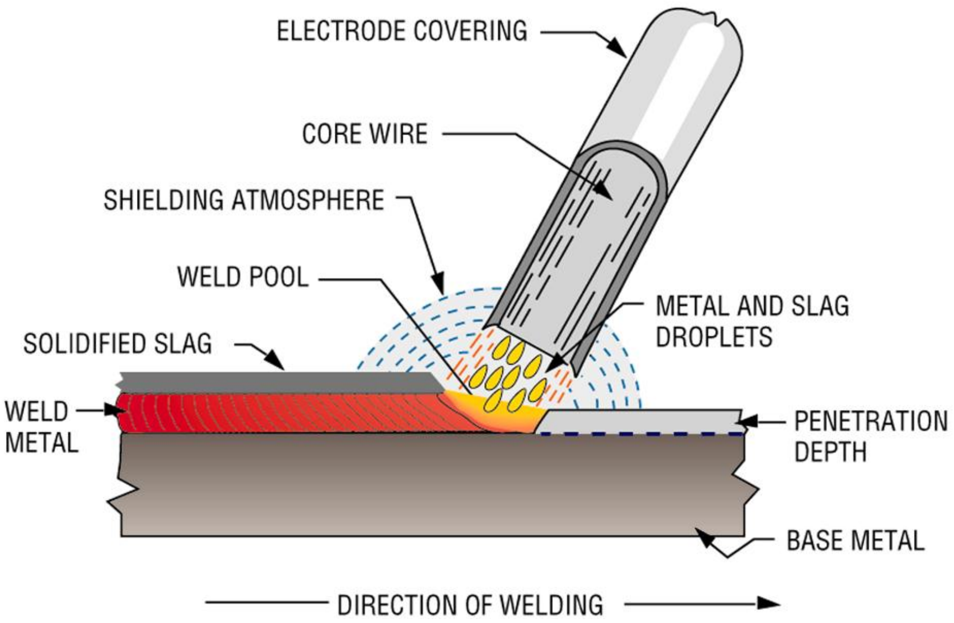
Shielded Metal Arc Welding (SMAW)

- An arc welding process in which coalescence of metals is produced by heat from an electric arc that is maintained between the tip of a covered electrode and the surface of the base metal in the joint being welded



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SMAW

Medium arc length

Long arc length

Electrode Covering

- **The electrode covering has numerous functions but depends on the type**
  - Provides a gas cover to shield the arc and prevent excessive atmospheric contamination of the molten filler metal
  - Provides scavengers, deoxidizers, and fluxing agents to cleanse the weld and (potentially) prevent excessive grain growth in the weld metal
  - Establishes the electrical characteristics of the arc
  - Provides a slag blanket to protect the hot weld metal from the air and enhance the mechanical properties, bead shape, and surface cleanliness of the weld metal
  - Provides a means of adding alloying elements to weld metal to alter the microstructure and mechanical properties of the weld metal

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SMAW Advantages

- Most widely used process worldwide – broad skill-base
- Equipment and consumable costs are low – “low-tech”
- Extremely versatile
- Easily implemented for field welding
- Relatively adaptable to part fit-up variances
  - Operator skill is required

Underwater welding with SMAW

SMAW Disadvantages

- Requires relatively high-skilled manual welder
- Deposition rate is low
- Defect rates are relatively high
- Fume generation rates are high

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Gas Tungsten Arc Welding (GTAW)

- An arc is formed between a nonconsumable (tungsten) electrode and the workpiece electrode
- The energy from the arc melts the workpiece, and the molten metal solidifies to form a weld bead
- Shielding gas provides the medium for arc formation and protects the molten pool and electrode from oxidation

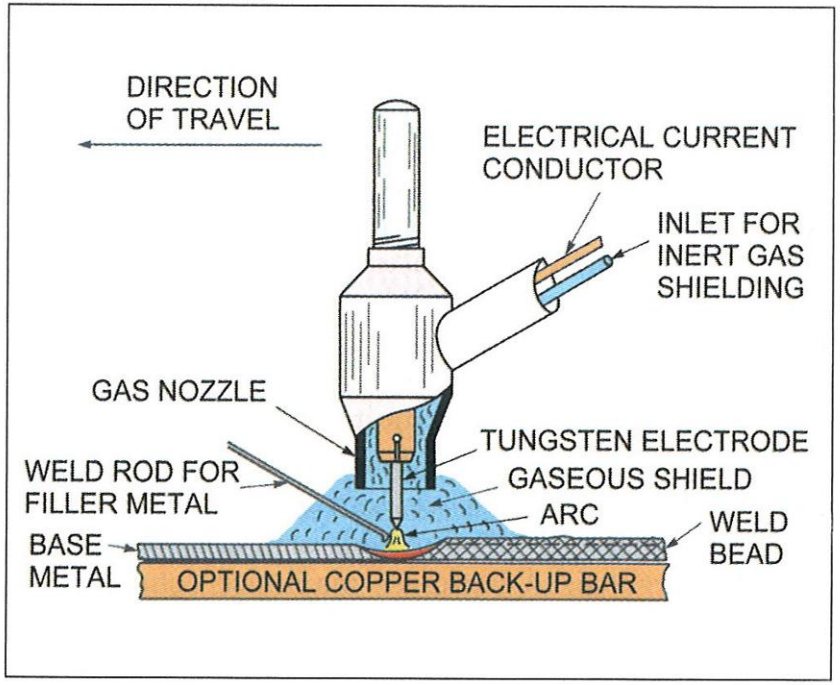

Figure 1.4—Schematic Representation of Gas Tungsten Arc Welding

Source: AWS Handbook 9th ed. Vol. 1

GTAW Process Terminology

- Gas Tungsten Arc Welding: GTAW - AWS Definition
- Tungsten Inert Gas Welding: TIG - Europe and worldwide, also often used in the U.S.
- Wolfram Inert Gas Welding: WIG - Used in Germany
- Heliarc: Original name in U.S.
- Argonarc: Original name in U.K.

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GTAW Pros & Cons

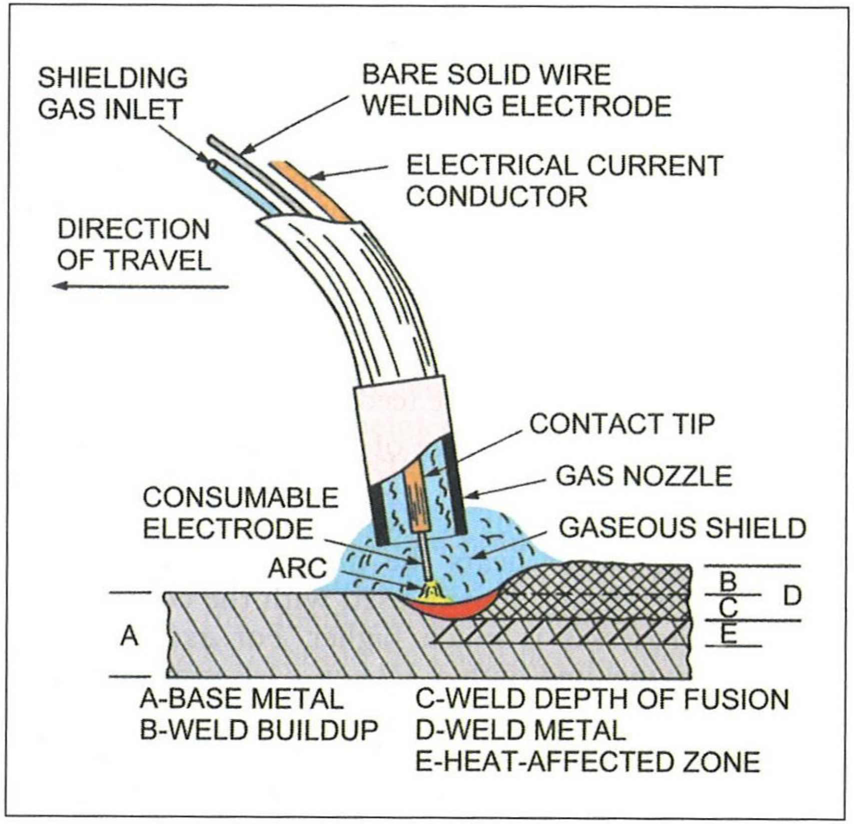
Advantages

- Can be used in all positions
- Provides excellent control on thin and intricate parts
- No slag or spatter; post weld cleaning often not required
- Use with or without filler wire
- Welds almost all metals
- Precise control of weld heat
- High quality

Disadvantages

- Lower deposition rates than consumable electrode processes
- Higher skill level than consumable electrode processes
- Requires high gas purity, low tolerance for drafty environments
- Low tolerance to contaminants
- Generally requires arc starting system
- Requires precise positioning of electrode

Gas Metal Arc Welding



Source: Adapted from Linnert, G. E., 1994, *Welding Metallurgy*, 4th ed., Miami: American Welding Society, Figure 6.12.

