Simulation of High Frequency Induction Welded Thick-Walled Line Pipe Products

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Introduction

High-Frequency Induction Welding (HFIW) is widely used for producing steel pipes in oil and gas, construction, and energy infrastructure. While thin-walled tube welding is well-studied, thick-walled pipes face challenges such as defect formation, microstructural inconsistencies, and reduced toughness. Simulating the HFI welding process presents an opportunity for optimisation, to address defect inclusion and improve the quality of thick-walled pipe welds.

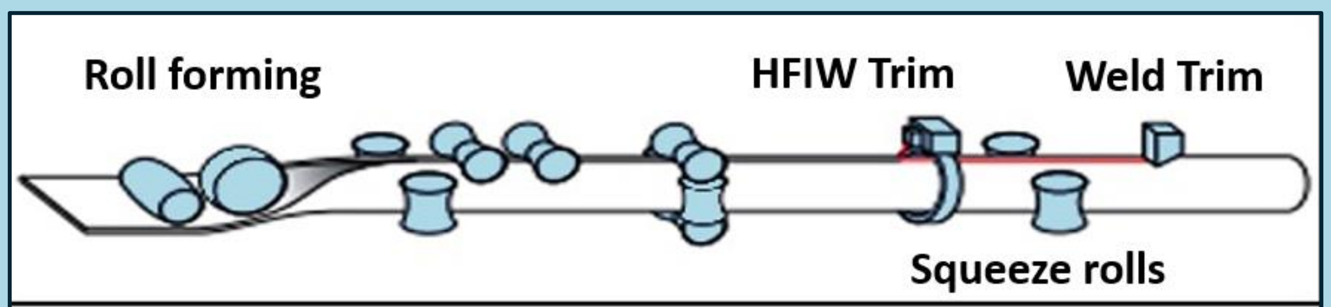


Fig 1: Schematic of the High-Frequency Induction Welding (HFIW) Process [1]

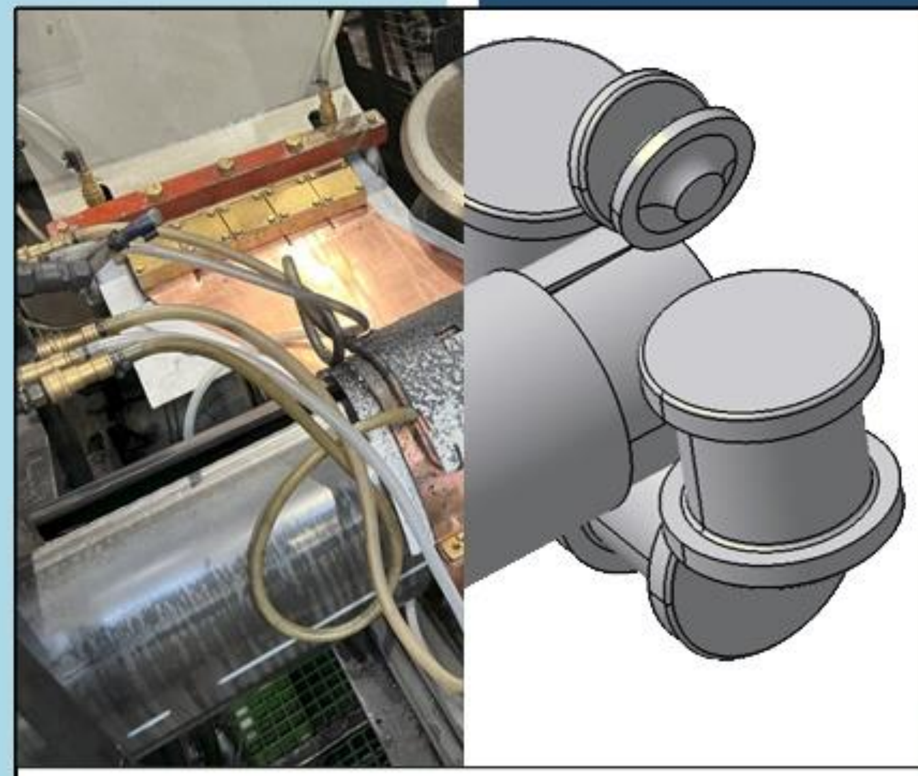


Fig 2. Comparison of Real-Life HFI Welding Setup and 3D Numerical Model of the Welding Process

Methodology

A 3D model was developed using Hartlepool welder measurements for the tube, coil, and impeder. Electromagnetic heating physics and temperature-dependent properties were applied, with translational motion simulating tube movement and edge closure during welding.

