Temperbead Welding Approach for Groove Welds in Refinery Applications

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Problem Statement

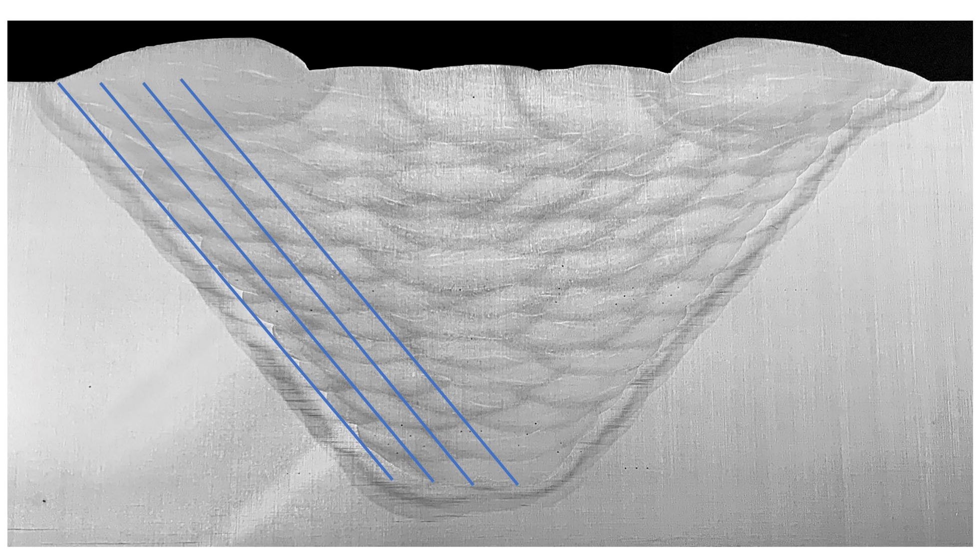
Highly hardenable pressure vessel steels are often employed in refinery applications for their high strength and toughness. When welding these low-alloy carbon steels, high hardness in the heat affected zone (HAZ) can lead to reduced toughness and leave them susceptible to cracking under certain conditions. In groove welds, temperbead welding (TBW) is a process by which multiple tempering layers can be laid along the faces of the grooves to temper the HAZ created by the first weld pass. The goal is to temper all fresh martensite generated in the process and force the formation of fresh martensite to an area of the weld that can be ground out. Developing TBW procedures that optimize tempering response in the HAZ can be incredibly time consuming and expensive. Computational modeling can be employed to reduce the burden in finding optimal TBW parameters.

Objectives

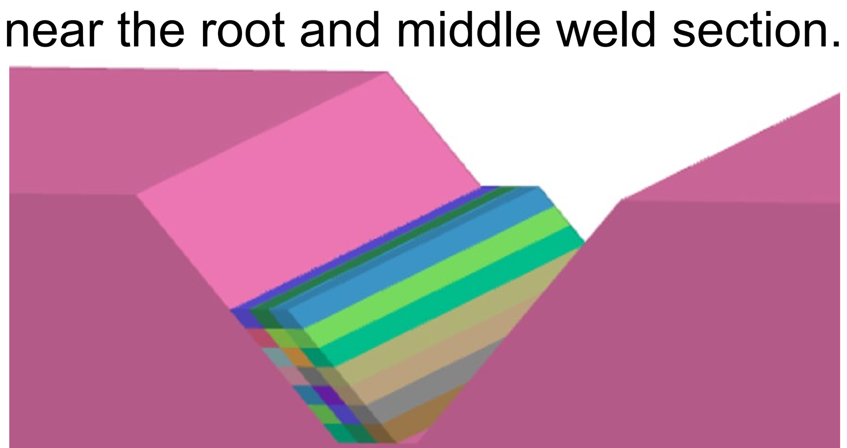
- Develop an FEA model for TBW in groove welding for refinery applications using a heat of SA-508 steel
- Analyze the results of a manually designed simulation based off a physical mockup created for TBW parameter development
- Demonstrate that hardness can be reduced in the HAZ using TBW procedures.
- Advance the TBW DoE module being developed at Ohio State for groove welding applications.

