Comparison of Friction Stir Weldments and Submerged-Arc Weldments in HSLA-65 Steel

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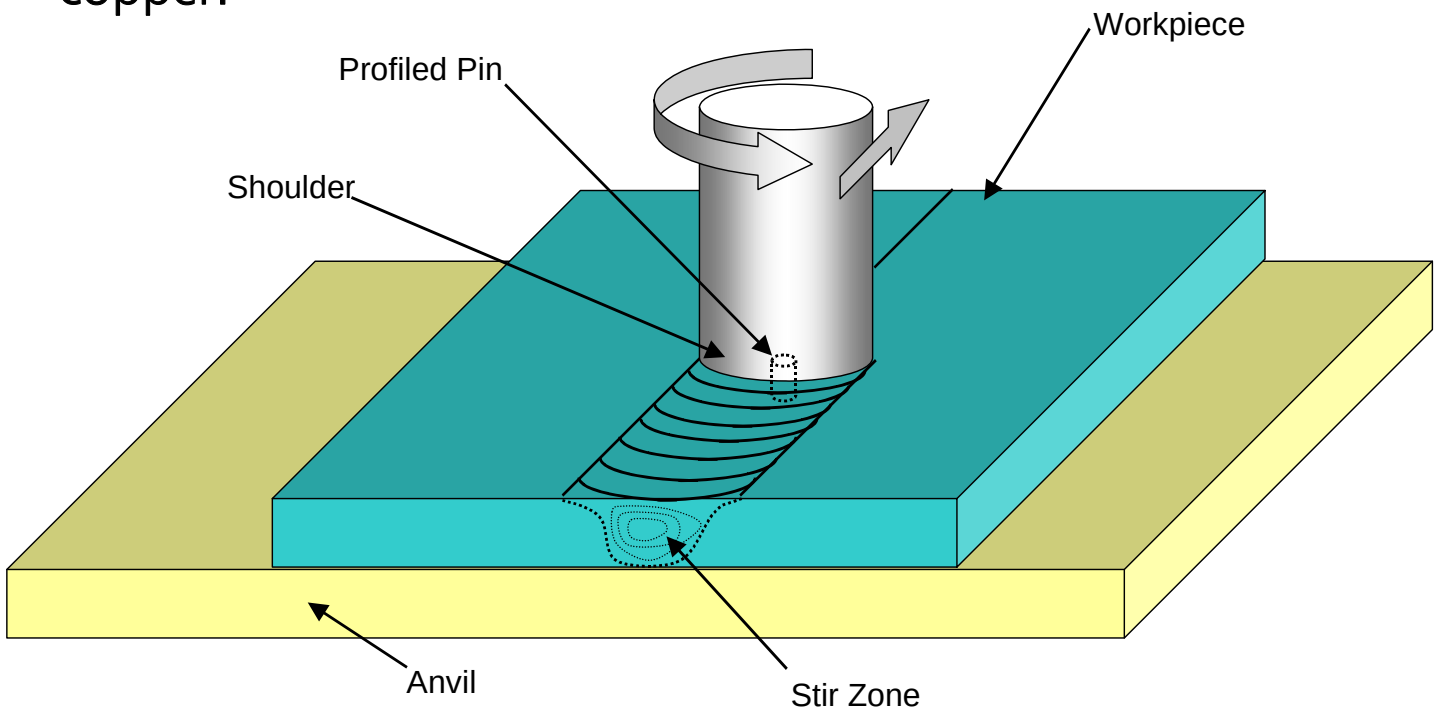
Description of FSW