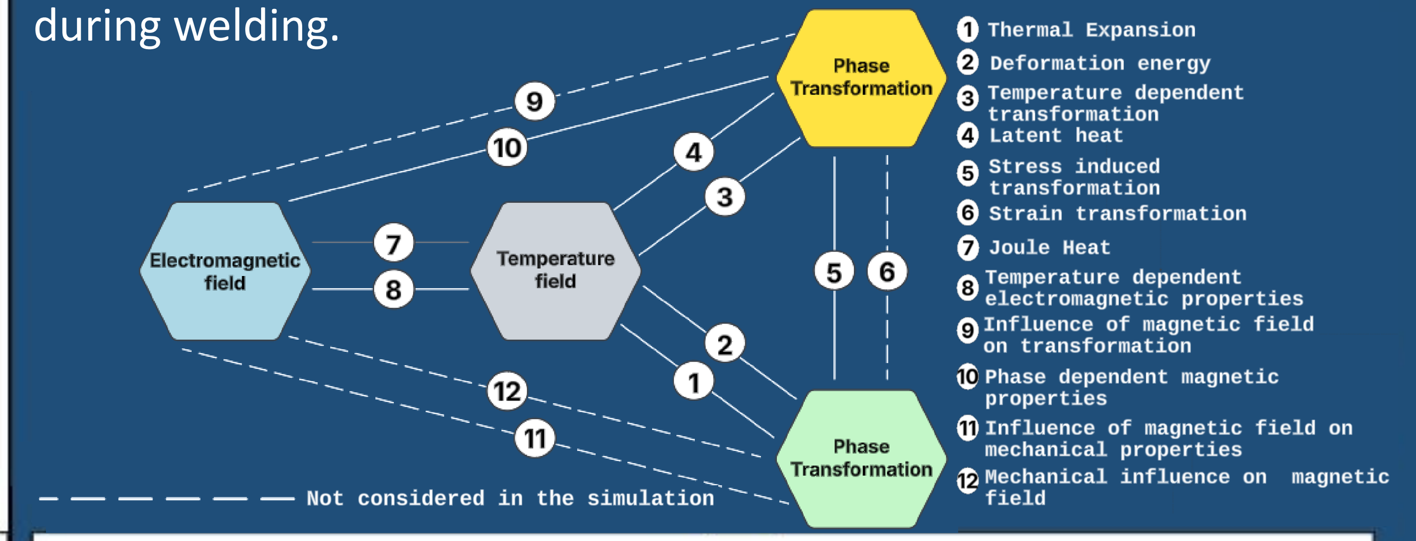


Fig 7: Interaction of Electromagnetic, Thermal, Mechanical, and Phase Transformation Fields in HFI Welding [3]

What is HFIW?

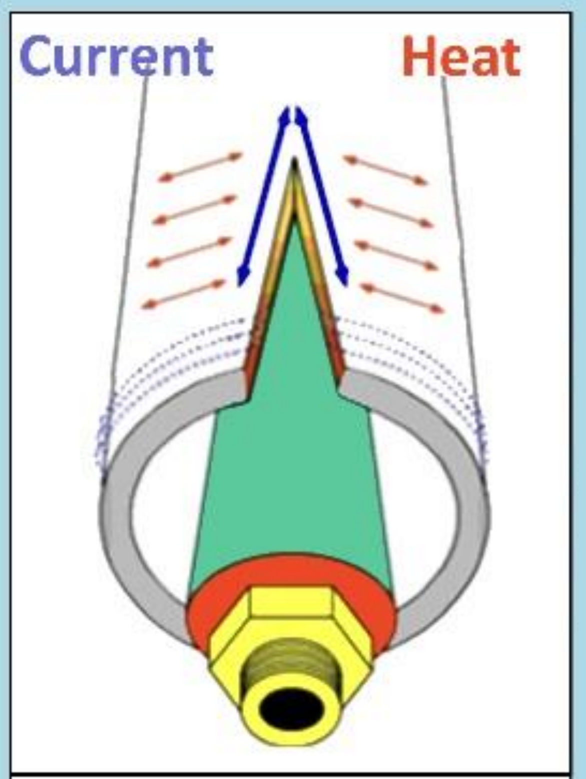
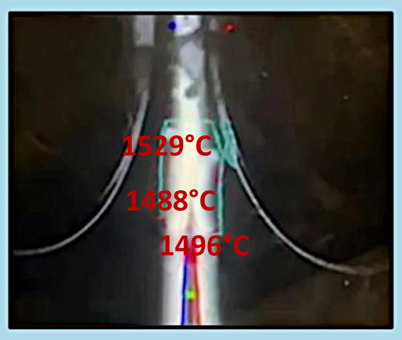