Figure 1.6—Schematic Representation of Gas Metal Arc Welding

Source: AWS Handbook 9th ed. Vol. 1

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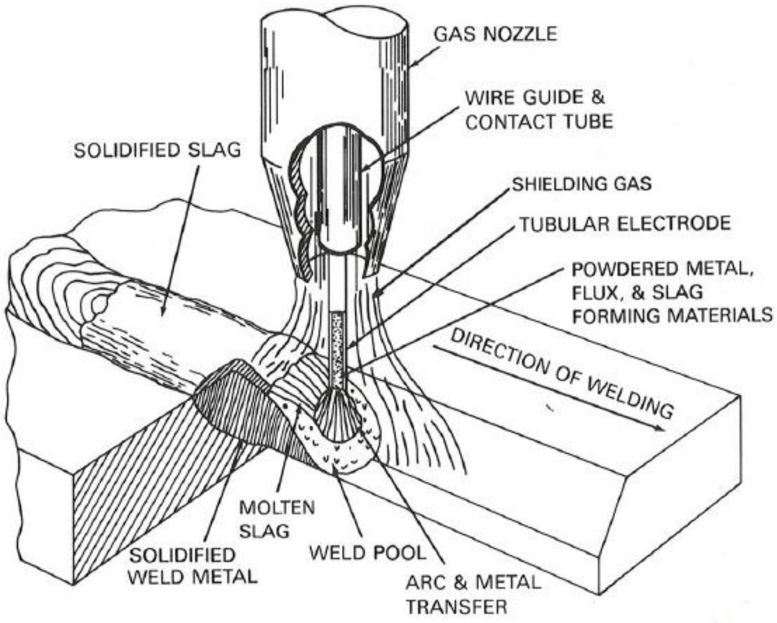
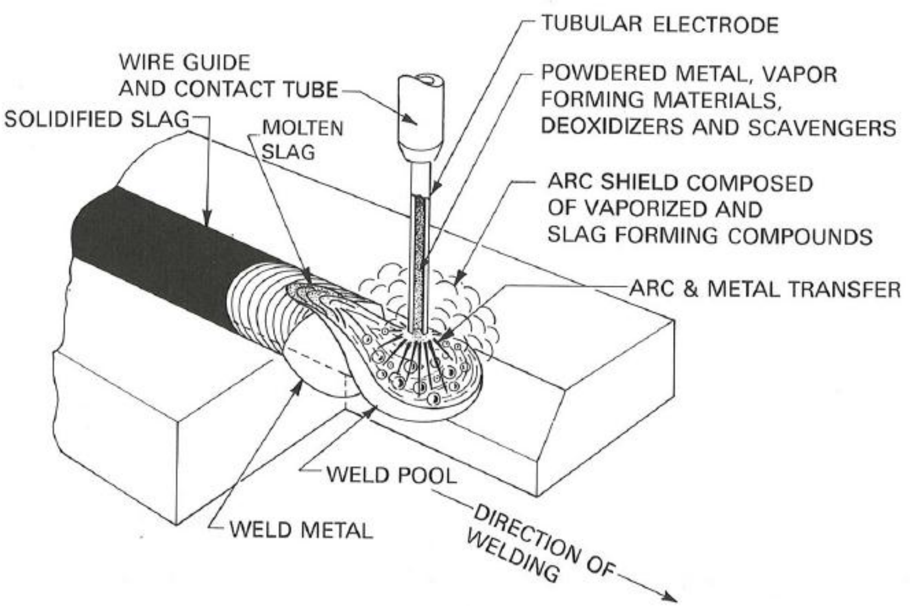
Flux Cored Arc Welding



Gas-Shielded FCAW



Self-Shielded FCAW

Courtesy of the AWS Welding Handbook, Volume 2, 8th Edition

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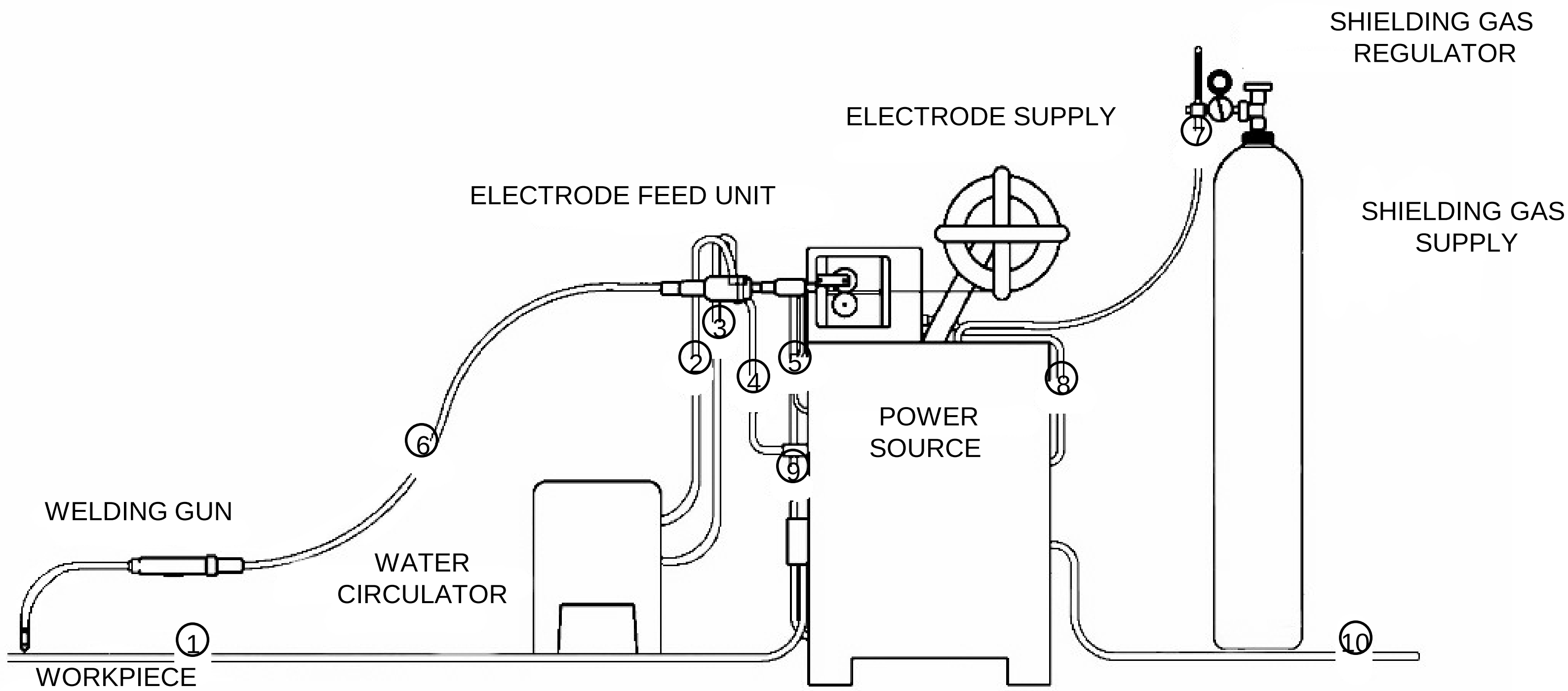
GMAW/FCAW Equipment



1. WORK LEAD
2. WATER TO GUN
3. WATER FROM GUN
4. GUN SWITCH CIRCUIT
5. SHIELDING GAS TO GUN
6. CABLE ASSEMBLY
7. SHIELDING GAS FROM CYLINDER
8. WELDING CONTACTOR CONTROL
9. POWER CABLE
10. PRIMARY INPUT POWER

Courtesy of the AWS Welding Handbook, Volume 2, 8th Edition

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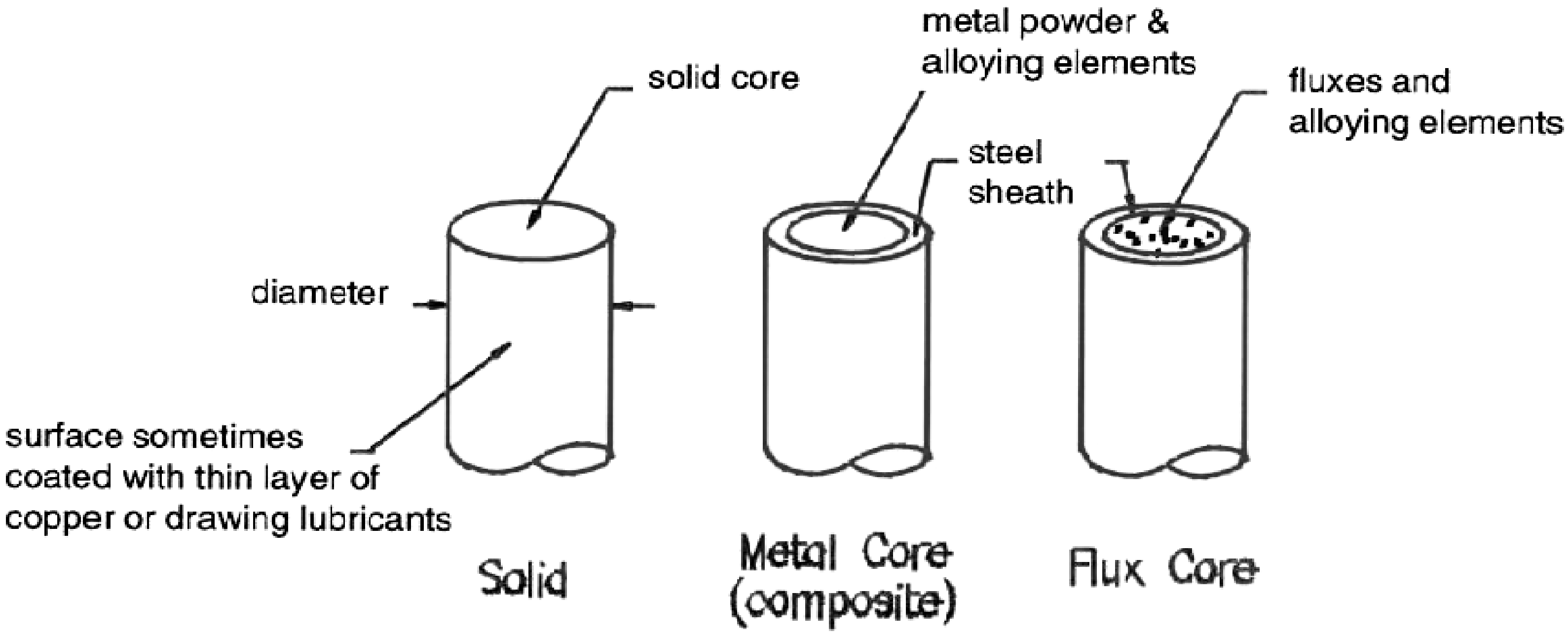
Types of Continuous Wire Electrodes