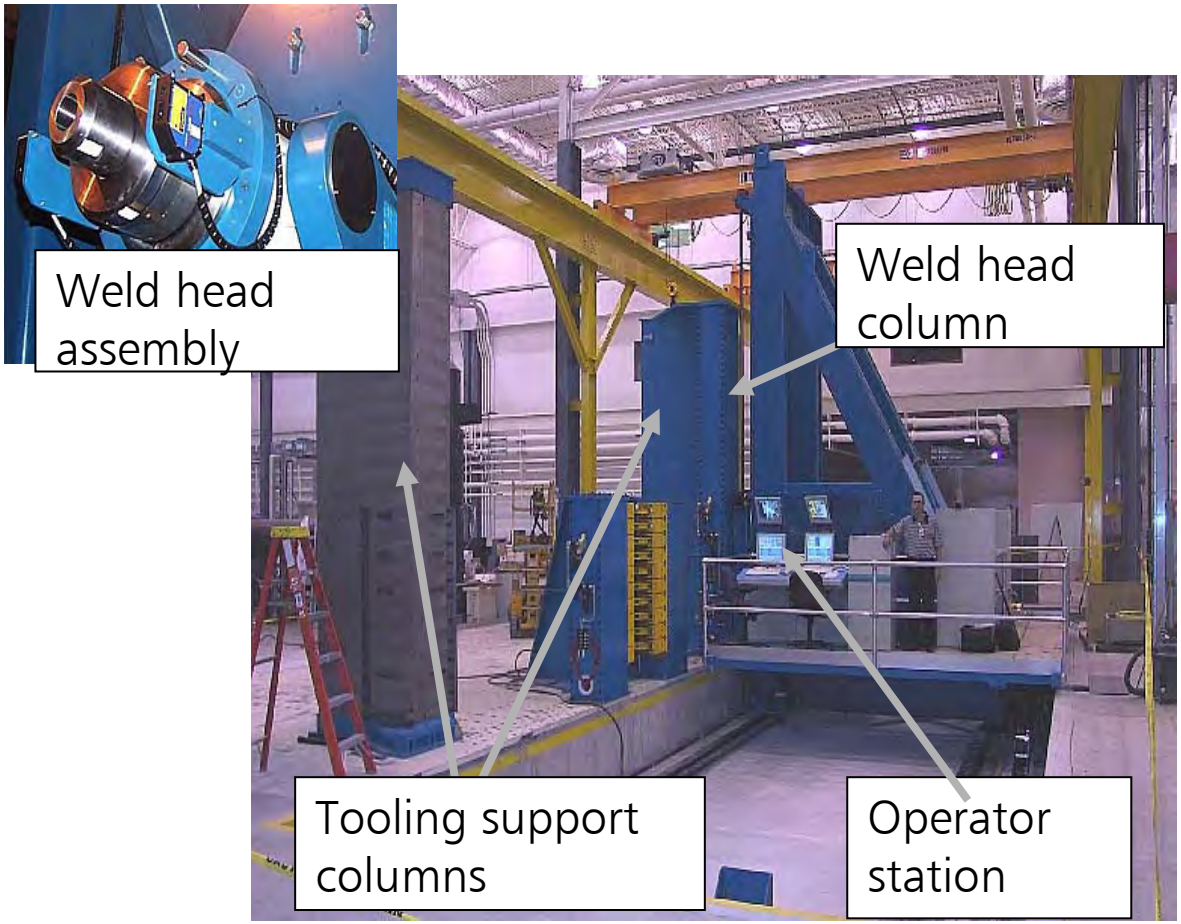
- Non-consumable profiled pin – utilizes friction and plastic work to heat, soften and "stir" workpiece material across the joint, producing a solid-state weld in materials such as aluminum, steel, titanium, magnesium, lead and copper.



Objectives

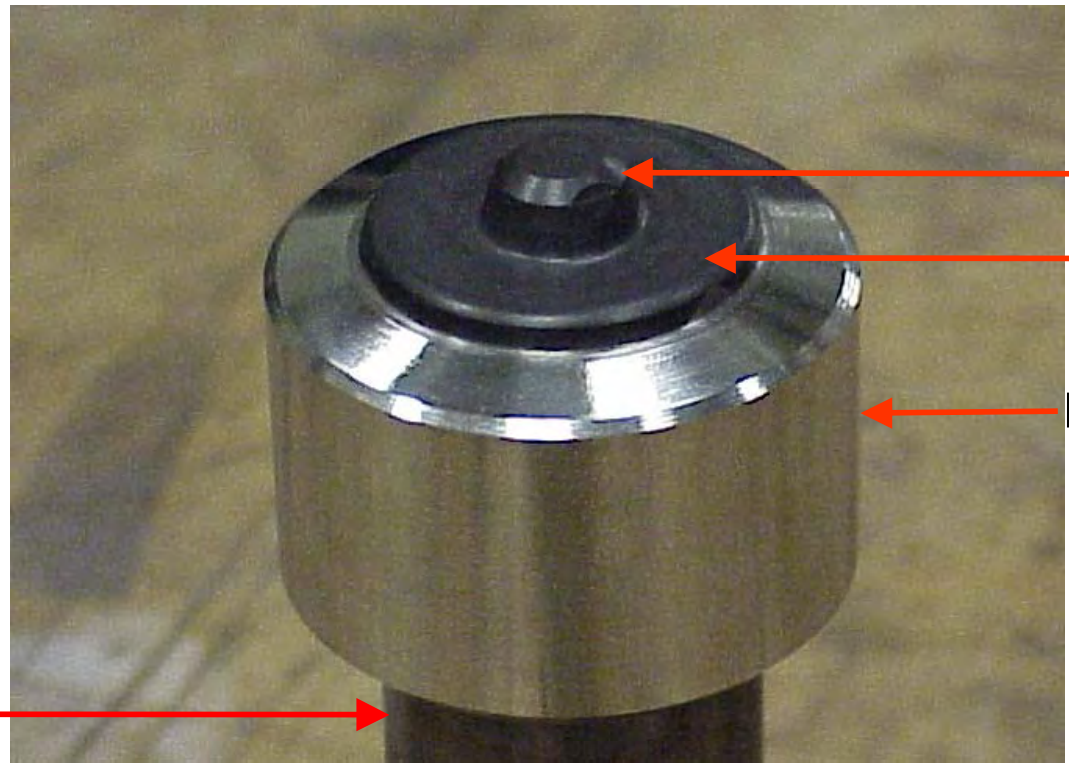
- Evaluate tools and equipment for FSW of steel
- Develop procedures and demonstrate the feasibility of FS welding 0.25-in HSLA-65 in 10-foot sections on a production-size, purpose-built FSW machine
- Measure and compare weld distortion with that of a conventional submerged-arc welding (SAW) weldment
- Characterize the mechanical properties and microstructures of the weld regions