Fig 3. Distribution of current (blue) & heat (red) in an induction welding process [2]

HFIW is a solid-state process for joining materials, mainly steel pipes and tubes, using high-frequency currents to heat the edges. A coil induces an electromagnetic field, concentrating the current along the edges. A V-shaped gap ensures efficient heating through skin and proximity effects, with mechanical pressure forging the joint.



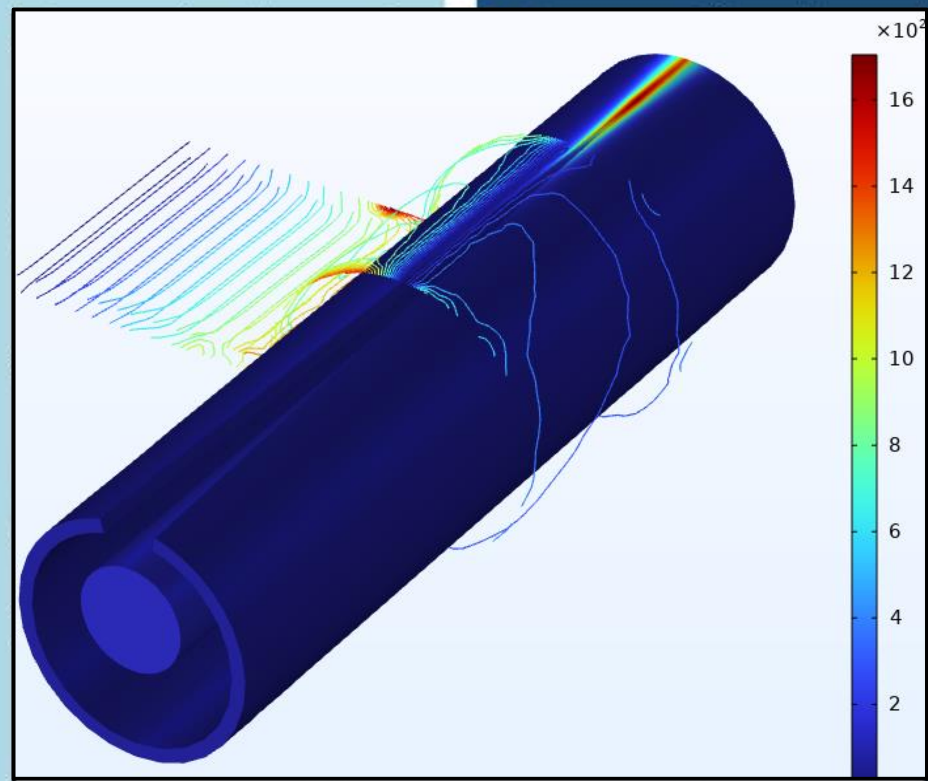
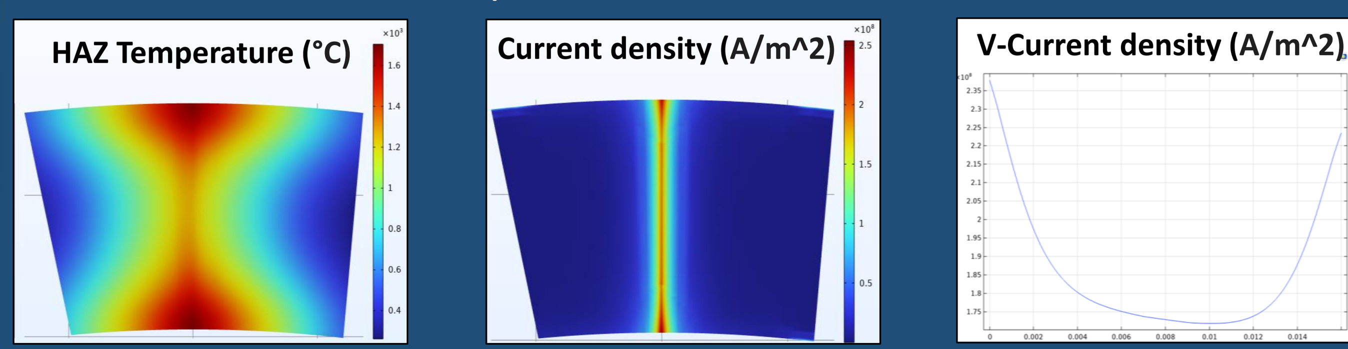