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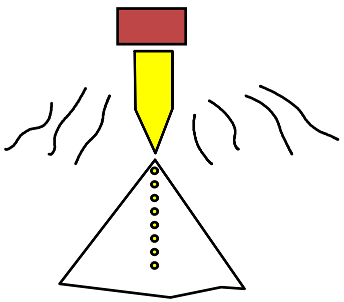
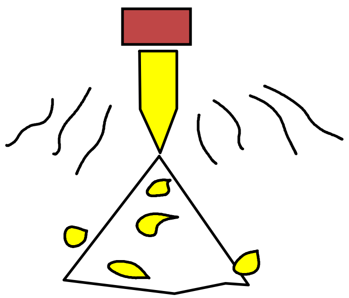
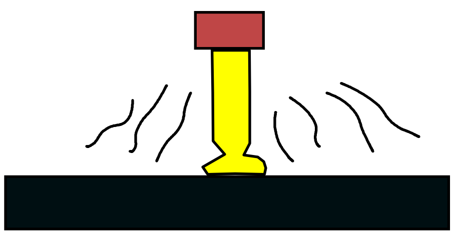
Modes of Metal Transfer



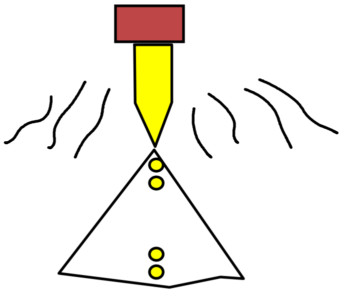
Spray



Globular



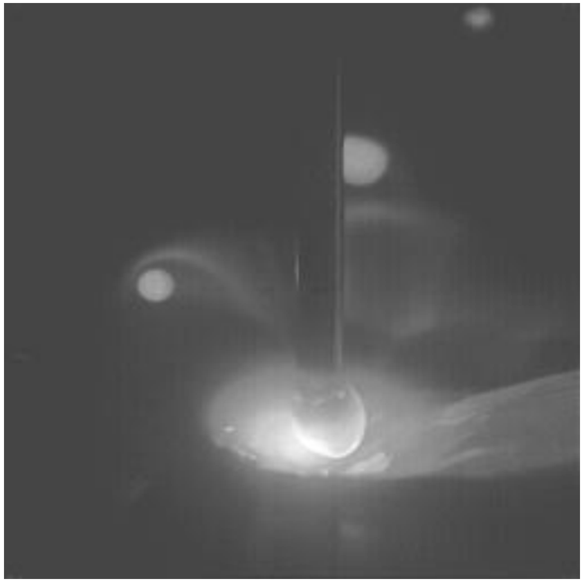
Short-circuiting



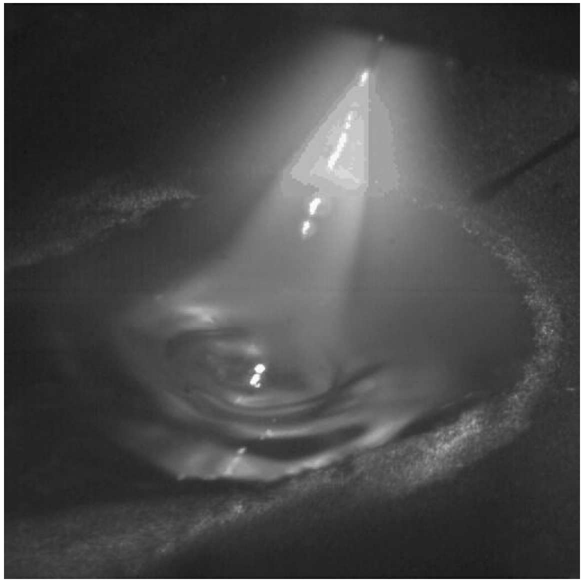
Pulse-spray

GMAW Transfer Modes

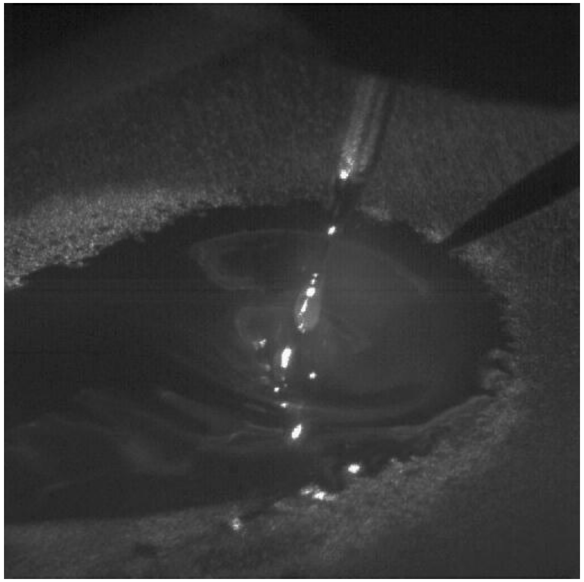
Short Circuit Mode



Spray Mode



Pulse Transfer



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GMAW Pros & Cons

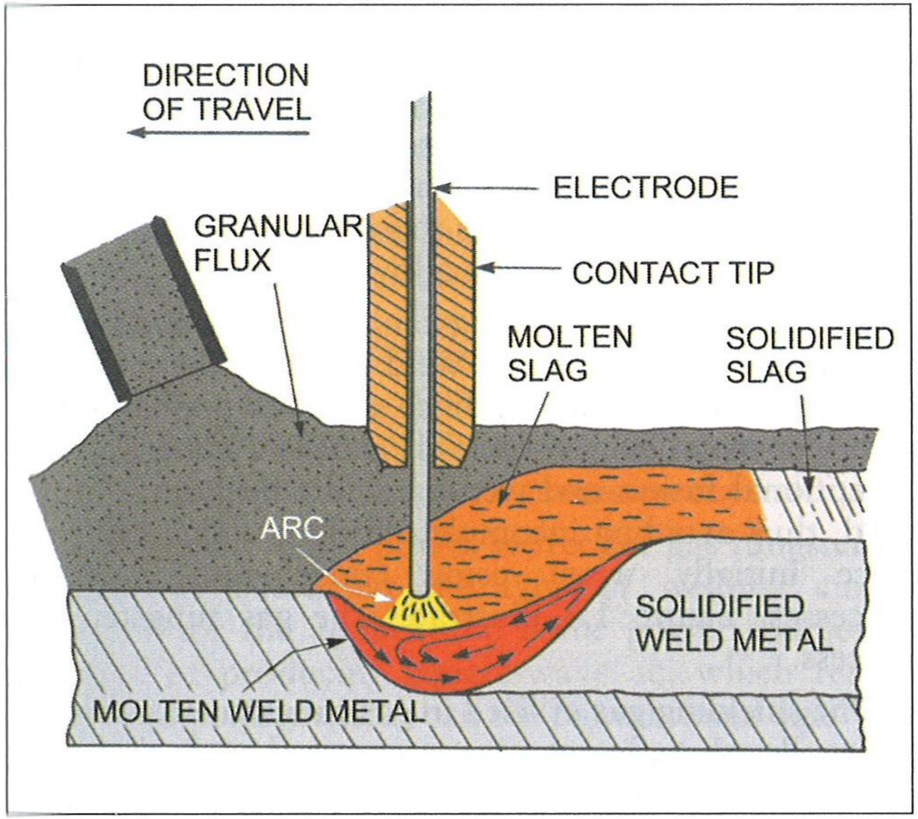
- **Advantages**
  - Welds all commercial metals
  - All positions
  - High deposition rates compared to GTAW and SMAW
    - Continuously fed filler wire
  - Long welds without stops and starts
  - Minimal post-weld and inter-pass cleaning
- **Disadvantages**
  - Welding equipment is more complex than that for SMAW
    - More difficult to use in hard to reach places
    - Welding torch size
  - Welding torch must be kept in close proximity to the workpieces in order to achieve adequate shielding
  - Arc must be protected against air drafts

FCAW Pros & Cons

- **Advantages**
  - High deposition rates
  - Deeper penetration than SMAW
  - High quality welds
  - Less pre-cleaning than GMAW
  - Slag covering helps with out-of-position welds
  - Self-shielded FCAW is draft tolerant
- **Disadvantages**
  - Slag must be removed
  - Higher fume generation than GMAW and SAW
  - Spatter
  - Equipment is more expensive and complex than SMAW
  - FCAW wire is more expensive

Submerged Arc Welding (SAW) Definition

- At least one consumable bare metal electrode
- Arc(s) produce heat
- Shielded by granular, fusible material on workpieces
- Uses similar welding variables as GMAW for procedure and operator qualification



Source: Adapted from Linnert, G. E., 1994, *Welding Metallurgy*, 4th ed., Miami: American Welding Society, Figure 6.18.

Figure 1.2—Schematic of Submerged Arc Welding

Source: AWS Handbook 9th ed. Vol. 1

SAW Pros & Cons

- **Advantages**
  - Superior weld quality
  - Often self cleaning
  - High deposition rates
  - Minimum edge preparation
  - No radiant energy
  - Minimum fume problem
- **Disadvantages**
  - Flux housekeeping
  - Usable only in flat position

Plasma Arc Welding (PAW) Definition

- **Nonconsumable electrode**
- **Heat is produced from a plasma jet**
  - Arc can be transferred or nontransferred
- **Shielding is obtained from the ionized gas**
  - Usually supplemented by an auxiliary source of shielding gas
- **Filler metal may of may not be used**
  - Cold wire feed, hot wire feed, dabber technique
- **Variables**
  - Plasma current
  - Orifice diameter and shape
  - Type of orifice gas
  - Flow rate of orifice gas
  - Type of shielding gas

