Welding of Haynes 282 to Steel to Enable Modular Rotors for Advanced Ultra Super-Critical Steam Turbines (FE-0031824)

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DOE/FE Spring R&D Project Review Meeting

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Project Details and Objectives

Project information

PI: Sudhir Rajagopalan

Funder: DOE Office of Fossil Energy (FE)

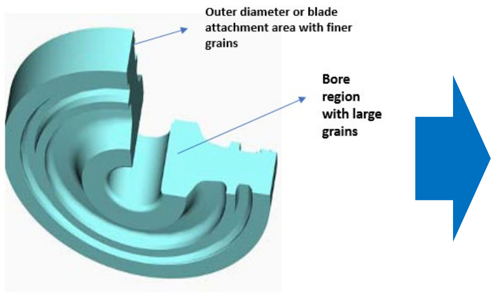
Strategic Partner: Siemens Energy Inc.

Total Project Funding: $1,408,866 (Federal Share $ 1,000,000 / Cost Share 408, 866)

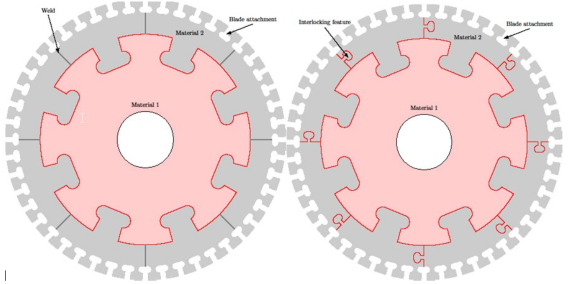
Project Background

- Rotor components in Advanced Ultra Super Critical (AUSC) steam turbines need to withstand temperatures in excess of 650 C; necessitates use of nickel based super alloys.
- Large monolithic superalloy forgings are prohibitively expensive (8-10 times costlier compared to 9-12%Cr steels according to earlier work sponsored by the DOE); Non-uniform properties; very limited supply base
- A modular rotor constructed by joining superalloys and steels ensures - Lower cost by limiting use of superalloys; Uniform and tailored mechanical properties over the cross section; Expands supply base within USA

Project Objectives



Monolithic forging



Modular Construction

1. Develop a welding methodology and viable welding geometries, to successfully join H282 to steel (e.g., 3.5CrMoNiV or 9%Cr steels)
2. Adapt the advanced ultrasonic inspection technique called Synthetic Aperture Focusing Technique (SAFT) to dissimilar weld metals and determine the minimum detectable flaw sizes; and;
3. Develop effective machining techniques to machine such hybrid structures with online tool wear monitoring and effect machine state metrics for optimal results.

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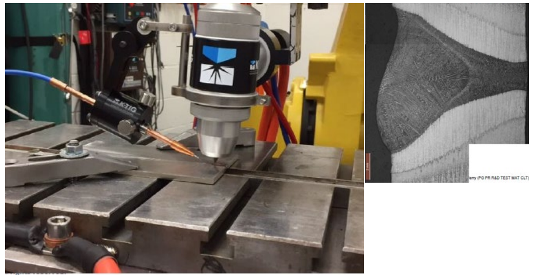
Technical Approach to Advance Technology

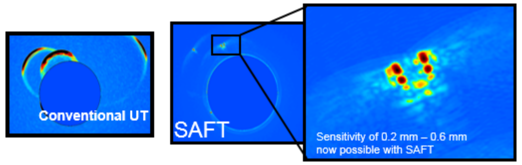
Welding

- Develop optimum weld designs for welding H282 to 3.5NiCrMoV steel using simulation software and down select the top three designs
- Weld H282 plates and / or rounds (up to 3” thickness) to 3.5NiCrMoV steel
- Metallurgical evaluation of welds



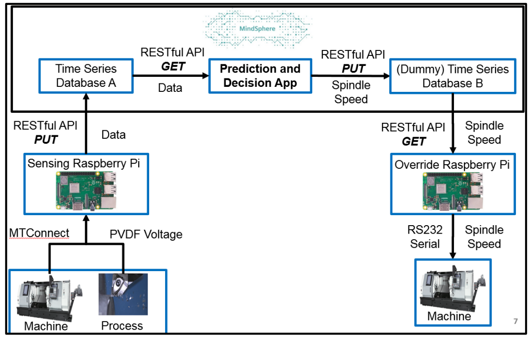
Ultrasonic Inspection

- Successful welds will be ultrasonically examined using Siemens internal advanced NDE techniques
- The resulting data will be post processed using the SAFT related software to improve the flaw detection resolution.



Machining

- Set up and configure the hardware and software infrastructure necessary for online monitoring of tool wear during machining of welded parts
- Plan and generate training data set and initiate machine learning
- Model Validation and Demonstration



Techno Economic Analysis

- R&D plan and project basis for a potential Phase 2. e.g., fabrication and testing of full-scale rotor disc.

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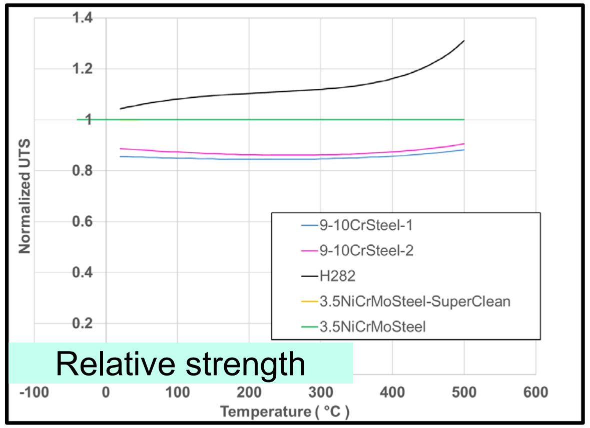
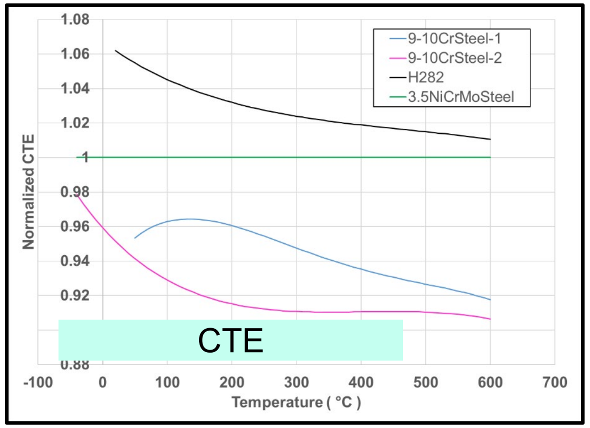
Welding H282 to 3.5NiCrMoV Steel – Materials