Production-size FSW facility at *CTC*



Details of PCBN tool used in FSW

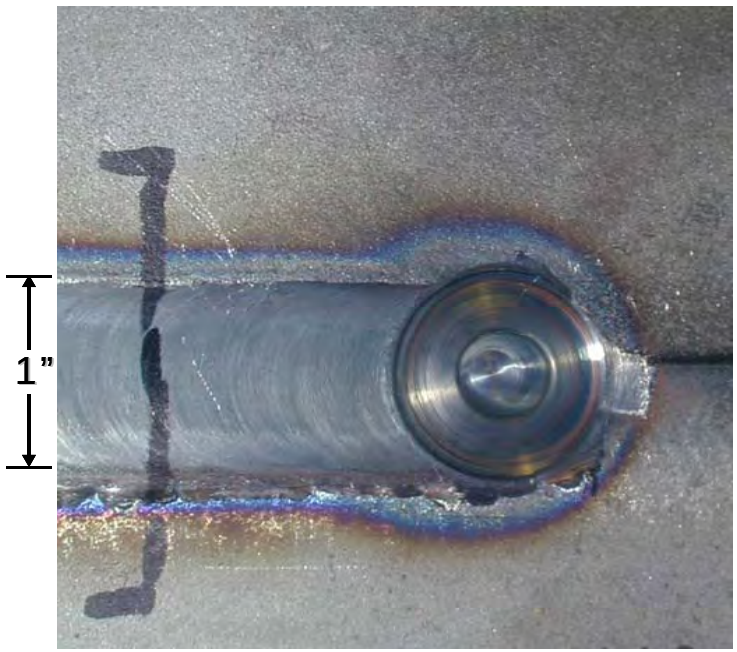
PCBN = Polycrystalline cubic boron nitride



Two-piece refractory metal pin and shoulder assembly

Appearance of FS welds in steel using PCBN tool with and without argon shielding

Argon shield

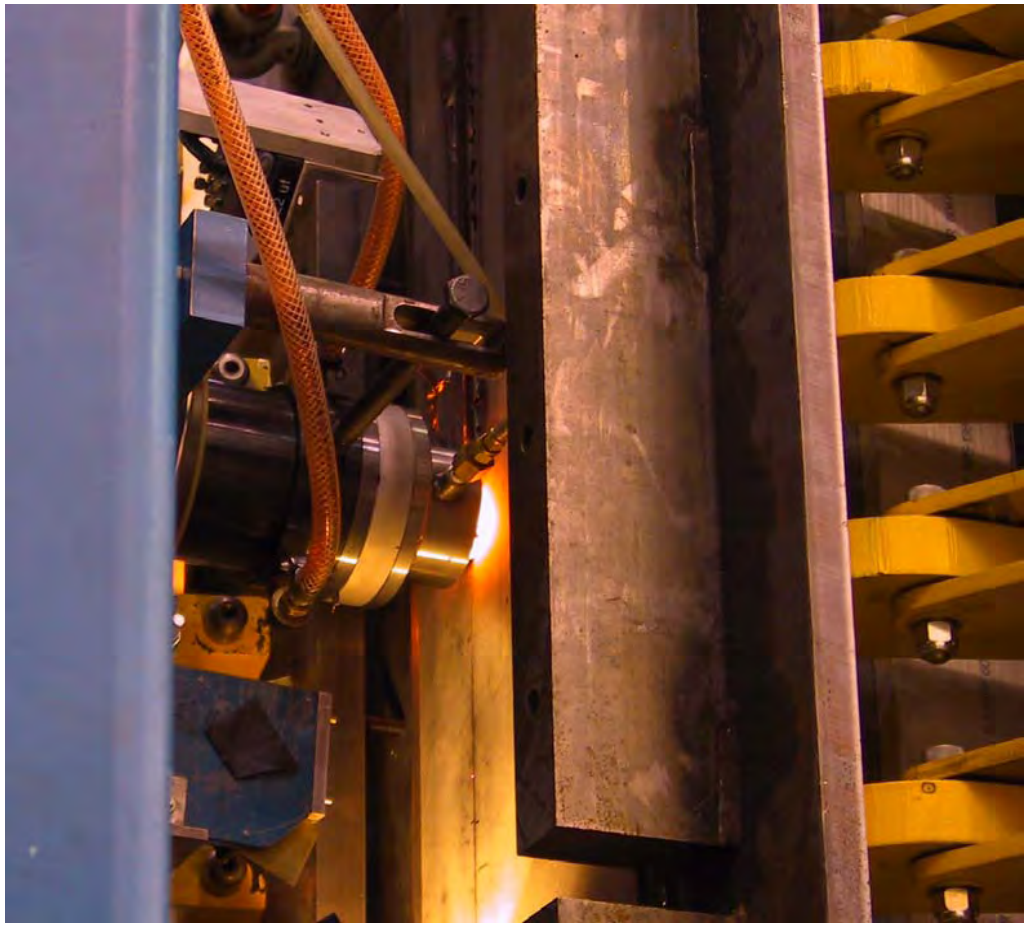


No gas shielding

FSW Parameters with W-Re tool

Groove	Tool Material	Pin Length, inch	Spindle Speed, rpm	Travel Speed, ipm	Energy Input, kJ/inch
Square butt	Mo-TZM shoulder W-25%Re pin	0.235	400	3	97