Plasma Arc Torch

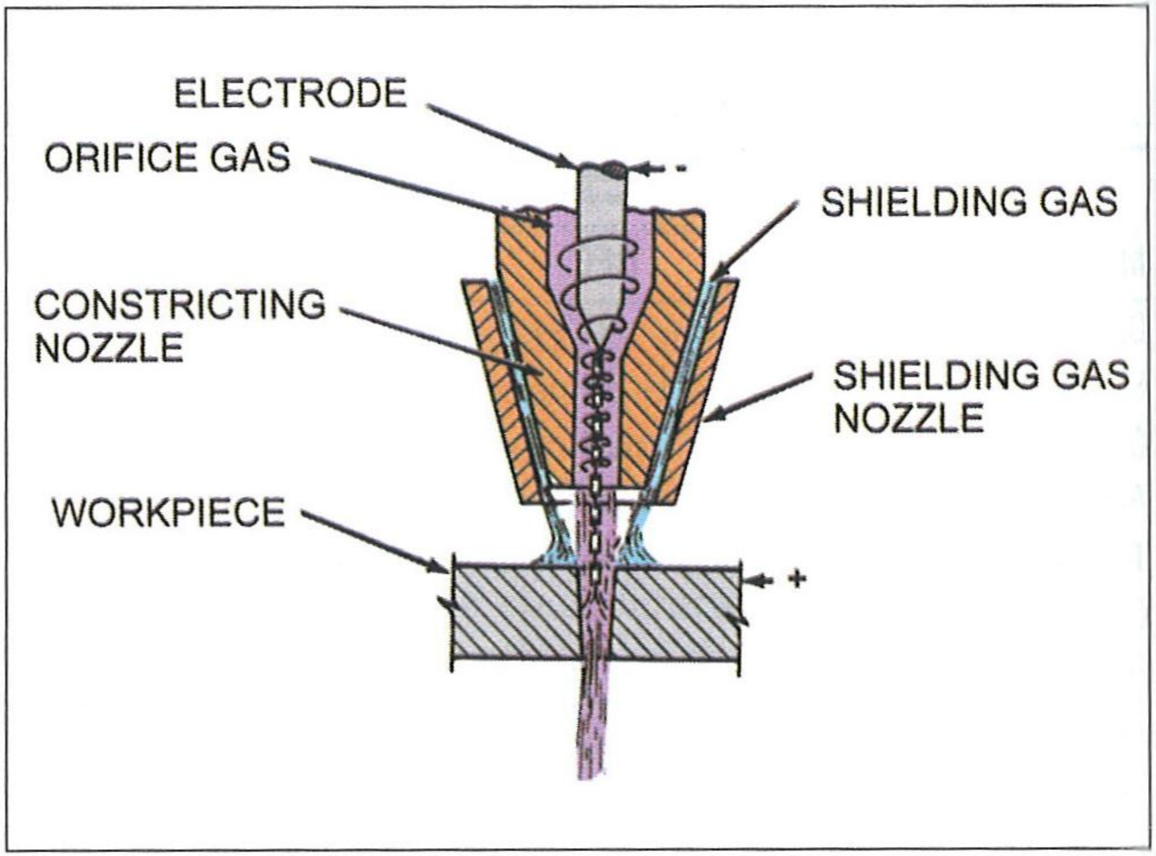


Figure 1.54—Schematic Representation of Plasma Arc Cutting

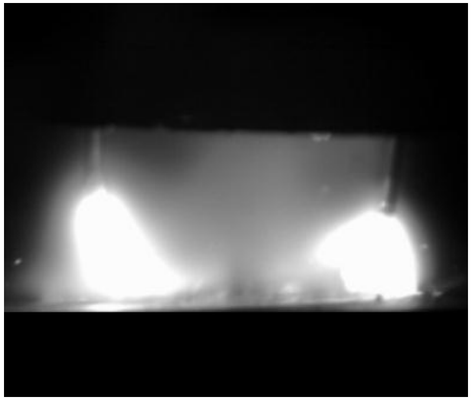
Source: AWS Handbook 9th ed. Vol. 1

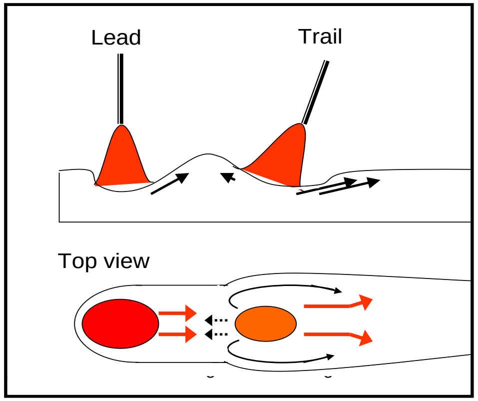
PAW Pros & Cons

- **Advantages**
  - Columnar plasma jet
    - Higher energy density enables faster welding speeds, lower heat input, and less distortion
    - Improved arc stability and tolerance to variations in torch-to-work distance
    - Permits the use of longer torch-to-work distances
    - Less welder skill is required (compared to GTAW)
- **Disadvantages**
  - Higher equipment cost
  - Lower tolerance to variations in fit-up
  - Manual PAW torches are more difficult to manipulate than manual GTAW torches

Tandem GMAW

- **A variation of standard GMAW with the following features:**
  - Two welding power sources
  - Two wire feeders
  - Two electrically isolated, independently controlled welding arcs
  - One weld pool





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Why Use Tandem GMAW?

- **Improve Productivity and Quality**
  - Increased deposition rates
  - Faster travel speeds
  - Maintain or improve overall weld quality, gap filling capability
- **Applications**
  - Long straight weld joints
  - Orbital applications
  - Mechanized processes
  - Automated processes

Figure 1

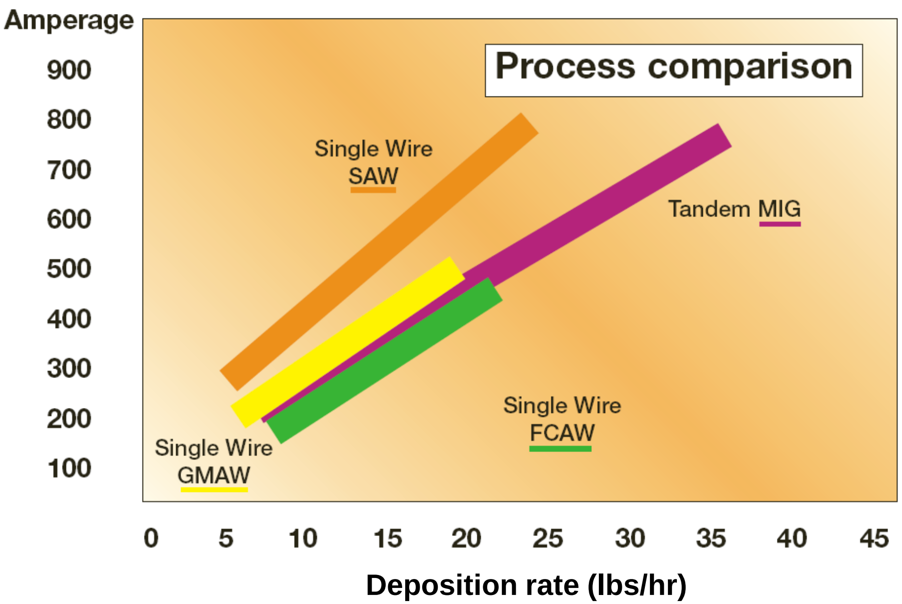

Image courtesy of Lincoln Electric

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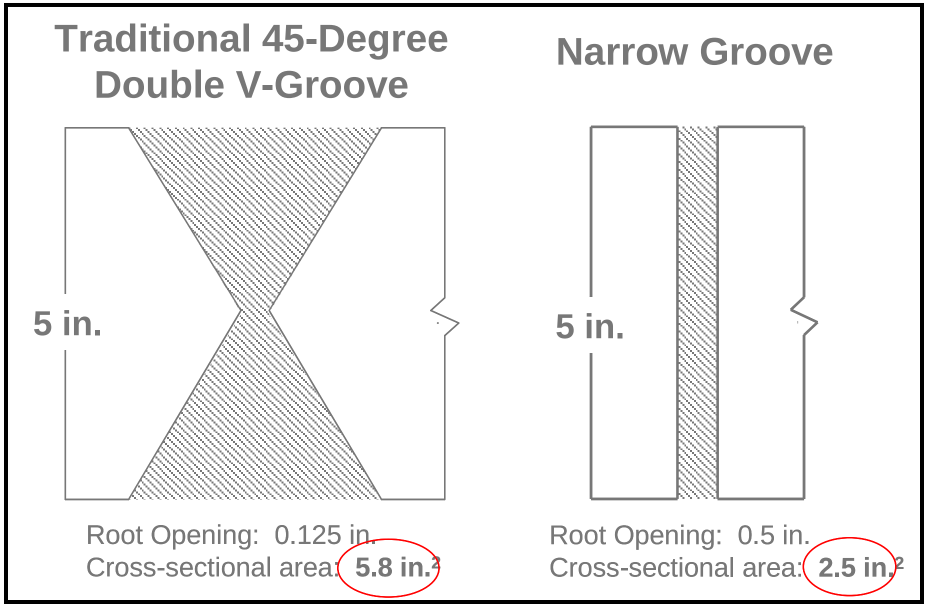
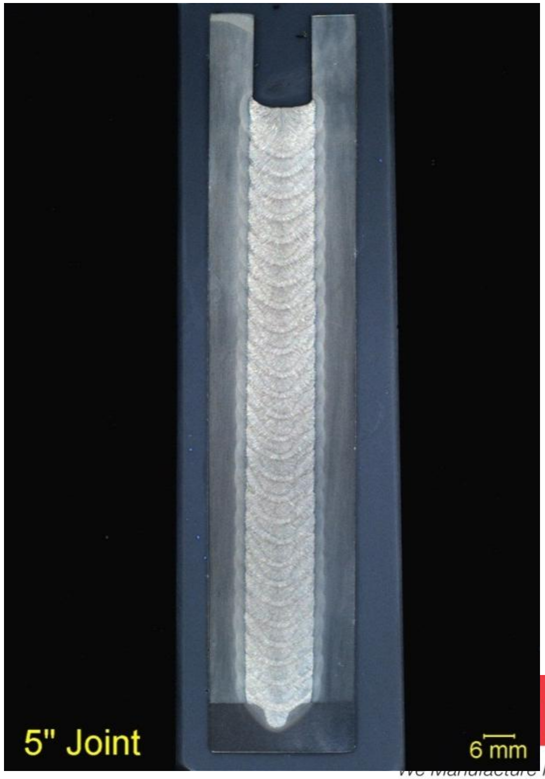
Narrow Groove Tandem GMAW

