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NSRP SP-7
Welding Technology Panel Meeting

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Presentation Summary

- Introduction
- Cold Wire Feed System
- Welding and Testing Result to Date
- Conclusions

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Introduction

- To achieve required strength and toughness in the weld metal of HSLA steels, maximum weld energy inputs must be observed which results in:
  - Reduced deposition rates
  - Many beads and layers of weld metal
- The large volume of weld metal needed to weld heavy sections results in reduced productivity and high fabrication cost.

Introduction

- Cold-wire feed submerged-arc-welding (SAW) process used to deposit additional filler metal.
- Weldments were made in 1.25 inch-thick HSLA-65, 2 inch-thick HSLA-100 and 0.5 inch-thick EH-36 steels with LA-71, MIL-100S-1, and LA-50 electrodes using MIL-100S-1F flux.
- Electrode diameter: 1/8 inch.
- Cold wire diameter: 1/16 inch for all weldments.

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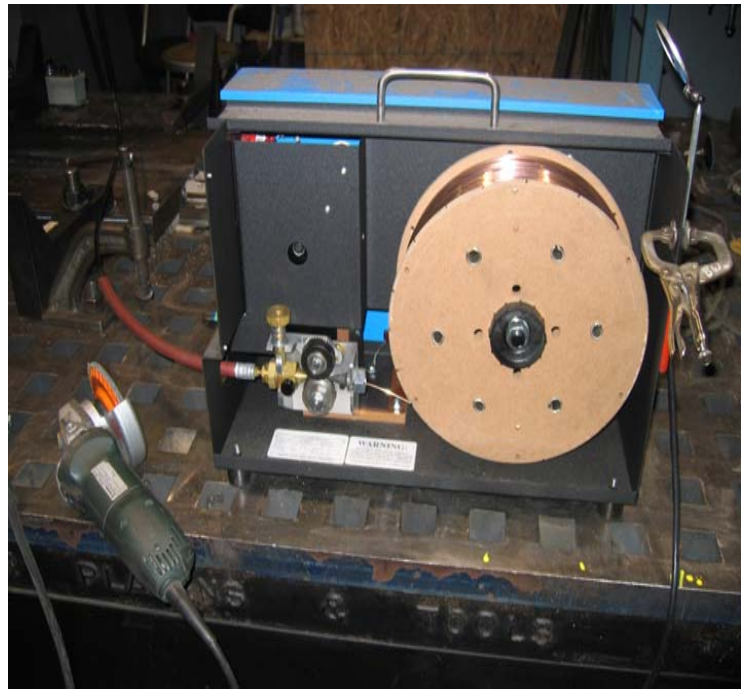
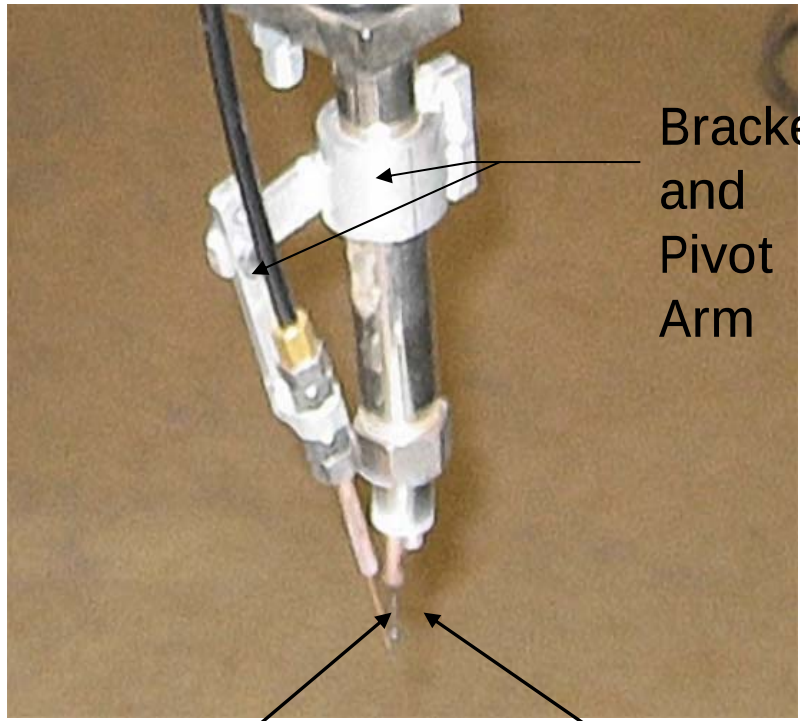
Cold Wire Feed System (Feeder)



CK WorldWide WF-3 GTAW Cold Wire Feeder

Cold Wire Feed System (Bracket)

- Adds a second cold wire to single-wire SAW Process.
- Current fed to electrode from a single power source.
- Cold wire speed separate from electrode.



Background Information HSLA-65

- Six- 1.25 inch-thick HSLA-65 weldments were fabricated.
- First weldment: single wire only at 88.7 kJ/in heat input.
- Weldments fabricated with Lincoln LA-71 electrodes and MIL-800H Flux.
- Root pass for all weldments remained constant at 62 kJ/in.

Welding Parameters CTC-024

Specimen Identification CTC-024	Wire Size (in)		Current	Avg. Amps	Avg. Volts	Avg. Travel Speed (ipm)	Wire Speed (ipm)	
Fill and Cap Passes	Electrode	Cold Wire					Electrode	Cold Wire
	0.125	N/A	DCEP	470	31.8	10	62	N/A

Input Electrode (kJ/in)	Reduction Factor		Effective Heat Input (kJ/in)		Calculated Deposition Rate (lb/hr)	
	Root Pass	Fill and Cap Passes	Root Pass	Fill and Cap Passes	Root Pass	Fill and Cap Passes
88.7	N/A	N/A	N/A	N/A	10.9	12.8

Note: Root pass welded at 410 amps, 30.2 volts, 12 ipm travel speed and 53 ipm wire feed speed (62 kJ/in). Deposition rate calculations reflect the deposition efficiency, heat input reflects process efficiency.

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Tensile Testing Results CTC-024

Specimen Identification	Specimen Diameter (inches)	Tensile Load (lbf)	Yield Load (lbf)	Tensile Strength (ksi)	Yield Strength (ksi)	Elongation Increase (%)	Reduction of Area (%)
TS.ST-01-1-CTC-024-TS1-024	0.4986	17744	15763	90.9	80.7	24	71
TS.ST-01-2-CTC-024-TS2-024	0.5001	17724	15755	90.2	80.2	24	70

These data were used as the benchmark (Heat Input was 88.7 kJ/in).

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CVN Testing Results CTC-024

Specimen Identification	Specimen Type	Size (mm x mm)	Temperature (°F)	Energy (ft-lbs)	Expansion (mils)	Appearance (% shear)
CV.SP-01-CTC-024-1	Type A	10 x 10	-20	43.0	39	46
CV.SP-01-CTC-024-2	Type A	10 x 10	-20	57.0	42	50
CV.SP-01-CTC-024-3	Type A	10 x 10	-20	43.0	35	61
CV.SP-01-CTC-024-4	Type A	10 x 10	-20	104.0	67	77
CV.SP-01-CTC-024-5	Type A	10 x 10	-20	46.0	34	42
			Average	**58.6**	**43.4**	**55.2**
			St. Dev.	**8.1**	**3.5**	**7.8**

Three full section side bends were performed and found to be acceptable with no cracking noted.

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Heat Input Reduction Factor

Electrode volume per unit time

$$e_{vol} = d_e^2 \cdot e_{speed}$$

Cold-wire volume per unit time

$$cw_{vol} = d_{cw}^2 \cdot cw_{speed}$$

Reduction factor calculation (C_{f_mod})

$$C_{f\_mod} = \frac{e_{vol}}{\left(e_{vol} + cw_{vol}\right)}$$

The reduction factor was used to calculate the effective heat input for the cold wire addition by multiplying electrode heat input by Cf_mod.