Material		3.5NiCrMoV	Haynes282	
Comment		Nominal Composition	2" x 30" x 36" Heat Ananlysis	2" x 30" x 33" Heat Analysis
Chemical Composition				
	Aluminum	0.005	1.56	1.53
	Antimony	0.001		
	Arsenic	0.004		
	Boron		0.005	0.005
	Carbon	0.275	0.061	0.06
	Chromium	1.65	19.54	19.42
	Cobalt		10.13	10.12
	Copper	0.03	<0.01	0.01
	Iron		0.89	0.87
	Manganese	0.02	0.06	0.05
	Molybdenum	0.43	8.49	8.49
	Nickel	3.5	Balance	Balance
	Phosphorus	0.0015	0.003	0.003
	Silicon	0.02	0.07	0.06
	Sulfur	0.002	0.003	<0.002
	Tin	0.0025		
	Titanium		2.19	2.18
	Tungsten		0.07	0.06
	Vanadium	0.115		
	Zirconium		0.011	0.011

H282 Plate in Solutioned condition

3.5NiCrMoV Steel – Hardened & Tempered





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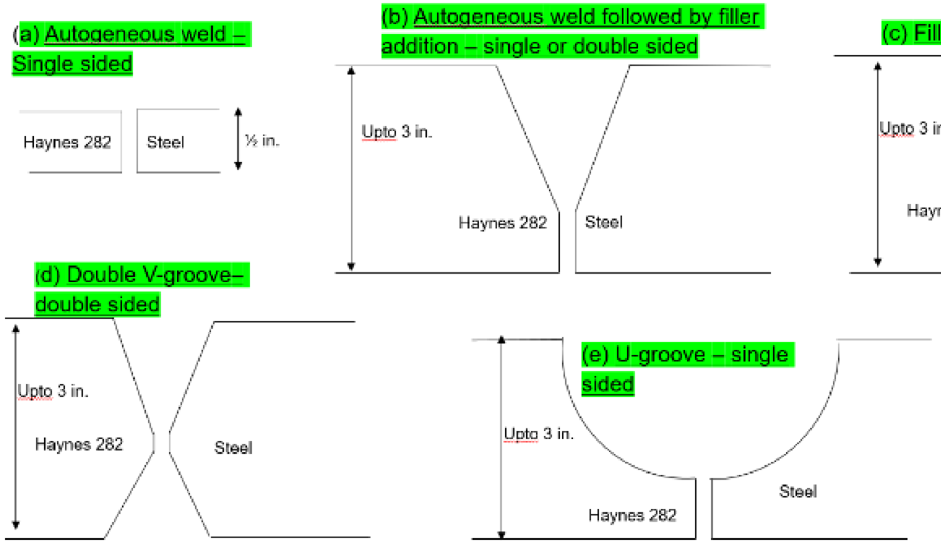
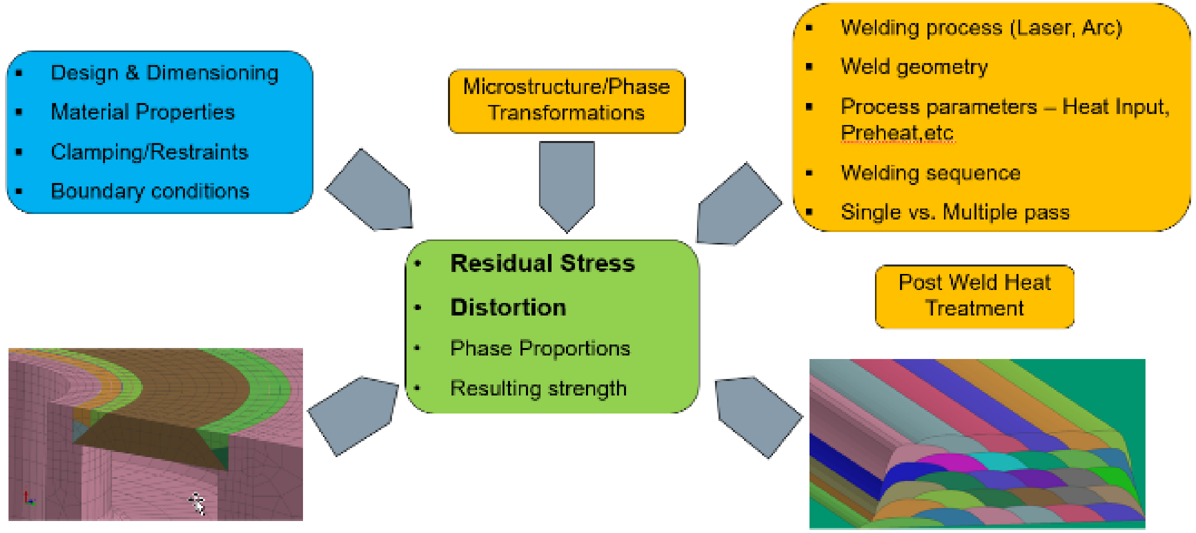
Welding H282 to 3.5NiCrMoV Steel – Weld Simulations



- Welding fillers:
  - ➢Haynes 282 (preferred)
  - ➢Steel filler, etc.