FSW of HSLA-65 with W-Re tool in progress



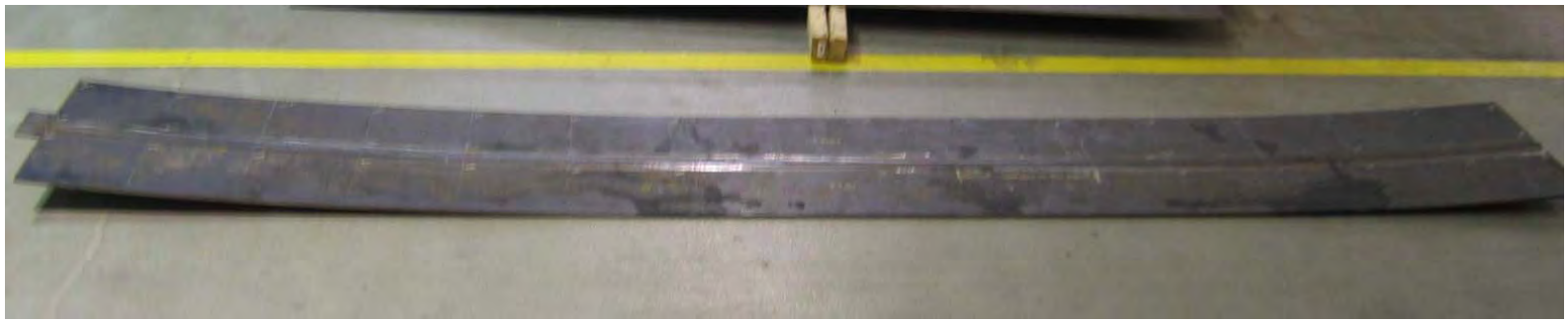
SAW Parameters for 0.25-inch HSLA-65

Groove	Electrode	Flux	Voltage v	Current amp	Travel Speed ipm	Energy Input kJ/inch
Square butt, 1/16" gap	ER-100S, 1/16"	Lincoln 800H	28	400	20	33.6