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Welding Parameters CTC-026

Specimen Identification CTC-026	Wire Size (in)		Current	Avg. Amps	Avg. Volts	Avg. Travel Speed (ipm)	Wire Speed (ipm)	
Fill and Cap Passes	Electrode	Cold Wire					Electrode	Cold Wire
	0.125	0.0625	DCEP	475	31.5	10	62	90

Avg. Heat Input Electrode (kJ/in)	Reduction Factor		Effective Heat Input (kJ/in)		Calculated Deposition Rate (lb/hr)	
	Root Pass	Fill and Cap Passes	Root Pass	Fill and Cap Passes	Root Pass	Fill and Cap Passes
89.7	0.702	0.734	43.5	65.2	15.6	17.4

CTC-024 welded at 62 kJ/in root pass and 88.7 kJ/in fill and cap passes. Parameters remained the same with the addition of a 1/16-inch diameter cold wire. Cold wire was leading.

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Deposition Rate Increase CTC-026 vs. CTC-024

Specimen Identification	Pass	Deposition Rate Single Electrode (lb/hr)	Deposition Rate Cold-Wire Process (lb/hr)	Percent Increase in Deposition Rate
CTC-026	Root Pass	10.9	15.6	43.1%
	Fill Passes	12.8	17.4	35.9%

With the addition of a cold wire (all other welding parameters remained the same as CTC-024) an increase of 43 and 36% in deposition was realized.

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Tensile Data Comparison CTC-024 vs. CTC-026

Specimen Identification	Test Temperature (°F)	Original Specimen Diameter (inches)	Ultimate Tensile Load (lbf)	0.2% Offset Yield Load (lbf)	Ultimate Tensile Strength (ksi)	0.2% Offset Yield Strength (ksi)	Elongation Increase (%)	Reduction of Area (%)
CTC-024-TS1	70	0.4986	17744	15763	90.9	80.7	24	71
CTC-024-TS2	70	0.5001	17724	15755	90.2	80.2	24	70

CTC-024 = 88.7 kJ/in calculated heat input.

Specimen Identification	Original Specimen Diameter (inches)	Ultimate Tensile Load (lbf)	0.2% Offset Yield Load (lbf)	Ultimate Tensile Strength (ksi)	0.2% Offset Yield Strength (ksi)	Elongation Increase (%)	Reduction of Area (%)
CTC-026-Tensile-1	0.4995	18183	16324	92.8	83.3	24	73
CTC-026-Tensile-2	0.4994	18299	16555	93.4	84.5	24	70

CTC-026 = 89.7 kJ/in calculated heat input, 65.2 kJ/in effective heat input.

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Charpy Data Comparison CTC-024 vs. CTC-026

Specimen Identification	Specimen Type	Size (mm x mm)	Temperature (°F)	Energy (ft-lbs)	Expansion (mils)	Appearance (% shear)
CV.SP-01-CTC-024-1	Type A	10 x 10	-20	43.0	39	46
CV.SP-01-CTC-024-2	Type A	10 x 10	-20	57.0	42	50
CV.SP-01-CTC-024-3	Type A	10 x 10	-20	43.0	35	61
CV.SP-01-CTC-024-4	Type A	10 x 10	-20	104.0	67	77
CV.SP-01-CTC-024-5	Type A	10 x 10	-20	46.0	34	42
			Average	**58.6**	**43.4**	**55.2**
			St. Dev.	**8.1**	**3.5**	**7.8**

Specimen Identification	Specimen Type	Specimen Size (mm x mm)	Test Temperature (°F)	Absorbed Energy (ft-lbs)	Lateral Expansion (mils)	Fracture Appearance (% shear)
CTC-026-1	Type A	10 x 10	-20	115.6	76	88
CTC-026-2	Type A	10 x 10	-20	80.0	55	84
CTC-026-3	Type A	10 x 10	-20	44.0	32	45
CTC-026-4	Type A	10 x 10	-20	53.0	41	62
CTC-026-5	Type A	10 x 10	-20	65.0	45	67
			Average	**71.5**	**49.8**	**69.2**
			St. Dev.	**28.1**	**16.8**	**17.4**

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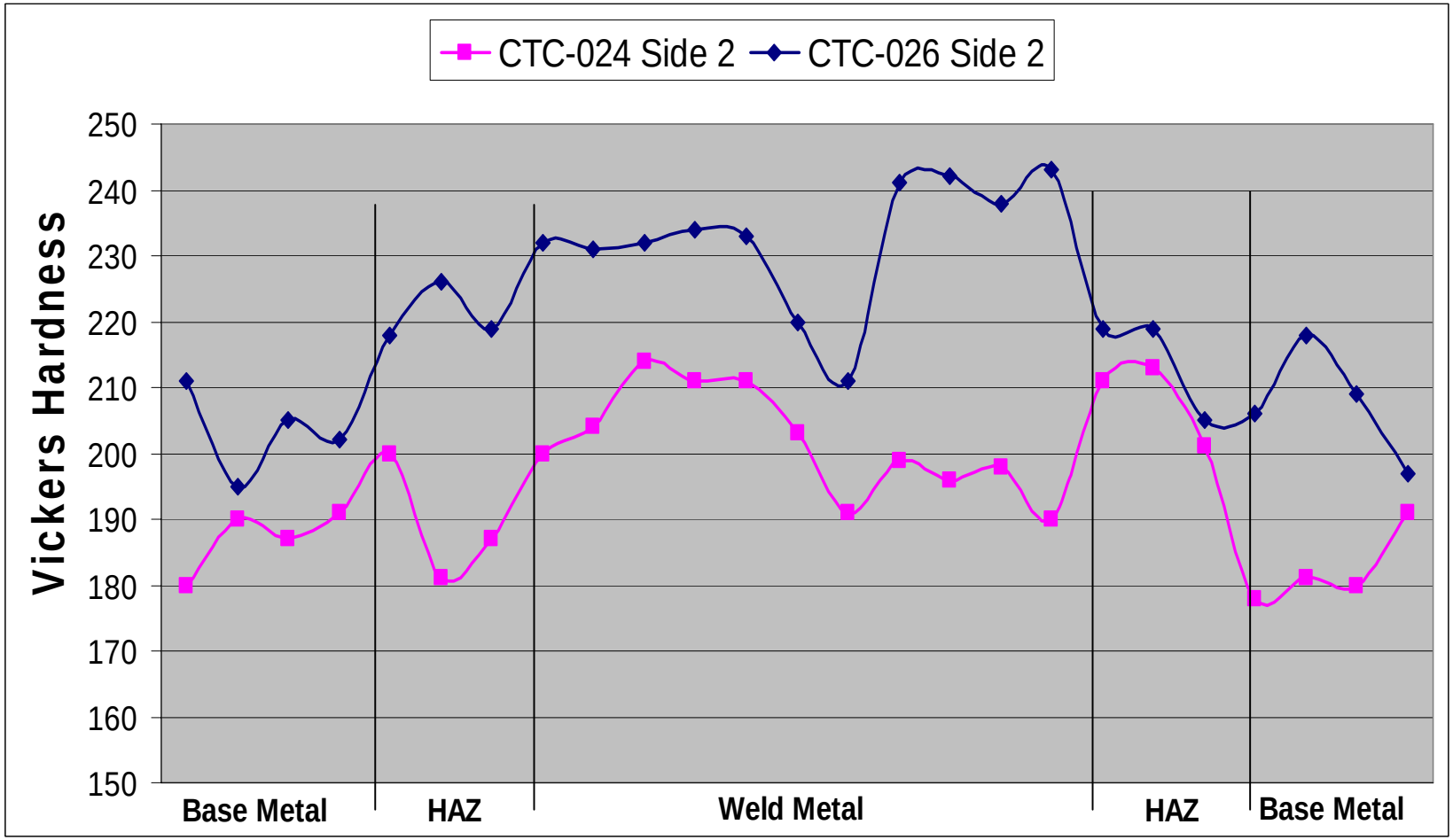
Hardness Comparison CTC-024 vs. CTC-026



Note the increase in hardness for the cold wire weldment. This indicates an effective reduction in heat input.

