Welding High Strength Materials

Offshore

September 2007

China

690 MPa (100Ksi) Yield Material

Jack-up Barge

- Leg's fabricated out of plate
- Leg "Can" design – "Pinned" in Position
- Double sided Longitudinal and Circumferential Welding

Jack-up Rig

- Leg's fabricated out of Rack & Chord
- Mobile Offshore Drilling Units (MODU's)
- Relocate between each well
- 400+ Units in Service; 67+ Under Construction

Base Materials

- ABS Grade EQ70
- Dillinger Dillimax 690
- INDUSTEEL Superelso 690 CR
- Aldur 700 QL1

Code Specifications

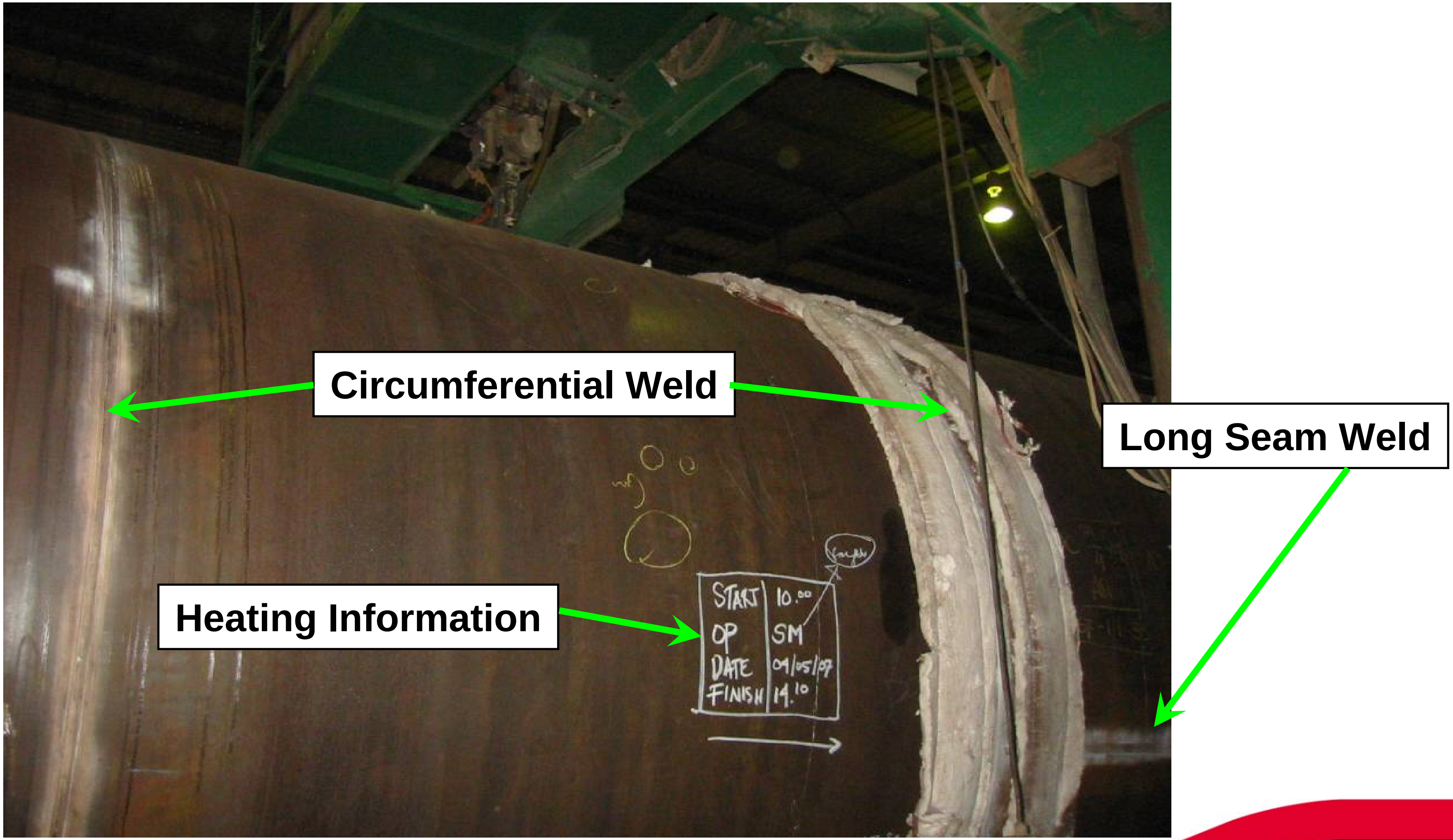
- **AWS D1.1/Annex M (i.e. 2001-2004) or AWS D1.1/D1.1M:2006 Table 4**
  - ASTM A514
  - ASTM A517
- ABS Part 3, Chapter 1, Appendix 3
  - ABS Grades of High Strength Q&T Steel
- EN10137 Part 2
  - Q&T High Strength Steel Grades

Part 3 Hull Construction and Equipment
Chapter 1 General
Appendix 3 Guide for Material Selection for ABS Grades of High Strength Quenched and Tempered Steel 3-1-A3

TABLE 2
Mechanical Properties Requirements for ABS Grades of High Strength Quenched and Tempered Steels *(1996)*

Grade of Steel	*Mechanical Properties* (1)			*Impact Test* (3)	
	Yield Strength N/mm² (kgf/mm², ksi)	*Tensile Strength N/mm² (kgf/mm², ksi)*	*Elongation* (5,6) *in 5.65 $\sqrt{A}$* (4) *minimum*	*Test Temperature °C (°F)*	*Energy Average J (kgf-m, ft-lb)*
AQ43 DQ43 EQ43 FQ43	420 (43, 61)	530/680 (54/69, 77/98)	18	0 (32) −20 (−4) −40 (−40) −60 (−76)	41 (4.2, 30) (2) L or 27 (2.8, 20) (1) T
AQ47 DQ47 EQ47 FQ47	460 (47, 67)	570/720 (58/73, 83/104)	17	0 (32) −20 (−4) −40 (−40) −60 (−76)	46 (4.7, 34) L or 31 (3.2, 23) T
AQ51 DQ51 EQ51 FQ51	500 (51, 73)	610/770 (62/78, 88/112)	16	0 (32) −20 (−4) −40 (−40) −60 (−76)	50 (5.1, 37) L or 33 (3.4, 24) T
AQ56 DQ56 EQ56 FQ56	550 (56, 80)	670/835 (68/85, 97/120)	16	0 (32) −20 (−4) −40 (−40) −60 (−76)	55 (5.6, 41) L or 37 (3.8, 27) T
AQ63 DQ63 EQ63 FQ63	620 (63, 90)	720/890 (73/91, 104/129)	15	0 (32) −20 (−4) −40 (−40) −60 (−76)	62 (6.3, 46) L or 41 (4.2, 30) T
AQ70 DQ70 EQ70 FQ70	690 (70, 100)	770/940 (78/96, 112/136)	14	0 (32) −20 (−4) −40 (−40) −60 (−76)	69 (7.0, 51) L or 46 (4.7, 34) T