Experimental Methods

A mockup of a groove weld for a refinery application was created using a heat of SA-508 steel in a mechanized GTAW process. The mockup was made in an attempt to find TBW parameters to reduce the HAZ hardness for the application. This mockup was sectioned, machined, polished, and etched to evaluate the bead geometry and map the tempering layers as shown below.

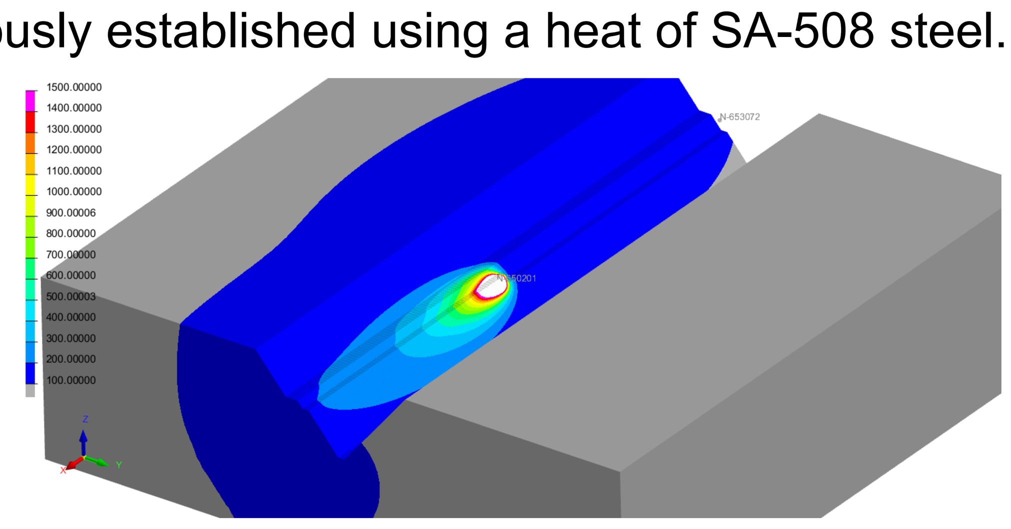


Alongside the physical sample section, the geometry and welding parameter ranges listed in the PQR were used to develop an FEA model to simulate HAZ hardness. The model was constructed and meshed within ESI's Visual Environment. Three tempering layers of seven beads were considered for this simulation to look at HAZ hardness near the root and middle weld section.