Fig 4. Results of HFI welding simulation in COMSOL, showing the temperature distribution in the V-shaped gap and current flow throughout the coil and tube.

Results

Figure 4 shows the preliminary results of the 3D model simulating HFI welding for thick-walled steel pipes. The pipe moves at a constant speed, and the edges meet at the weld point, reaching the target temperature of 1450°C, closely matching real-life conditions. Temperature-dependent material properties were incorporated, and the heat distribution highlights electromagnetic heating effects at the V-shaped gap. The model assumes ideal edge alignment and excludes mechanical compression, focusing on thermal behaviour. Future iterations will explore dynamic edge closure and material displacement.



Aims and objectives

1- To create a 3D FEA model to allow interrogation of input parameter variability on weld quality.

2-To allow the mechanical compression aspect to assess oxide expulsion as a function of thickness.

3-How can numerical simulation be used to understand the consequences of process variability in HFI welding?

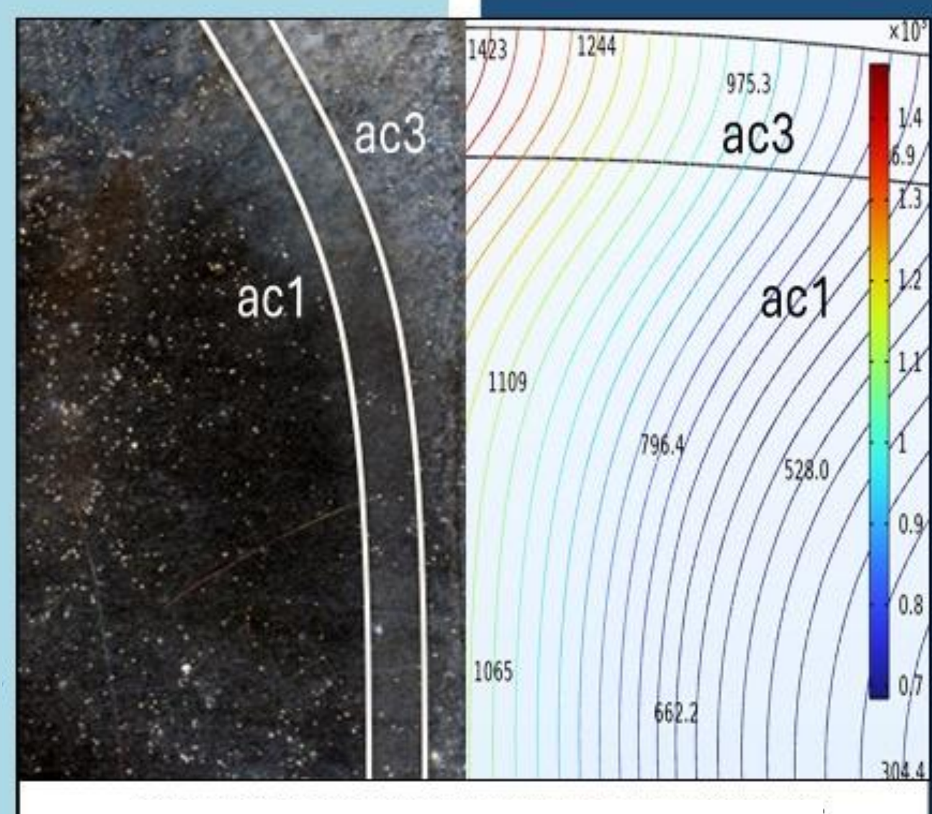
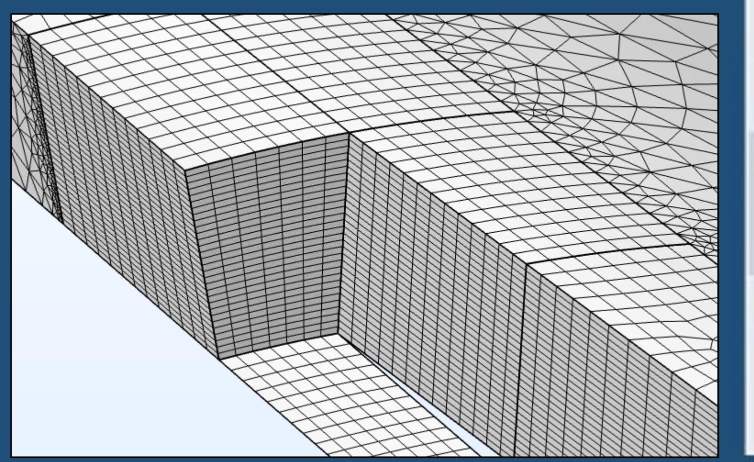