“CAN” Welding on EQ 70 Material

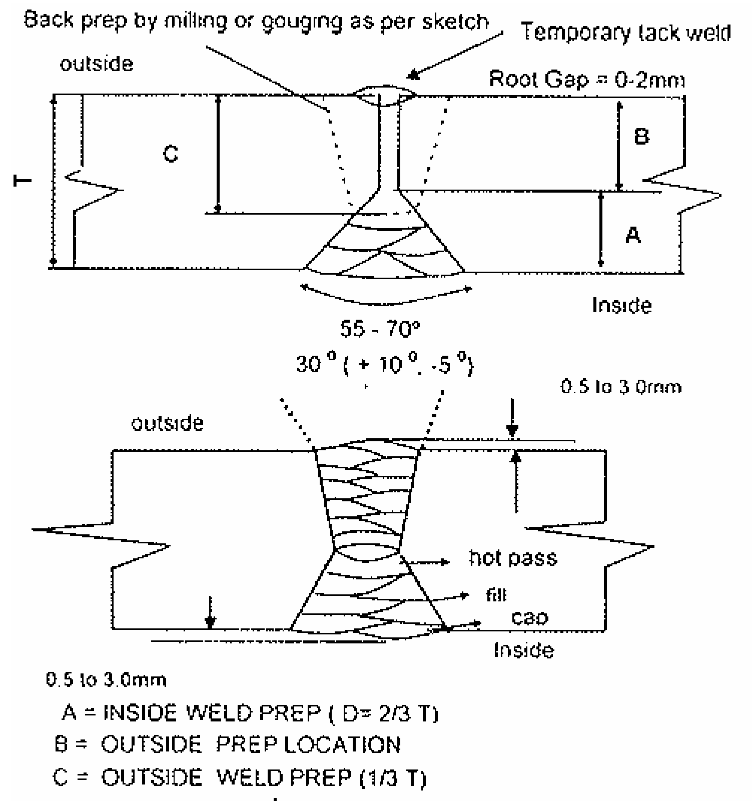


"CAN" Welding

Resistance Heating

Single V Prep with Back Mill or Gouging

1. Preheat Base Metal
2. Temporary Tack Weld on O.D.
3. Weld Single V joint on I.D. with SAW
4. Back Mill O.D. or Carbon-Air Arc Gouge & Grind
5. Perform NDT to ensure sound metal (e.g. PT or MT)
6. Weld O.D. with SAW
7. Post Heat “Soak” Weld

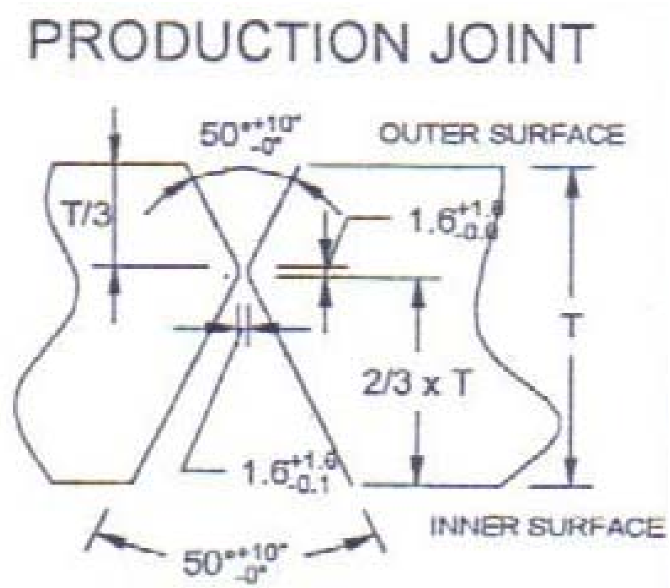


Notes:

- Once Welding Starts – Complete w/o Stopping
- After welding is complete heat “soak” the weld area at 150ºC - 200ºC for 2-3 hours

Double V Prep with Root Pass Welding

1. Preheat Base Metal
2. Root & Hot Passes with GMAW or FCAW-GS
3. Weld Single V joint on Side 1 with SAW
4. Back Grind or Carbon-Air Arc Gouge to sound metal on 2nd Side
5. Perform NDT to ensure sound metal
   (e.g. PT or MT)
6. Weld Side 2 with SAW
7. Post Heat “Soak”



Notes:

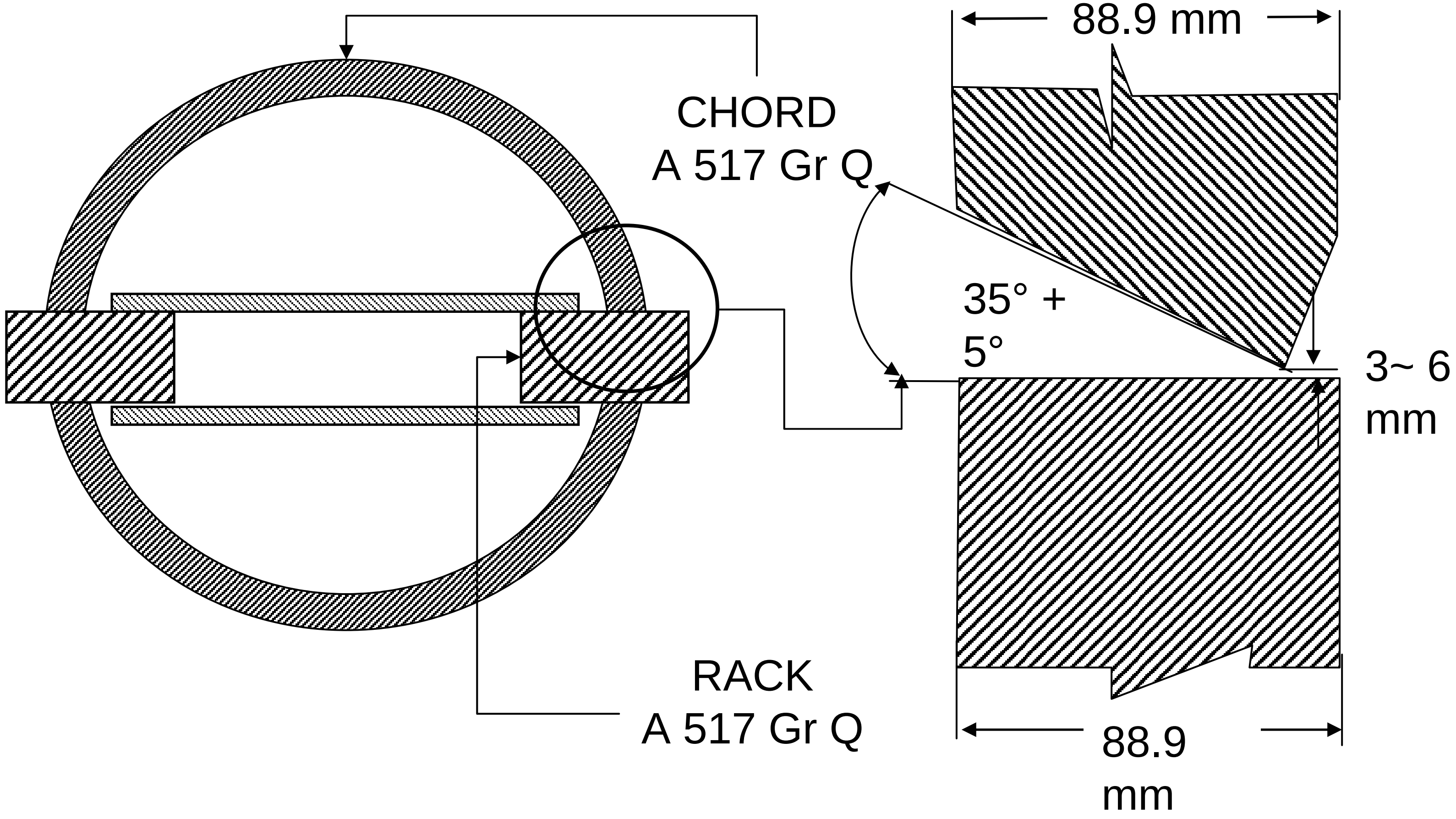
- Once Welding Starts – Complete w/o Stopping
- After welding is complete heat “soak” the weld area at 150°C - 200°C for 2-3 hours

