Weld Repair of Manganese Frogs for Enhanced Safety in Shared Service

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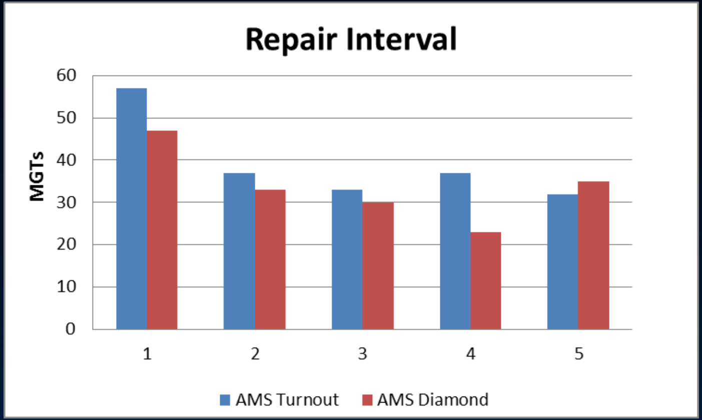
Background: Overview



- Austenitic manganese steel (AMS)
  - Highly work-hardenable
  - Resistant to wear
  - High toughness
- Shortest-lived track segments
- Current repair methods cannot restore original durability
- Low interpass temperature requirement limits productivity
- Often repairs cannot be properly completed, causing further damage

Background: Welding AMS

- Temperature of base material must be kept low to retain mechanical properties
- AWS D15.2 specifies a temperature 1 in. (25 mm) from weld of 500°F (260°C)
- Significant variation with manual/semi-automatic processes
- Special welding techniques
  - limit overheating
  - eliminate cracking
  - limit productivity

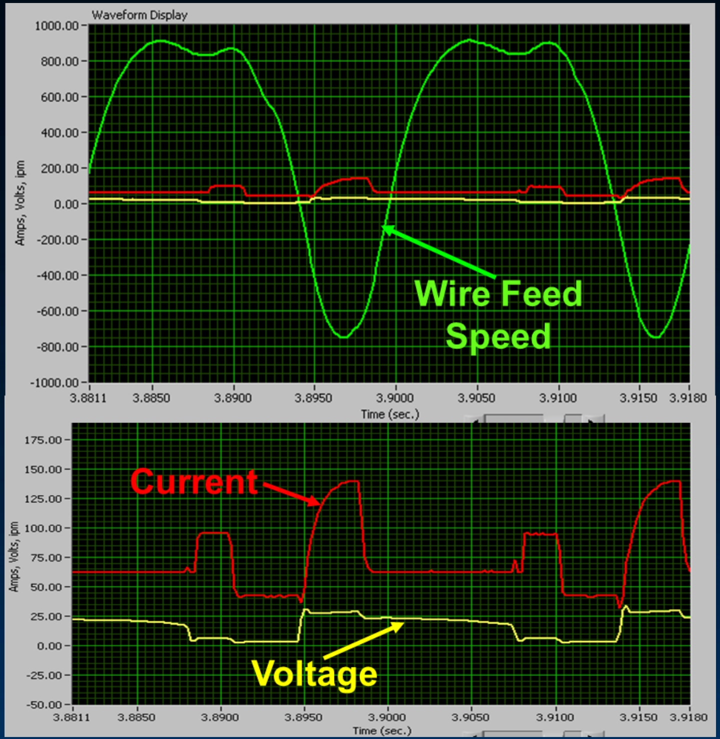
Background: Breakouts

- Most repairs are of “breakouts”
- Frog casting plastically deforms before fully work-hardening
- Fractures initiate in damaged material
- Broken off when “flowed” material comes in contact with the wheels
- Maintenance grinding is critical

Frog Type	1st grinding	2nd grinding	3rd grinding	Steady-state grinding interval
Pre-hardened AMS frog	5 MGT	20 MGT	-	20 MGT
Weld repaired AMS frog	1 day	1 week	1 month	20 MGT

Background: Proposed Processes

- Automated FCAW
  - Higher travel speeds + wire feed speeds = higher productivity
  - More consistent than manual/ semi-automatic welding
- Reciprocating Wire Feed (RWF)
- Wire Motion Synchronized with Current Waveform
  - Minimal spatter
  - Low voltage/heat input



RWF current, voltage, and WFS

Objective

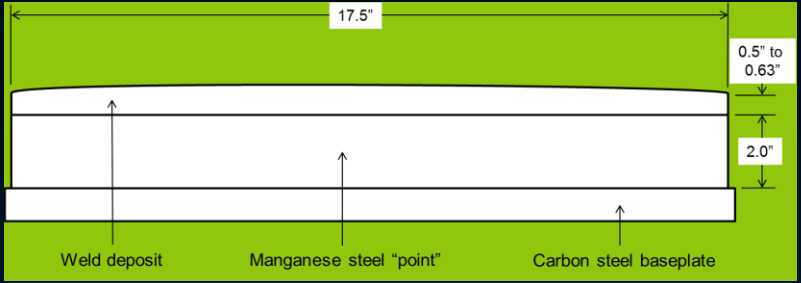
- Determine whether automating FCAW process variations can:
  - Improve weld quality
  - Provide quality control
  - Improve productivity
  - Increase repair life
  - Improve ride quality

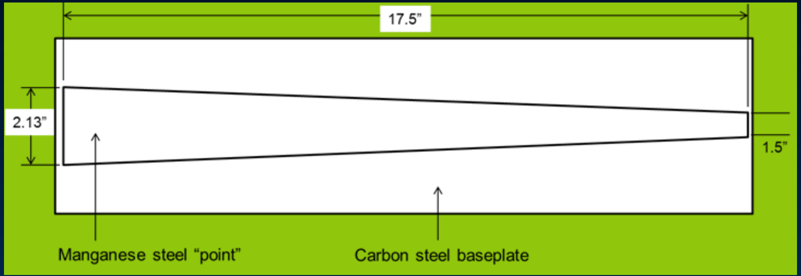
Approach

- Using #20 frog point “mock-ups”
  - Evaluate current industry repair techniques
  - Evaluate Automated FCAW and RWF FCAW
- Evaluate with mechanical and radiographic testing (RT)
- Select a single automated process
- Develop welding sequence on AMS frog
- Repair 2 AMS frogs
- Evaluate repaired frogs at TTCI