Fig 5. Heat-Affected Zone (HAZ) at the HFI Weld Point: Experimental vs. Simulated Results

Future work

Future work will refine the 3D finite element analysis (FEA) model to improve accuracy and computational efficiency. A finer mesh will be applied to capture thermal gradients in the HAZ and enhance weld quality analysis.



Parameters	
Coil position	Coil frequency
Current	Weld speed
Vee angle	Coil/tube gap
Tube thickness	Impeder/tube gap
Impeder Position	Tube diameter
Impeder size	Material properties

Experimental Data

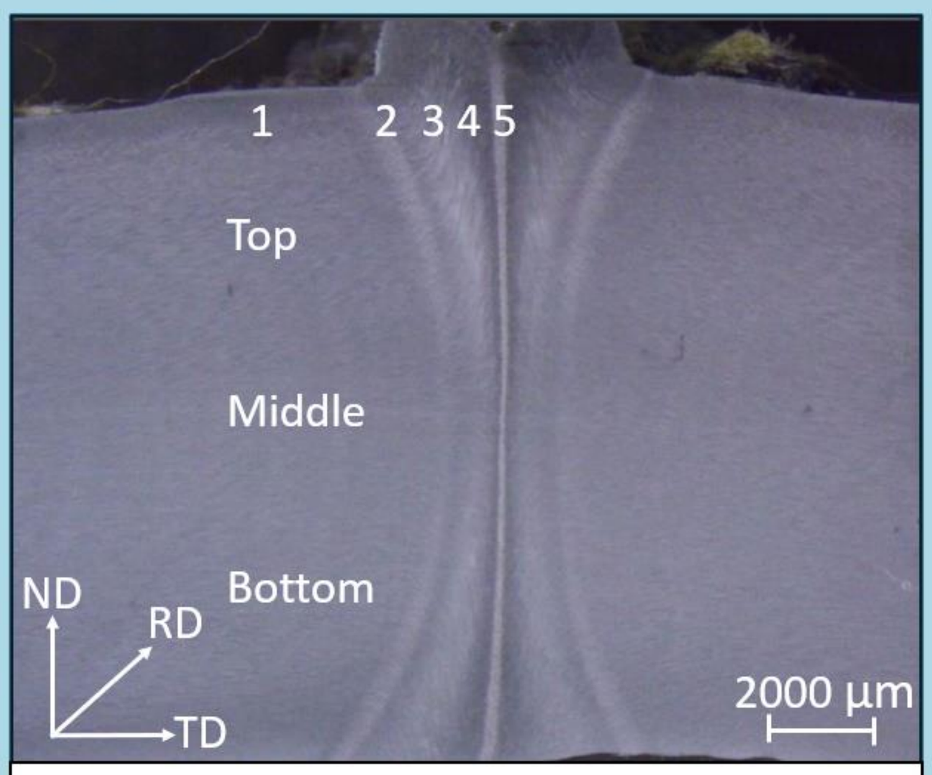


Fig 6. Overview of weld on the 16 mm thick pipe prior to PWHT. Zones associated with the weld: 1–base metal, 2–TMAZ, 3–4 HAZ, and 5–BL [4]

A thermal imaging camera was used to capture temperature distribution during HFI welding, providing validation data for the simulation model. The obtained samples contain distinct microstructural zones, as shown in Figure 6, where Ac1 and Ac3 distances can be measured to estimate local temperatures. These