- Weld simulations to down select various weld parameters and weld geometries up to 3" or 75 mm thick plates
- Sysweld and Siemens Star CCM+ were used for the simulations

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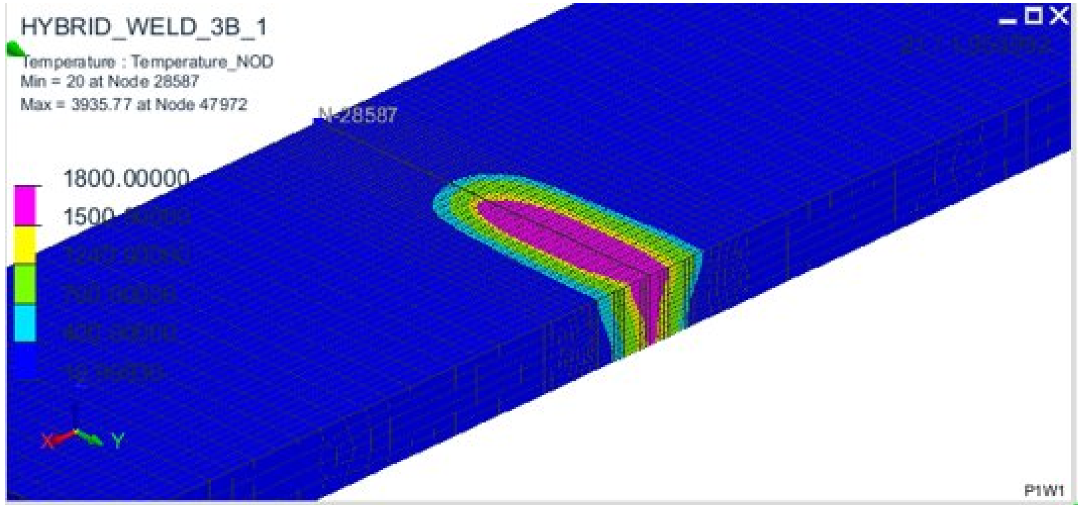
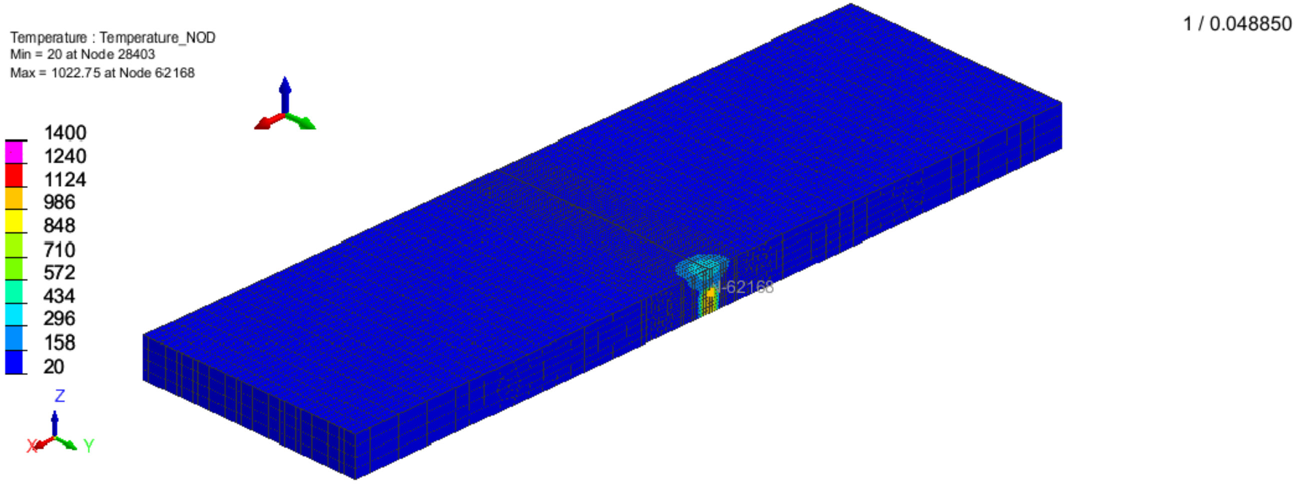
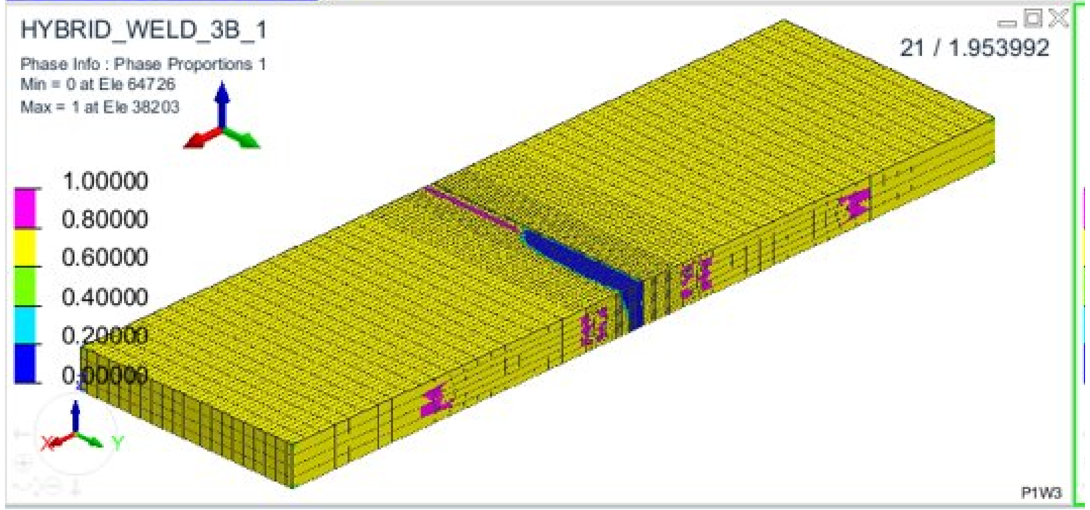
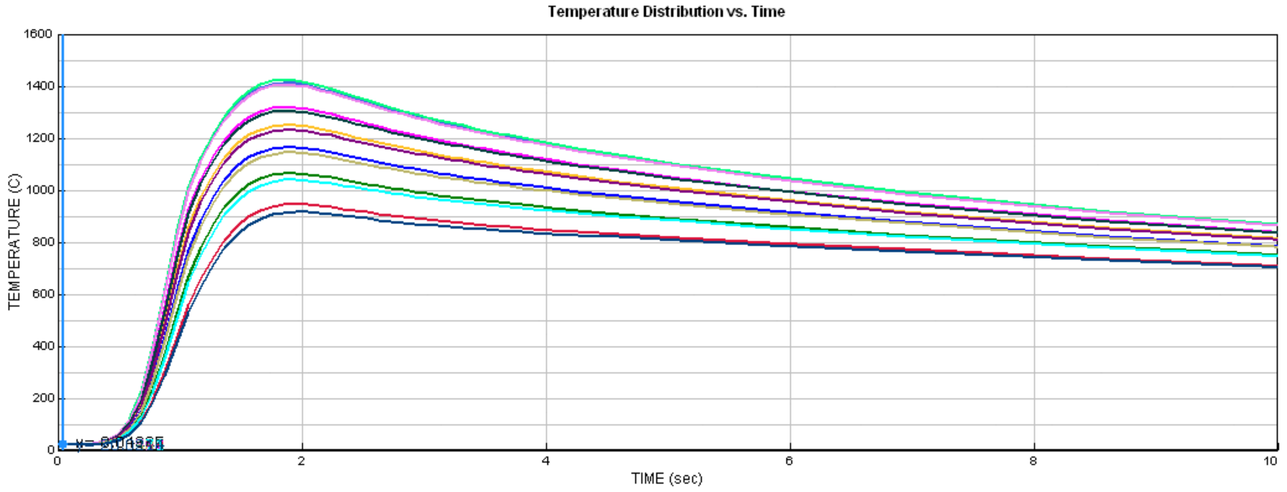
Representative Autogenous Butt joint weld simulations of H282-Steel Snapshot of Temperature and Phase distribution vs welding time