Baseline Welding

- Per AWS D15.2, Handbooks
- Short-circuiting transfer mode
- 35 to 50°(push) travel angle
- Bead width and length 5/8- and 5-in.
- Bead sequencing
  - Point to heel
  - Stagger craters
  - Avoid side-by-side beads
- Fill craters by reversing direction
- Peen all but first and last layers
- Maximum temperature of 500° to 600°F measured 1 in. from weld

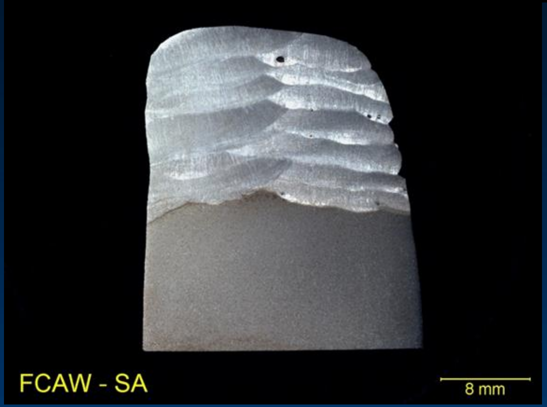




Process	Electrode Diameter (in.)	Current (A)	Voltage (V)	Travel Speed (ipm)	Heat Input (kJ/in.)	Deposition Rate (lbs/hr.)	Time per Layer (min.)	Thickness per Layer (in.)
SMAW	5/32	180	24	4 to 6	45 to 65	3	20	0.045
FCAW	1/16	200	27	6	60	7 to 8	6.1	0.086

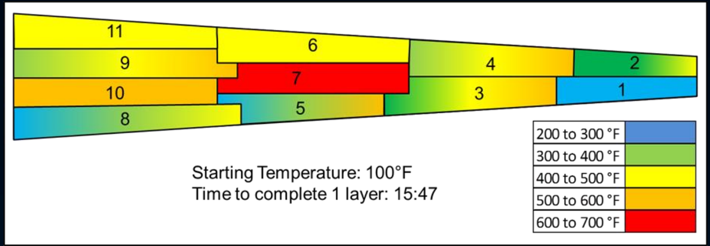
RT/Visual Inspection of Baseline Welds

- SMAW
  - **Heat input: 60 kJ/in.**
  - RT: Scattered porosity throughout
  - Cross section: 2 vertical cracks
- Semi-automatic FCAW
  - **Heat input: 45 to 65 kJ/in.**
  - RT: Scattered porosity
  - Improved quality over SMAW

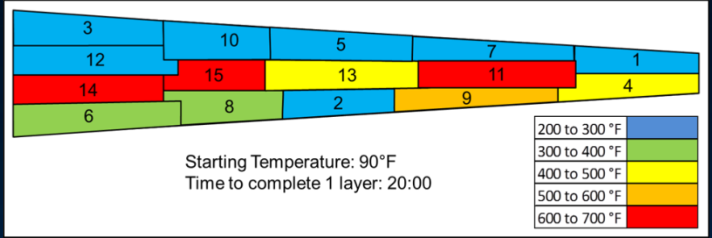


Interpass Temperature Trials

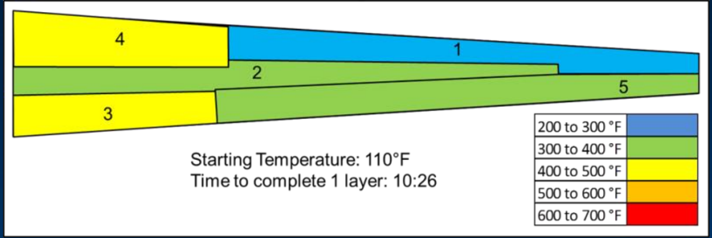
- SMAW
- #20 Point mock-ups
- No delay between passes
- Industry recommended vs. two EWI sequences
- Staggered long weld beads resulted in lower heat and cycle time