Rack to Chord Welding

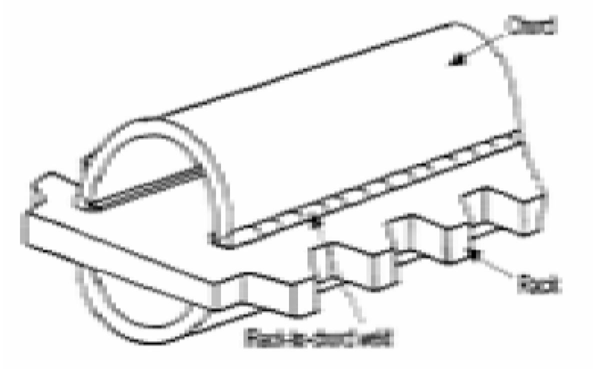
Resistance Heating

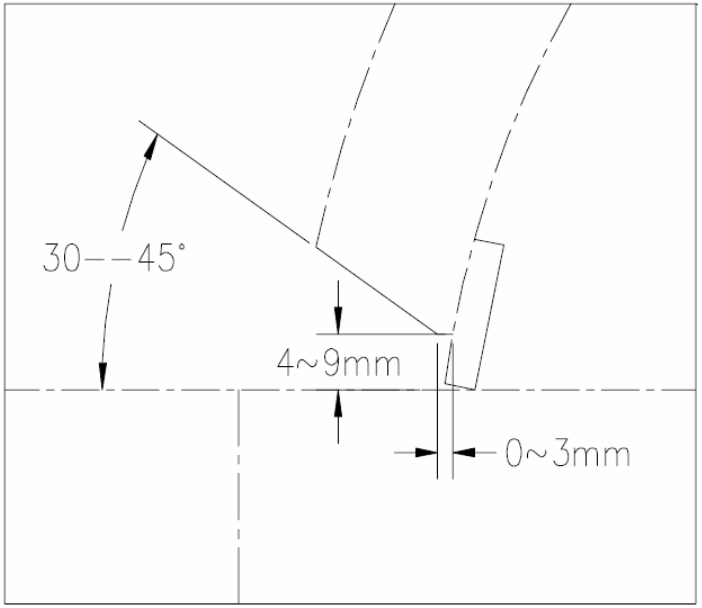
Simultaneous Welding
Positioned for SAW

Rack to Chord Welding



Rack to Chord Welding





Rack to Chord Welding – Root & Hot Pass

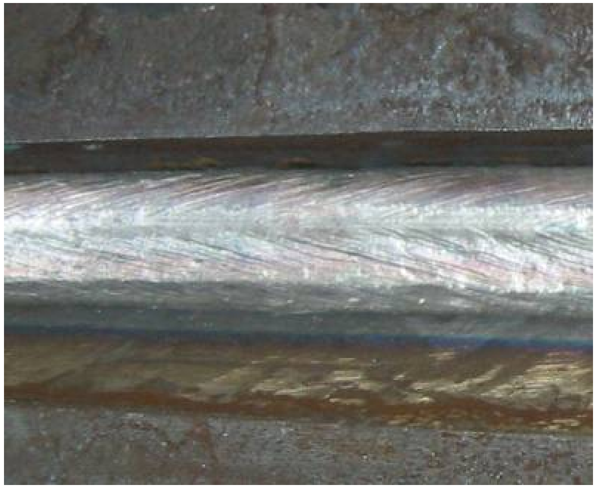
1. Preheat Base Metal with Resistance Heating
2. Be sure Joint is Clean
3. Positioned in 2G/2G Overhead
4. Root & Hot Passes
   - FCAW-GS
   - GMAW
   - SMAW
5. ABS Approved Lincoln Consumable Options
   - LNM MoNiVa
   - OS 690-H (Europe)
   - Pipeliner® G90M (USA)
   - Conarc 80 (Europe)
   - Excalibur® 11018M MR (USA)

2G Overhead Position

After First Pass - GMAW

Rack to Chord Welding - SAW

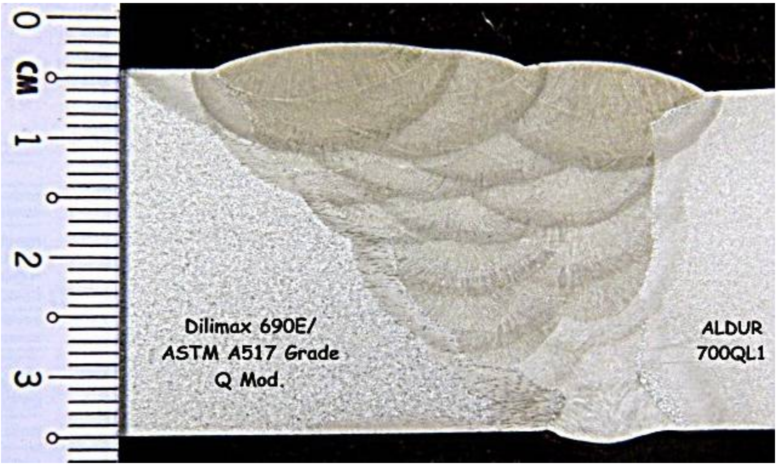
1. Preheat Base Metal with Resistance Heating
2. Interpass Cleaning – Power Brushing or Grinding if necessary
3. Do not stop until welding is complete
4. Check Interpass Temp. around 25mm from joint
5. Use only enough flux to get a little flash through – Do NOT smother the arc with flux
6. Preferred Lincoln Consumables
   - LAC M2 with 888 or Mil800H Flux
   - LNS 168 /P230