Single-pass weld over grooved copper backing bar

Completed 10-foot long, 0.25-inch thick HSLA-65 weldments

SAW

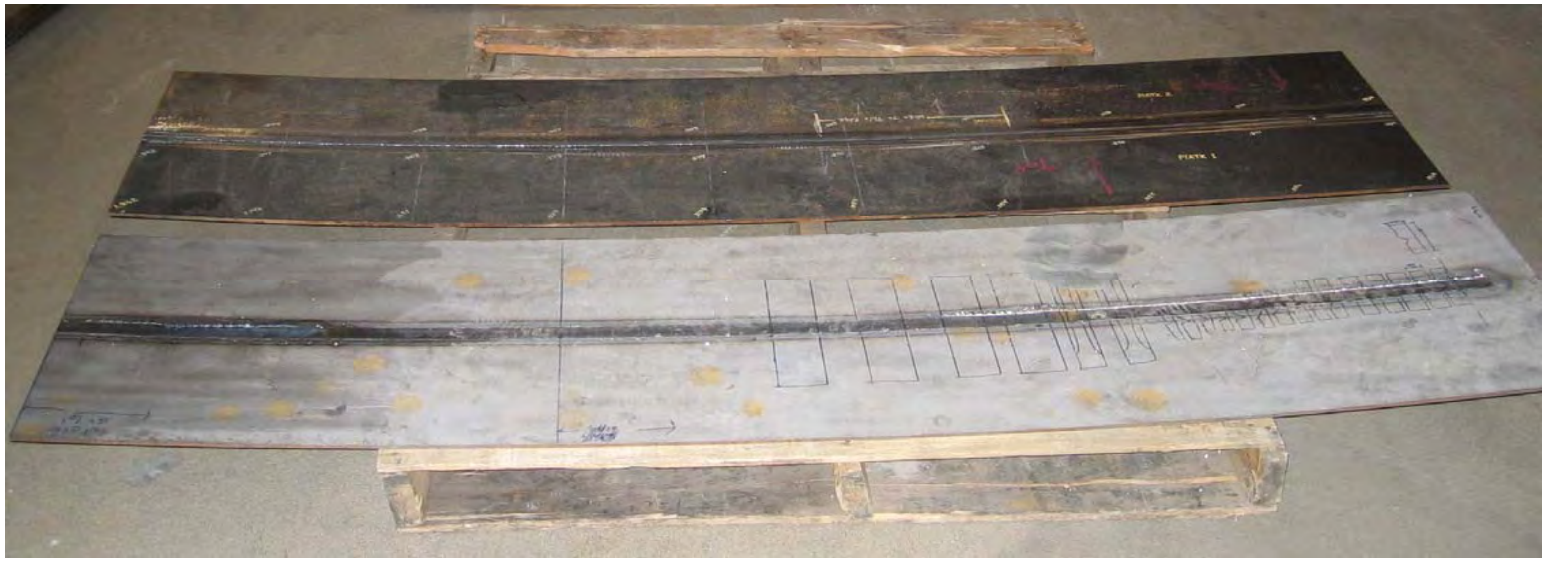


FSW

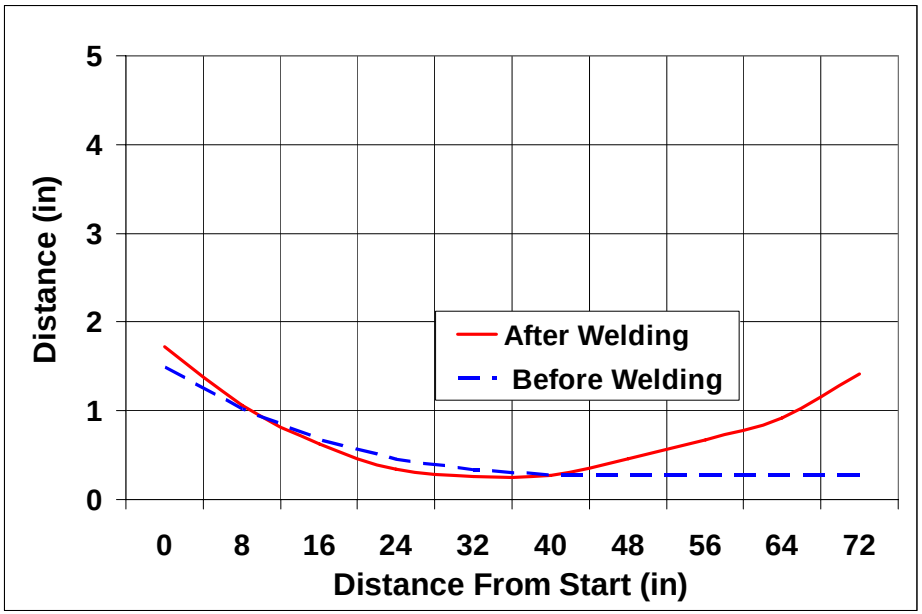
Appearance of 0.25-inch thick HSLA-65 weldments after trimming to 6 feet