Industry Recommended



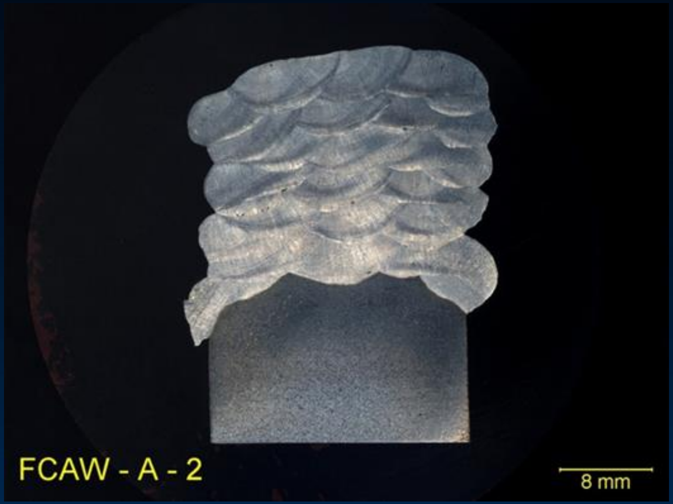
EWI Sequence 1



EWI Sequence 2

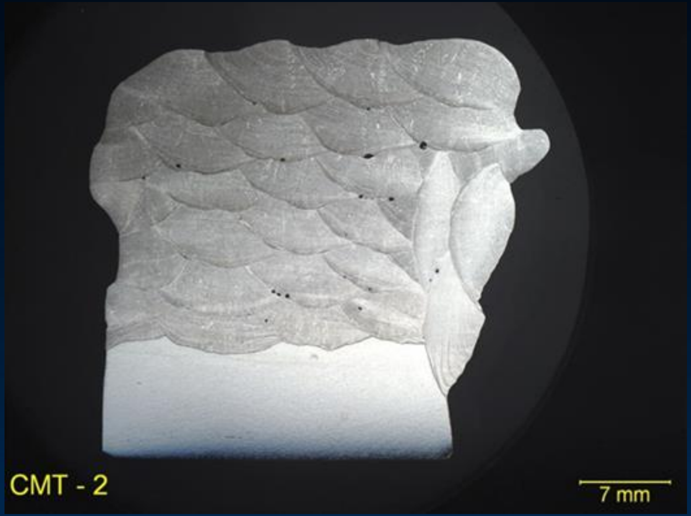
Automated FCAW Trials

- Solid Electrodes Not Commercially Available
  - Self-shielded FCAW Electrode
  - 75% Argon/25% CO_2 Shielding Gas
- Two Parameter Sets
  - Corner Parameters
    - TS: 15 ipm, A: 140, V: 21
    - **Heat Input: 12 kJ/in.**
    - Corner beads without drooping
  - High-deposition Parameters
    - TS: 15 ipm, A: 200, V: 28
    - **Heat Input: 23.5 kJ/in.**



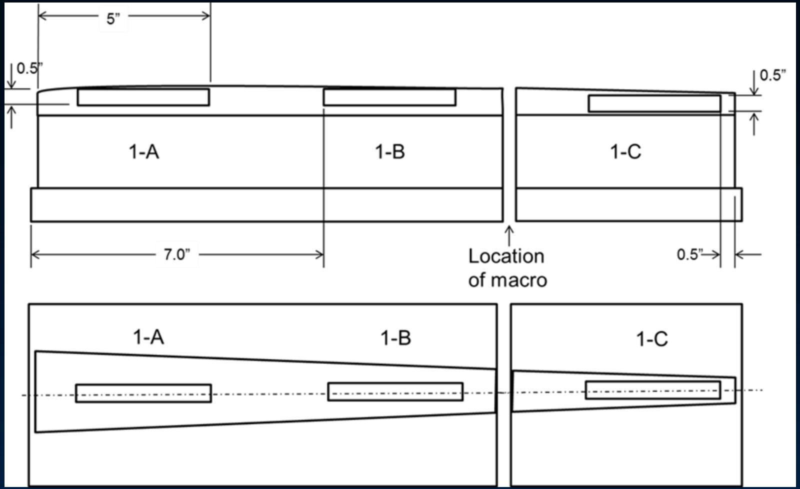
Reciprocating Wire Feed Trials

- Solid Electrodes Not Available
  - Self-shielded FCAW Electrode
  - 75% Argon/25% CO_2 Shielding Gas
- Two Parameter Sets Developed
  - Corner parameters
    - Travel Speed: 24 ipm, A: 150, V: 17.5
    - **Heat Input: 7 kJ/in.**
    - Corner beads without drooping
  - High-deposition Parameters
    - Travel Speed: 13 ipm, A: 195, V: 18.5
    - **Heat Input: 15.7 kJ/in.**
    - Weave added to promote wetting/tie-in



Tensile Testing of Mock-up Welds

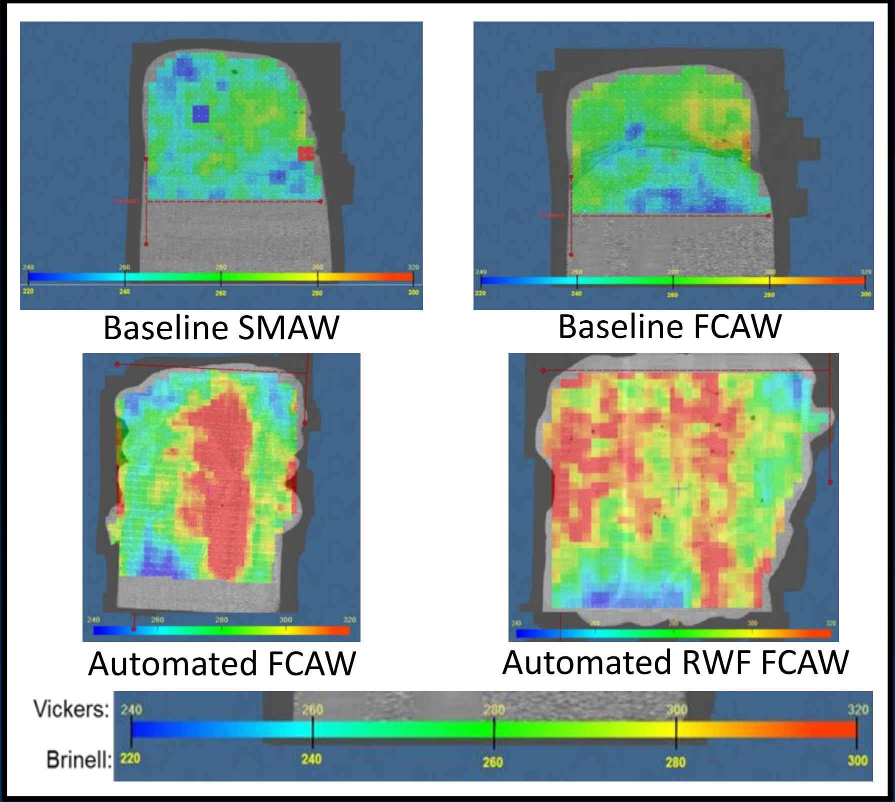
- All YS higher than D15.2 baseline
- All UTS except SA FCAW higher than D15.2 baseline