- **Conventional approaches to joining thick sections include**
  - High deposition-rate processes with conventional joint designs
    - GMAW, SAW
    - V-groove, double V-groove
  - Low deposition-rate processes with narrow-groove designs
    - Cold-wire GTAW
    - Hot-wire GTAW
    - Parallel or near-parallel sidewalls
- **Narrow-groove tandem GMAW**
  - High deposition-rate process in a narrow groove
  - Reduced joint volume
  - Excellent sidewall fusion
  - Reduced distortion

Benefit: Reduced Joint-Volume

- **For a 5-in.-thick joint**
  - > 75% reduction in joint volume compared to a single-V groove
  - > 55% reduction in joint volume compared to a double-V groove
- **Bead placement**
  - Single bead per layer
  - Minimal torch positioning required





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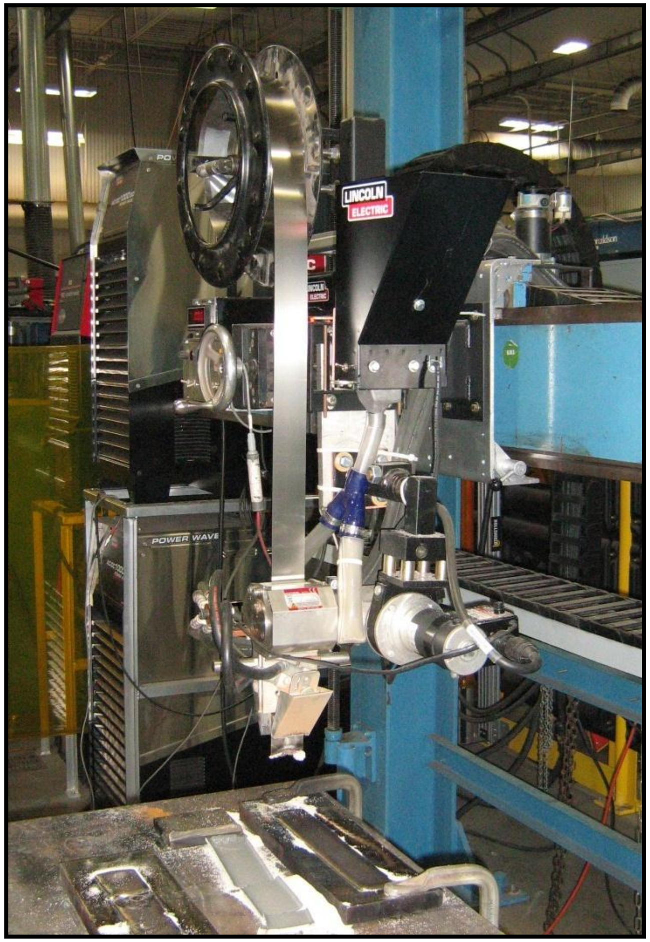
Strip Cladding Process Description

- **Welding takes place under a granular flux which melts and forms a slag to protect the molten weld pool**
- **Strip electrodes are 0.5mm thick range in width from 30 to 120mm**
- **Deposits wide, flat weld beads with minimal dilution of the base material.**
- **Two process variations based on conductivity of the slag**
  - Submerged arc strip cladding & electroslag strip cladding



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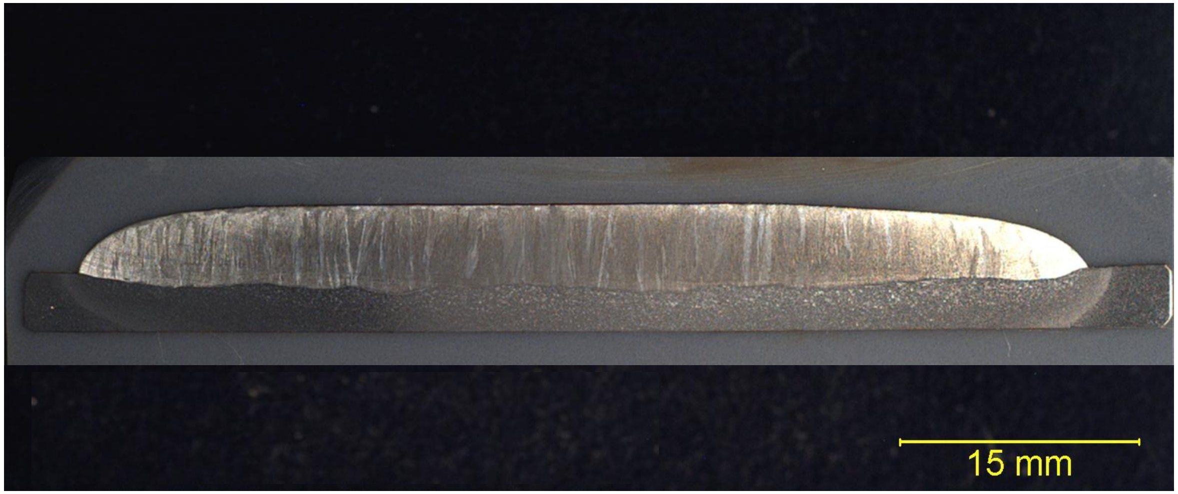
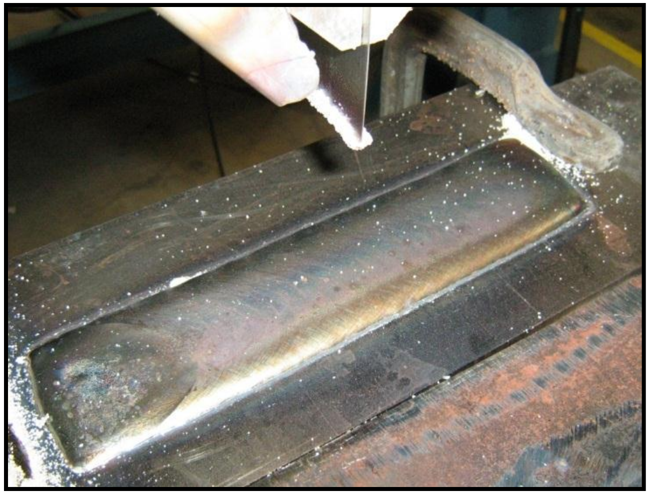
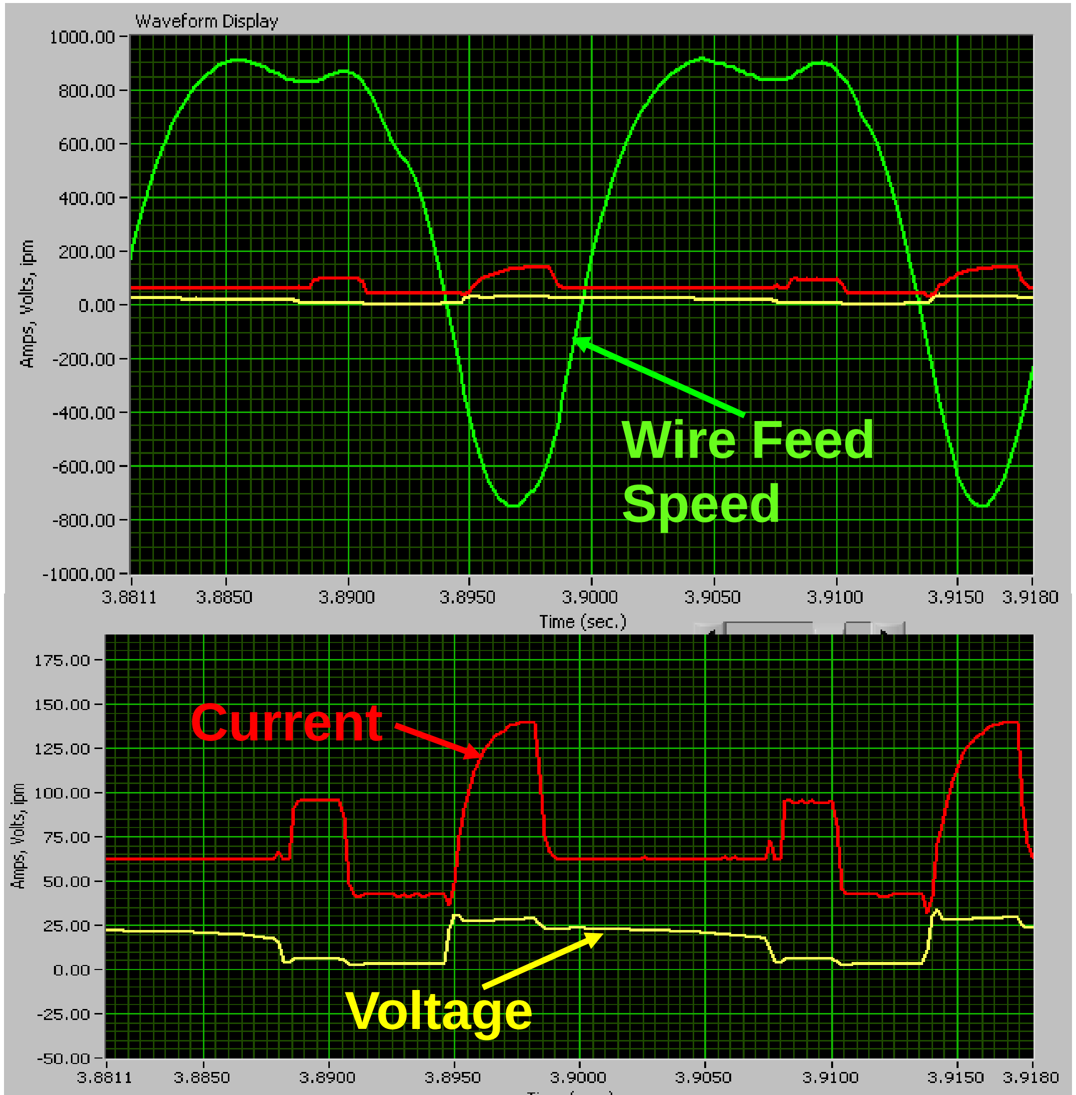
Submerged Arc Strip Cladding