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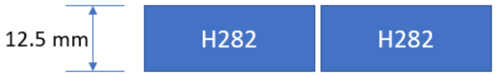
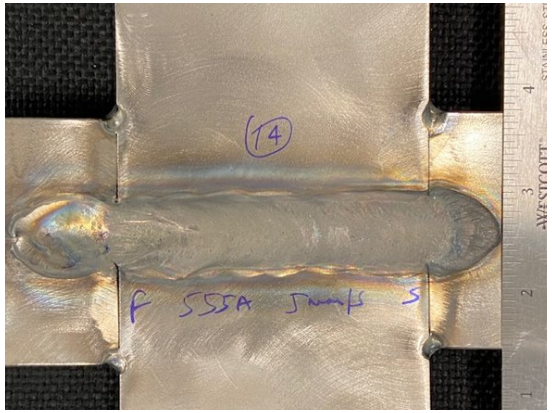
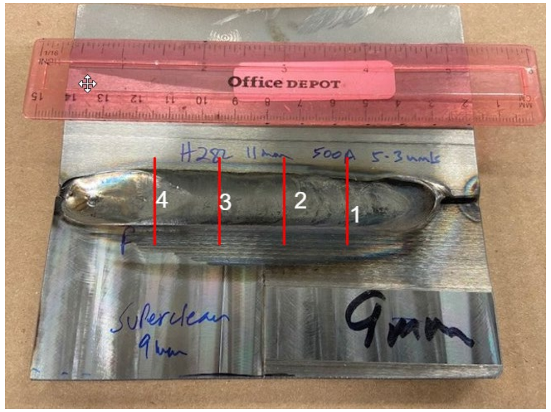
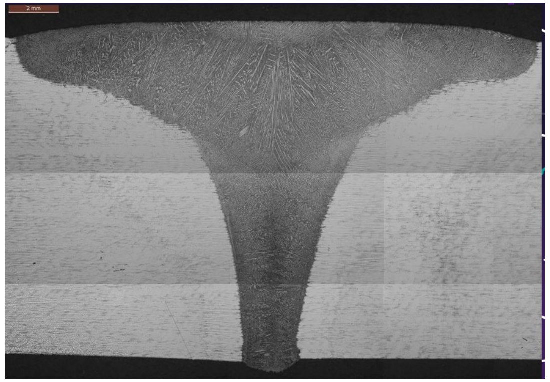
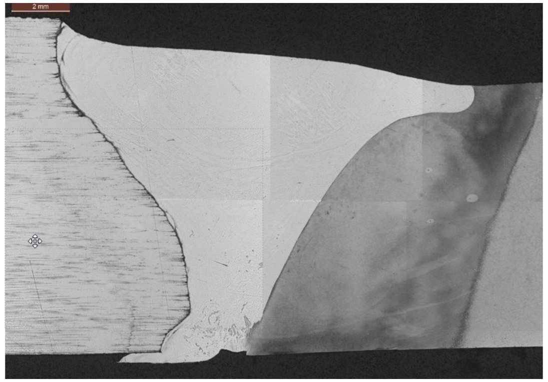
Welding of H282-Steel Results – ½” to 3” plates successfully welded