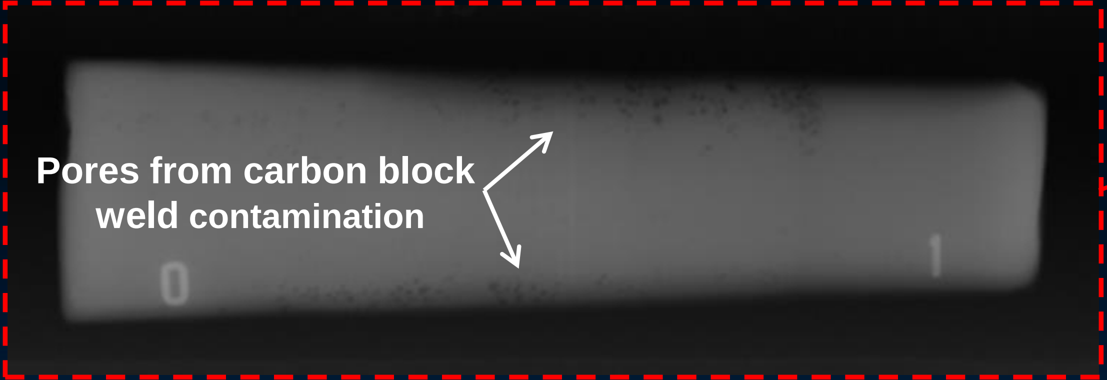
Property	Typical Casting Properties	Mock-up Material	Baseline SMAW	Baseline SA FCAW	FCAW-A	RWF FCAW
Tensile Strength (ksi)	100 to 145	142	117	96	125	121
Yield Strength (ksi)	50 to 57	59	83	74	83	86

Hardness

- Higher hardness in automated mock-ups
- May be related to internal heat build-up
  - Less wait time required between passes/layers

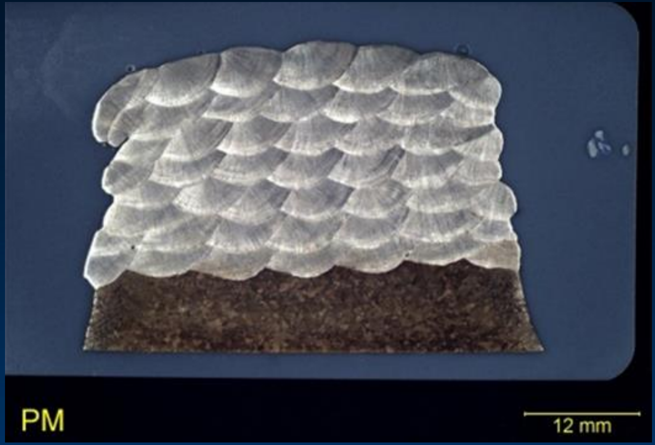


Evaluation of Damaged Frog Section



Partial Frog Repair

- Automated FCAW selected for all subsequent trials
- Previously repaired material removed w/ CAG and grinding
- Low and High HI parameters used

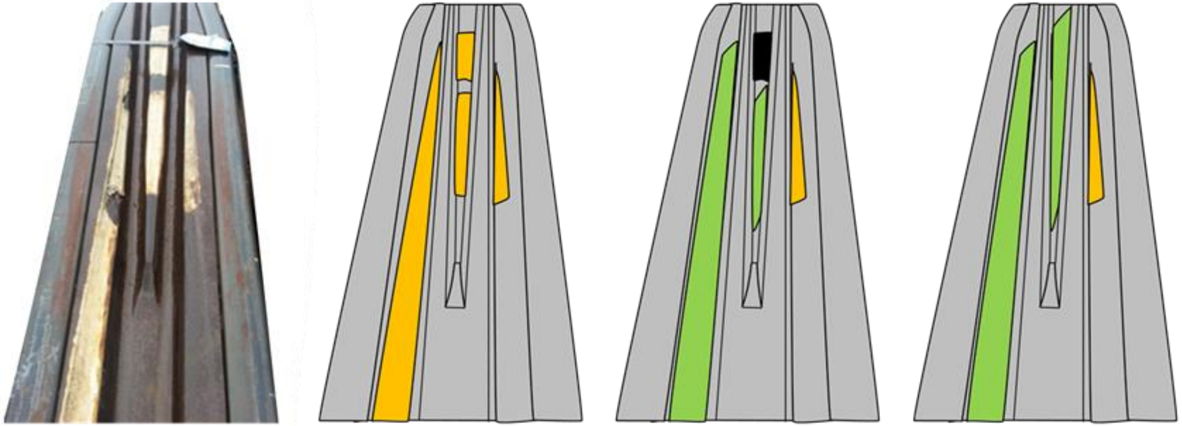


Partial Frog Repair Test Results

Property	Typical Casting Properties	Mock-up Material	Baseline SMAW	Baseline SA FCAW	FCAW-A	RWF-FCAW	FCAW-A on Partial Frog (point)	FCAW-A on Partial Frog (wing)
Tensile Strength (ksi)	100 to 145	142	117	96	125	121	112.1	109.5
Yield Strength (ksi)	50 to 57	59	83	74	83	86	73.7	74.7

Location	Test Temp. (°F)	Absorbed Energy (J)	Absorbed Energy (ft-lbs)	Lateral Expansion (mm)	Lateral Expansion (mils)	Shear (%)
Point	-30.28	40.67	30	0.6	23.62	100
Point	-30.28	43.39	32	0.68	26.77	100
Point	-30.28	44.74	33	0.44	17.32	100
Wing	73.4	84.06	62	1.25	49.21	100
Wing	73.4	115.24	85	1.41	55.51	100
Wing	73.4	90.84	67	1.34	52.76	100