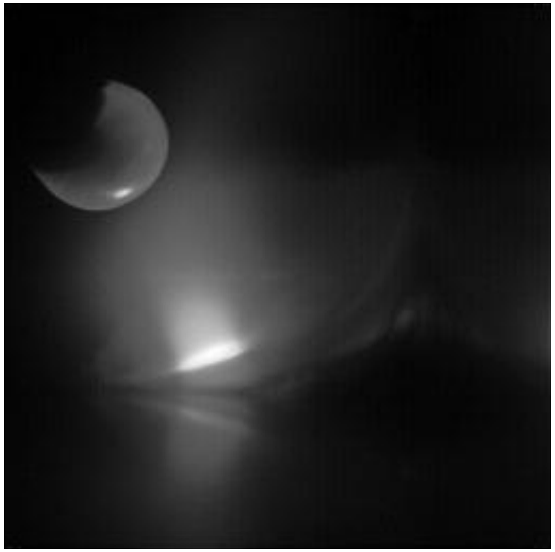
- **Travel Speed: ≈ 11-21 cm/min (≈ 4.3 to 8.3 in/min)**
- **Deposition Rates**
  - 60mm strip: 9 to19.5 kg/hour (19.8 to 42.9 lbs/hour)
  - 90mm strip: 28 to 33 kg/hour (61.6 to 72.6 lbs/hour)
  - 120mm strip: 30 to 35 kg/hour (66 to 77 lbs/hour)
- **Dilution: 18- to 25%**
- **Main disadvantage is the heat input**
  - Heat input: 250- to 280-kJ/in)





Reciprocating Wire Feed GMAW





Capable of Extremely Low Currents and Voltages

NO Short Circuiting

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RWF-GMAW Equipment

- Fronius CMT
- Jetline CSC
- SKS Systems
- Panasonic AWF

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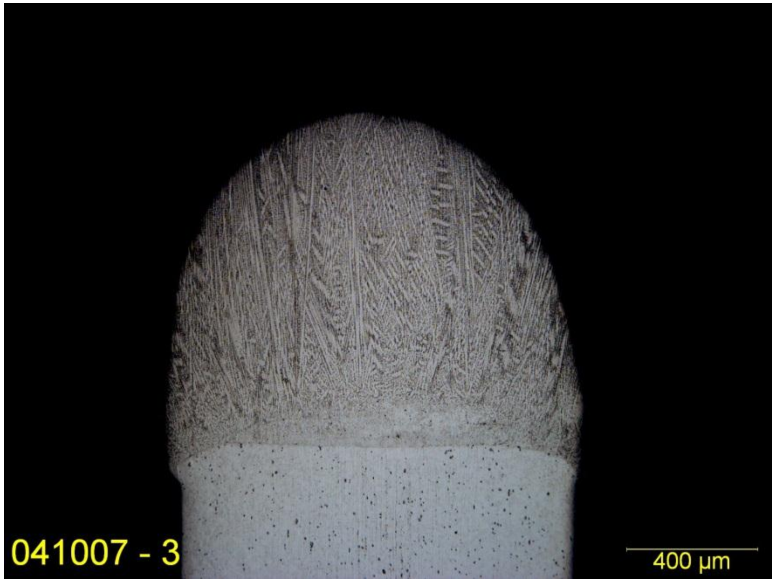
Alloy 718 Edge Buildups

- CRP program
- Alloy 718 edge, 0.040-in wide
- Alloy 625 wire
- Heat input of 383-J/in
- Significant commercial aerospace work done since



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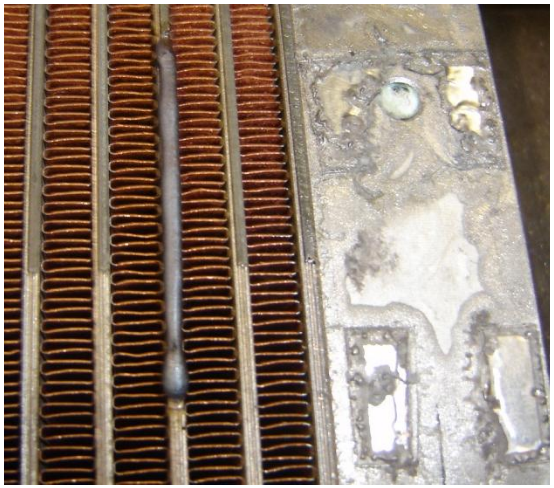
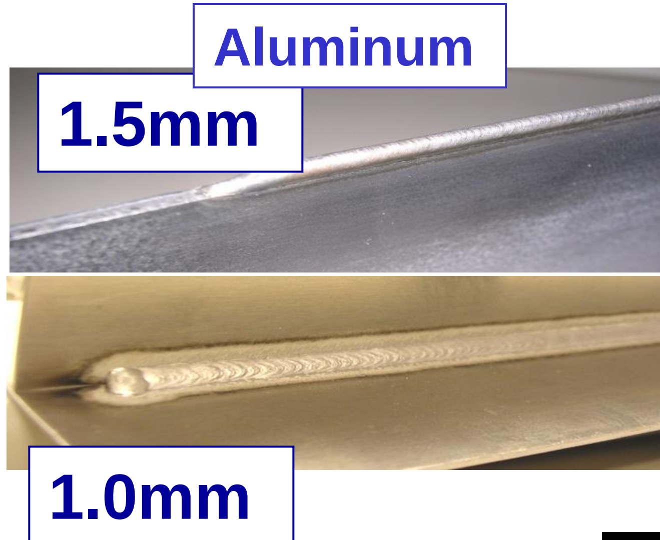
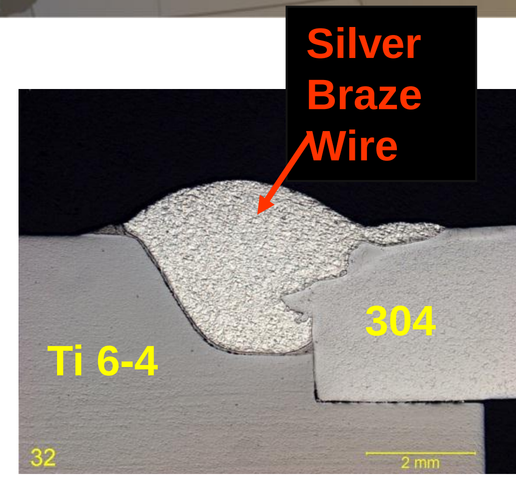
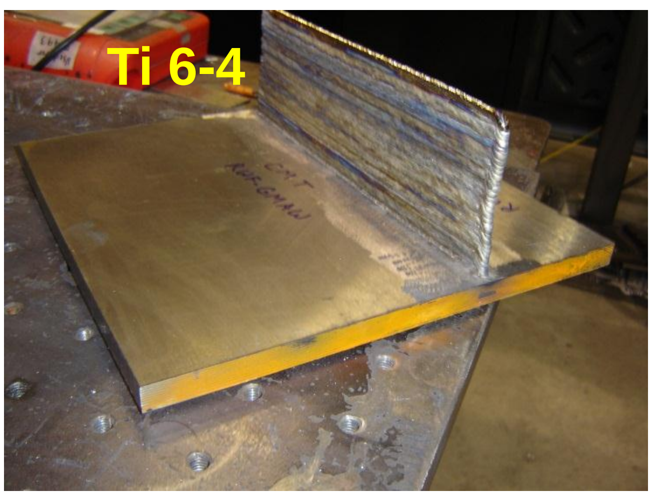
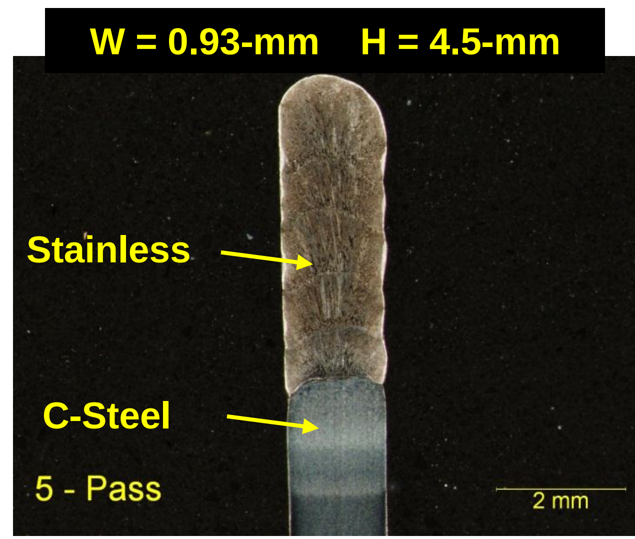
CMT Applications



