Weld Characterization of Electron Beam Pipe Welds on Niobium for Superconducting Radio-Frequency (SRF) Cavities

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Overview & Problem Statement

Overview:
Electron Beam Welding (EBW) is a prominent process for joining high-purity niobium for use in superconducting radiofrequency (SRF) cavities in particle accelerators. Niobium is a refractory alloy known for its highly efficient wave-conducting properties at cryogenic temperatures (2K). It can sustain high RF surface magnetic fields, is workable, and has low RF surface resistance at these low temperatures. EBW allows for minimization of contamination of the pure niobium, which prevents damage to niobium's properties. EBW is done in a vacuum to ensure this pure state of niobium.

Problem Statement:
Even with the immense benefits of pure niobium usage in SRF cavities, minimal research has been conducted on its characteristics, particularly in EBW. Ensuring optimal EBW parameters can ensure proper performance of SRF cavities.

Image Credit: U.S. Department of Energy

Methods

Objective: Assess weld characteristics of pure niobium as a function of EBW parameters. Quantifying preheat effects as a function of EBW parameters. Develop a Simufact Welding™ model for EBW of high purity niobium.

Approach:
- Nine pipe welds were made using EBW different parameters - an 4.11mm x 1.54mm deflection pattern was used
- Samples were cut, mounted, ground, and etched.
- Simufact Welding™ was used to model pipe welds Niobium pipe welds using the electron beam heat source
- Weld, root, and crown analysis was utilized using the Ash OMNI-Core Macroscope
- Process window was constructed for EBW of niobium under different deflection conditions

$$\delta_z = \sqrt{\frac{\alpha C_p}{V_s}}$$

$\delta_z = thermal\ diffusion\ length\ (mm)$
$\alpha = thermal\ diffusivity\ (\frac{mm^2}{s})$
$C_p = Circumference\ of\ Pipe\ (mm)$
$V_s = Travel\ Speed\ (\frac{mm}{s})$

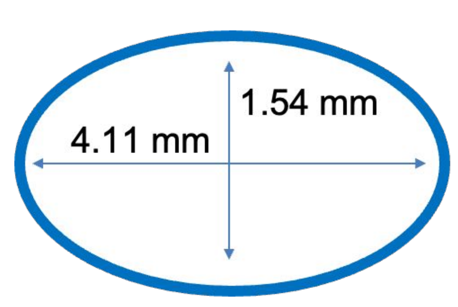

Figure 1: Electron Beam Deflection Pattern

Table 1: EBW parameters for Niobium Pipe Welds

Set	Sample ID	AV	BC	Feed	Energy Input
		kV	mA	mm/s	J/mm
OSU1	-1 / -2	50	70	5.06	691.21
OSU1	-3 / -4	50	47	3.38	696.15
OSU1	-5 / -6	50	58	4.22	687.26
OSU2	-1 / -2	50	56	3.38	829.46
OSU2	-3 / -4	50	56	5.06	552.97
OSU2	-5 / -6	50	48	2.53	947.95
OSU3	-1 / -2	50	61	5.06	602.34
OSU3	-3 / -4	50	81	5.06	799.83
OSU3	-5 / -6	50	80	4.22	947.95

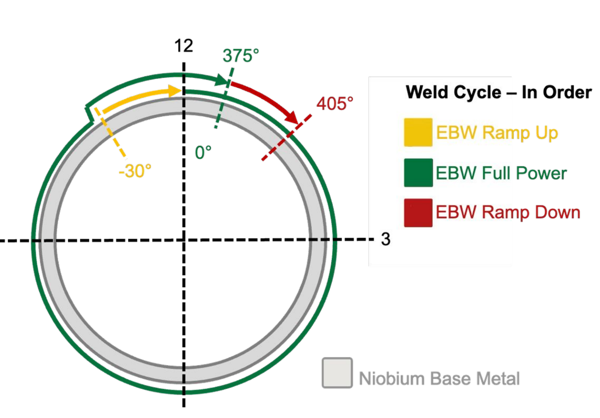

Figure 2: Pipe Weld Procedure

Discussion

The data demonstrates a correlation between an increase in weld root width and orientation within the repass zone, as shown by sharp increase in weld root width at about 270°. Thermal diffusion length increased as feed rate slowed and energy input increased. Weld root width was steady outside of the repass zone. Weld crown width remained steady throughout experiment, and was not affected by the repass zone. Simufact® welding simulations produced similar results to experimental welding, but will require more calibrating and is only a guide for future welds.