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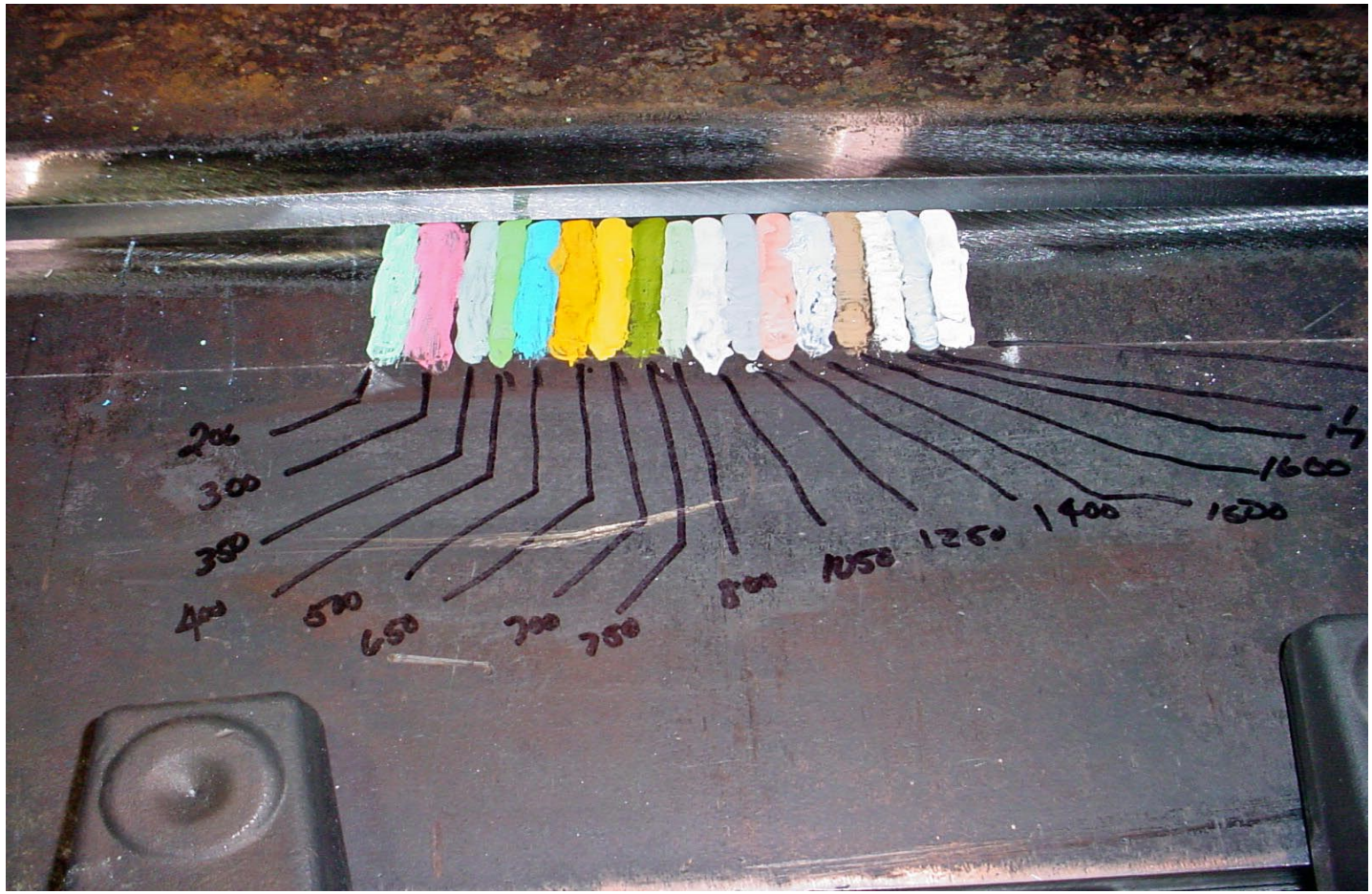
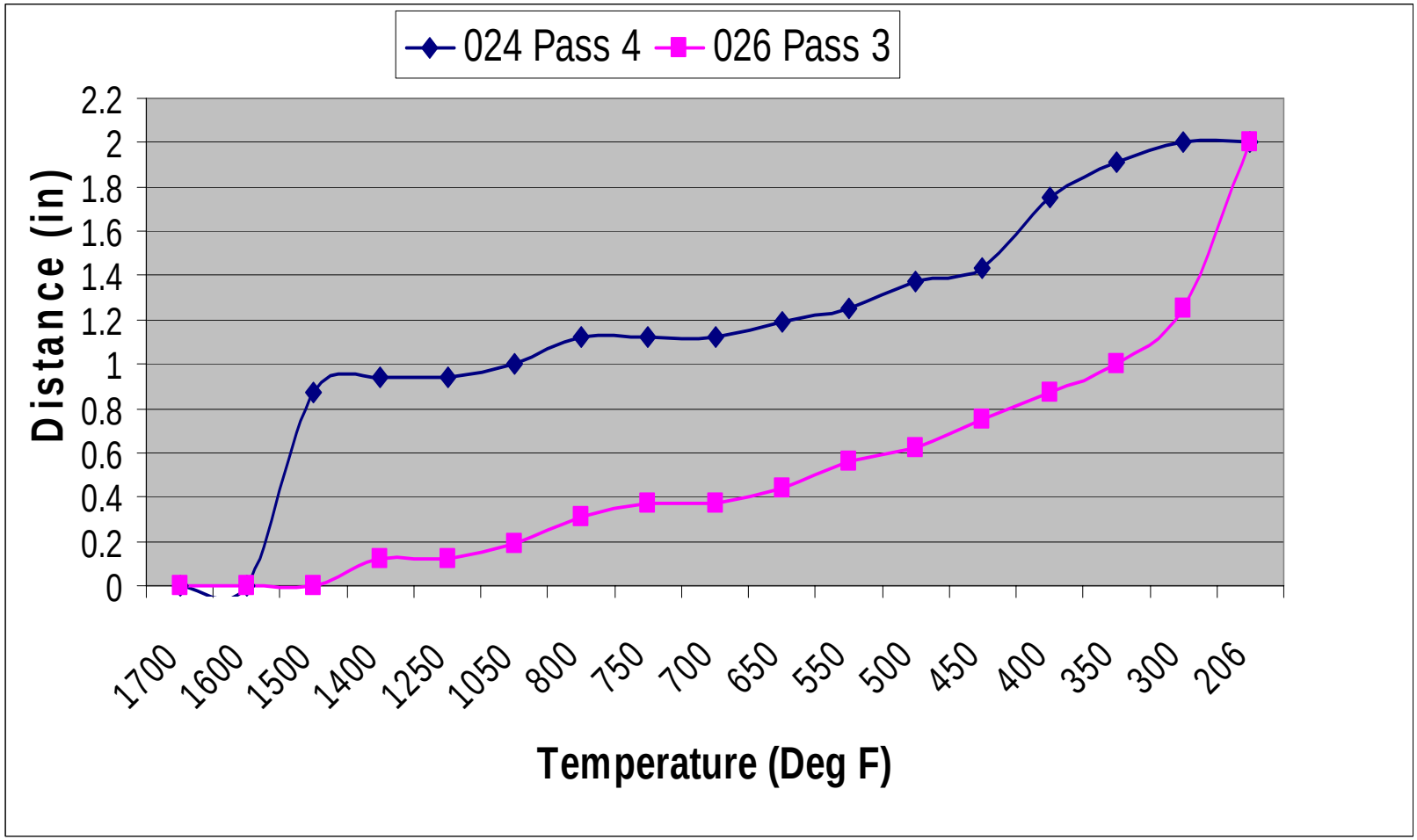
Heat Color Example



Indicating paint was from Tempil (Tempillag G Temperature indicating liquid).

Surface Temperature of Plate CTC-024 and CTC-026



A significant reduction in the amount of heat being transferred to the plate.

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Welding Parameters CTC-027

Specimen Identification CTC-027	Wire Size (in)		Current	Avg. Amps	Avg. Volts	Avg. Travel Speed (ipm)	Wire Speed (ipm)	
Fill and Cap Passes	Electrode	Cold Wire					Electrode	Cold Wire
	0.125	0.0625	DCEP	475	31.9	10	62	90

Avg. Heat Input Electrode (kJ/in)	Reduction Factor		Effective Heat Input (kJ/in)		Calculated Deposition Rate (lb/hr)	
	Root Pass	Fill and Cap Passes	Root Pass	Fill and Cap Passes	Root Pass	Fill and Cap Passes
90	0.702	0.734	43	69.5	15.6	17.4

Parameters remained the same as CTC-026. Cold wire was lagging as opposed to leading as with CTC-026 weldment.