Low Alloy Cored Wire Submerged Arc

Advantages of LAC vs Solid Wire w/ Neutral Flux

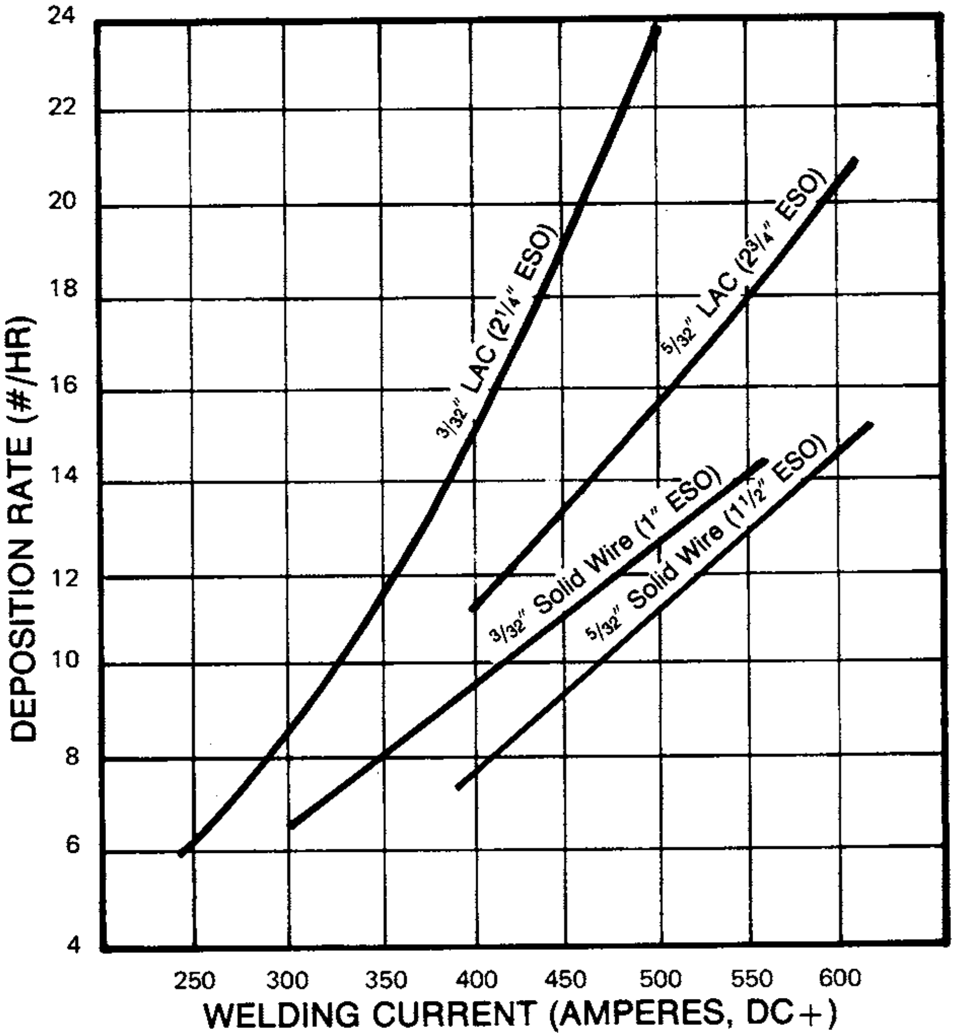
- Higher Deposition Rates at same Amperage
- Advantage of Extended Stick-out
  - Better impact properties in the HAZ
  - More resistance to hot cracking
  - Reduced penetration and less admixture