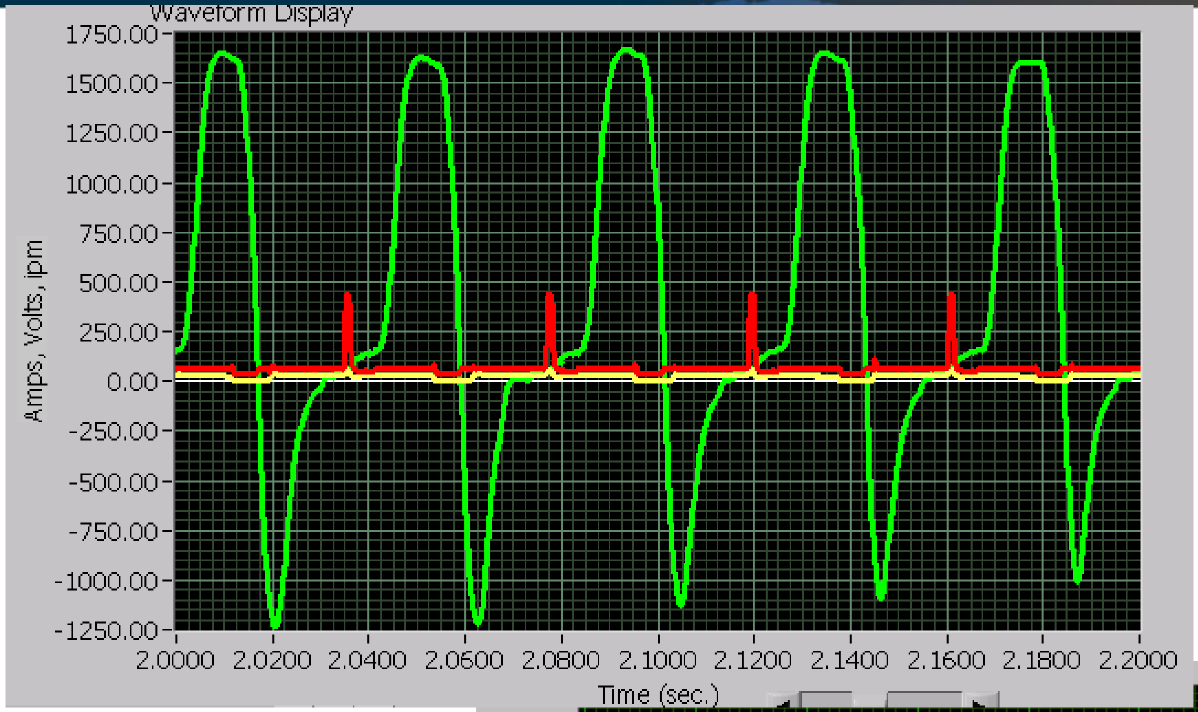


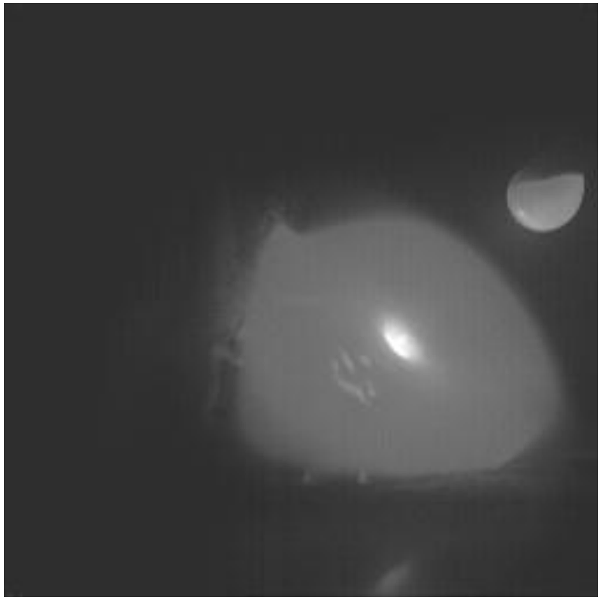






CMT + Pulse Welding





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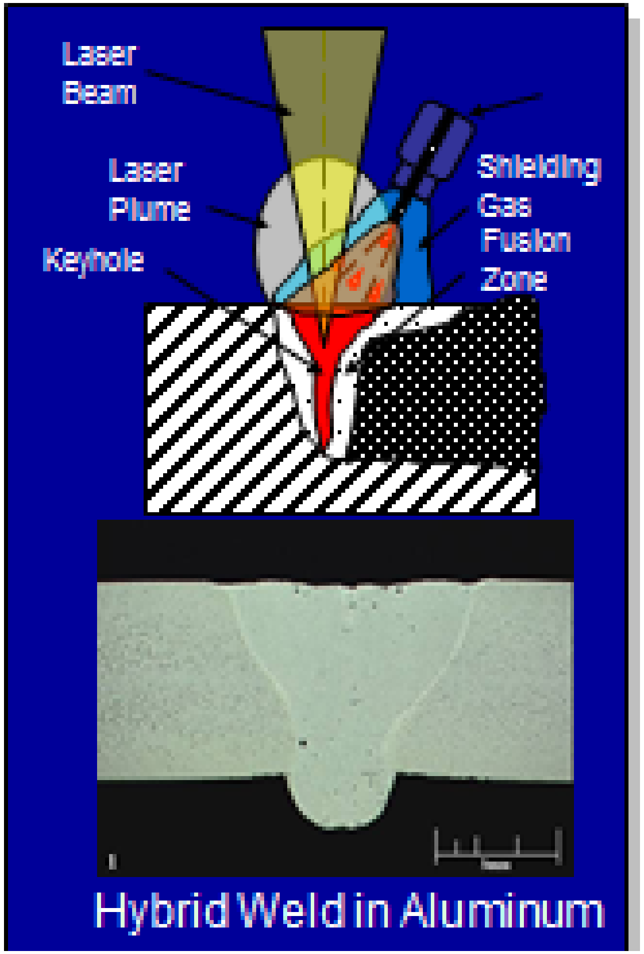
Hybrid Laser-GMAW



- **Arc and laser coupled as one process**
  - High travel speed with increased penetration
  - Flexibility of fiber delivery
  - Tolerance to gap and alignment
  - Potential to use laser to stabilize conventional processes
- **Applications**
  - Welding of Al structures
  - Fabricated Ti structures
  - High strength steels

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Hybrid Laser GMAW
(Note keyhole from laser in puddle)

[Video of Laser/GMAW Hybrid Welding]

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Example Applications

- GTAW of super-conductor
- Mechanization vs. manual / semi-auto
- Arc-based titanium additive manufacturing
- Onsite engineering assistance
- Opacity reduction
- T-GMAW development at EWI

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GTAW of Super-Conductor

- **Composite super-conductor bands**
  - Pure silver & proprietary powder
- **Problem**
  - End was manually welded to the fitting and copper draw bar attached
  - Part is drawn into a ribbon. During drawing the weld broke
  - Found to be due to lack of penetration / incomplete fusion

GTAW of Super-Conductor

- **EWI's involvement**
  - Diagnosed failure as lack of penetration / fusion
  - Pure silver melts at a point rather than a range
    - Redesigned joint to allow built-in backing
  - Developed mechanized welding procedures
    - Full penetration joint, 350-A, 70-sec start delay
  - Specified welding system, onsite support for implementation in production

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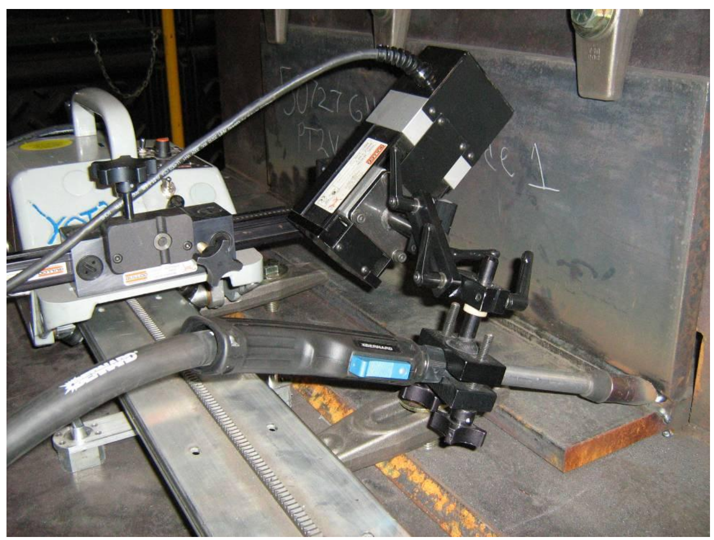
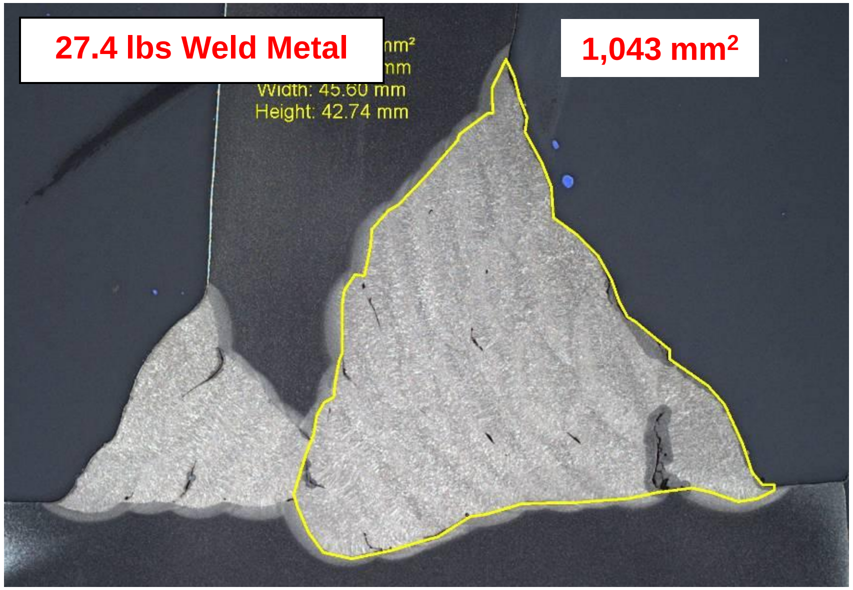
Mechanization Example

- Double bevel complete joint penetration weld
- Vertical position, upward progression
- Objective is to increase productivity by implementing simple mechanization over baseline semi-automatic GMAW

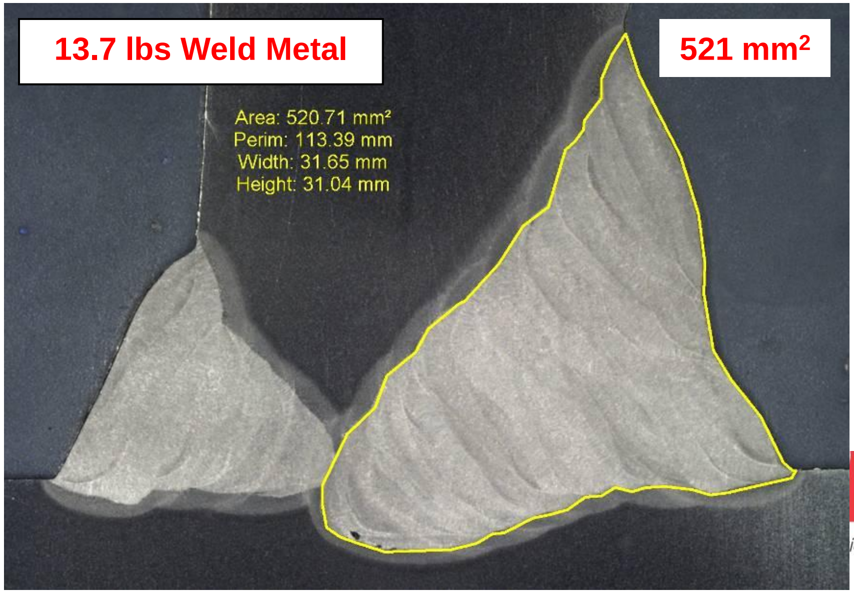


Mechanization Example

- **145 ipm Wire Feed Speed**
- **3.7 lbs/hr Deposition rate**
  - Within Current Qualified Procedure
- **25 Passes**
- **535 Total Minutes**
  - Arc Time = 340 min
  - Cleaning Time = 72 min
  - Gouging Time = 27 min
  - Post Gouge Cleanup = 96 min