TBW CAD Model

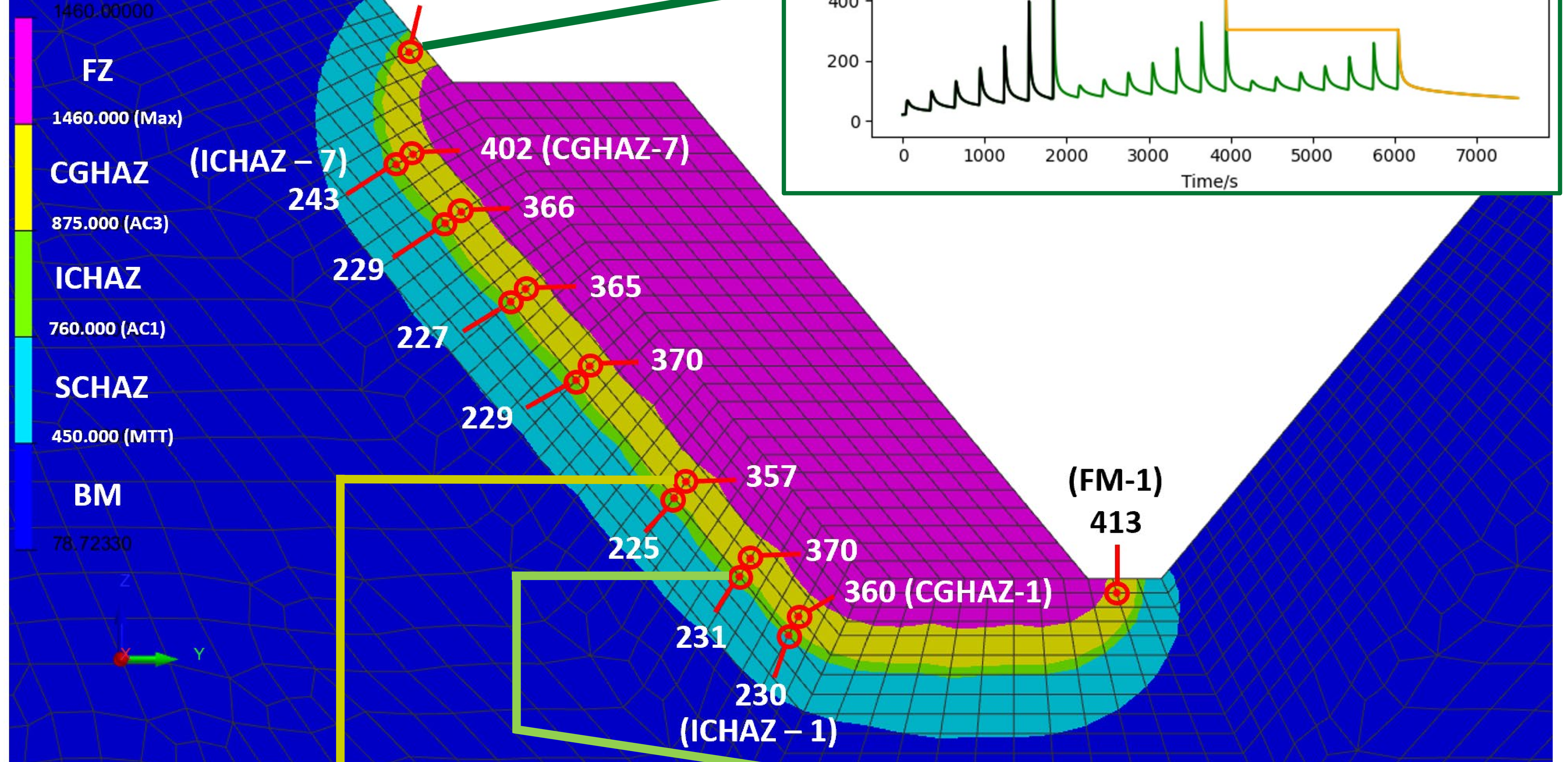
A Goldak equivalent heat source was fitted to the weld beads within the heat input parameters in the PQR. Thermal histories were generated by the welding process simulated using the FEA software SYSWELD. Thermal histories in the HAZ were extracted in several areas and run through tempering response software to calculate GBP (tempering efficiency parameter) and predict hardness. The equations used in this simulation were previously established using a heat of SA-508 steel.