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Deposition Rate Increase CTC-024 vs. CTC-027

Specimen Identification	Pass	Deposition Rate Single Electrode (lb/hr)	Deposition Rate Cold-Wire Process (lb/hr)	Percent Increase in Deposition Rate
CTC-027	Root Pass	10.9	15.5	42.2%
	Fill Passes	12.8	17.4	35.9%

Note: Deposition rates and percentage increase did not change from CTC-026. All parameters were the same as CTC-026 except the cold wire was lagging the electrode in lieu of leading the electrode.

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Tensile Data Comparison CTC-024 vs. CTC-027

Specimen Identification	Test Temperature (°F)	Original Specimen Diameter (inches)	Ultimate Tensile Load (lbf)	0.2% Offset Yield Load (lbf)	Ultimate Tensile Strength (ksi)	0.2% Offset Yield Strength (ksi)	Elongation Increase (%)	Reduction of Area (%)
CTC-024-TS1	70	0.4986	17744	15763	90.9	80.7	24	71
CTC-024-TS2	70	0.5001	17724	15755	90.2	80.2	24	70

CTC-024 = 88.7 kJ/in calculated heat input.

Specimen Identification	Original Specimen Diameter (inches)	Ultimate Tensile Load (lbf)	0.2% Offset Yield Load (lbf)	Ultimate Tensile Strength (ksi)	0.2% Offset Yield Strength (ksi)	Elongation Increase (%)	Reduction of Area (%)
CTC-027-Tensile-1	0.4989	18187	16391	93.0	83.8	24	70
CTC-027-Tensile-2	0.4997	18209	16372	92.8	83.5	25	72

CTC-027 = 90 kJ/in calculated heat input 65.2 kJ/in effective heat input.

Note: CTC-026 tensile strength was 92.8 and 93.4 ksi and yield strength was 83.3 and 84.5 ksi.

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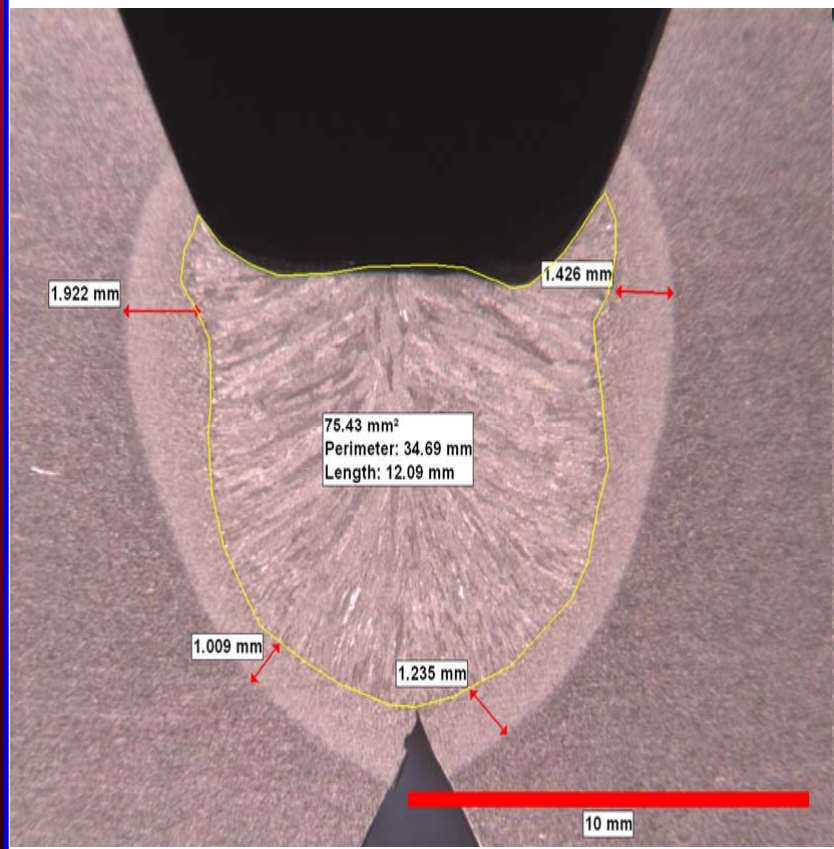
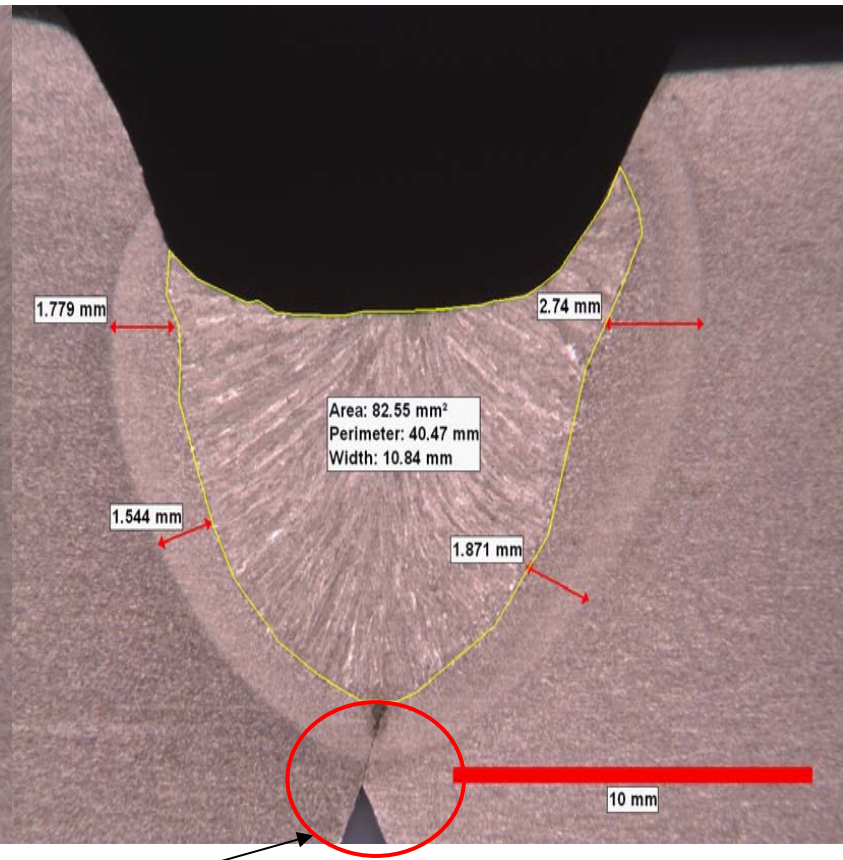
Weld Volume and Penetration

CTC-026, Cold Wire Leading

CTC-027, Cold Wire Lagging





Note the difference in penetration and weld volume.

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Charpy Data Comparison CTC-024 vs. CTC-027

Specimen Identification	Specimen Type	Specimen Size (mm x mm)	Test Temperature (°F)	Absorbed Energy (ft-lbs)	Lateral Expansion (mils)	Fracture Appearance (% shear)
CV.SP-01-CTC-024-1	Type A	10 x 10	-20	43.0	39	46
CV.SP-01-CTC-024-2	Type A	10 x 10	-20	57.0	42	50
CV.SP-01-CTC-024-3	Type A	10 x 10	-20	43.0	35	61
CV.SP-01-CTC-024-4	Type A	10 x 10	-20	104.0	67	77
CV.SP-01-CTC-024-5	Type A	10 x 10	-20	46.0	34	42
			Average	**58.6**	**43.4**	**55.2**
			St. Dev.	**8.1**	**3.5**	**7.8**

Specimen Identification	Specimen Type	Specimen Size (mm x mm)	Test Temperature (°F)	Absorbed Energy (ft-lbs)	Lateral Expansion (mils)	Fracture Appearance (% shear)
CTC-027-1	Type A	10 x 10	-20	82.5	56	76
CTC-027-2	Type A	10 x 10	-20	76.2	54	74
CTC-027-3	Type A	10 x 10	-20	73.0	52	73
CTC-027-4	Type A	10 x 10	-20	76.3	54	74
CTC-027-5	Type A	10 x 10	-20	73.6	52	73
			Average	**76.3**	**53.6**	**74.0**
			St. Dev.	**3.8**	**1.7**	**1.2**