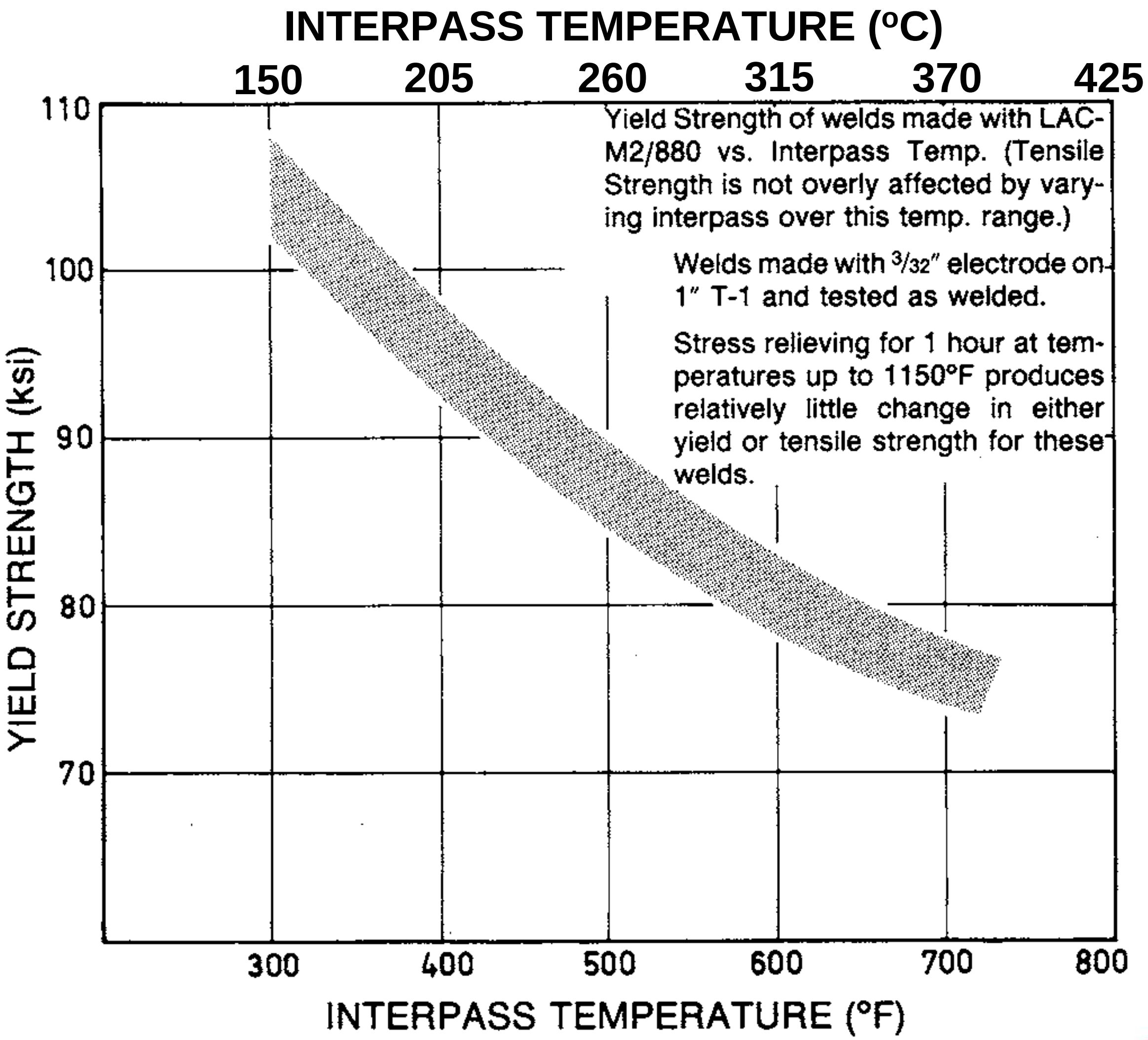
LAC M2 with 888 Flux

- ABS 4YQ690M Approval

Deposition Rate Advantage of LAC vs Solid Wire



Effect of Interpass Temp. on Yield Strength



Recommended Equipment Set-up

- Either a CC or CV Lincoln SAW power sources is recommended
- Proper knurled drive rolls for cored wire
- M10214 Flux Core Wire Straightener
- Positive Contact Nozzle Assembly
  - K148A (for 3/32)
  - K148B (for 5/32)
- Mechanical Nozzle Extension
  - K149-3/32
  - K149-5/32
- Mechanical Guide Tip
  - KP1976-3 (for 3/32)
  - KP 1976-4 (for 5/32)

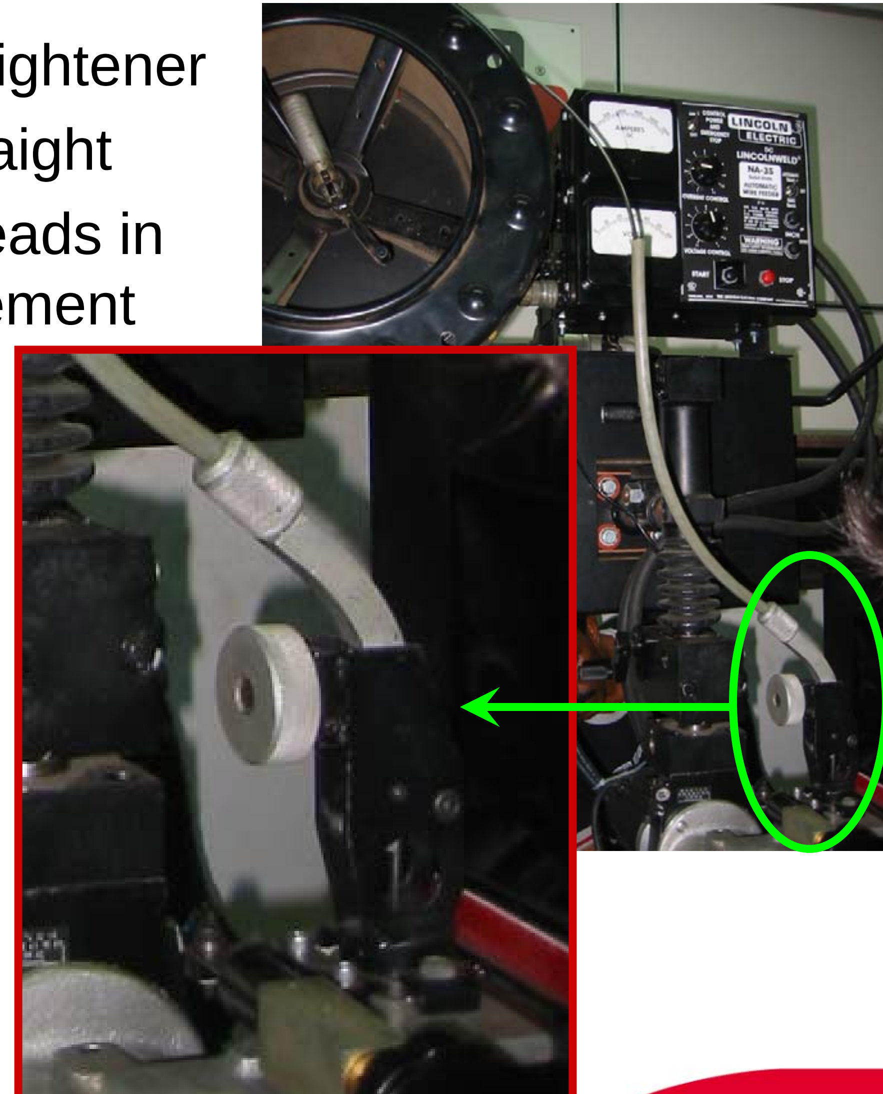
K148 Above

← K148 w/ K149 Attached

Best Practice Welding Set-up

- Use M10214 Flux Core Wire Straightener
- Verify that Wire is coming out Straight
- Use consistent overlap of weld beads in center of joint for best grain refinement

Set-up for Split Pass



Starting Procedures

1. Remove extension guide before fine tuning the starts to prevent potential damage to the K149
2. Cut the electrode clean at an angle before each start
3. If using Lincoln CC equipment mode, Good starting should be easily obtained
4. If other equipment or CV mode is used, be sure to do as follows:
   - Set inching wire feed speed below 60 in/min
   - On CV, a hot start should be used
   - Electrode should be inched up approximately 3mm above the work surface before starting
   - The electrode should not touch the work