SAW

FSW

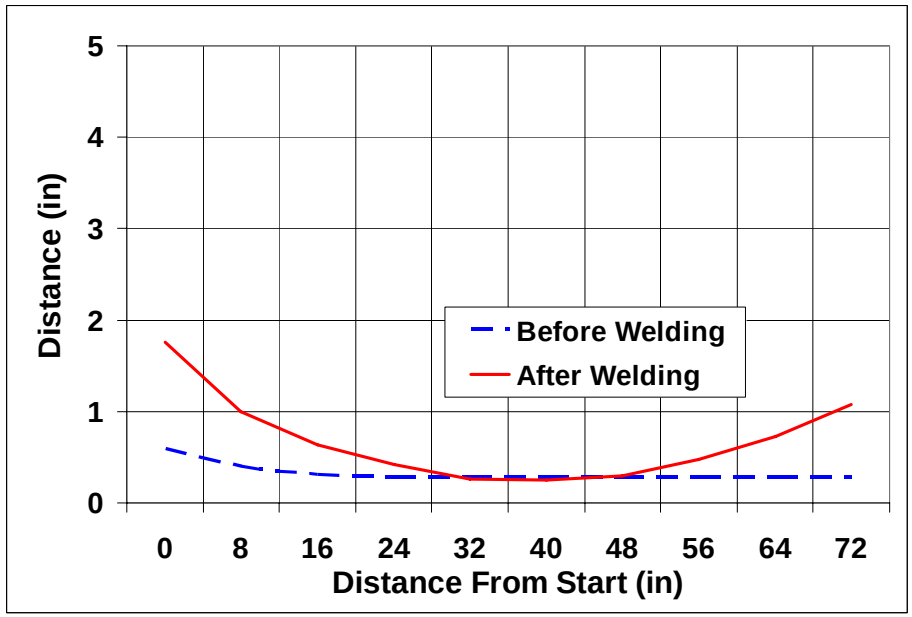


Longitudinal distortion in 6-foot lengths of HSLA-65 weldments



FSW W-Re tool

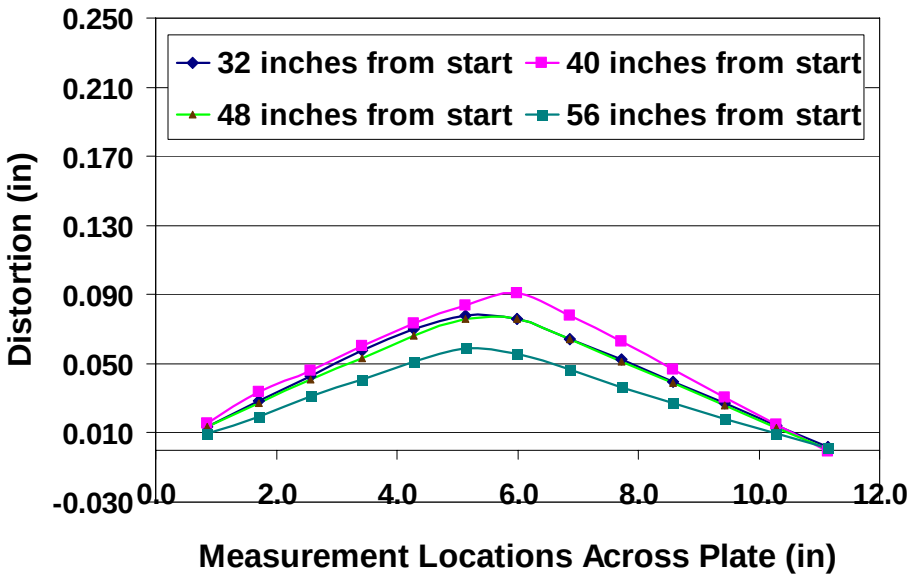
Maximum difference = 1.147 inch



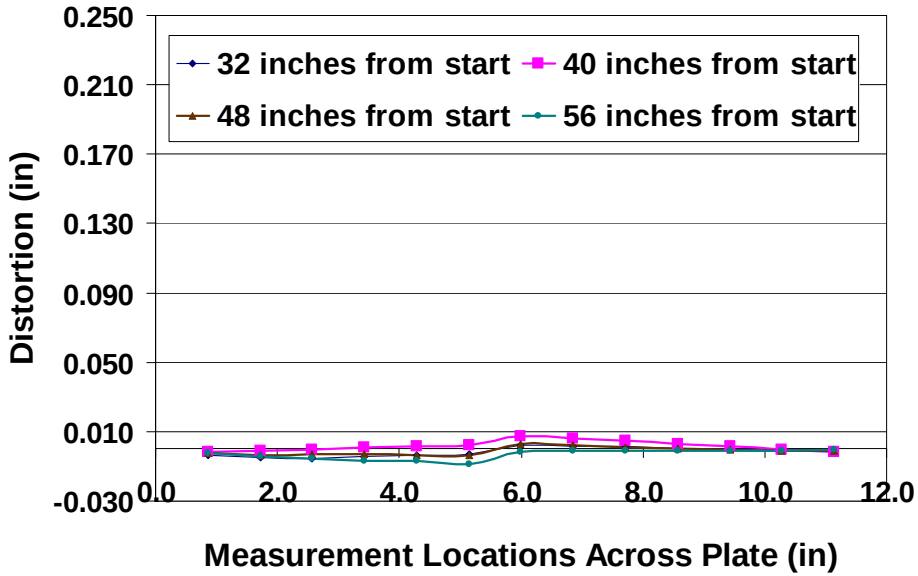
SAW

Maximum difference = 1.163 inch

Transverse distortion in 6-foot lengths of HSLA-65 weldments



SAW



FSW

Transverse tensile properties of SAW and FSW in 0.25-inch HSLA-65

Code	Tensile Strength (ksi)	Yield Strength (ksi)	Gage Length (inches)	Elongation (%)	Reduction of Area (%)	Fracture Location
SAW1	87.7	73.0	2.00	14.5	52.0	Base
SAW2	85.0	72.0	2.00	12.0	49.5	Base
Mean	**86.4**	**72.5**		**13.3**	**50.8**	
FSW1	87.5	70.5	2.00	18.0	48.4	Base
FSW2	86.1	69.2	2.00	16.5	55.3	Base
Mean	**86.8**	**69.8**		**17.3**	**51.9**	

CVN toughness of SAW and FSW in 0.25-inch HSLA-65

Material	Location	Test Temperature, °F	Specimen Size	ft-lb	Shear, %
SAW	Weld metal	-20	1/2	13	47
SAW	Weld interface	-20	1/2	12	57
SAW	HAZ 1-mm	-20	1/2	9	47
FSW	Stir zone	-20	1/2	55	76
FSW	Weld interface	-20	1/2	10	52
FSW	HAZ 1-mm	-20	1/2	12	61
Base Metal	Plate, transverse	-40	1/2	7	41

Chemical Composition of HSLA-65 Plate

Element	*CTC* Analysis	ASTM A 945 Req.
C	0.084	0.10 max
Mn	1.3	1.10–1.65
P	0.016	0.025 max
S	0.018	0.010 max
Si	0.01	0.10–0.50
Cu	0.09	0.35 max
Ni	0.028	0.40 max
Cr	0.05	0.20 max
Mo	0.01	0.08 max
V	0.056	0.10 max
Ti	0.008	-
Nb	0.031	0.05 max
Al	0.041	0.08 max

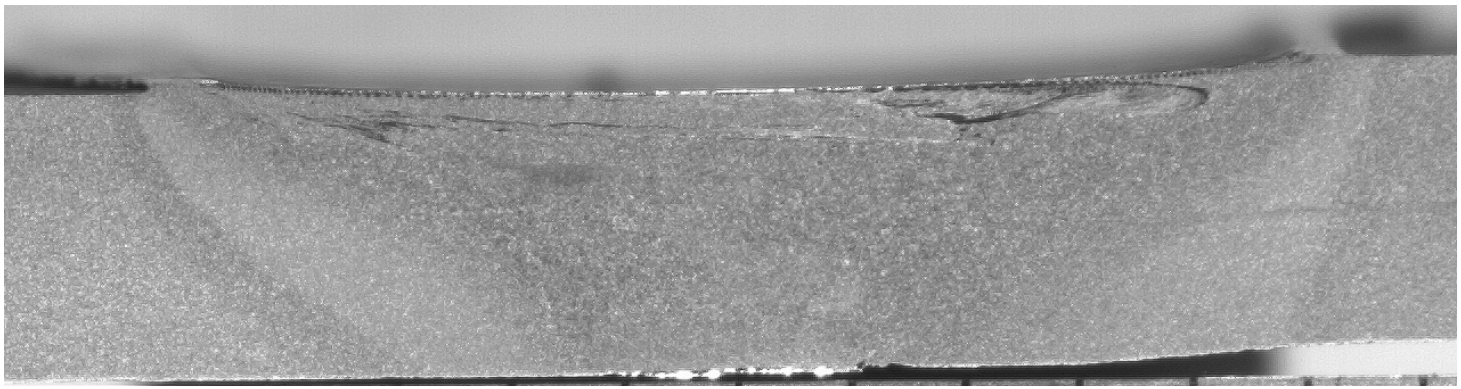
Guided bend test results for SAW and FSW in 0.25-inch HSLA-65