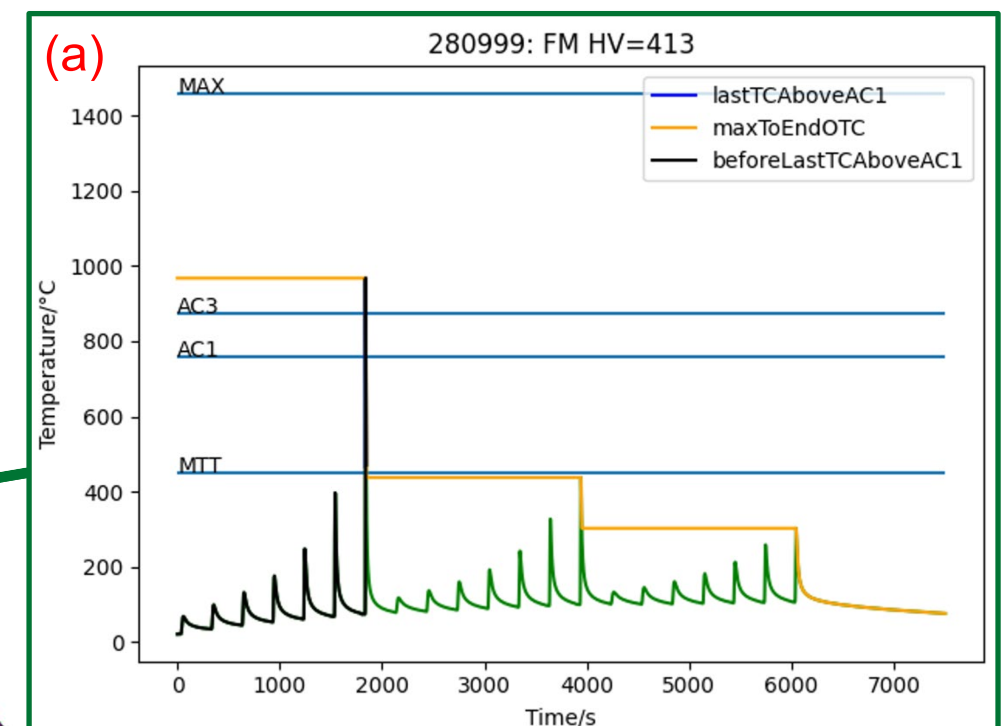


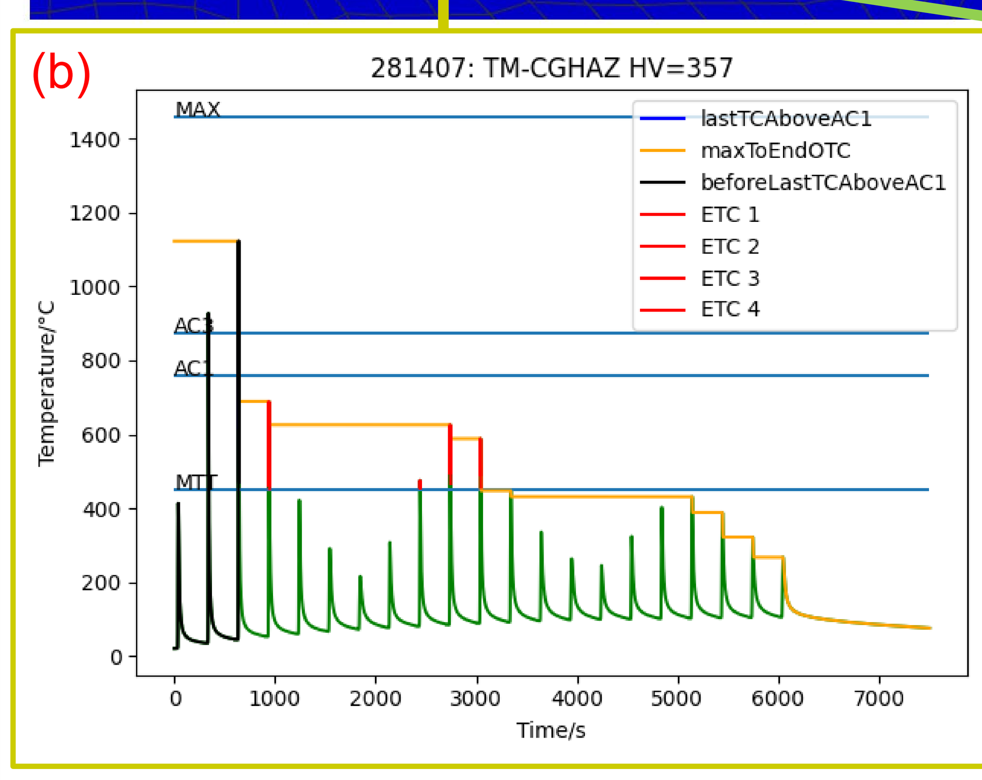
(Heat Source Simulating a Weld Bead in TBW FEA Model)

Results and Discussion

FEA Model Results from TBW Simulation (Three Tempering Layers of Seven Passes Each)







