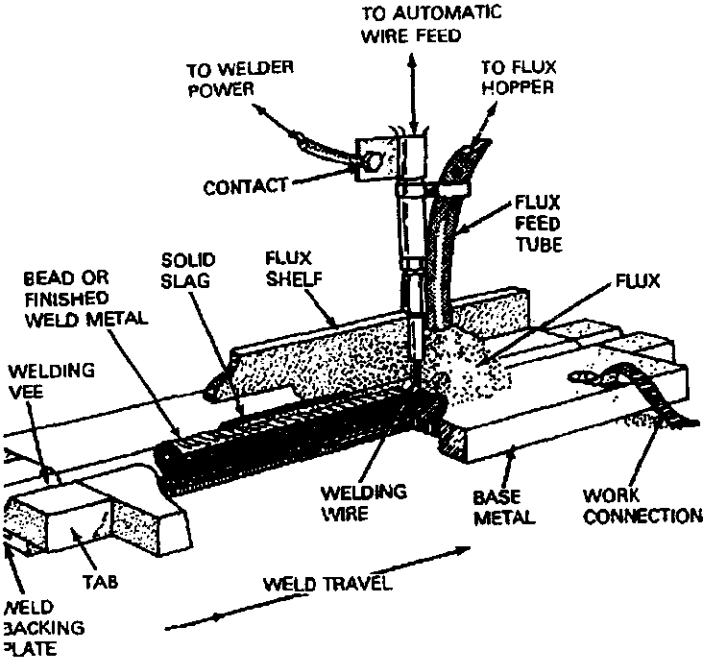
Welding Processes

Submerged Arc Welding (SAW)

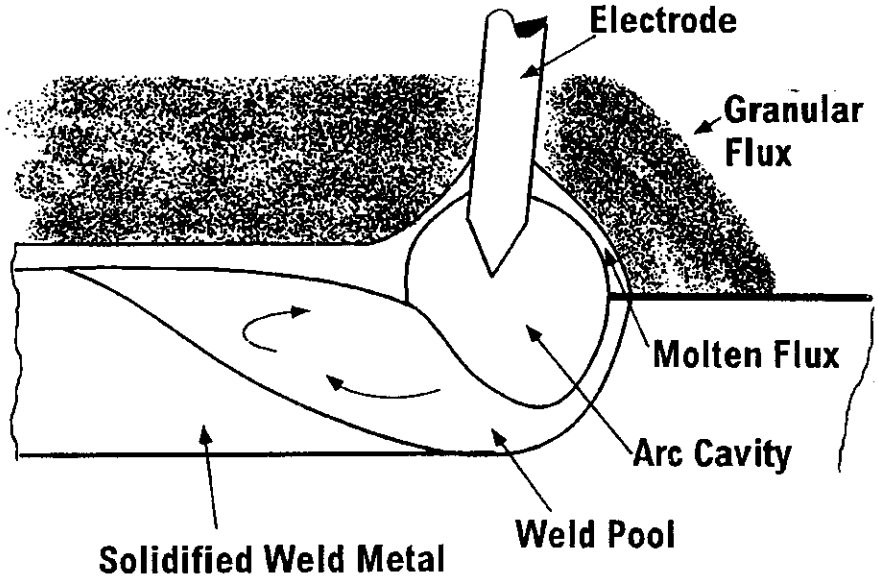
SAW: Process Fundamentals

- In SAW the welding heat source is an arc maintained between a consumable electrode and the workpiece
- The arc and molten metal are "submerged" in a blanket of granular fusible flux
- The electrode is continuously fed into the arc and additional flux is distributed in front as the weld head moves along the joint

Submerged Arc Welding



SAW Weld Pool



SAW Electrodes

- Functions of the electrode:
  - Conducts electrical current to the arc
  - Supplies joint filler material
- Electrodes may consist of
  - solid rod or wire
  - composite electrode (a metallic sheath encasing metal powders)

SAW Fluxes

- Functions of the flux
  - Establish the electrical characteristics of the electrode and arc stability
  - Control the composition and metallurgy of the weld deposit
  - Supply additional filler material
  - Control weld bead shape
- Flux constituents
  - The flux consists of granular minerals and metals in the form of fused and crushed or bonded agglomerated particles

SAW Flux Types for Steels

- Various formulations in use
  - Calcium silicate
  - Manganese silicate
  - Aluminate rutile or basic
  - Basic fluorides
- Fluxes termed "neutral" or "active" according to their potency in modifying weld composition
- Also categorized as "basic" or "acid" based on various indices e.g.:

$$B = \frac{CaO + CaF_2 + MgO + K_2O + Na_2O + \frac{1}{2}(MnO + FeO)}{SiO_2 + \frac{1}{2}(Al_2O_3 + TiO_2 + ZrO_2)}$$