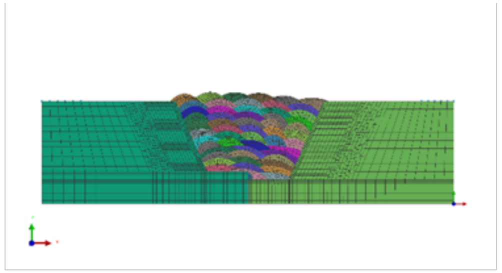


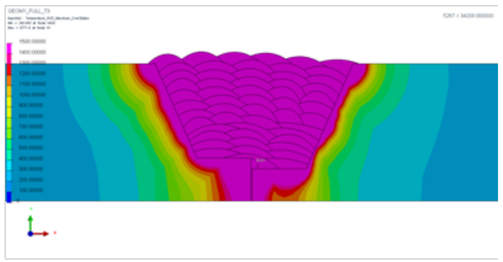


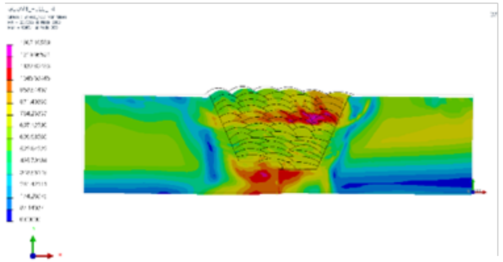


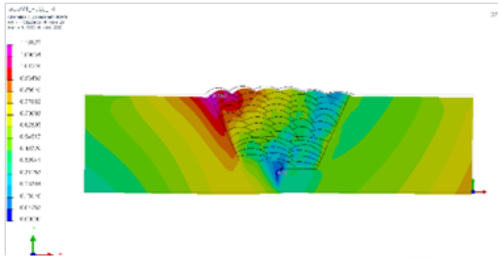


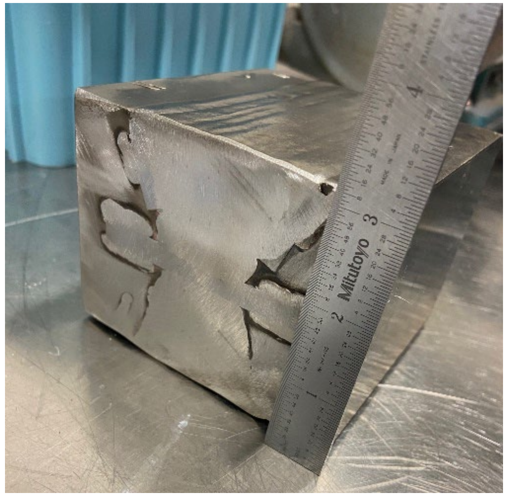


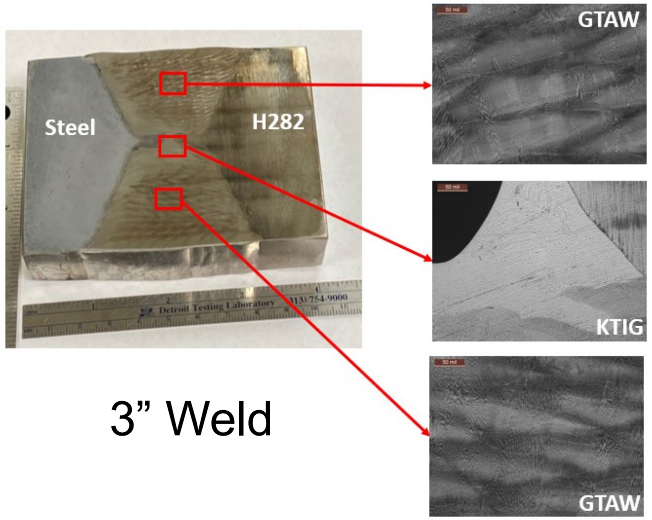












3” Weld

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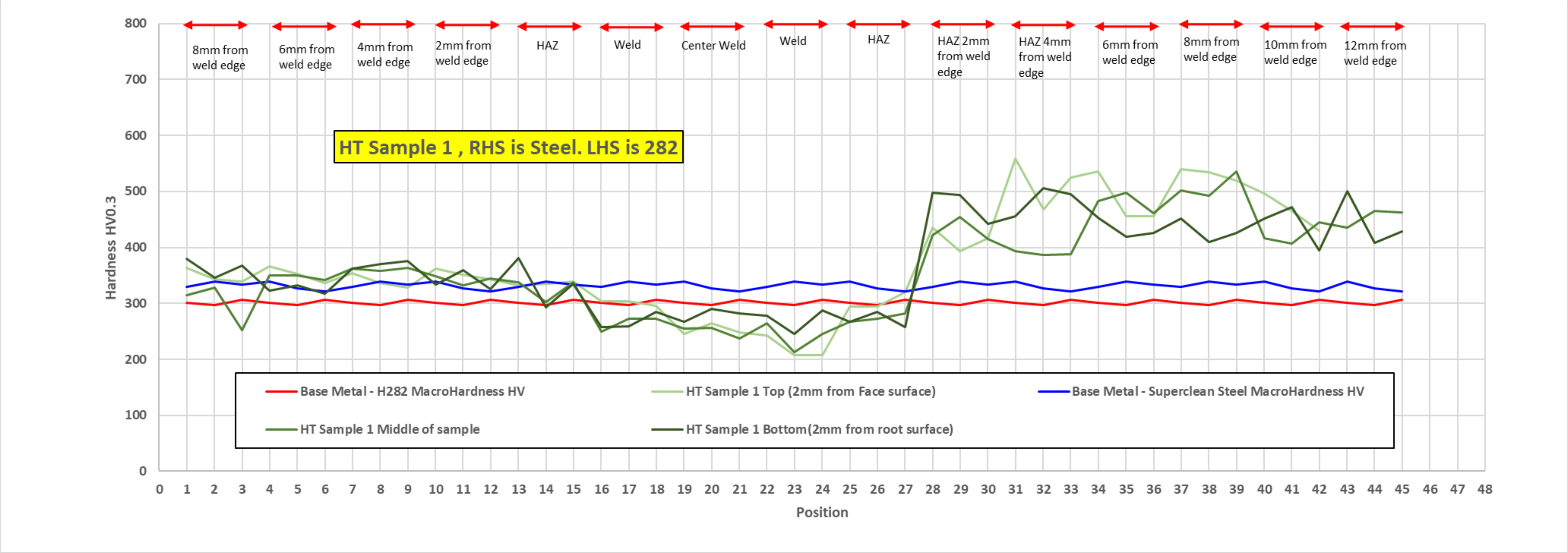
H282-Steel Weld Hardness Profile Across Weld for ½” thick plates