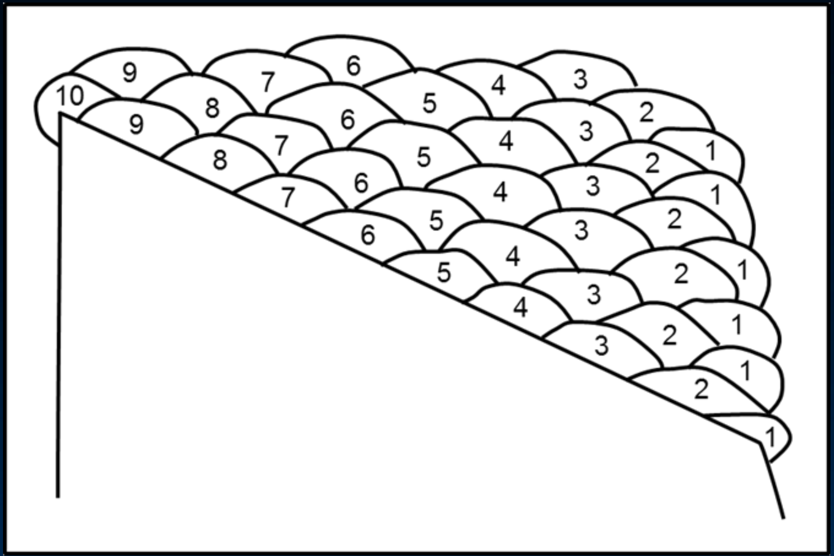
Full-sized Frog Preparation



Photograph of partial frog as-received | Partial frog sections in need of repair in orange | Repaired partial frog sections in green | Repaired full-length frog sections in green

Frog #1 Welding

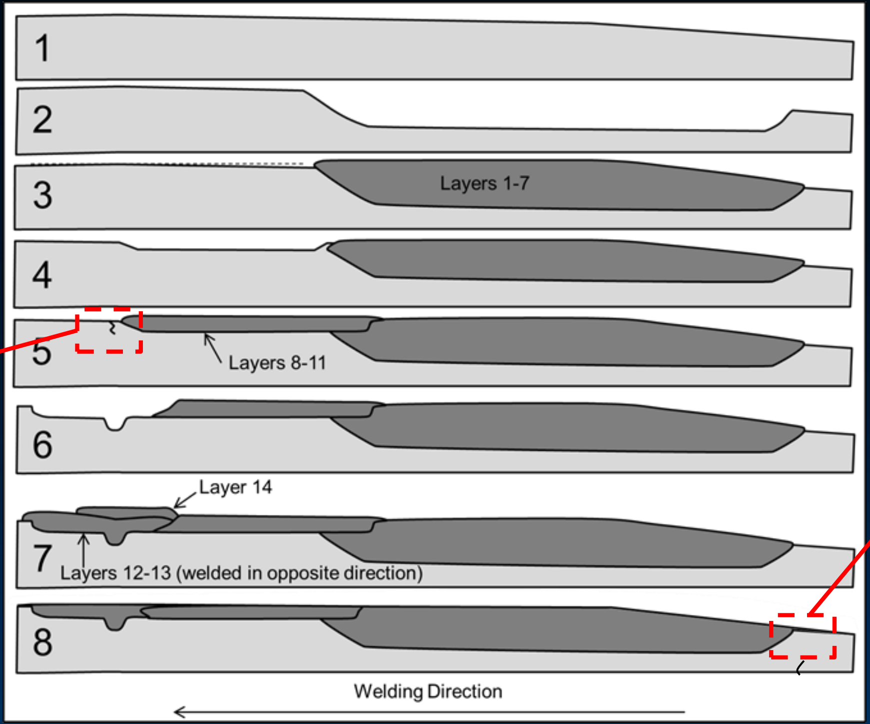
- Sequence Developed on Partial Frog
- Conformal Frog
  - More prone to cracking defects during weld repairs
  - Crack at heel repaired at EWI
  - Crack in point found after finish-grinding at TTCI
  - Future testing TBD



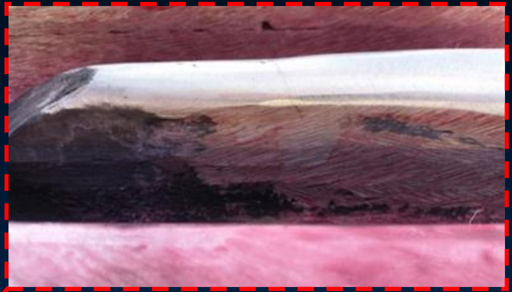
Wing bead sequence

Frog #1 Welding

Heel Crack (EWI)