SAW Fluxes

- "Acid" silicate fluxes are active types
- Active fluxes and/or electrodes deoxidized with silicon and manganese are useful when making single pass welds on scaled or rusty steel plate.
  - However, Si and Mn build up may give poor toughness and soundness in multi-pass welds
- Basic fluxes give optimum strength and toughness in steel welds

Classification of SAW Electrodes and Fluxes for Carbon Steel

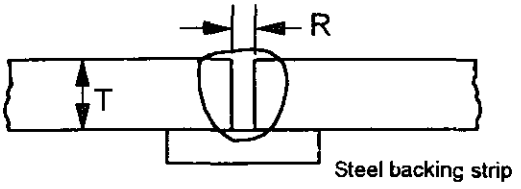
- AWS/ASME A5.17 specification
- Solid electrodes are classified on the basis of their chemical composition
- Composite electrodes and fluxes are classified according to the composition of the weld metal deposited with a particular electrode
- FXXX-EXXX designates a flux/wire combination
  - e.g., F7A6-EM12K

SAW Welding Procedures

- Operating Variables (in approximate order of importance for weld quality)
  - welding current
  - flux type and particle size distribution
  - welding voltage
  - welding speed
  - electrode size
  - electrode stick-out
  - type of electrode
  - width and depth of flux layer

SAW Welding Procedures

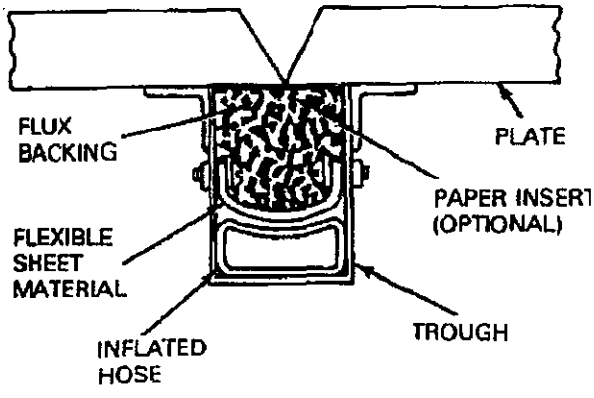
Single-electrode single pass welding of steel plate with backing strip



T	R	Current A	DCEP V	Travel Speed mm/s	Electrode dia. mm	Electrode consumption kg/m
6	3	900	33	11	4.8	.248
13	5	1100	34	8	5.6	.685

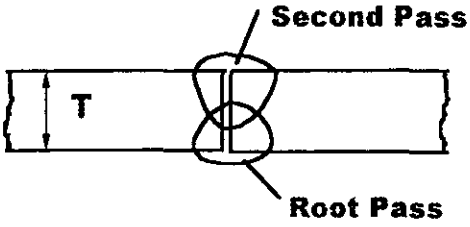
SAW Welding Procedures

Flux backing technique for single sided welding, e.g. ship panel manufacturing lines



SAW Welding Procedures

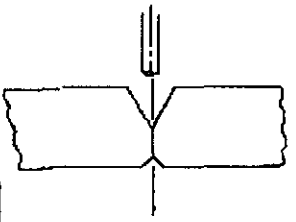
Single-electrode two-pass welding of steel plate



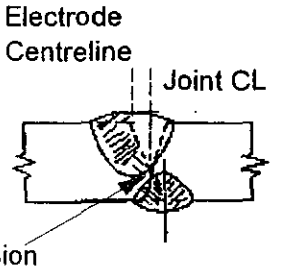
T	Pass	Current A	DCEP V	Travel Speed mm/s	Electrode dia. mm	Electrode consumption kg/m
10	Root	500	33	14	4	343
10	Second	650	35	14	4	
15	Root	900	36	9	4.8	745
15	Second	950	36	9	4.8	