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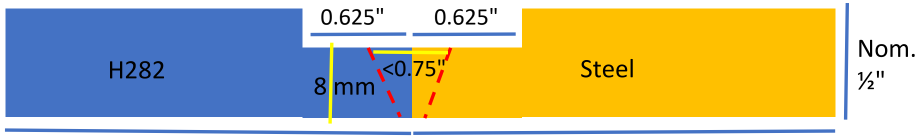
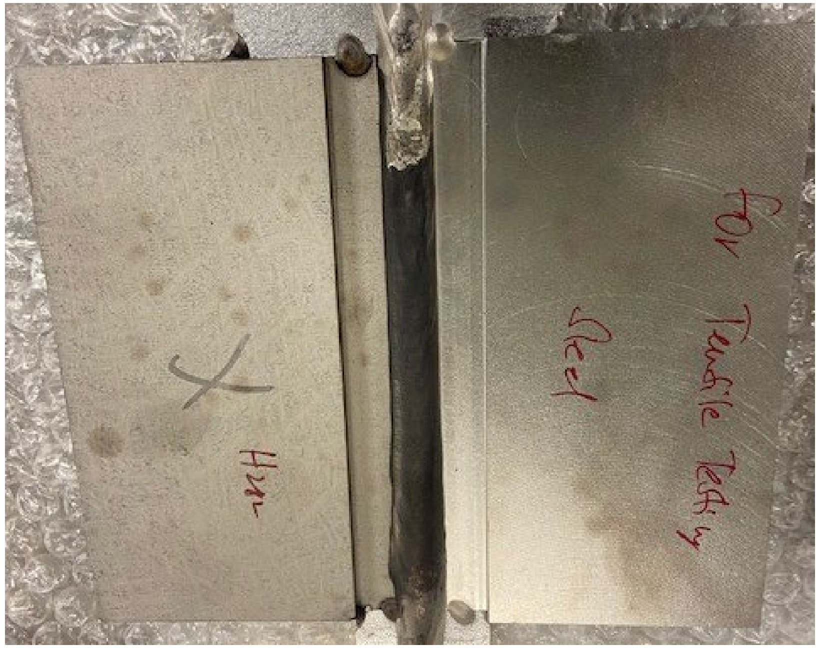
Mechanical Property Testing of H282-Steel Weld Joint per ASME Section IX





Representative tensile weld specimen

- Post weld heat treated according to profile developed
  - 2075F/3h+1850F/2h+1450F/8h+1040F/8h

- Tension and Bend tested at room temperature as per ASME Section IX
  - Tensile specimen- ¼" diameter per geometry (c) per section QW462.1(d)
  - Two transverse face and two transverse root bend specimens per section QW 462.3 (a)

Test #	Test Temperature (°C)	0.2% Yield Stress (MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)	Reduction of Area (%)	Failure Location
1	21	454	757	5.4	21.8	Weld
2	21	481	767	6.6	30.6	Weld

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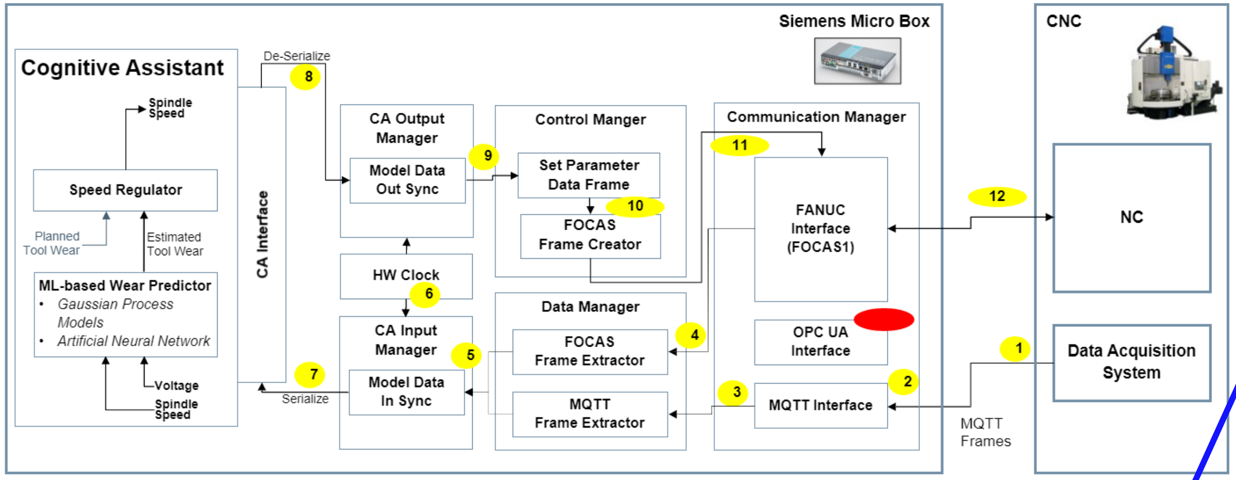
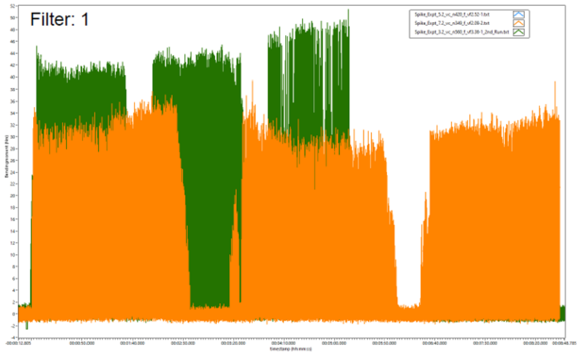
Autonomous Machining Control of H282-Steel weld Samples – Cognitive Assistant Architecture and Initial Trials