Controls Inside an NA-3S

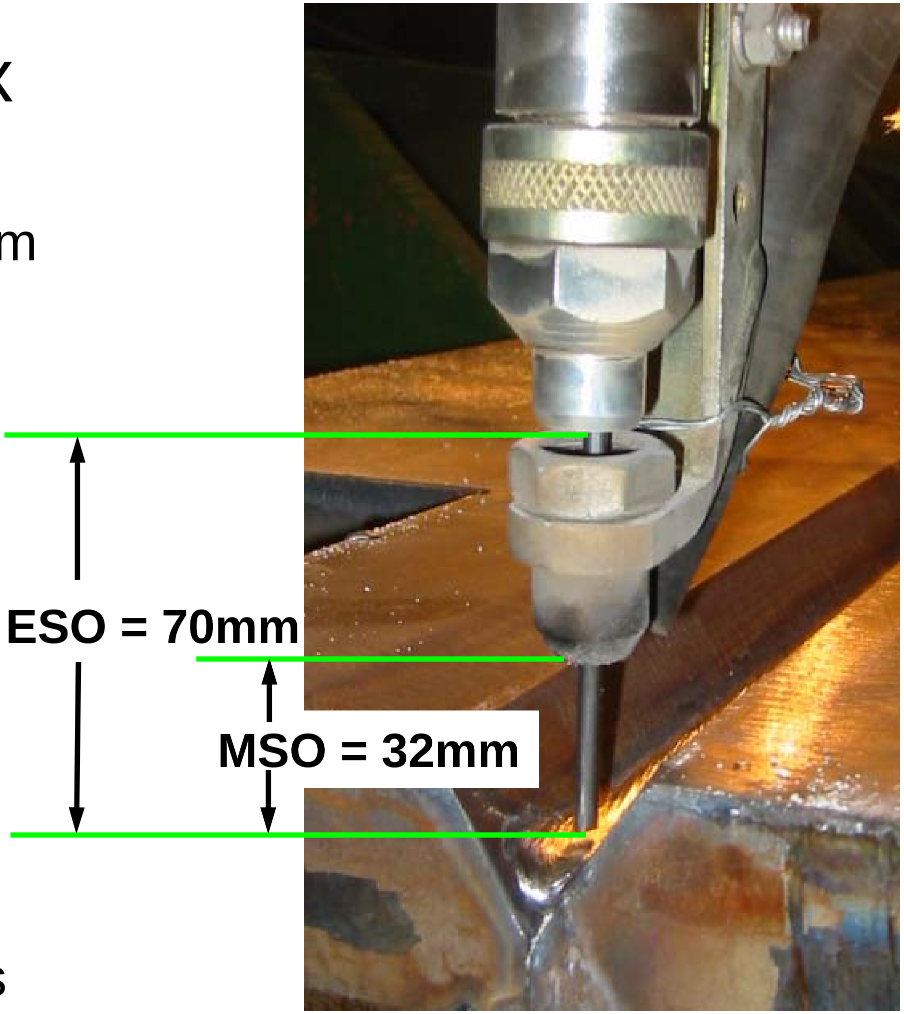
Best Practice Welding Procedures

5/32” LAC M2 with 888 Flux

- Electrical Stick Out (ESO) = 70mm
- Mechanical Stick Out (ESO) = 32mm

Welding Procedures

- 500 amps @ 28-29 Volts
- Heat Input: 1.75 – 2.0 KJ/mm
- Do not allow plate to fall below 120^{o}C after welding is started
- Must be 150^{o}C before Welding
- Maximum 170^{o}C Interpass temp
- After welding is complete “soak” weld at 150^{o}C - 200^{o}C for 2-3 hours

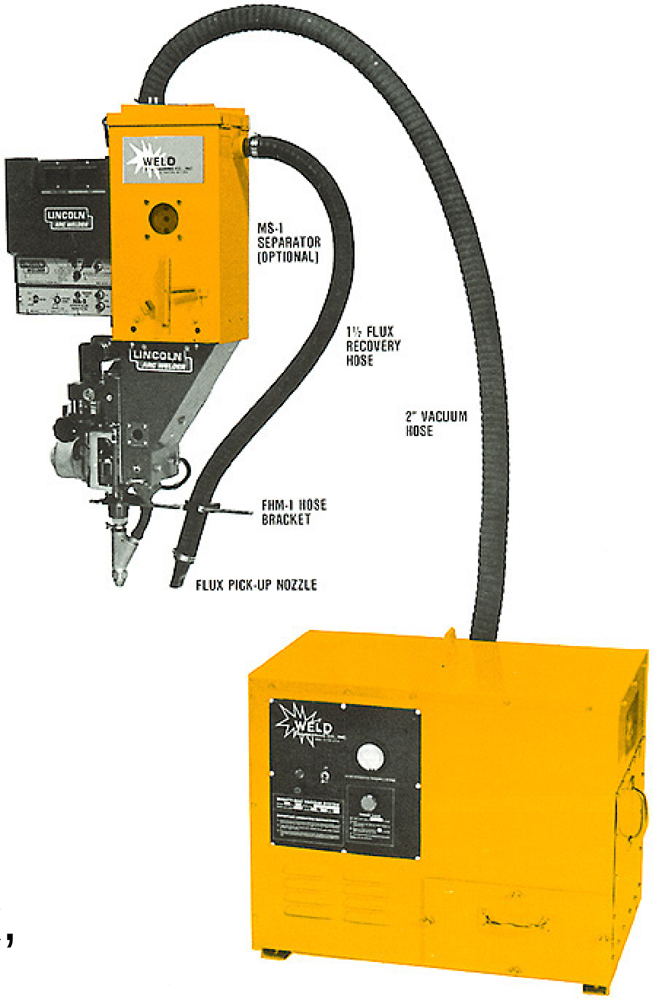


Flux Storage and Preparation

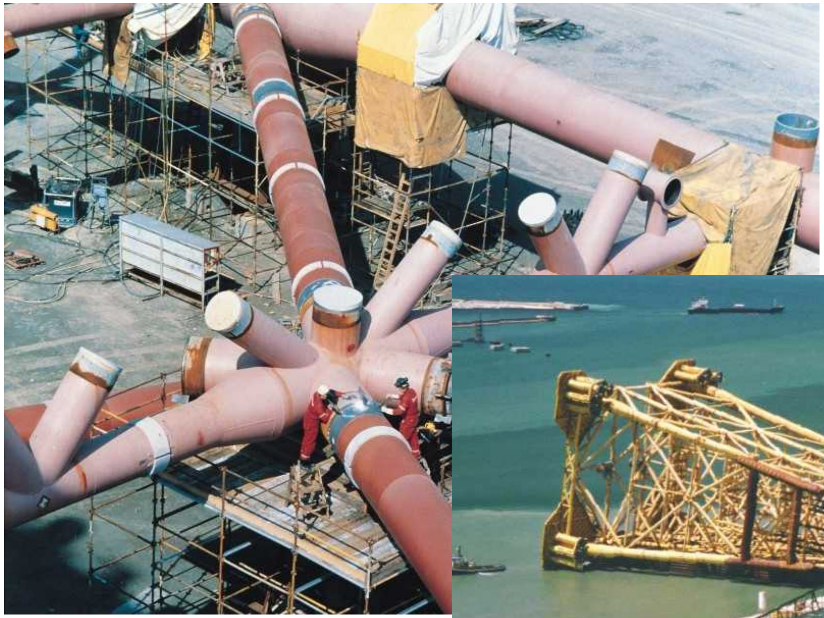
- Re-Dry Flux at 300º C and hold at this temperature for at least 2 hours
- The entire mass should be raised to 300C and a thermometer should read 300C in the center
- After Re-dry either:
  - Use flux immediately (or)
  - Put into holding oven at 125º C
- Hoppers should be emptied when welding is suspended for more than an hour. Left over flux should be brought back for re-drying
- Hoppers should have covers and heated if possible
- Flux driven by compressed air needs special attention to insure compressed air is extremely dry!

Handling Flux During Welding

- Flux recovery units maximize flux efficiency
- Clean up time is minimized
- Recycled flux shall be cleaned of slag, metal, mill scale and other contaminates
- Prevent damage of flux by heavy impingement
- Remove excess fines from the recycled flux
- Recovered flux must be kept sealed and dry
- Continue to add new flux to recycled flux, a 50/50 mix is best for optimal performance



Offshore Construction



High Strength Low Alloy

Copper Base Alloys

Mild Steel

Duplex

Nickel Base Alloys

Austenitic Stainless Steel

Low H_2 Packaging

Sahara ReadyBagTM
The packaging solution for any hazardous flux storage conditions

Sahara Ready Pack

Low hydrogen, Moisture resistant vacuum-packed stick electrodes

Discontinuities

- Porosity
- Slag Inclusions
- Lack of Fusion
- Cracks – Never Acceptable = Defect

Cracks Need Immediate Attention!