SAW Welding Procedures

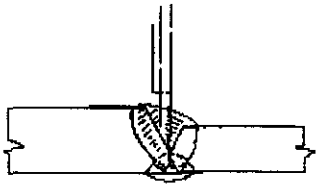
Electrode alignment in two-pass welds



Correct



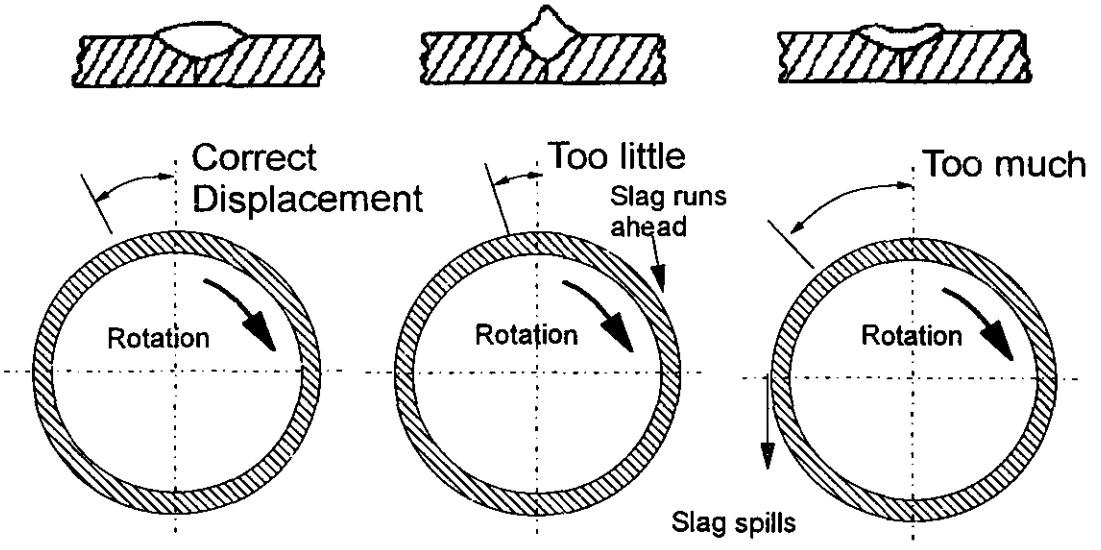
Incorrect



Exception-unequal thicknesses

SAW Welding Procedures

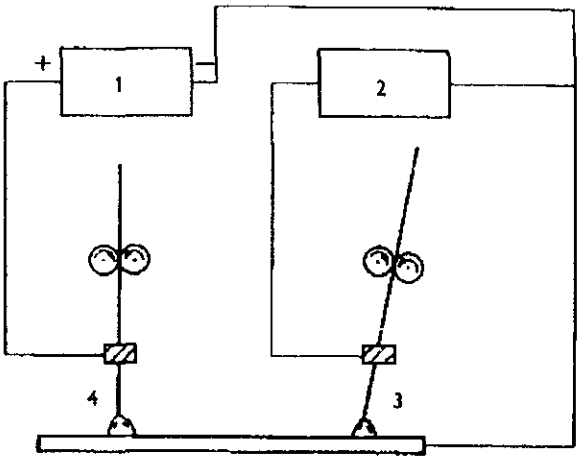
Electrode position effects in circumferential welding



SAW Variants

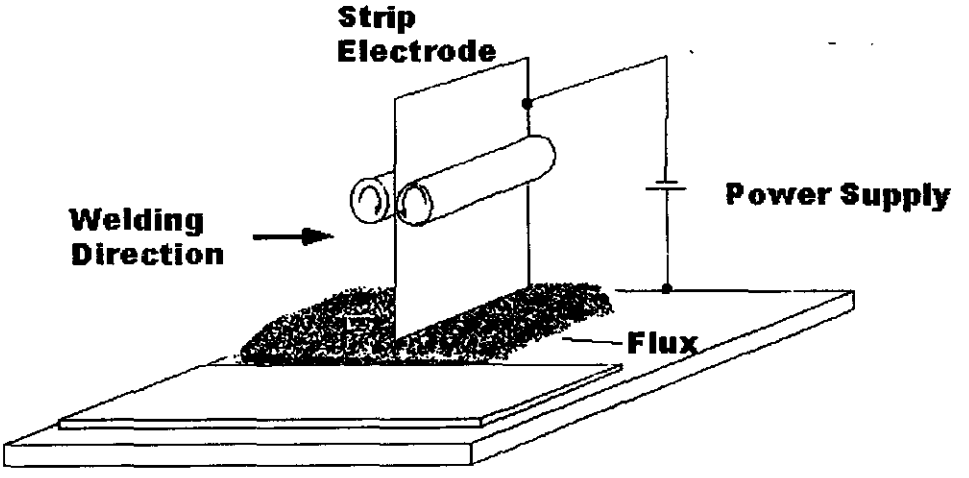
Twin-wire dc/ac system:

1-dc power source, 2-ac power source, 3-trail arc, 4-lead arc



SAW Variants

Strip Cladding

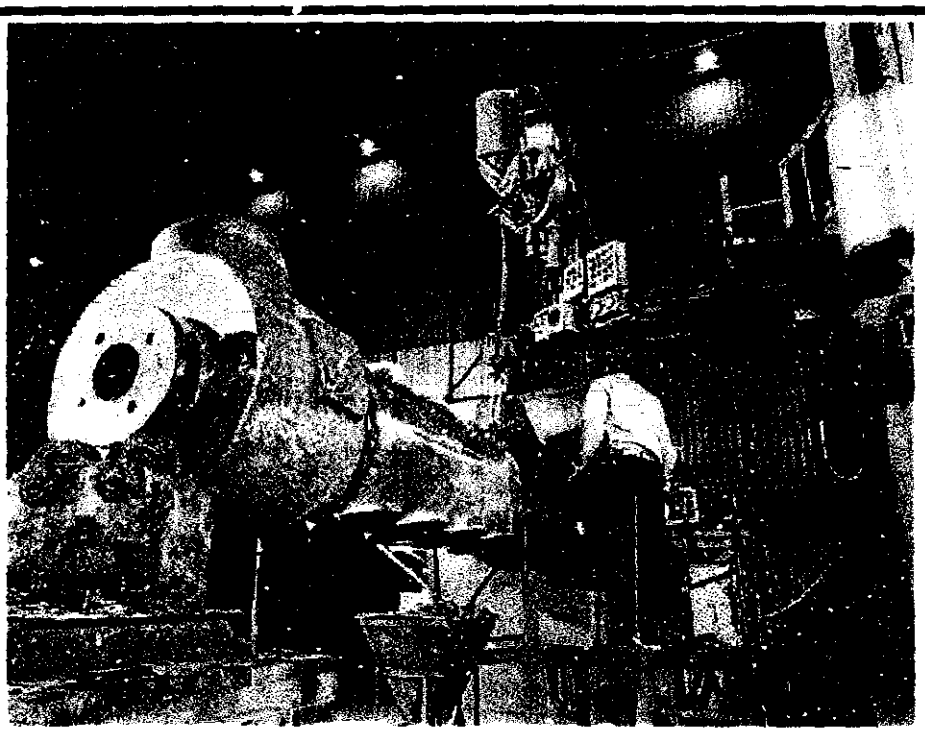


E.g. cladding the internal surfaces of pressure vessels

SAW Equipment

- Power Supply
  - Constant current or constant voltage type 100% duty cycle 1000 A output
- Wire Feeder
  - Constant speed (for constant voltage power supplies) or voltage sensing (for constant current power supplies)
- Travel & Positioning Device
  - e.g. weld head crawler or rotary positioner
- Flux delivery/recovery system
- Process Controls
  - welding current, travel/workpiece positioning, wire feed sequencing

SAW Applications



SAW Applications

- Joining heavy sections in steel, stainless steels
  - pressure vessel & piping circumferential & longitudinal seams
  - plate girder fabrication
  - ship panel subassembly
- Surfacing
  - multi-wire & strip cladding variants

SAW Capabilities & Limitations

+ High deposition rates and productivity
+ Tolerant to variations in joint edge preparation and fit up
+ Good weld mechanical properties (with appropriate choice of welding procedure)

– Flat or horizontal position only
– Mostly limited to steels, stainless steel and nickel alloys
– Flux and slag residues

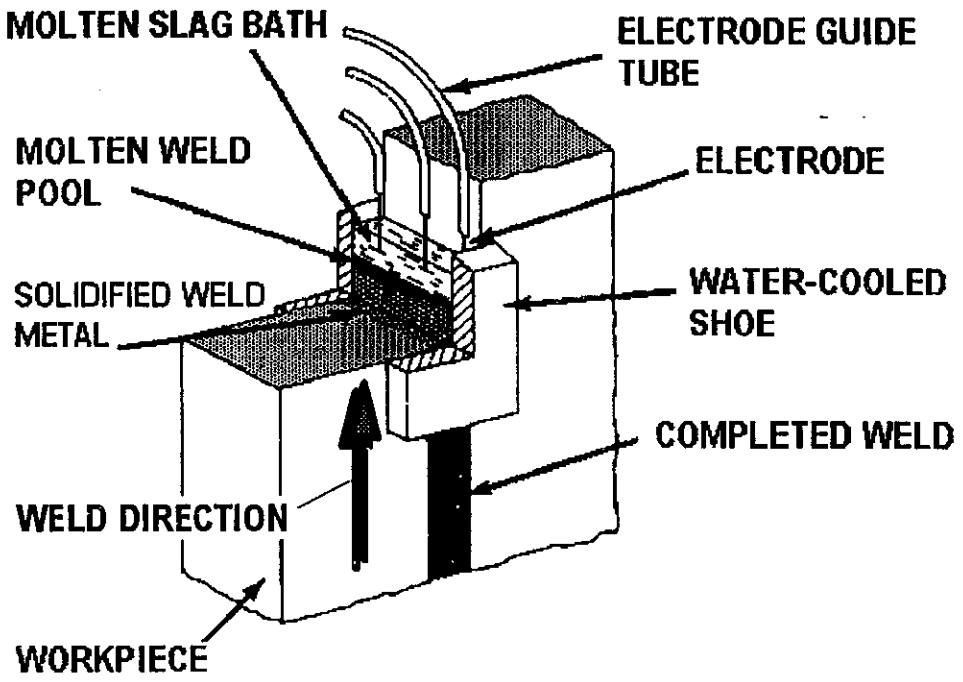
Welding Processes

Electro-Slag Welding (ESW)