Code	Bend Type*	Results
SAW FB1	Face	No cracking
SAW FB2	Face	No cracking
SAW RB1	Root	Acceptable edge crack
SAW RB2	Root	No cracking
FSW FB1	Face	Crack greater than 1/8"
FSW FB2	Face	No cracking
FSW RB1	Root	No cracking
FSW RB2	Root	No cracking

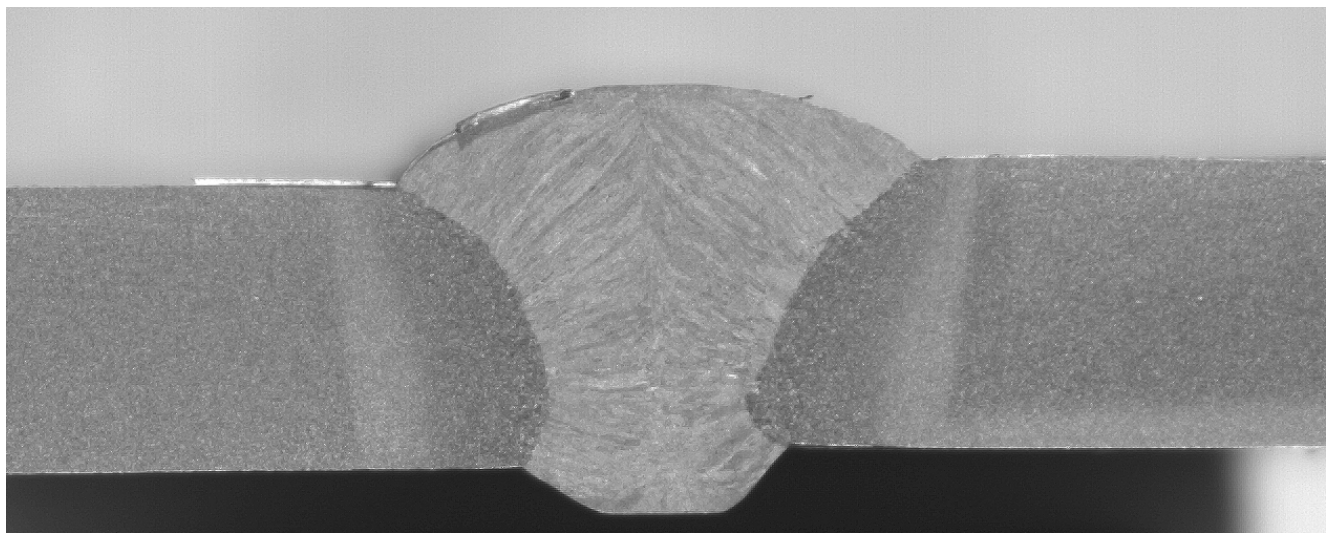
*2T bend radius

Transverse section of W-Re FSW and SAW in 0.25-inch HSLA-65

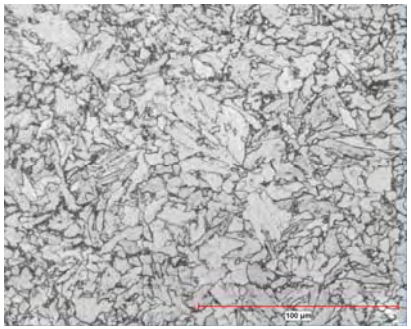
FSW



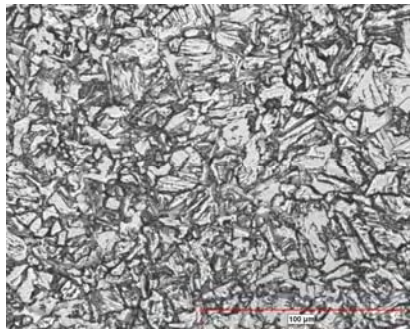
SAW



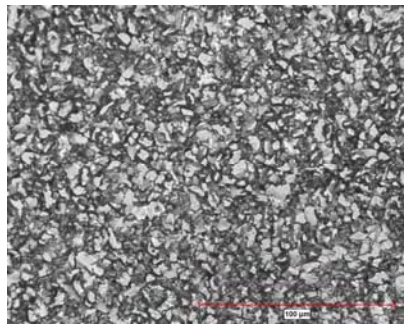
Microstructures of weld regions in FSW and SAW HSLA-65