Weld Failure

- Over-loading
- Under Designed
- Fatigue
- Above Normally seen in Service

Focus on Application/Design

Fabrication Cracking

- Solidification Cracking
- Cracking related to Cooling
- Weld Shrinkage Stresses
- Surrounding Rigidity Stresses
- Occur Close to time of Fabrication

None are the Result of Service Loads

Two Cracking Categories

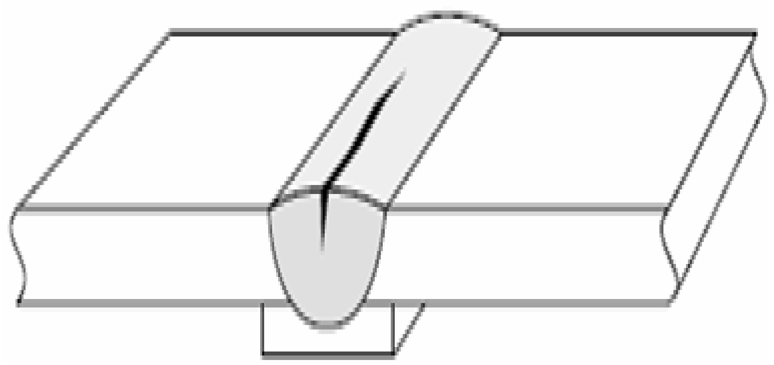
1. Hot Cracks
   - Occur at Elevated Temperature
   - Usually Solidification Related
2. Cold Cracks
   - Occur After Weld Metal as Cooled to RT
   - May be Hydrogen Related

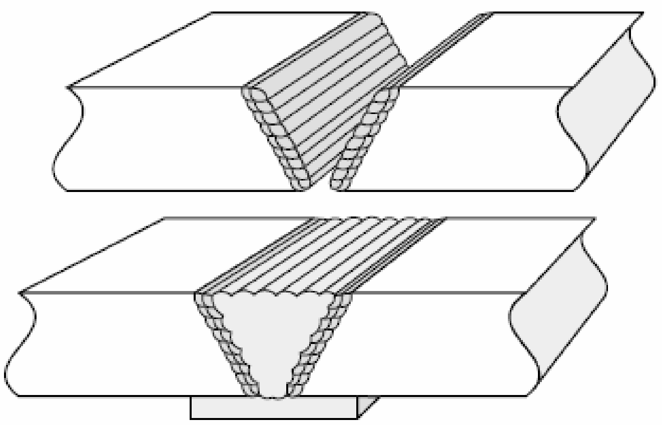
Focus on Finding the Solution & Correct

Separation in the Center of the Weld Bead

Segregation Induced

- Low melting point constituents segregate to weld bead centerline (C, Pb, Zn, Cu, P, S)
- Minimize Admixture
  - Minimum Penetration
  - Change Joint Design
  - Use Buttering
- Reduce low T_m Elements (Use "good" steel)
- For Sulfur, use higher Mn electrodes
- Use Buttering Layers deposited by a low energy process such as SMAW

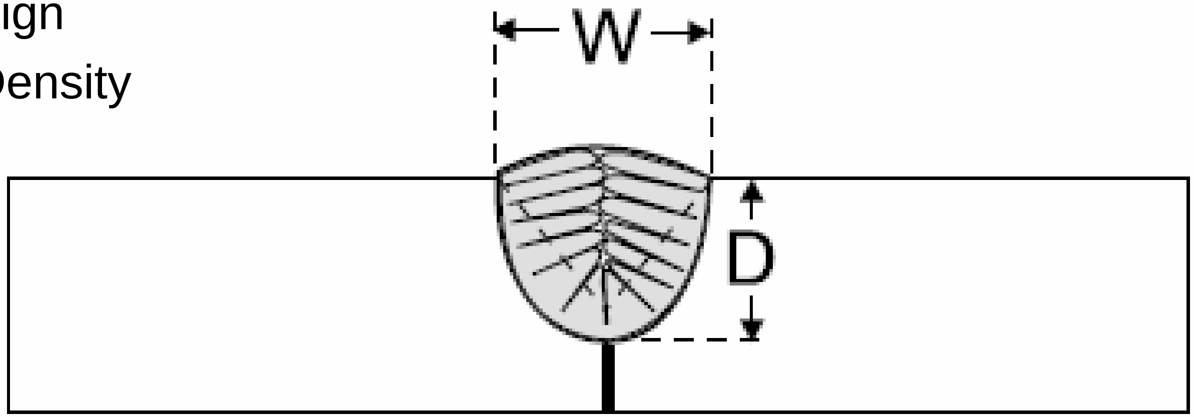




Separation in the Center of the Weld Bead

Bead Shape Induced

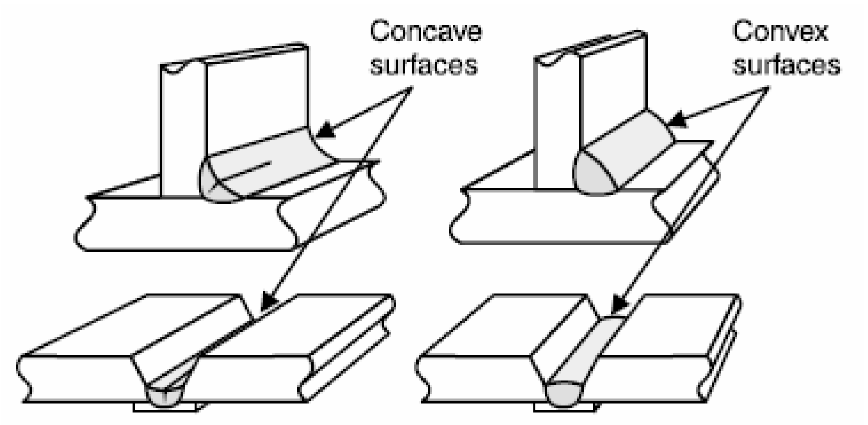
- Associated with Deep Penetrating Process
  - SAW
  - CO_2 Shielded FCAW
- "Popsicle" Cracking
- Improper Width-to-Depth Ratio
  - Target 1:1 to 1.4:1 Width-to-Depth
- Change Joint Design
- Reduce Current Density



Separation in the Center of the Weld Bead

Surface Profile Induced

- Concave Weld – internal shrinkage stresses will place weld metal surface into tension
- Convex Weld – conversely, internal shrinkage stresses will pull the surface into compression
- Change Profile to Convex by
  - Reducing arc voltage
  - Reduce travel speed
  - If welding vertical down, change to vertical-up welding