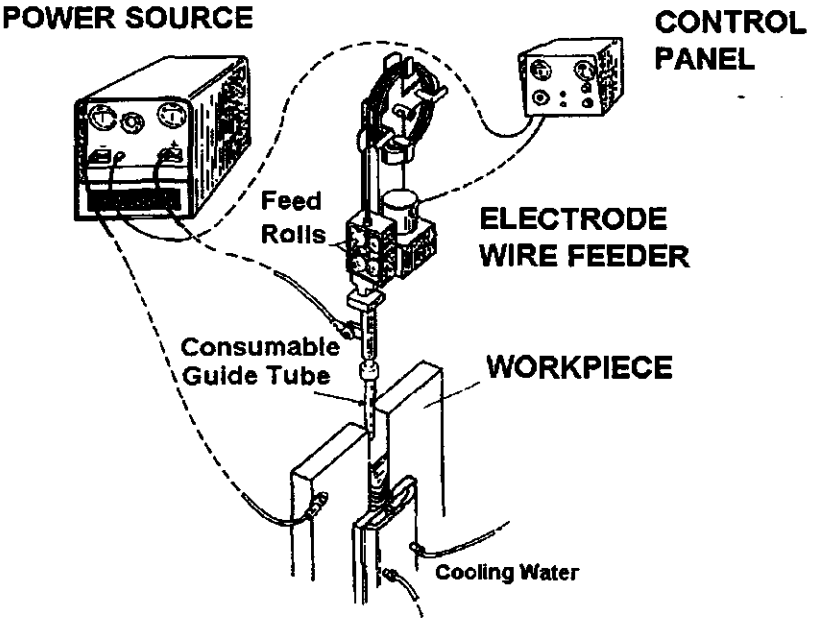
ESW Process Fundamentals

- In ESW, electrical current passes from a continuous electrode to the workpiece through a conductive molten slag
- Resistance heating of the slag supplies the welding heat source. The slag also shields the weld pool from contamination
- The weld is formed by melting and resolidification of the joint edges and filler