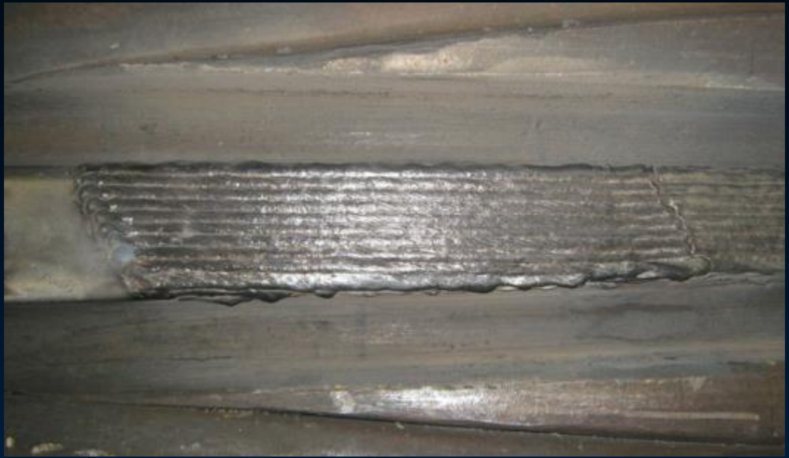


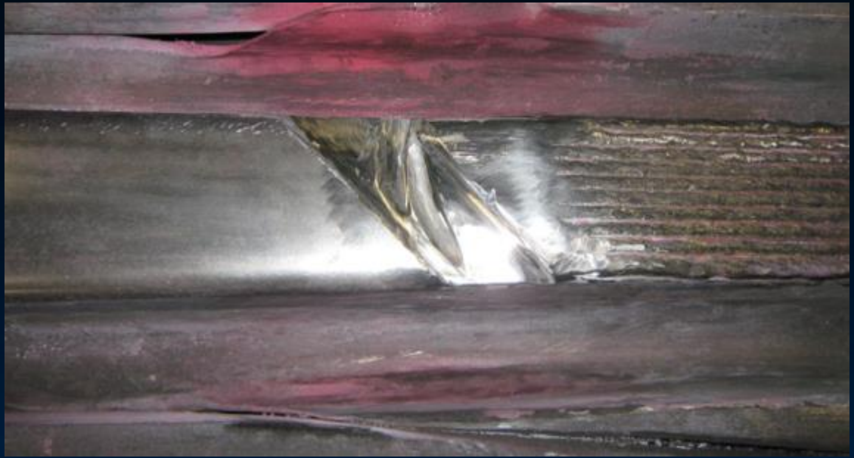
Point Welding Sequence

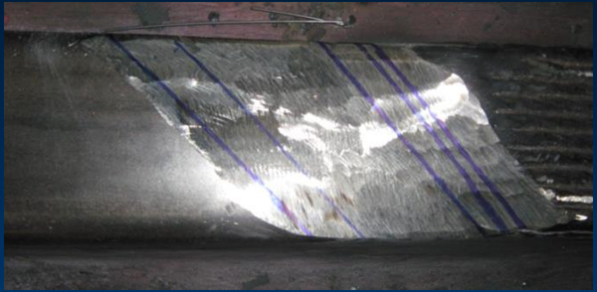


Point Crack (TTCI)

Frog #1 Heel Crack Repair







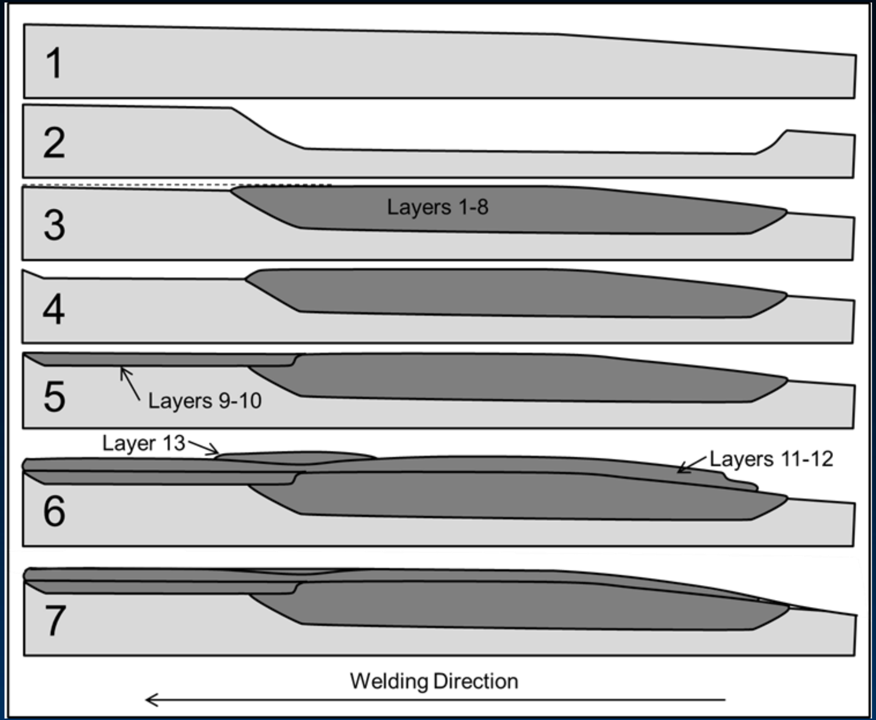
Frog #2 Welding

- Sequence Developed on Partial Frog
- Flat Frog
  - Less prone to cracking defects during weld repairs
  - No cracks found during welding or finish grinding
- Currently in TTCI's Test Track

Frog #2 Welding

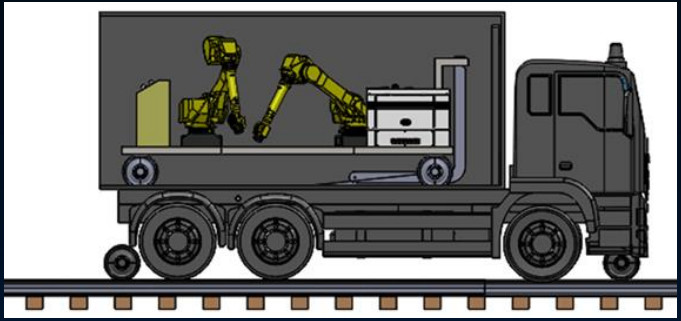
Step 4: Grinding preparation for taper-fill layer

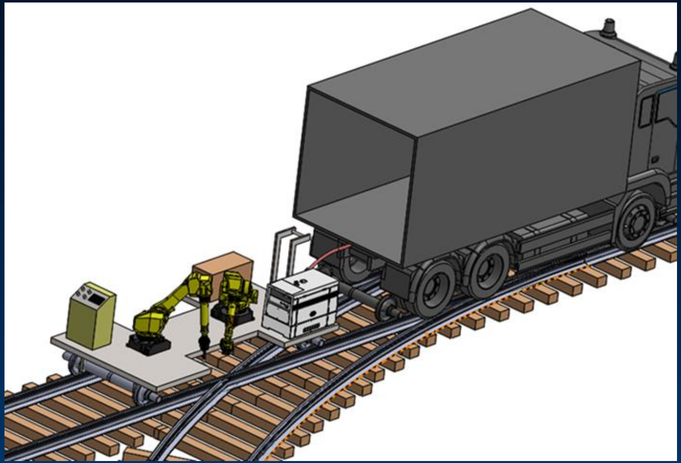
Step 5: Welding of taper-fill layer



Automation Concept

- Retractable cart
- 6-axis arc welding robot
- 6-axis water-jet cutting robot
- Need for adaptive fill TBD
  - Would require vision system