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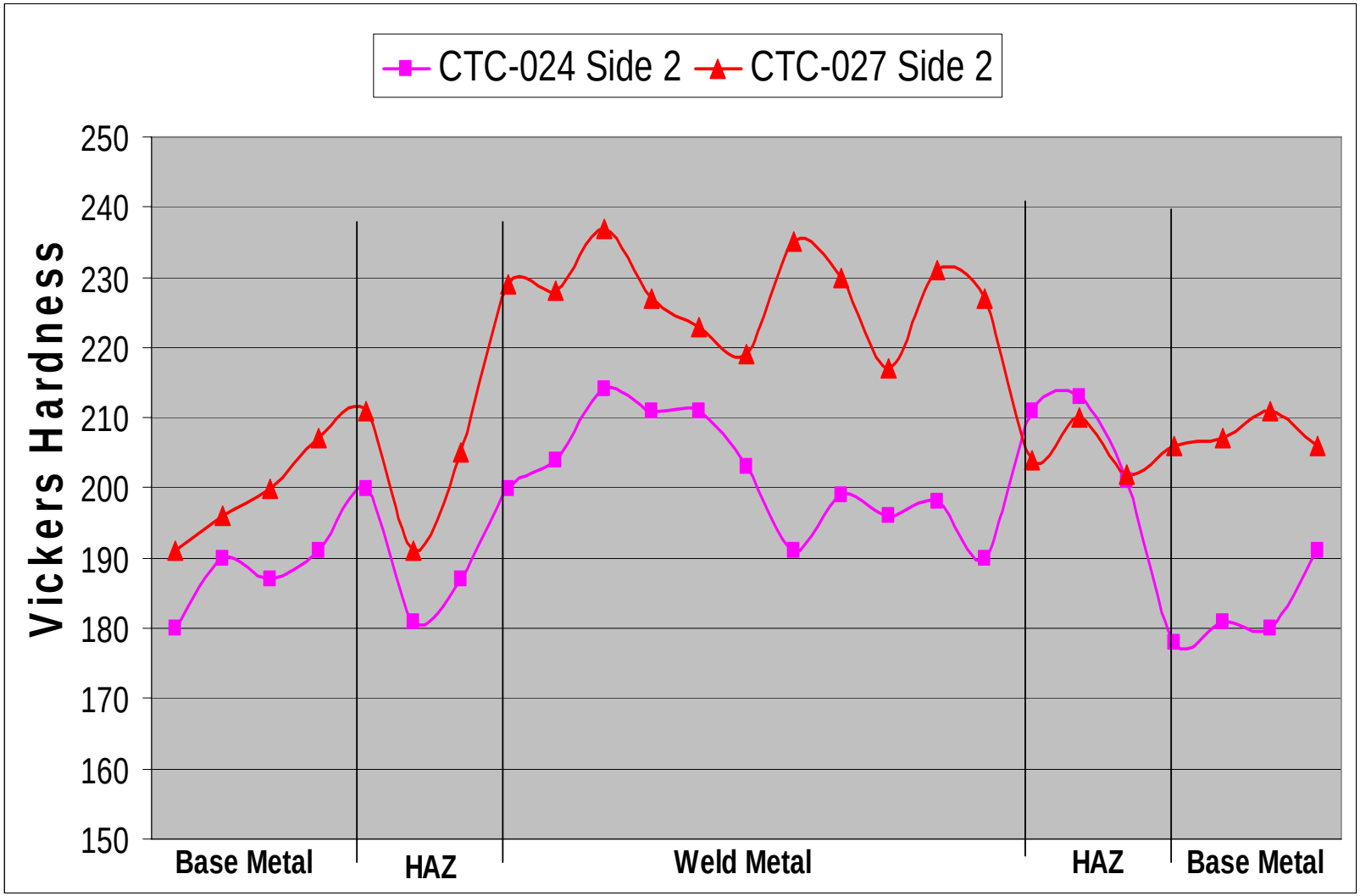
Hardness Comparison CTC-024 vs. CTC-027



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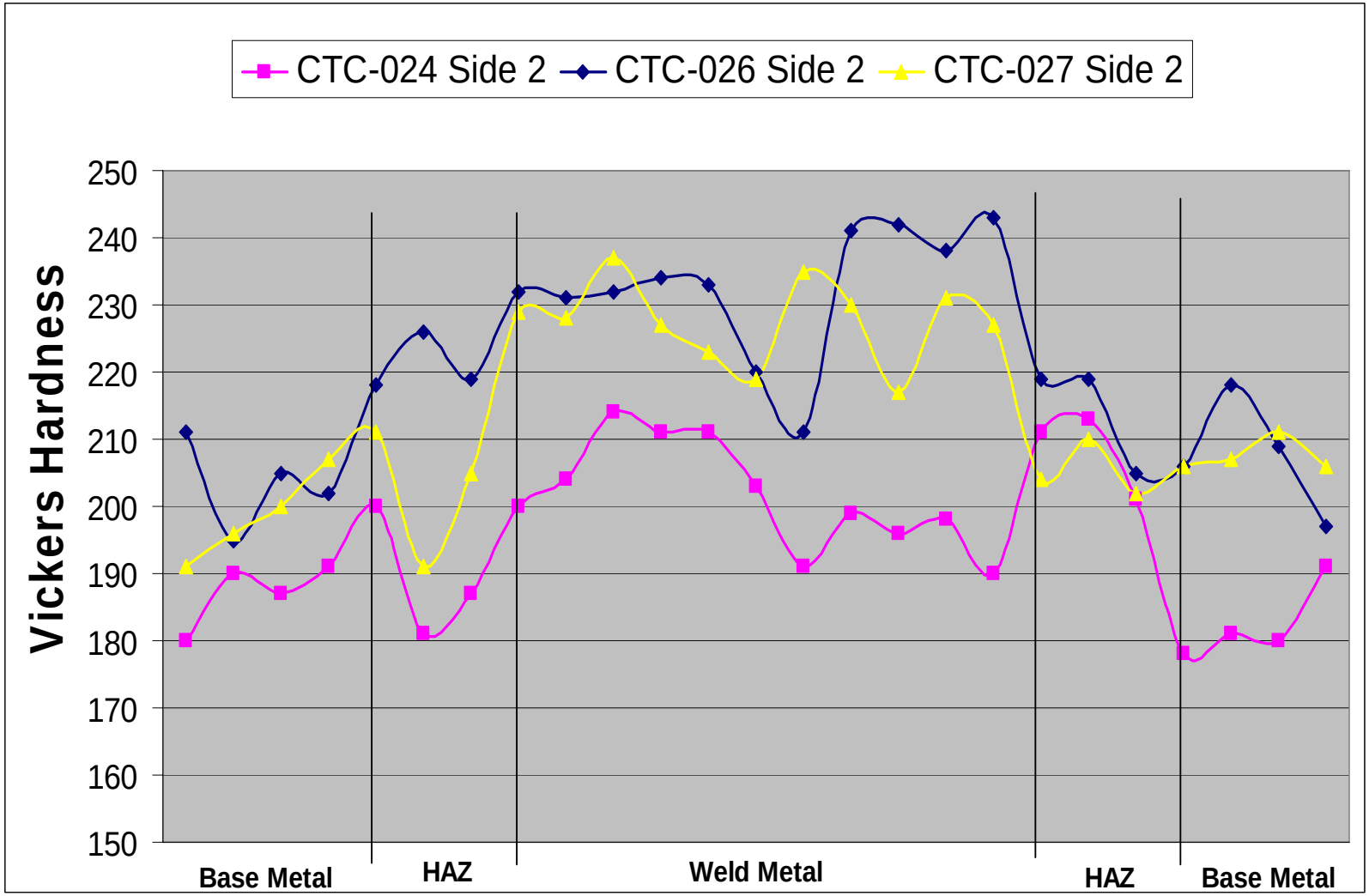
Hardness Comparison CTC-024 vs. CTC-026 and CTC-027