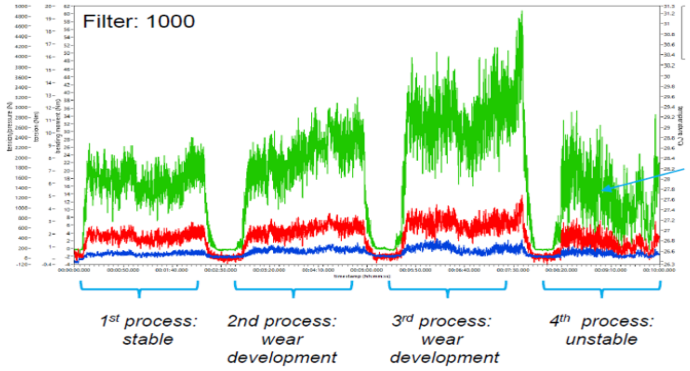
Cognitive Assistant Architecture

Initial machining trials showing the different bending moment experienced by the machine tool when machining H282 at different spindle speeds. A higher wear rate of the cutting tool is observed by observing the machining metrics



Material	Exp No	Axial Depth Cut (a_p)	Radial Depth of Cut or Step Over (a_e)	Spindle Speed, RPM (n)	Feed per Minute (V_f)	# of Cutting Tool	# of Cutting Edges	SFM	Remarks
Soft Material	3.2	0.020"	0.600"	560	3.36	1	2	140	One insert tip ran two times on same
Soft Material	7.2	0.020"	0.600"	349	2.09	1	2	90	

Tension, torsion and bending forces experience by the cutting tool during machining of steel.



Material	Exp No	Axial Depth Cut (a_p)	Radial Depth of Cut or Step Over (a_e)	Spindle Speed, RPM (n)	Feed per Minute (V_f)	# of Cutting Tool	# of Cutting Edges	SFM
Hard Material	6.1	0.020"	0.600"	387	2.32	1	2	100

The cognitive assistant will autonomously alter machining parameters by tracking the cutting tool forces as the tool transits from H282 to steel

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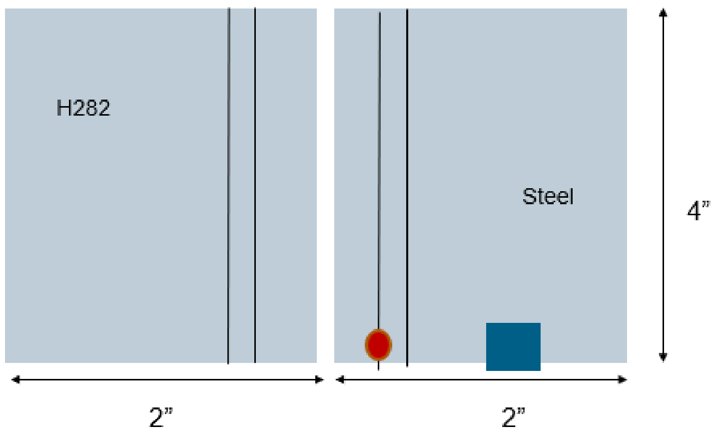
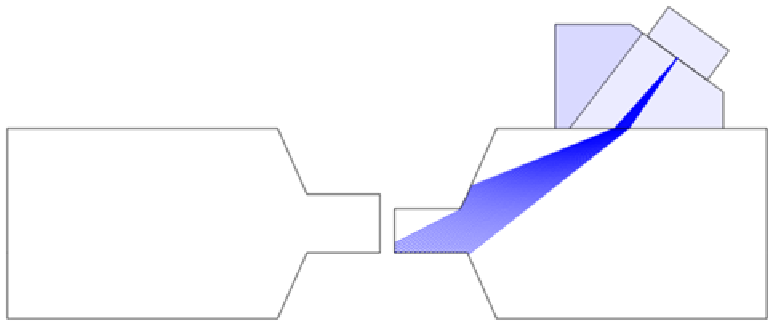
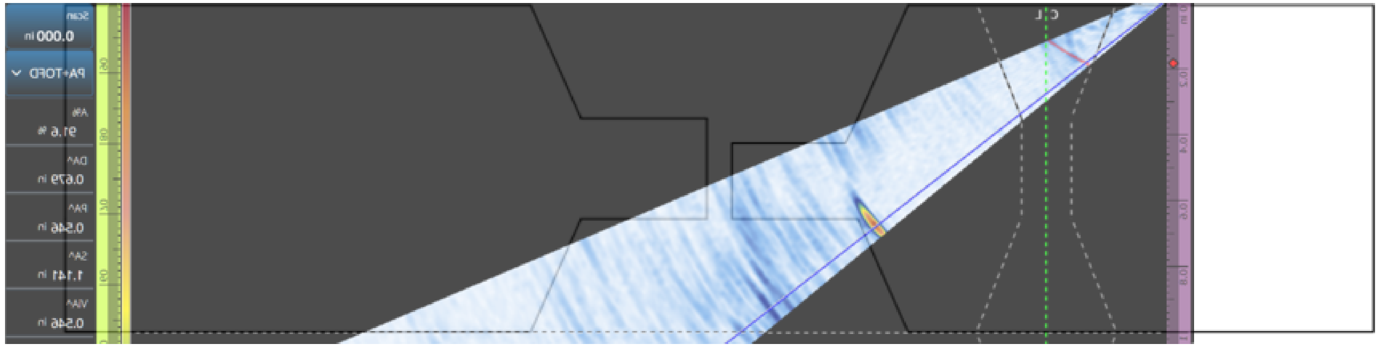
NDE of Weld Joints using Phased Array UT (PAUT) and Total Focusing Method (TFM)