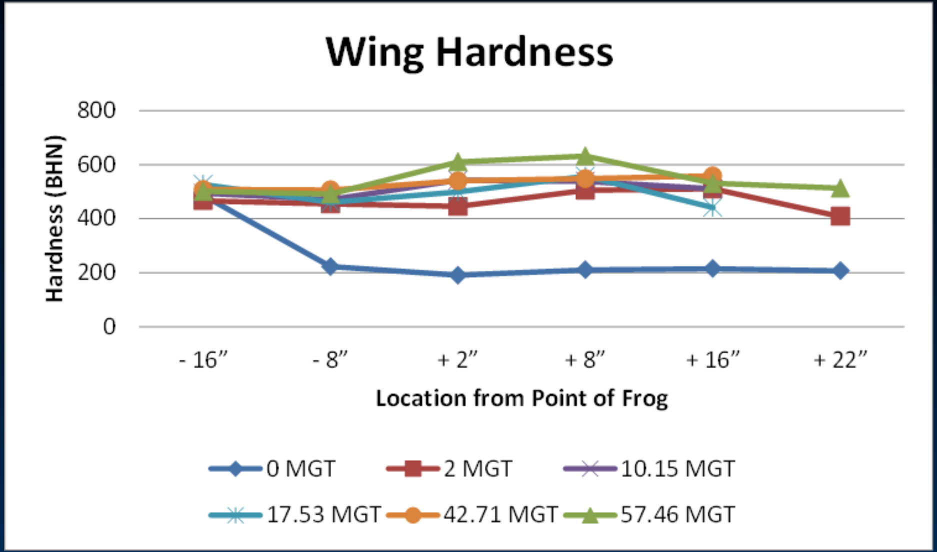
Frog #2 Testing Results

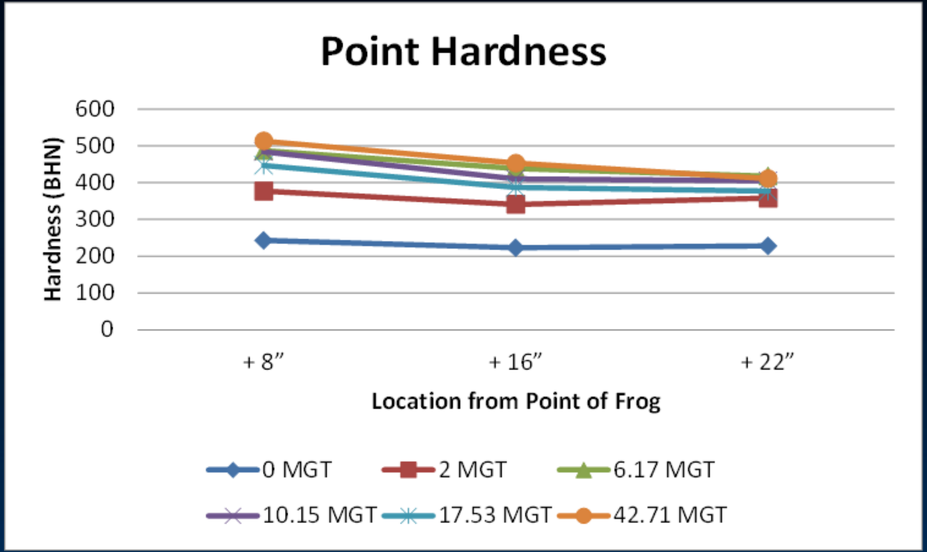
- Placed in open track in high-tonnage loop (HTL) at Facility for Accelerated Service Testing (FAST)
  - 100-car train
  - 315,000 pound cars
  - 40 miles per hour

Frog #2 Testing Results

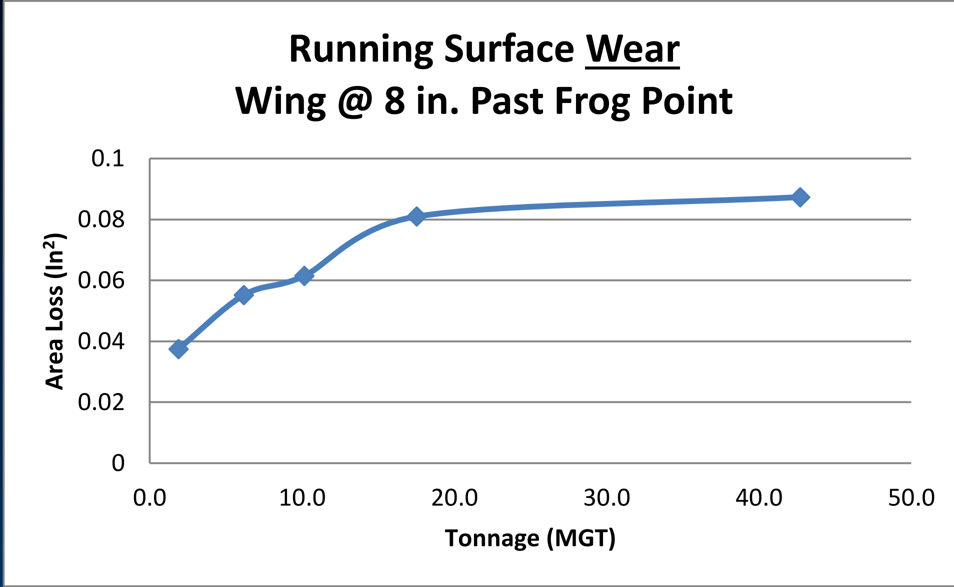
- 78.18 MGTs to date
- Maintenance grinding at 10.15 MGTs
  - Bulge in gage face of wing
  - “Flow” length of point
  - HAZ dip in wing
- Maintenance grinding at 17.53 MGTs
  - Gage corners of wing and point
- No visible surface defects or major metal flow
- No additional maintenance grinding has been required