ESW: Process Fundamentals



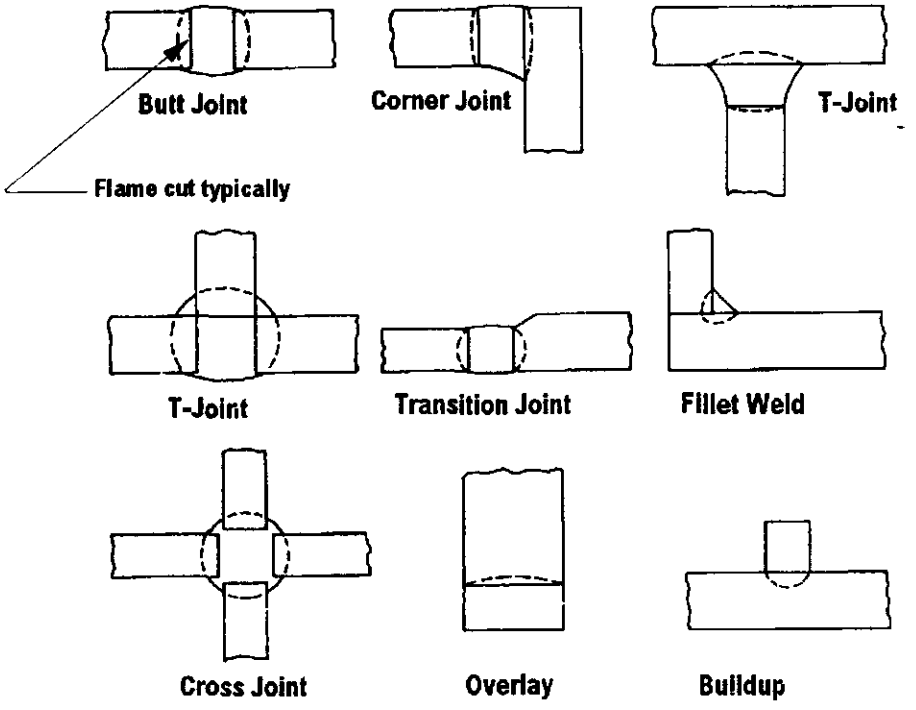
ESW Consumable Guide Method



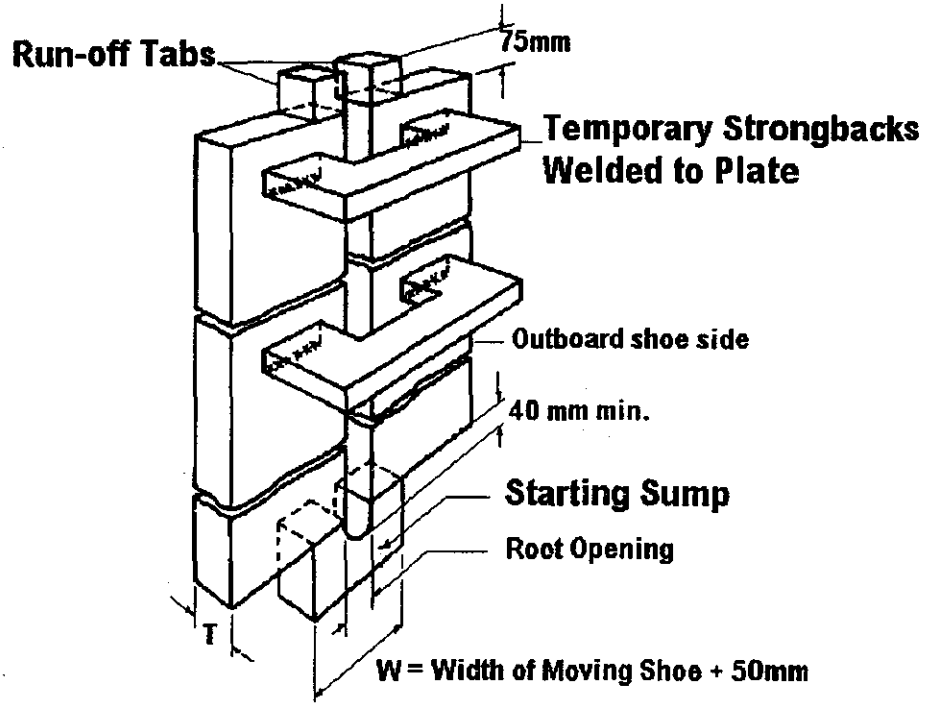
ESW Welding Procedures

- Process Variables
  - Joint Preparation & Fit-up
  - Welding Current
  - Welding Voltage
  - Electrode Extension
  - "Form Factor"
  - Electrode Oscillation
  - No of Electrodes & Spacing

ESW: Joint Types



ESW: Joint Fit Up and Alignment



ESW Welding Procedures

Typical ESW Welding Conditions

Single electrode, non-oscillating, carbon steel

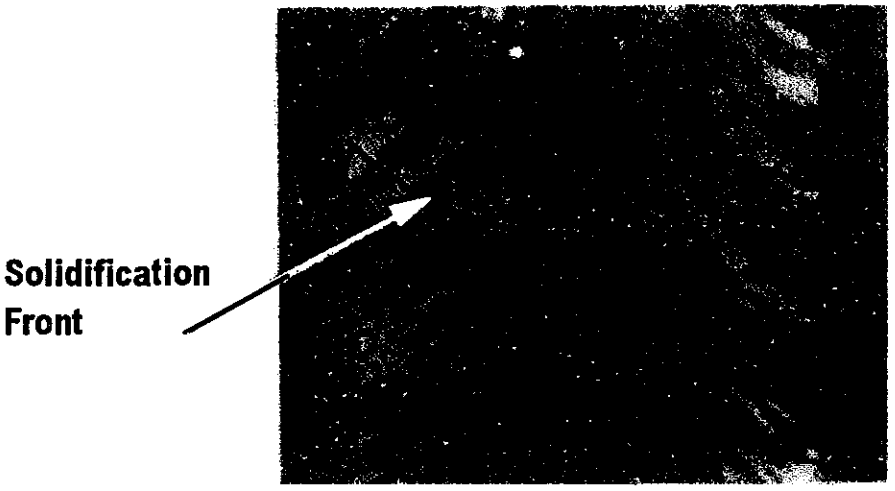
Plate Thickness (mm)	Joint Opening (mm)	Welding Current (A)	Welding Voltage (V)
25	25	600	38
50	25	700	39
75	25	700	52