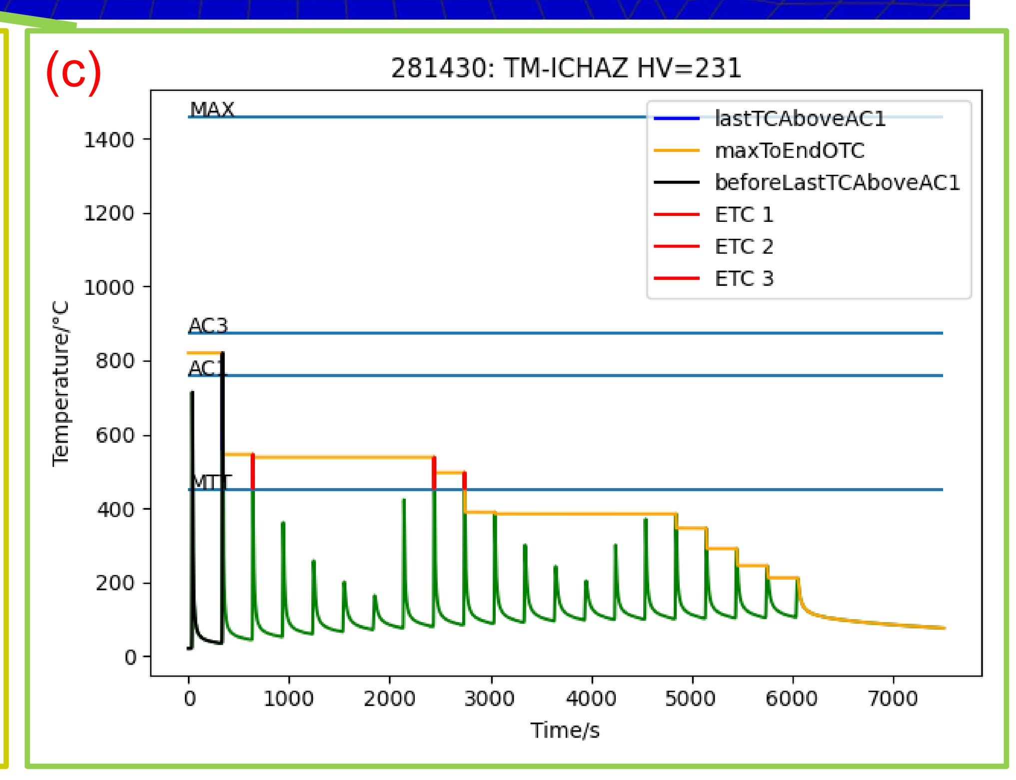


Table 1: Calculated Final Hardness (HV10) and Hardness Drop from Peak in TBW Simulation

	Coarse Grain HAZ (CGHAZ)			Intercritical HAZ (ICHAZ)			Fresh Martensite (FM)
Bead	Hardness (HV10)	Hardness Drop	**Bead**	Hardness (HV10)	Hardness Drop	**Bead**	Hardness (HV10)
1	360	53	**1**	230	60	**1**	413
2	370	43	**2**	231	59	**2**	413
3	357	56	**3**	225	65	**3**	
4	370	43	**4**	229	61	**4**	
5	365	48	**5**	227	63	**5**	
6	366	47	**6**	229	61	**6**	
7	402	11	**7**	243	47	**7**	

- The FEA model is displayed above with results for maximum temperature solved for. Thermal histories were extracted at the nodes circled in red in the coarse grain HAZ (CGHAZ) and intercritical heat HAZ (ICHAZ). and run through hardness predicating equations. These hardness results are displayed on the FEA model and in Table 1.
- The maximum hardness recorded was 413 HV, which was seen in areas where fresh martensite was formed, but no tempering occurred as temperatures did not exceed 450 C, the minimum tempering temperature (MTT). Refer to Figure (a)
- In areas of the CGHAZ where further weld passes allowed for tempering of the fresh martensite to occur, significant hardness drops were observed (Table 1). Areas with more temperature spikes above MTT (but below AC1) had more drop in hardness.
- Tempering was also observed in the ICHAZ leading to hardness drops (Table 1). In areas of the CGHAZ that were intercritically reheated with further tempering passes, the hardness could not be predicted as the software is still under development.
- Figures (b) and (c) are examples of CGHAZ and ICHAZ thermal histories respectively

Conclusions and Future Work

- HAZ hardness drop behavior with tempering passes in TBW for groove welding can be effectively modeled and predicted using SYSWELD
- Further thermomechanical testing is needed to develop tempering response for intercritically heated CGHAZ
- Further work will implement the groove weld geometry into the TBW DoE module being developed at OSU using SYSWELD software. This will allow several welding parameters to be tested to optimize HAZ tempering response for TBW.

Acknowledgments

- Ramon Silva (ESI) for helping with the meshing and Goldak heat source configuration in the FEA model
- Dr. Boian Alexandrov (OSU) for advising on this project.
- Eun Jang (OSU) and Yuxiang Luo (OSU) for tempering response equation and hardness prediction software
- Dr. Jorge Penso (Shell) for sponsoring this project and providing materials for developing the model.