Acknowledgements

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Results & Conclusion

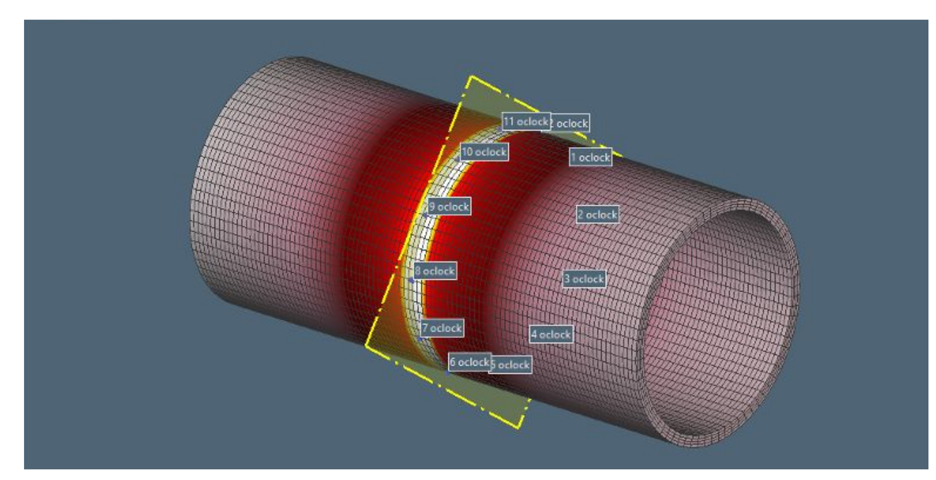

Figure 3: Simulated Pipe OSU 1, Tube 1-2 Modelling Courtesy of Richard Li

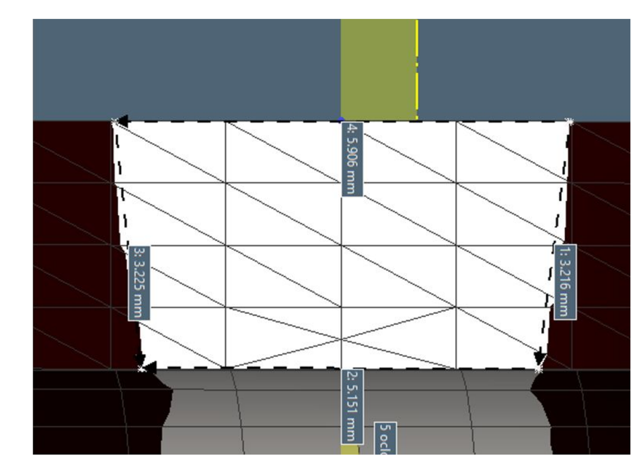

Figure 4: Simulated Pipe OSU 1, Tube 1-2 Modelling

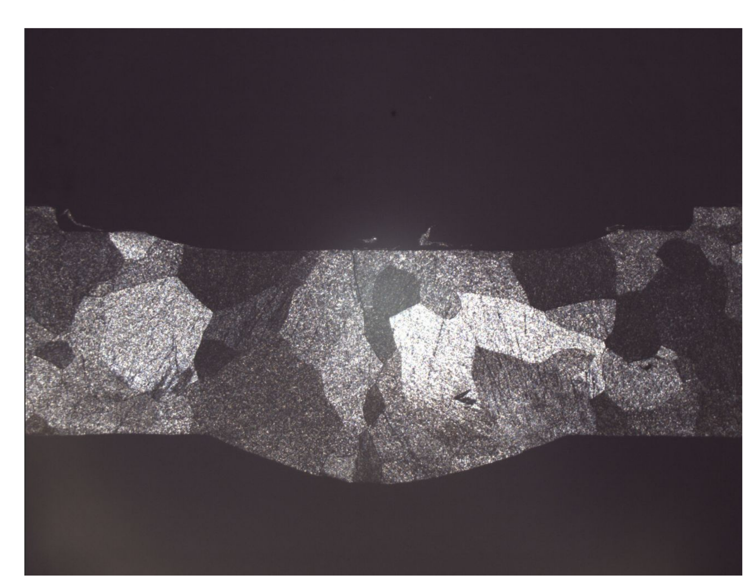

Figure 5: Pipe OSU 1 Tube 1-2, 6 o'clock

Experimental Crown	6.44mm
Experimental Root	5.34mm
Simufact® Weld Crown Width	5.91mm
Simufact® Weld Root Width	5.15mm