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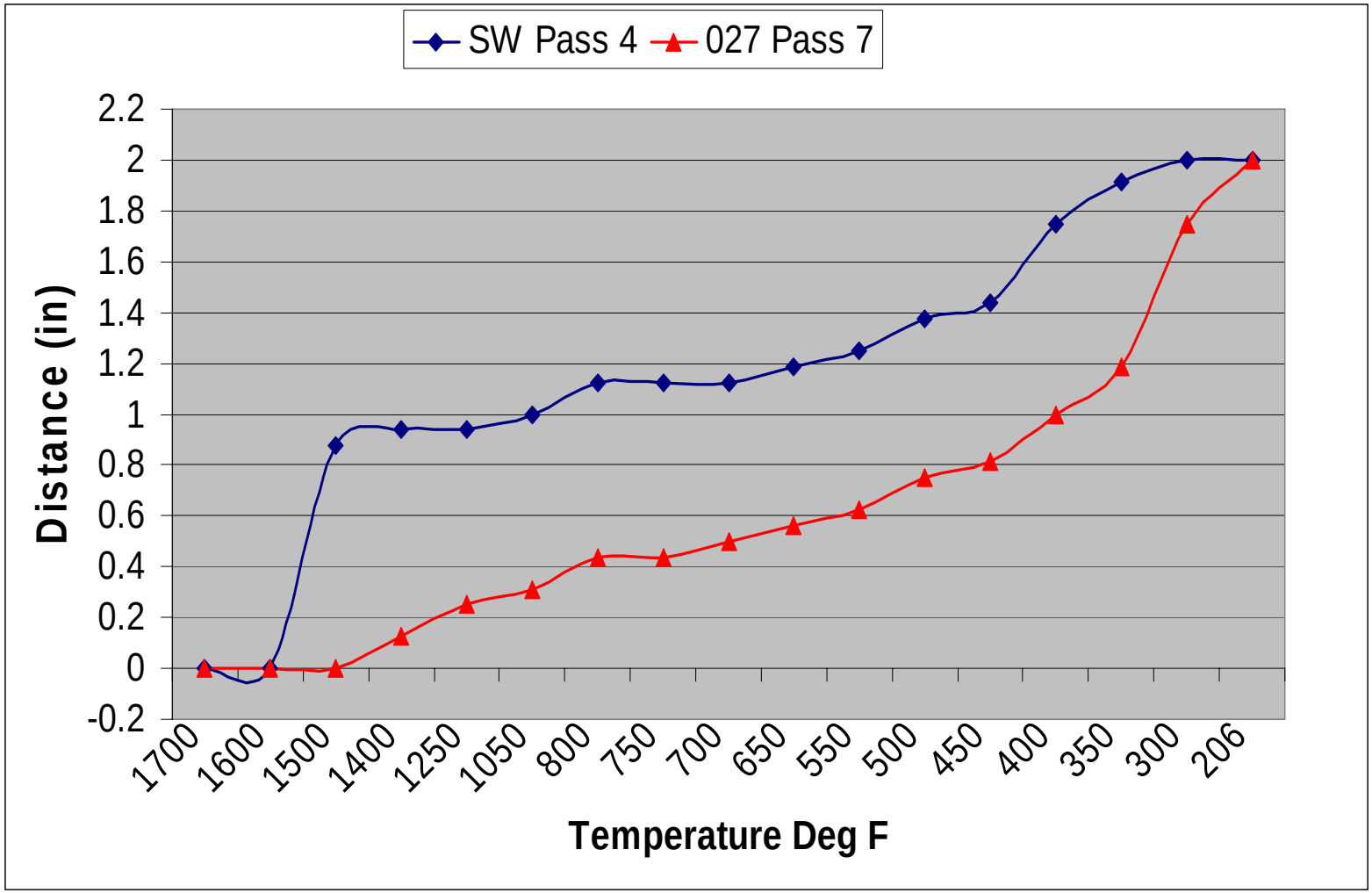
Surface Temperature of Plate CTC-024 and CTC-027



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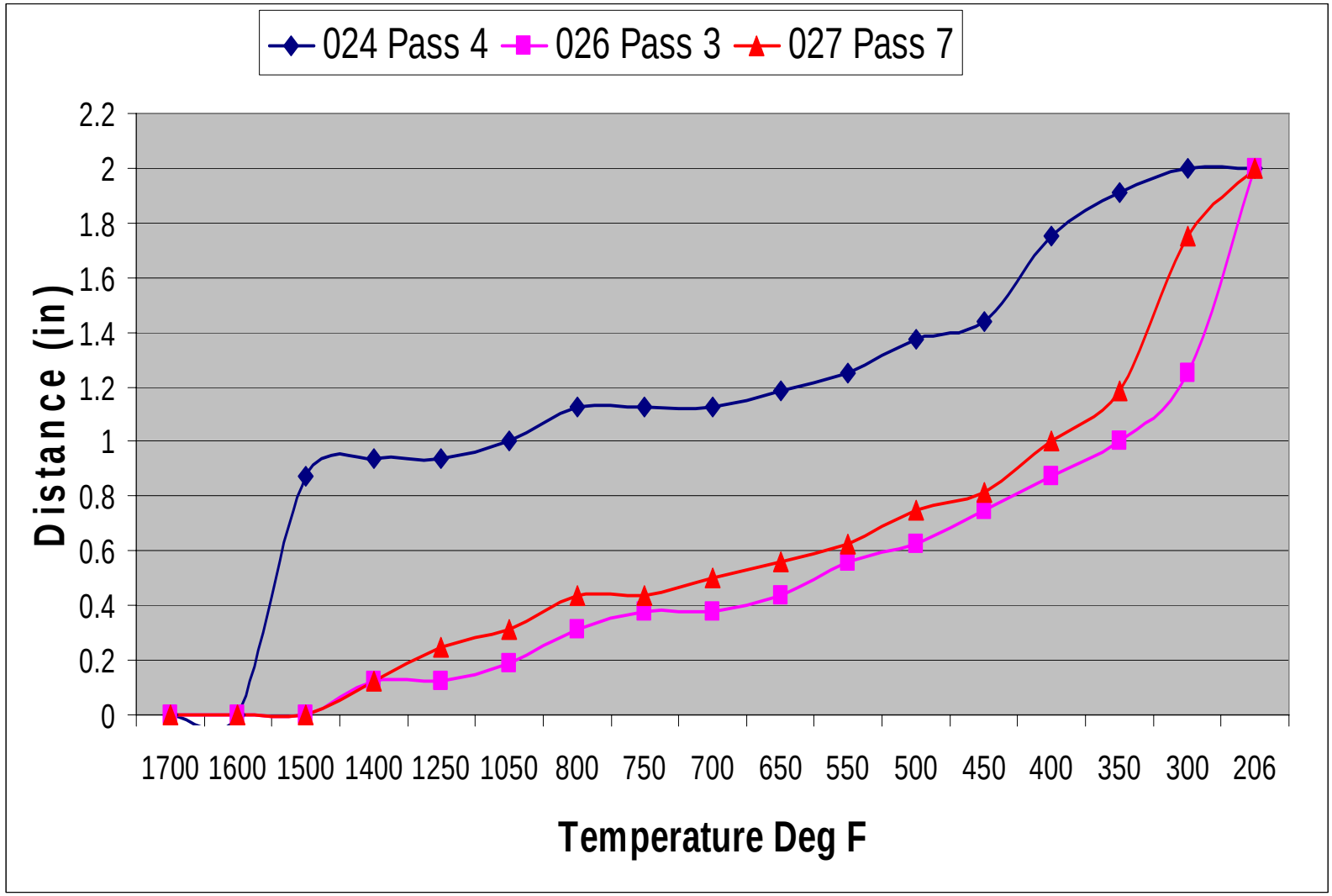
Heat At Surface of Plate CTC-024 CTC-026 and CTC-027



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Welding Parameters CTC-028

Specimen Identification CTC-028	Wire Size (in)		Current	Avg. Amps	Avg. Volts	Avg. Travel Speed (ipm)	Wire Speed (ipm)	
Fill and Cap Passes	Electrode	Cold Wire					Electrode	Cold Wire
	0.125	0.0625	DCEP	512	32.5	9	71	110

Avg. Heat Input Electrode (kJ/in)	Reduction Factor		Effective Heat Input (kJ/in)		Calculated Deposition Rate (lb/hr)	
	Root Pass	Fill and Cap Passes	Root Pass	Fill and Cap Passes	Root Pass	Fill and Cap Passes
110.9	0.702	0.721	51.7	79.6	15.5	20.3

Cold wire was leading the electrode during welding of CTC-028. Deposition rate calculations reflect the deposition efficiency, heat input reflects process efficiency.

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Deposition Rate Increase CTC-024, and CTC-026 vs. CTC-028

Specimen Identification	Pass	Deposition Rate Single Electrode (lb/hr)	Deposition Rate Cold-Wire Process (lb/hr)	Percent Increase in Deposition Rate
CTC-026	Root Pass	10.9	15.6	43.1%
	Fill Passes	12.8	17.4	35.9%

CTC-026 = 89.7 kJ/in calculated heat input 65.2 kJ/in effective heat input.