ESW: Weld Metal Grain Structure

Transverse Section

Longitudinal Section at A-A

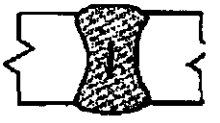
ESW: Weld Grain Structure



ESW: Weld Faults

(a) Porosity

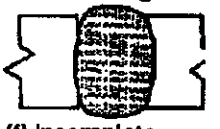
(b) Centre-Line Cracking



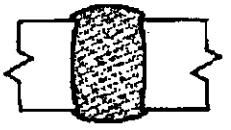
(c) Centre-Line Cracking

(d) Incomplete Fusion

(e) Incomplete Fusion



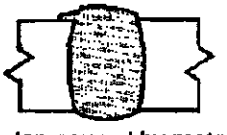
(f) Incomplete Fusion



(g) Overlap

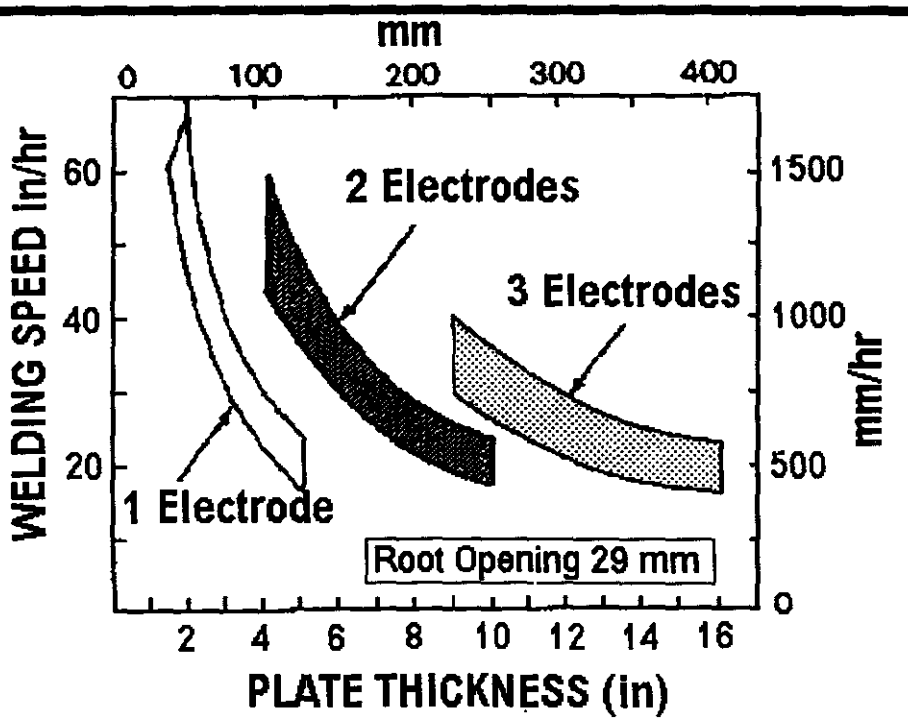
(h) Underfill

(i) Copper pickup & internal cracks



(j) Overlap caused by metal spillage

ESW: Production Rates



ESW Applications

- Most types of carbon steels, low alloy and stainless steels
- Pressure vessel longitudinal seams
- Heavy structural fabrications, machinery

ESW Capabilities and Limitations

+ Very high deposition rates
+ Ability to weld very thick materials
+ Minimum joint preparation requirements
+ Minimum materials handling

– Limited to carbon, low alloy and some stainless steels
– Joints must be vertically positioned
– Risk of stop/start defects

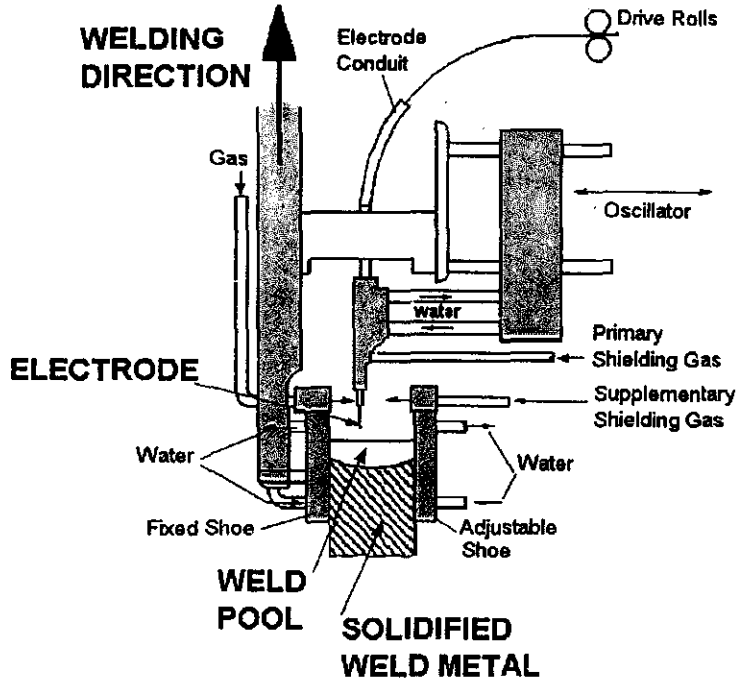
Welding Processes

Electro Gas Welding (EGW)

EGW Process Fundamentals

- In EGW the welding heat source is an arc maintained between a continuous electrode and the weld pool
- The weld is formed by melting and resolidification of the joint edges and filler in the vertical position
- The weld zone is shielded from contamination by shielding gas and/or flux supplied from flux-cored wire

EGW Process Fundamentals



EGW Welding Procedures

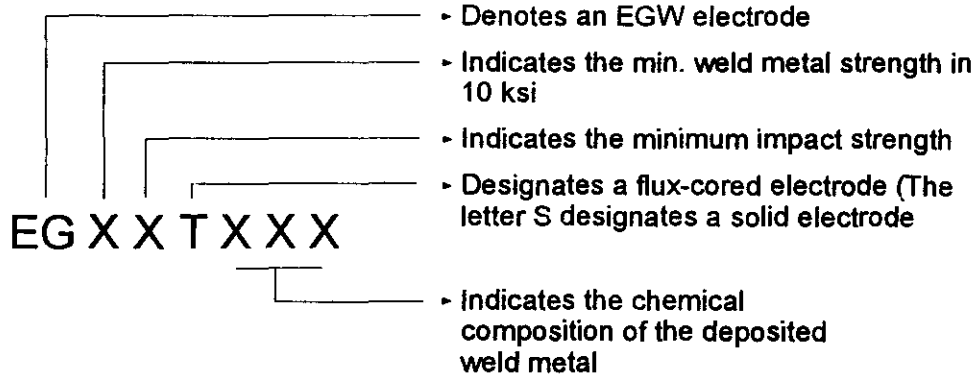
- Operating Variables
  - Materials and consumables
  - Joint fit-up and alignment
  - Welding Voltage
  - Welding Current/Electrode Feed Speed
  - Electrode Extension
  - Electrode Oscillation