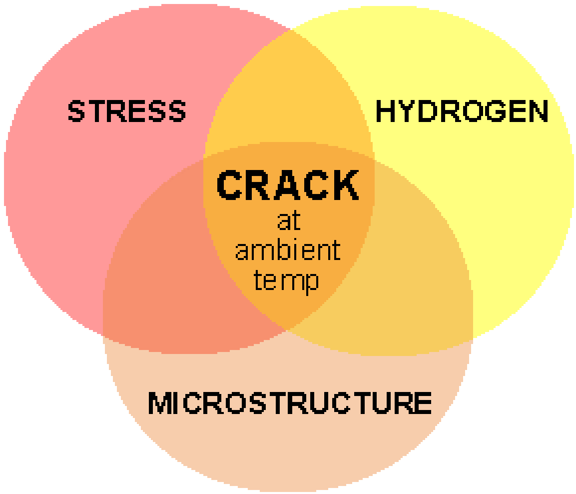


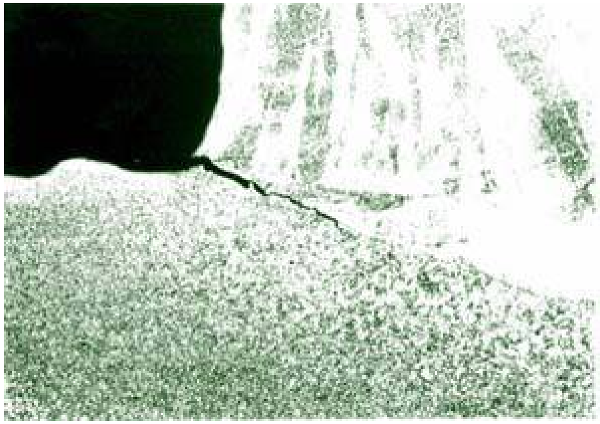
Fabrication Hydrogen Cracks

- Occurs in HAZ or Weld Metal
- May be delayed
- Can be Longitudinal or Transverse

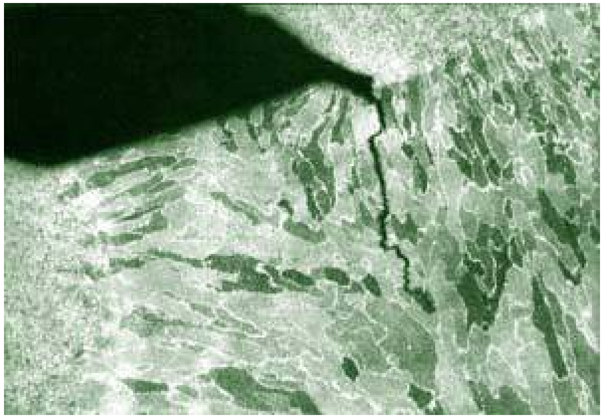
Factors Involved

- All three factors must come together
- Remedy is to reduce one or more of the factors





HAZ Hydrogen Crack



Weld Metal Hydrogen Crack

Hydrogen Factor

- If no Hydrogen then no Hydrogen Cracking
- Moisture and Organic Compounds are the primary sources of H_2
- Hydrogen presence can be controlled once identified:
  - Consumable – moisture in fluxes or dirt/grease on wires
  - Surface Contamination – grease, dirt, rust or moisture on the joint faces
  - Atmosphere – particularly in humid conditions
- **Limit Hydrogen Content in Deposited Welds**
  - Welding consumables must be properly maintained
  - Welding surfaces must be clean and dry
  - Preheat promotes hydrogen escape through longer cooling cycles
  - Control Interpass temperature and time
  - Avoid large thick weld beads which increases diffusion distances
  - Heat "Soak" the weld after welding is completed

Sensitive Microstructure Factor

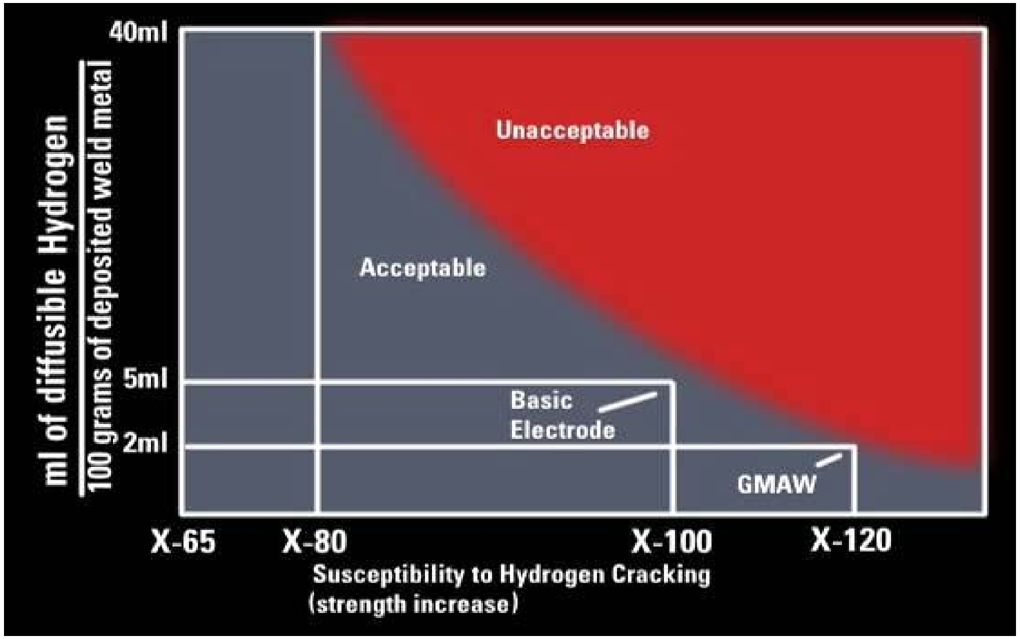
- As hardness increases so does the risk of cracking
- Proper Control of Cooling Rate is Important
  - Maintain Proper Preheat
  - Use Higher Heat Input where possible
  - Control Interpass Temperature
  - Control of the Heat Sink (when possible)
- **High Risk Regions**
  - Rapid Cooling (i.e. Quench Effect) during the weld thermal cycle
  - HAZ has the greatest risk in the grain-coarsened HAZ, adjacent to the fusion boundary
  - Hardenability also increases with alloy content and carbon level

Stress Factor

- Residual Stresses are unavoidable but their magnitude is a function of:
  - Weld Size
  - Joint Geometry
  - Fit-up
  - External Restraint
  - Yield Strengths of Parent and Weld Material
- **Reducing the Stress**
  - Good Fit-up will reduce the severity of local stress
  - Use buttering technique onto the weld preparation before filling the joint
    - Buttering residual stress will be lower
    - HAZ associated with buttering will be tempered by thermal cycle of fill passes
    - Hydrogen will diffuse out of the buttering as the main fill is introduced

Fabrication Hydrogen Crack - Transverse

- Occurs in the Weld Metal as a result of longitudinal residual stress
- Normally associated with high strength materials
- Following Welding and Consumable Handing Procedures is critical!



The Nobel Roger Lewis
Built by Dalian Shipbuilding Industry Co. Ltd.
Dalian, People's Republic of China

Designed to Operate in Water Depths of 400 ft (122 m)
Equipped to drill HP/HT wells to 30,000 ft (9,144m)