Specimen Identification	Pass	Deposition Rate Single Electrode (lb/hr)	Deposition Rate Cold-Wire Process (lb/hr)	Percent Increase in Deposition Rate
CTC-028	Root Pass	10.9	15.5	42.2%
	Fill Passes	14.6	20.3	39.0%

CTC-028 = 110 kJ/in calculated heat input 79.6 kJ/in effective heat input.

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Tensile Data Comparison CTC-024 vs. CTC-028

Specimen Identification	Test Temperature (°F)	Original Specimen Diameter (inches)	Ultimate Tensile Load (lbf)	0.2% Offset Yield Load (lbf)	Ultimate Tensile Strength (ksi)	0.2% Offset Yield Strength (ksi)	Elongation Increase (%)	Reduction of Area (%)
CTC-024-TS1	70	0.4986	17744	15763	90.9	80.7	24	71
CTC-024-TS2	70	0.5001	17724	15755	90.2	80.2	24	70

CTC-024 = 88.7 kJ/in calculated heat input.

Specimen Identification	Original Specimen Diameter (inches)	Ultimate Tensile Load (lbf)	0.2% Offset Yield Load (lbf)	Ultimate Tensile Strength (ksi)	0.2% Offset Yield Strength (ksi)	Elongation Increase (%)	Reduction of Area (%)
CTC-028-Tensile-1	0.4999	18078	16275	92.1	82.9	23	66
CTC-028-Tensile-2	0.5000	17959	16226	91.5	82.6	22	68

CTC-028 = 110 kJ/in calculated heat input 79.6 kJ/in effective heat input.

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Charpy Data Comparison CTC-024 vs. CTC-028

Specimen Identification	Specimen Type	Specimen Size (mm x mm)	Test Temperature (°F)	Absorbed Energy (ft-lbs)	Lateral Expansion (mils)	Fracture Appearance (% shear)
CV.SP-01-CTC-024-1	Type A	10 x 10	-20	43.0	39	46
CV.SP-01-CTC-024-2	Type A	10 x 10	-20	57.0	42	50
CV.SP-01-CTC-024-3	Type A	10 x 10	-20	43.0	35	61
CV.SP-01-CTC-024-4	Type A	10 x 10	-20	104.0	67	77
CV.SP-01-CTC-024-5	Type A	10 x 10	-20	46.0	34	42
			Average	**58.6**	**43.4**	**55.2**
			St. Dev.	**8.1**	**3.5**	**7.8**

Specimen Identification	Specimen Type	Specimen Size (mm x mm)	Test Temperature (°F)	Absorbed Energy (ft-lbs)	Lateral Expansion (mils)	Fracture Appearance (% shear)
CTC-028-1	Type A	10 x 10	-20	55.0	39	59
CTC-028-2	Type A	10 x 10	-20	94.1	61	81
CTC-028-3	Type A	10 x 10	-20	30.1	21	43
CTC-028-4	Type A	10 x 10	-20	110.2	72	87
CTC-028-5	Type A	10 x 10	-20	55.2	40	59
			Average	**68.9**	**46.6**	**65.8**
			St. Dev.	**32.5**	**20.1**	**18.0**

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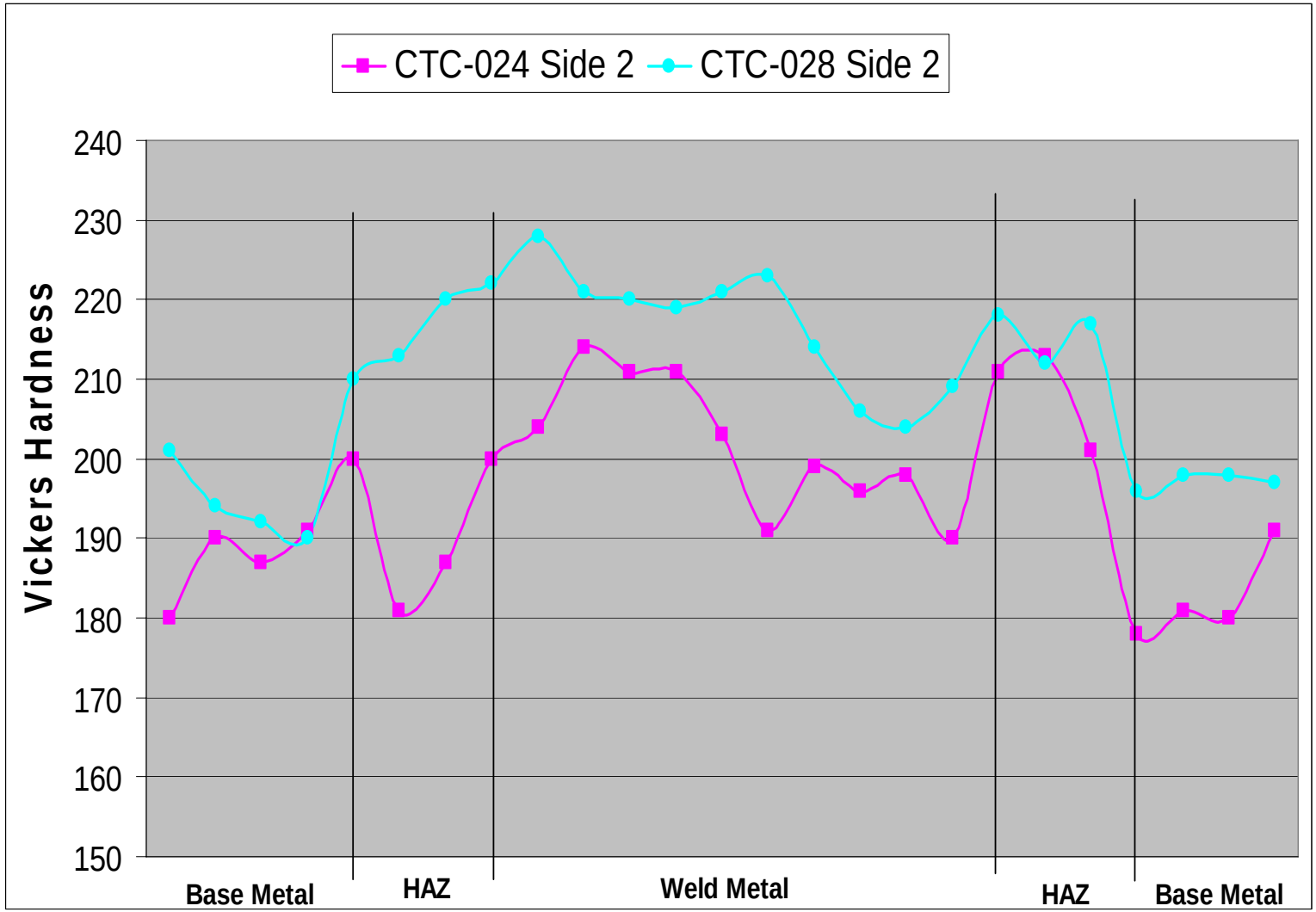
Hardness Comparison CTC-024 vs. CTC-028



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Summary for Weldment CTC-029

- CTC-029 same weld parameters and heat input as CTC-028 except cold wire lagging the electrode.
- Tensile strength for CTC-029 was 91.2 and 90.7 ksi, and yield strength was 80.6 and 80.8 ksi.
- Tensile strength for CTC-024 was 90.9 and 90.2 ksi, and yield strength was 80.7 and 80.2 ksi.
- Average toughness for CTC-029 was 84.4 ft-lbs with no sample less than the required 30 ft-lbs as stated in CVN 78 Fabrication PPD, section 10, paragraph 10.7.