distances help correlate thermal profiles with material transformations. The experimental results will be validated as shown in Figure 5, comparing measured and simulated temperature distributions to assess the model's accuracy in predicting heat-affected zone behaviour.

Future work will integrate mechanical compression into the simulation to assess oxide expulsion as a function of thickness and weld integrity. A new model will simulate the state before edge contact, applying force to analyse material flow during compression. The simulation will track flow lines, aligned with mesh movement, to evaluate oxide expulsion at the bond line. Flow lines in Figure 6, Zone 3, will help validate the model by analysing their angles. Comparing results with experiments will provide insights into compression's effect on material flow and weld quality.

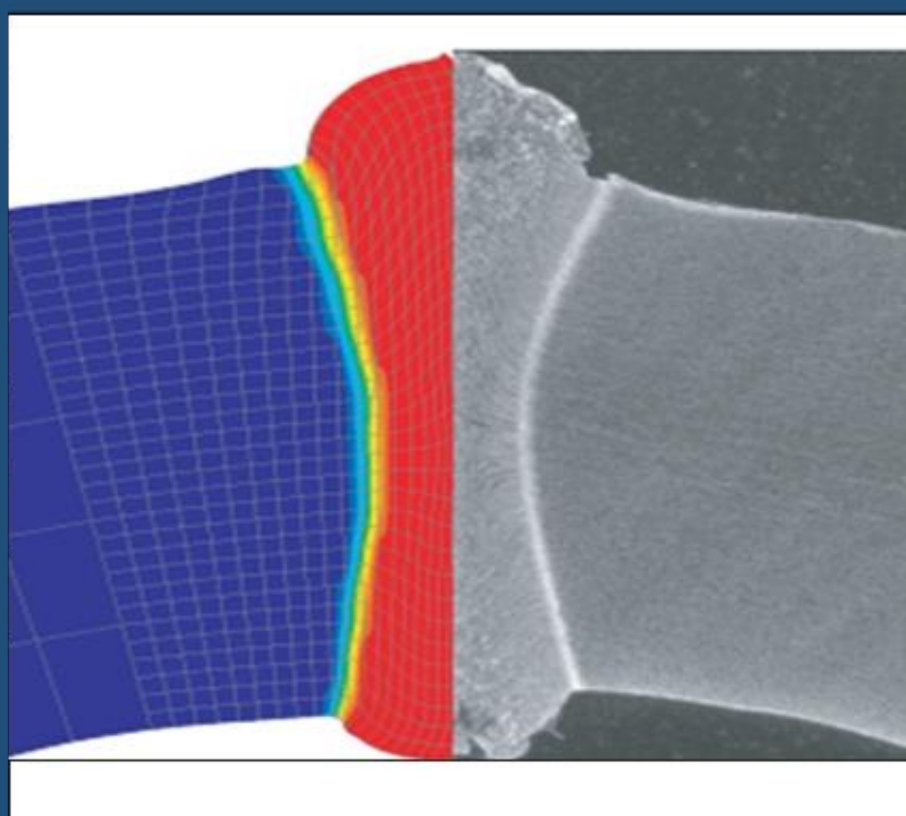


Fig 8. Comparison of the weld bead and heat affected zone [4]

References

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