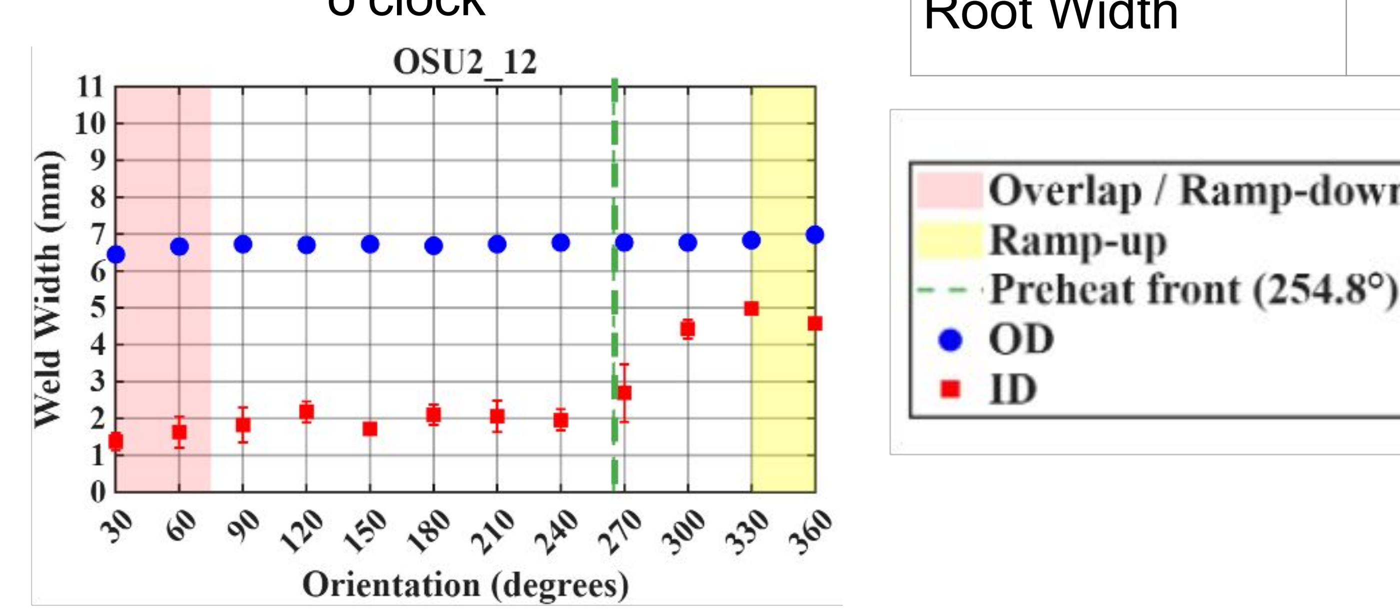

Figure 6: Weld Root and Crown Width Evolution in Pipe OSU 2, Tube 1-2

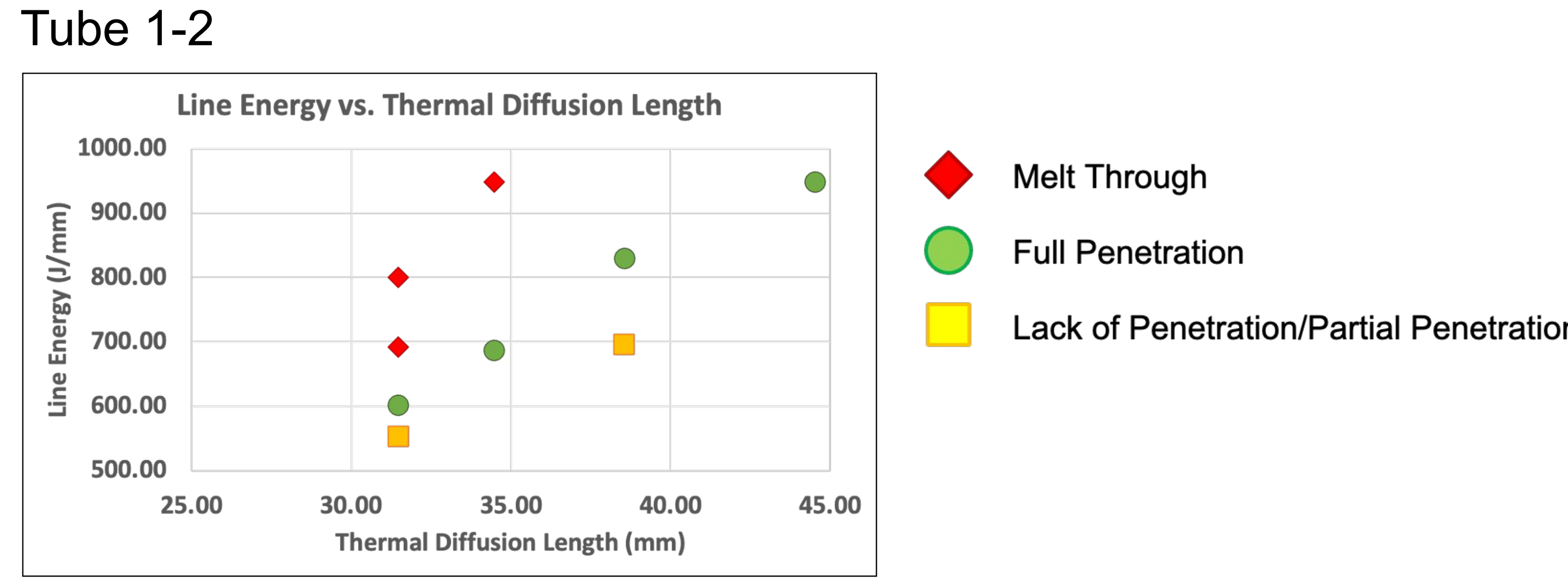

Figure 7: Weld Process Window Map for Niobium Pipe

Conclusion:
- Crown width was maintained throughout weld evolutions, whereas root width increased at point of preheat front
- Weld widths are relatively stable until repass zone is entered, when trends show a spike in width
- At current conditions, Simufact® simulation produces similar, yet not identical, results to experimental crown and root widths