- **184 ipm Wire Feed Speed**
- **4.7 lbs/hr Deposition Rate**
  - Within Current Qualified Procedure
- **12 Passes**
- **199 Total Minutes**
  - Arc Time = 121 min
  - Cleaning Time = 15 min
  - Gouging Time = 3.25 min
  - Post Gouge Cleanup = 9 min

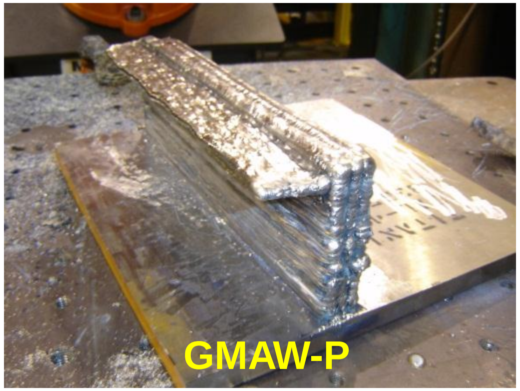


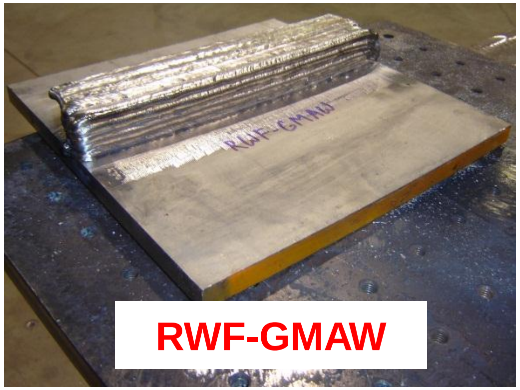
Arc-Based Additive Manf.

- **Titanium components are often produced via machining**
  - Start with a solid block then machine part out
  - Material availability
    - Lead time increases non-linearly with material size (long lead times)
    - Potential for industry shortage on titanium
- **Objectives of program**
  - Characterize five arc welding processes with regards to titanium additive manufacturing
  - Build two vehicle parts via additive manufacturing using the selected process
- **Processes**
  - PAW (Powder), GMAW-P, GTAW-HW, RWF-GMAW, PAW (Wire)

Arc-Based Additive Manf.

- **Demonstrated arc-based processes for titanium additive manufacturing**
  - PAW (Powder)
  - GMAW-P
  - GTAW (Hot Wire)
  - RWF-GMAW
  - PAW (Wire)





Onsite Engineering Examples

- **Aluminum ammunitions container**
  - GTAW, GMAW-P
  - Problems: visual inspection & leak testing
  - Recommendations
    - Welder training, start / stop procedure development, etc
- **Stainless steel, high strength, disk (9-ft diameter)**
  - GMAW-P welding of inserts
  - Problem: post weld cracking
  - Recommendation: weld in over-aged condition, PWHT
- **Aluminum skid**
  - Welder training, welding procedure and performance qualification, fabrication procedures recommendations
- **High carbon steel suspension component**
  - GMAW
  - Problem: cracking, code interpretation & conformance
  - Worked with welding & testing personnel to meet code requirements
- **Etc.**

Codes & Standards

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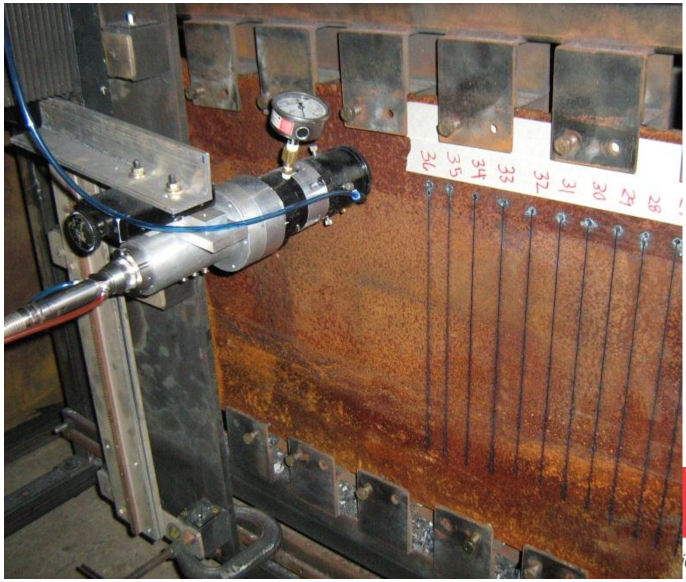
Opacity Reduction

- **Naval vessels are dismantling at PSNSY using oxyfuel gas cutting (OFC)**
  - Process is cost effective and efficient
  - Produces large amounts of visible emissions which has led to compliance issues with air pollution requirements
- **Objectives**
  - Determine the combination of fuel gas, flow rates, torch type, etc that result in the lowest opacity for the OFC process
  - Evaluate other hot working methods (plasma arc cutting, laser cutting, etc) as an alternative to OFC

Opacity Reduction

- **Industry survey of cutting technology**
- **DOE approach**
  - Significantly increased the number of variables evaluated
- **OFC variables screened**
  - Fuel gases (5)
  - Surface conditions (3)
  - Plate thickness (2)
  - Tip types (3)
  - Torch types (4)
  - Fuel gas flow rate (2)
  - Oxygen flow rate (2)
- **DOE for PAC and laser cutting**

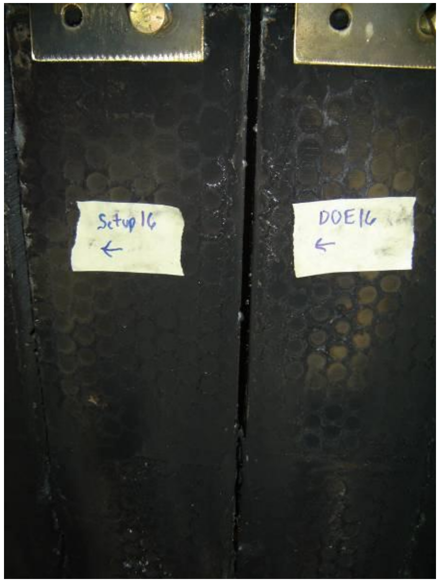


Opacity Reduction

Opacity Reduction – Results

- Opacity strongly correlates with the amount of organic material burned
- Laser produces least opacity followed by OFC and PAC
- OFC best practices recommended for two fuel gases

Torch	Harris 62-5E Low Flow	
Tip Size	6 (general purpose)	
Fuel Gas	Propane	MagneGas
Fuel Pressure (psi)	2	3
Oxygen Pressure (psi)	55	55



- Also provided best parameters for PAC

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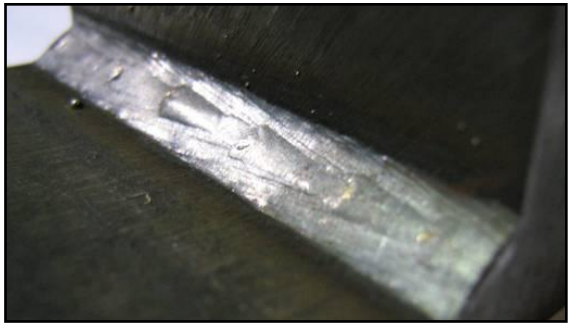
T-GMAW Development at EWI

- High-speed fillet welds
  - 3/16-in. fillet welds at 80 ipm
  - 0.25-in.-thick plate
  - Deposition rate: 22 lb/hr

- High-speed welding of sheet metal
  - Solid steel wire
    - 1.0- to 1.4-mm-thick high-strength steel
    - Full-penetration square-groove welds
    - Travel speeds: 138 to 177 ipm
  - Silicon-bronze wire (T-GMA braze welding)
    - 0.7- to 0.75-mm-thick galvanealed steel
    - Travel speed: 138 ipm
    - Minimal backside coating degradation



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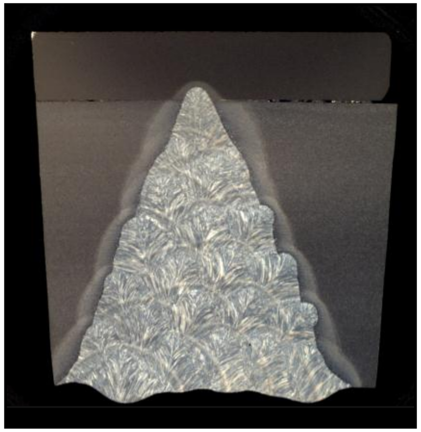
T-GMAW Development & EWI

- **Flat (1G) position**
  - Deposition rates up to 38-lbs/hr
  - Travel speeds of 25- to 50-ipm
- **Out-of-position, thick section**
  - Horizontal
    - Deposition rate: 25-lbs/hr (+194%)
    - Travel speed: 32-ipm (+185%)
    - Heat input: 28-kJ/in (-33%)
  - Overhead
    - Deposition rate: 15-lbs/hr (+233%)
    - Travel speed: 35-ipm (+536%)
    - Heat input: 10-kJ/in (-76%)



Questions?

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Additive Manufacturing Consortium
Operated by EWI

Nuclear Fabrication Consortium
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Navy Joining Center
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Rail Manufacturing Technology Center
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