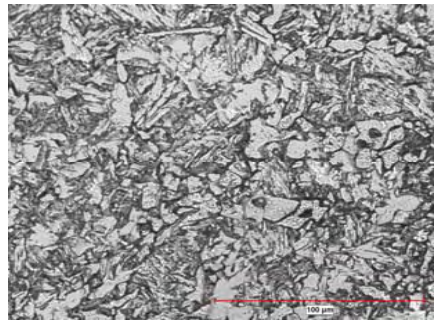
Base Metal



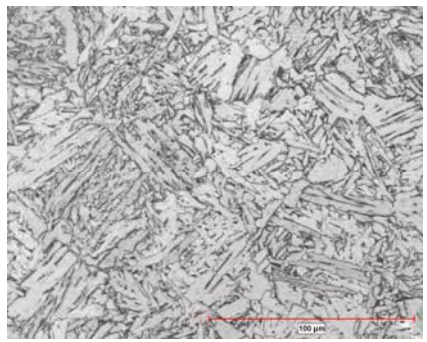
FSW HAZ



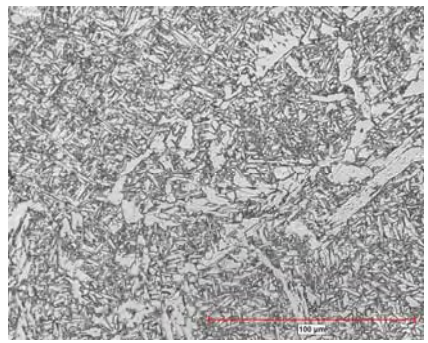
FSW TMAZ



FSW SZ

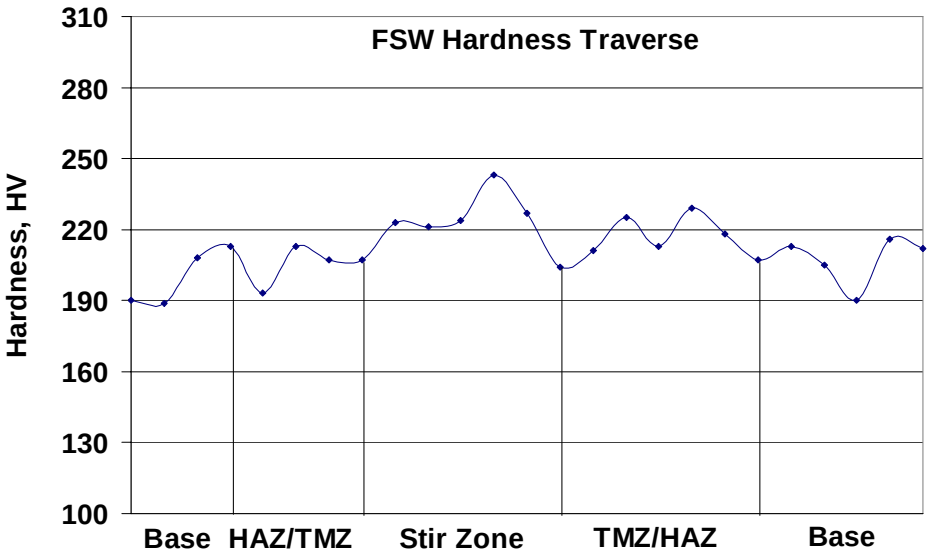


SAW HAZ

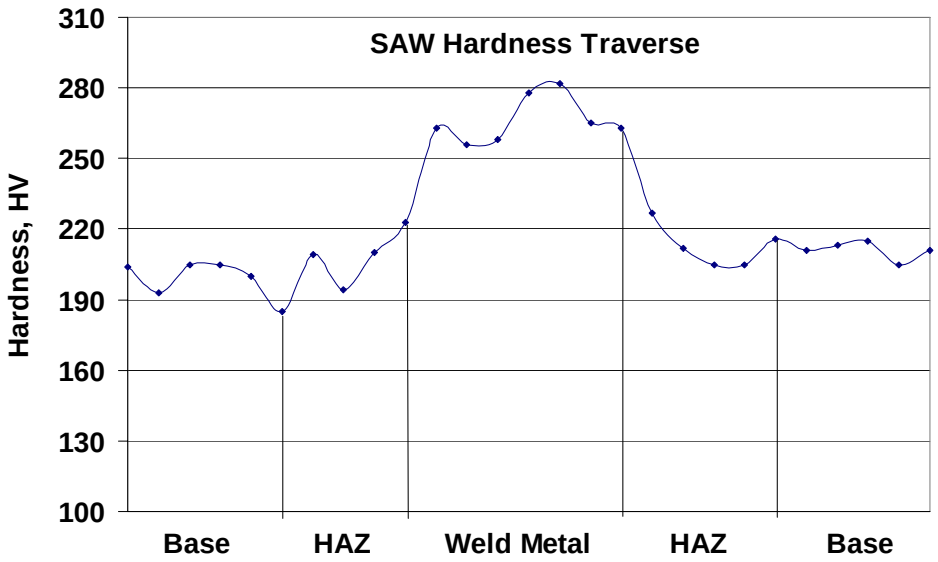


SAW WM

Microhardness across the weld region in FSW and SAW HSLA-65



FSW



SAW

Summary

- Weldments up to 10 feet long were made on a production-size FSW facility in 0.25-inch HSLA-65 steel
- A two-piece refractory alloy tool was developed with a W-25%Re pin and Mo-TZM shoulder; however the shoulder exhibited substantial wear
- Both FSW and SAW weldments in 0.25-inch HSLA-65 had overmatching transverse weld strength
- Face and root bend tests were generally satisfactory in both SAW and FSW 0.25-inch HSLA-65. One of the face-bend test specimens in the FSW weldment failed due to imbedded tool shoulder material

Summary (cont.)

- The hardness across the FSW weld region was relatively uniform
- The CVN toughness of the FSW stir zone was significantly higher than in the SAW weld metal. There was little difference in HAZ toughness for FSW and SAW
- Both the FSW and SAW weldments exhibited significant longitudinal distortion. The SAW weldment exhibited significant transverse distortion; whereas the FSW weldment was essentially flat
- The present study has demonstrated that FSW is technically feasible for fabricating HSLA-65 steel components for structural applications