EGW Consumables

- Both flux cored and solid wires are used in EGW
- EGW flux cored wires contain less slag-forming compounds than FCAW electrodes
- Flux-cored and solid wires are available in various chemical compositions to achieve desired weld metal strength and notch toughness.

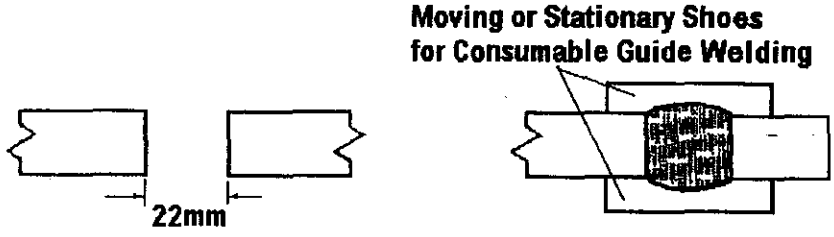
Classification of EGW Consumables

- AWS A5.26 *Specification for Consumables Used for Electrogas Welding of Carbon and High Strength Low Alloy Steels*

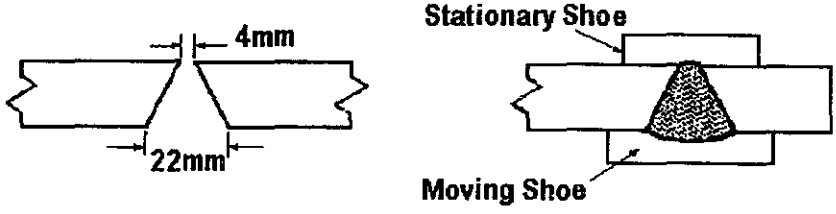


Example: **EG 6 2 S-1**: Solid carbon-manganese EGW electrode with 60 ksi min strength and 20ft-lb impact energy at -40F

EGW Welding Procedures



(A) Butt Joint With Square Groove Weld



(B) Butt joint with Single V Groove Weld

EGW Welding Procedures

Typical Conditions for Electrogas Welds Using a 3 mm Diameter AWS Class EG72T1 Electrode with Moving Shoes

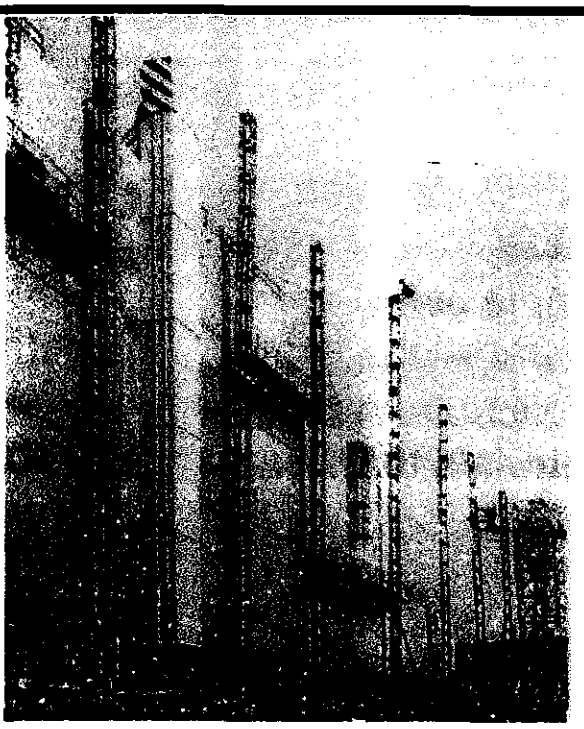
Thickness mm	Joint Opening mm	Current A	Voltage V	Electrode Feed Speed mm/s	Electrode Extension mm	Travel Speed mm/s	Oscillation Distance mm
12	12	450-500	35-37	120	50	2.5	-
25	20	625-675	40-42	150	75	1.25	-
37	19	625-675	40-42	150	75	.7	19

EGW Equipment

- Power supply
- Electrode feeder
- Electrode guide
- Electrode guide travel and oscillator
- Retaining shoes
- Controls

EGW: Applications

The principal applications of EGW include storage tanks, pressure vessels, structural members and ship hulls.



EGW Capabilities and Limitations

+ High Deposition Rates
+ Simple Joint Preparation
+ Applicable to thinner materials than ESW

- Limited to carbon, low alloy and some stainless steels
- Joints must be vertically positioned
- Risk of stop/start defects