INDICATION #1, Start Location:

Depth: 0.679" = 17.24mm

Baseline trials are in progress to eventually improve flaw detection in dissimilar welds

Next Steps

- Complete NDE trials and demonstrate flaw detection improvement when inspecting H282-Steel welded joints
- Complete machining trials and autonomously change machining parameters during machining of H282-Steel weld joint using cognitive assistant and to reduced tool wear.
- Technoeconomic Analysis

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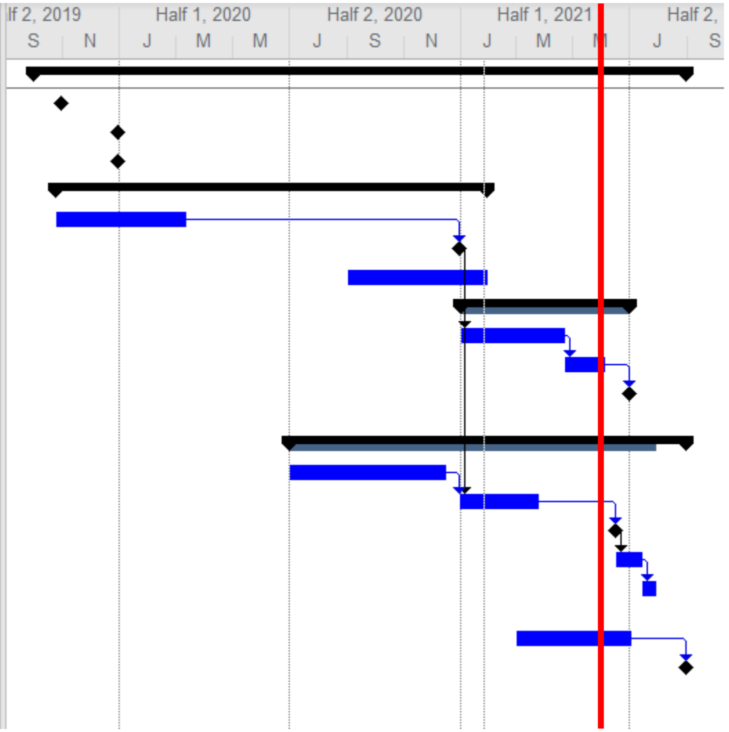
Schedule

Milestone	Deliverable Name	Task Name	Start	Duration	Finish	Resource Names
No		**Task 1.0 Project management and planning**	**Tue 10/1/19**	**500 days**	**Mon 8/30/21**	
Yes		Revised PMP plan. Update due 30 days after award.	Tue 10/1/19	30 days	Wed 10/30/19	
Yes		Data Management Plan	Tue 10/1/19	90 days	Sun 12/29/19	
Yes		Workforce Readiness Plan	Tue 10/1/19	90 days	Sun 12/29/19	
No		**Task 2.0 Welding of H282 to rotor steels**	**Thu 10/24/19**	**332 days**	**Fri 1/29/21**	
No		Task 2.1 Develop weld designs and weld geometries	Thu 10/24/19	5 mons	Wed 3/11/20	
Yes		Task 2.2 Weld H282 plates and rounds	Wed 7/1/20	6.55 mons	Wed 12/30/20	
No		Tas 2.3 Metallurgical Evaluation of welds	Tue 9/1/20	5.45 mons	Fri 1/29/21	
No		**Task 3.0 – Ultrasonic Inspection of H282 - Steel welds**	**Fri 1/1/21**	**129 days**	**Wed 6/30/21**	
No		Task 3.1 Ultrasonic examination of weld using SAFT	Fri 1/1/21	4 mons	Thu 4/22/21	
No		Task 3.2 Software Post processing of NDE data	Fri 4/23/21	1.5 mons	Thu 6/3/21	
Yes		Task 3.3 Report on improvement in Flaw detection resolution using SAFT Technique	Fri 6/4/21	19 days	Wed 6/30/21	
No		**Task 4.0 Machining of H282 - Steel welds**	**Wed 7/1/20**	**304 days**	**Mon 8/30/21**	
No		Task 4.1 Setup and configure the hardware and software	Wed 7/1/20	6 mons	Tue 12/15/20	
No		Task 4.2 Plan and generate training data set.	Thu 12/31/20	3 mons	Wed 3/24/21	
Yes		Task 4.3 Machine learning using training data sets	Thu 3/25/21	3 mons	Wed 6/16/21	
No		Task 4.4 Model Validation and demonstration	Thu 6/17/21	1 mon	Wed 7/14/21	
No		Task 4.5 Report on software algorithm with ability to actively monitor tool wear and alter machine state to reduce tool wear.	Thu 7/15/21	10 days	Wed 7/28/21	
No		**Task 5.0 Phase 2 Planning and Technoeconomic Analysis**	Tue 3/2/21	88 days	Thu 7/1/21	
Yes		**Technoeconomic analysis of welding Haynes 282 to steel for modular rotors for AUSC steam Turbines**	Tue 7/6/21	40 days	Mon 8/30/21	



Progress as of May 2021. The project is on schedule.

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Contact

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