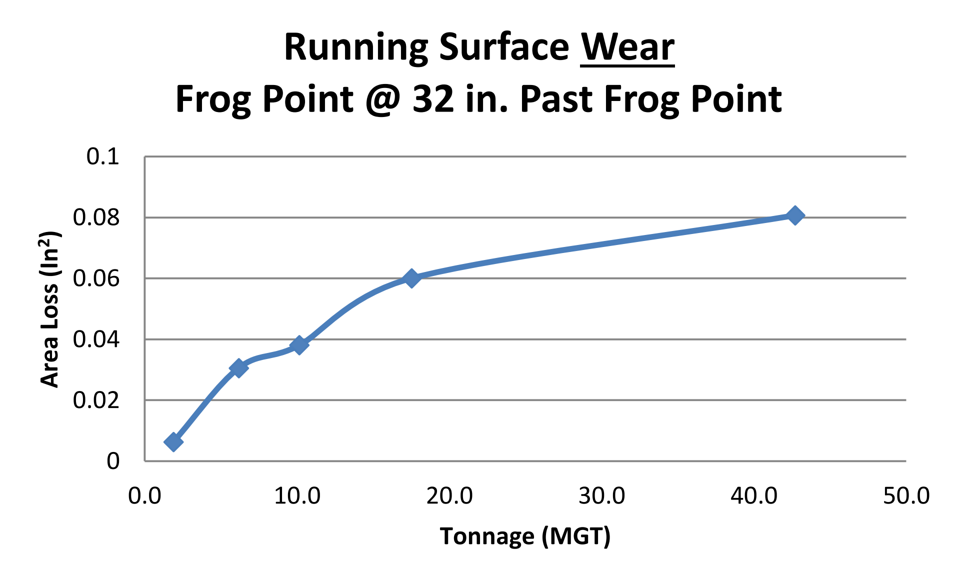
Frog #2 Testing Results: Hardness Data





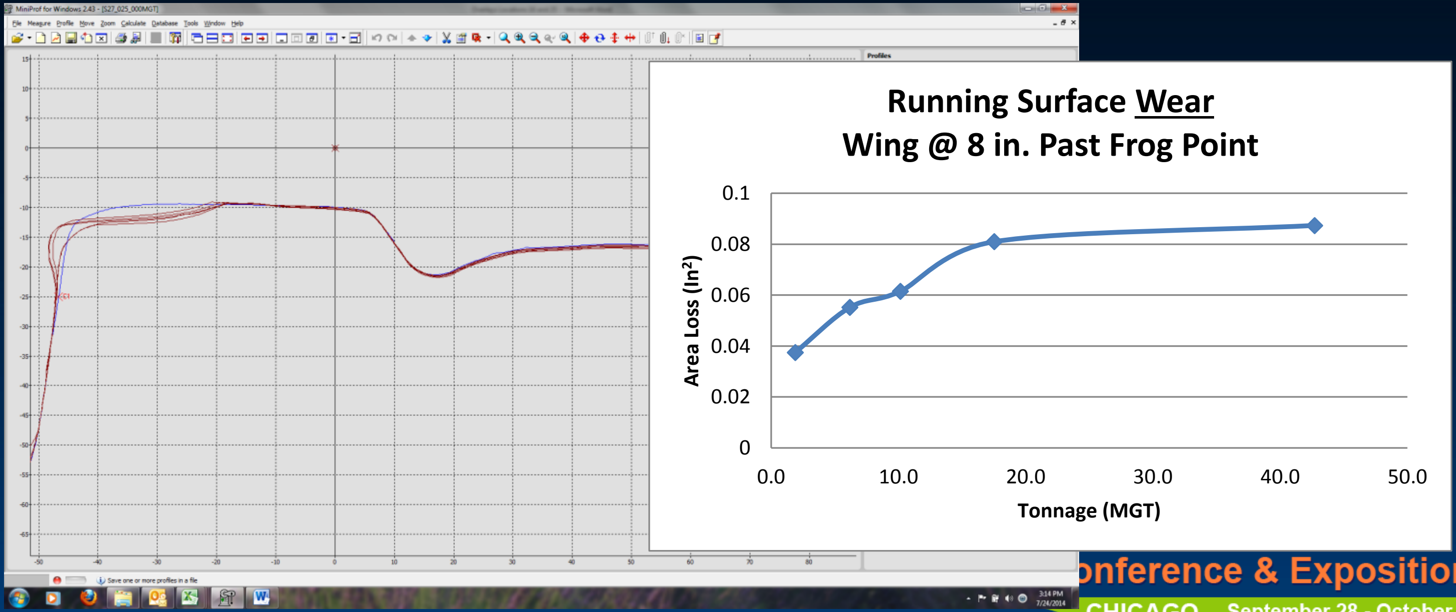
Frog #2 Testing Results: Running Surface Wear





Frog #2 Testing Results

- Running surface height loss is relatively uniform
- Deformation rates have stabilized well before maintenance limits are reached



Conclusions

- Automated FCAW can be successfully applied to AMS frogs for:
  - Improved productivity
  - Increased weld quality
  - Lower interpass temperatures
- RWF FCAW
  - Further reduces heat input
  - Equipment is more complex

Conclusions

- Conformal frog required specialized welding techniques to mitigate cracking at interface between the weld repaired area and work-hardened base material.
- In-track testing to date suggests the performance of frogs repaired with automated FCAW is better than those repaired with existing methods.

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