Welding Parameters CTC-030

Specimen Identification CTC-030	Wire Size (in)		Current	Avg. Amps	Avg. Volts	Avg. Travel Speed (ipm)	Wire Speed (ipm)	
Fill and Cap Passes	Electrode	Cold Wire					Electrode	Cold Wire
	0.125	0.0625	DCEP	570	33	9	76	110

Avg. Heat Input Electrode (kJ/in)	Reduction Factor		Effective Heat Input (kJ/in)		Calculated Deposition Rate	
	Root Pass	Fill and Cap Passes	Root Pass	Fill and Cap Passes	Root Pass	Fill and Cap Passes
124.1	0.702	0.734	52.1	91	15.4	21.3

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Deposition Rate Increase CTC-024, and CTC-028 vs. CTC-030

Specimen Identification	Pass	Deposition Rate Single Electrode (lb/hr)	Deposition Rate Cold-Wire Process (lb/hr)	Percent Increase in Deposition Rate
CTC-028	Root Pass	10.9	15.5	42.2%
	Fill Passes	14.6	20.3	39.0%

CTC-028 = 110 kJ/in calculated heat input 79.6 kJ/in effective heat input.

Specimen Identification	Pass	Deposition Rate Single Electrode (lb/hr)	Deposition Rate Cold-Wire Process (lb/hr)	Percent Increase in Deposition Rate
CTC-030	Root Pass	10.9	15.4	41.3%
	Fill Passes	14.6	21.4	46.6%

CTC-030 = 125 kJ/in calculated heat input 91 kJ/in effective heat input.

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Tensile Data Comparison CTC-024 vs. CTC-030

Specimen Identification	Test Temperature (°F)	Original Specimen Diameter (inches)	Ultimate Tensile Load (lbf)	0.2% Offset Yield Load (lbf)	Ultimate Tensile Strength (ksi)	0.2% Offset Yield Strength (ksi)	Elongation Increase (%)	Reduction of Area (%)
CTC-024-TS1	70	0.4986	17744	15763	90.9	80.7	24	71
CTC-024-TS2	70	0.5001	17724	15755	90.2	80.2	24	70

CTC-024 = 88.7 kJ/in calculated heat input.

Specimen Identification	Original Specimen Diameter (inches)	Ultimate Tensile Load (lbf)	0.2% Offset Yield Load (lbf)	Ultimate Tensile Strength (ksi)	0.2% Offset Yield Strength (ksi)	Elongation Increase (%)	Reduction of Area (%)
CTC-030-Tensile-1	0.4994	17823	15298	91.0	78.1	25	70
CTC-030-Tensile-2	0.4994	17564	14996	89.7	76.6	26	70

CTC-030 = 125 kJ/in calculated heat input 91 kJ/in effective heat input.

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Charpy Data Comparison CTC-024 vs. CTC-030

Specimen Identification	Specimen Type	Specimen Size (mm x mm)	Test Temperature (°F)	Absorbed Energy (ft-lbs)	Lateral Expansion (mils)	Fracture Appearance (% shear)
CV.SP-01-CTC-024-1	Type A	10 x 10	-20	43.0	39	46
CV.SP-01-CTC-024-2	Type A	10 x 10	-20	57.0	42	50
CV.SP-01-CTC-024-3	Type A	10 x 10	-20	43.0	35	61
CV.SP-01-CTC-024-4	Type A	10 x 10	-20	104.0	67	77
CV.SP-01-CTC-024-5	Type A	10 x 10	-20	46.0	34	42
			Average	**58.6**	**43.4**	**55.2**
			St. Dev.	**8.1**	**3.5**	**7.8**

Specimen Identification	Specimen Type	Specimen Size (mm x mm)	Test Temperature (°F)	Absorbed Energy (ft-lbs)	Lateral Expansion (mils)	Fracture Appearance (% shear)
CTC-030-1	Type A	10 x 10	-20	71.0	49	73
CTC-030-2	Type A	10 x 10	-20	71.0	49	73
CTC-030-3	Type A	10 x 10	-20	57.0	43	62
CTC-030-4	Type A	10 x 10	-20	90.0	59	86
CTC-030-5	Type A	10 x 10	-20	86.0	58	82
			Average	**75.0**	**51.6**	**75.2**
			St. Dev.	**13.2**	**6.8**	**9.3**

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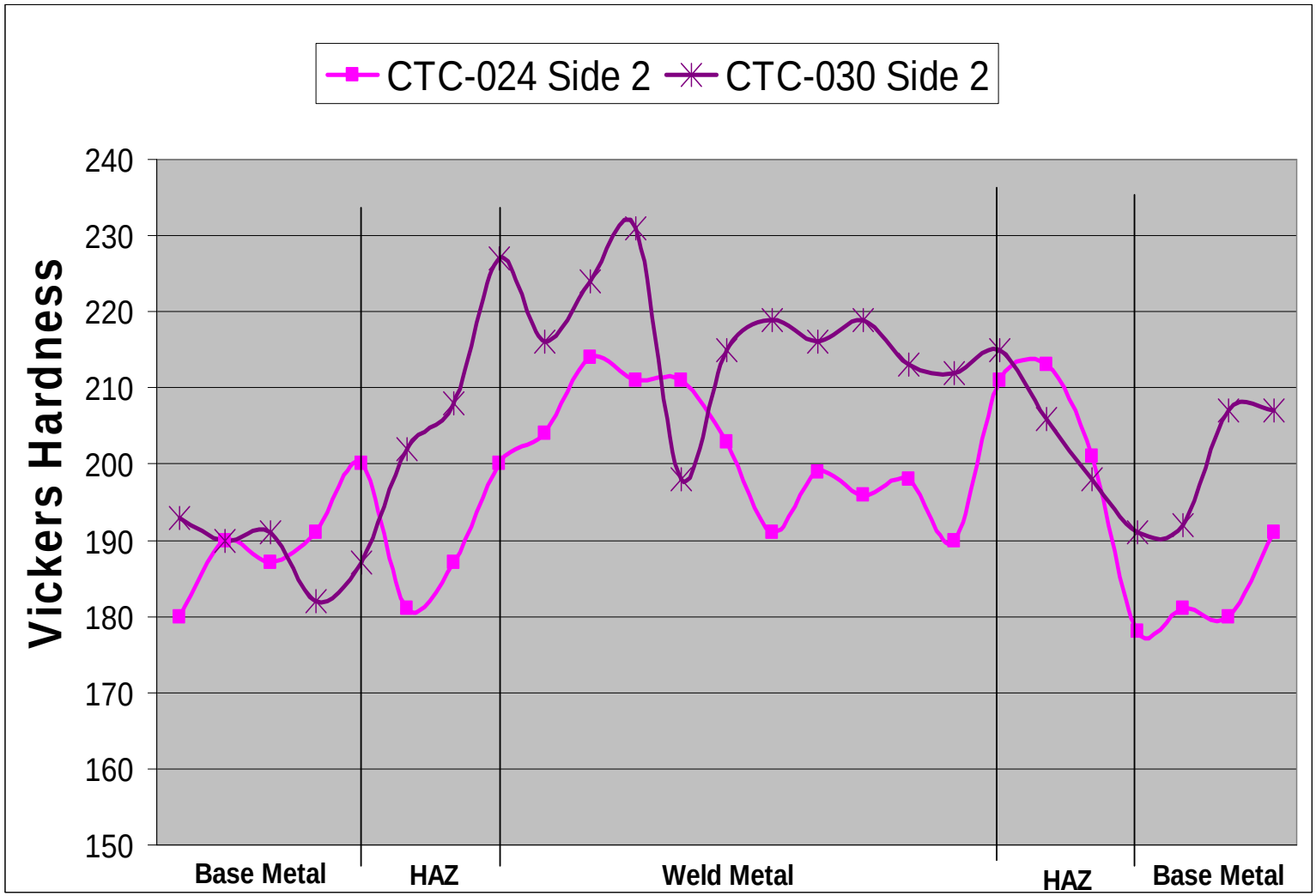
Hardness Comparison CTC-024 vs. CTC-030



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Summary

- 6 Weldments were made in HSLA-65 material.
- 1 weldment made with a single wire at 89 kJ/in heat input: benchmark.
- 5 weldments made using cold wire process with calculated heat inputs from 89 kJ/in to 124 kJ/in (Effective heat inputs from 65 kJ/in to 91 kJ/in).
- Deposition rates were increased between 36 and 47%.

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Conclusions

- Hardness readings indicate an increase in cooling rate of cold wire weldments compared to single wire weldment.
- Increase in cooling rates indicates decrease in heat input and produces harder microstructure.
- This suggests that effective heat input for cold wire process is plausible.
- All cold wire weldments showed excellent mechanical properties.
- Current results indicate that higher heat inputs could still be achieved without sacrificing mechanical properties.