INL/CON-22-67329-Revision-0

GCR: Development of Improved Alloy 800H Weldment

June 2022

Changing the World's Energy Future

Tate Patterson, Ryann Elizabeth Bass

Idaho National Laboratory

INL/CON-22-67329-Revision-0

GCR: Development of Improved Alloy 800H Weldment

Tate Patterson, Ryann Elizabeth Bass

June 2022

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

GCR: Development of Improved Alloy 800H Weldment

Advanced Reactor Technologies Program

Advanced Materials R&D Program Review

June 7 and 8, 2022

Tate Patterson

Idaho National Laboratory

Contributors

- Ryann Bass, Tom Lillo, Mike McMurtrey, Tate Patterson, and Sam Sham (INL)
- Richard Wright (Structural Alloys, LLC)

Fiscal Year 2022 (FY-22) Work Packages

- AT-22IN060405, Long-Term VHTR Material Qualification - INL

Outline

- Motivation
- Alloy 617 Filler Metal
- UTP A 2133 Mn Filler Metal

U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Motivation

Background

The expected minimum stress-to-rupture of the weld is a function of the stress rupture factor (R) and the expected minimum stress-to-rupture (S_r) of the base metal.

where,

$$R = \frac{\text{average rupture strength of the filler metal}}{\text{average rupture strength of the base metal}}$$

Motivation

Table HBB-I-14.10C-1
Stress Rupture Factors for Alloy 800H Welded With SFA-5.11 ENiCrFe-2 (INCO A)

U.S. Customary Units

Temp., °F	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
850–900	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
950	1.00	1.00	1.00	1.00	0.98	0.95	0.92	0.90	0.86	0.83
1,000	1.00	1.00	1.00	1.00	0.98	0.94	0.90	0.86	0.82	0.78
1,050	1.00	1.00	1.00	1.00	0.98	0.94	0.89	0.85	0.81	0.76
1,100	1.00	1.00	1.00	1.00	0.98	0.94	0.89	0.84	0.79	0.75
1,150	1.00	1.00	1.00	1.00	0.98	0.93	0.88	0.83	0.77	0.72
1,200	1.00	1.00	1.00	1.00	0.98	0.93	0.87	0.81	0.75	0.70
1,250	1.00	1.00	1.00	1.00	0.98	0.92	0.85	0.80	0.73	0.68
1,300	1.00	1.00	1.00	1.00	0.97	0.91	0.84	0.77	0.71	0.65
1,350	1.00	1.00	1.00	1.00	0.96	0.89	0.82	0.75	0.68	0.62
1,400	1.00	1.00	1.00	1.00	0.95	0.87	0.80	0.73	0.65	0.59

SI Units

Temp., °C	10 h	30 h	100 h	300 h	1 000 h	3 000 h	10 000 h	30 000 h	100 000 h	300 000 h
450–475	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	0.99	0.97	0.95	0.94	0.91	0.89
525	1.00	1.00	1.00	1.00	0.98	0.94	0.91	0.88	0.84	0.80
550	1.00	1.00	1.00	1.00	0.98	0.94	0.90	0.86	0.82	0.77
575	1.00	1.00	1.00	1.00	0.98	0.94	0.89	0.85	0.80	0.76
600	1.00	1.00	1.00	1.00	0.98	0.94	0.89	0.84	0.79	0.74
625	1.00	1.00	1.00	1.00	0.98	0.93	0.88	0.83	0.77	0.72
650	1.00	1.00	1.00	1.00	0.98	0.93	0.87	0.81	0.75	0.70
675	1.00	1.00	1.00	1.00	0.98	0.92	0.85	0.80	0.73	0.68
700	1.00	1.00	1.00	1.00	0.97	0.91	0.84	0.77	0.71	0.65
725	1.00	1.00	1.00	1.00	0.96	0.90	0.83	0.76	0.69	0.63
750	1.00	1.00	1.00	1.00	0.95	0.88	0.81	0.74	0.66	0.60

Table HBB-I-14.10C-2
Stress Rupture Factors for Alloy 800H Welded With SFA-5.14 ERNiCr-3 (INCO 82)

U.S. Customary Units

Temp., °F	10 hr	30 hr	100 hr	300 hr	1,000 hr	3,000 hr	10,000 hr	30,000 hr	100,000 hr	300,000 hr
850–900	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
950	0.89	0.90	0.90	0.90	0.89	0.89	0.88	0.87	0.86	0.86
1,000	0.85	0.86	0.86	0.86	0.85	0.85	0.84	0.84	0.82	0.81
1,050	0.88	0.88	0.88	0.88	0.87	0.86	0.85	0.84	0.83	0.81
1,100	0.91	0.91	0.91	0.90	0.89	0.88	0.87	0.85	0.83	0.81
1,150	0.94	0.93	0.93	0.92	0.90	0.89	0.87	0.85	0.83	0.81
1,200	0.96	0.96	0.95	0.93	0.92	0.90	0.88	0.86	0.83	0.81
1,250	0.99	0.98	0.96	0.95	0.93	0.91	0.88	0.85	0.82	0.80
1,300	1.00	1.00	0.98	0.96	0.93	0.91	0.88	0.85	0.82	0.78
1,350	1.00	1.00	0.99	0.96	0.94	0.91	0.87	0.84	0.77	0.68
1,400	1.00	1.00	1.00	0.97	0.94	0.89	0.79	0.71	0.62	0.54

SI Units

Temp., °C	10 h	30 h	100 h	300 h	1 000 h	3 000 h	10 ,000 h	30 000 h	100 000 h	300 000 h
450–475	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	0.93	0.94	0.94	0.94	0.93	0.93	0.92	0.92	0.91	0.91
525	0.87	0.88	0.88	0.88	0.87	0.87	0.86	0.85	0.84	0.83
550	0.86	0.87	0.87	0.87	0.86	0.85	0.84	0.84	0.82	0.81
575	0.89	0.89	0.89	0.89	0.88	0.88	0.86	0.84	0.83	0.81
600	0.92	0.92	0.92	0.91	0.89	0.88	0.87	0.85	0.83	0.81
625	0.94	0.93	0.93	0.92	0.90	0.89	0.87	0.85	0.83	0.81
650	0.96	0.96	0.95	0.93	0.92	0.90	0.88	0.86	0.83	0.81
675	0.99	0.98	0.96	0.95	0.93	0.91	0.88	0.85	0.82	0.80
700	1.00	1.00	0.98	0.96	0.93	0.91	0.88	0.85	0.82	0.78
725	1.00	1.00	0.99	0.96	0.94	0.91	0.87	0.84	0.78	0.71
750	1.00	1.00	1.00	0.97	0.94	0.90	0.82	0.76	0.67	0.59

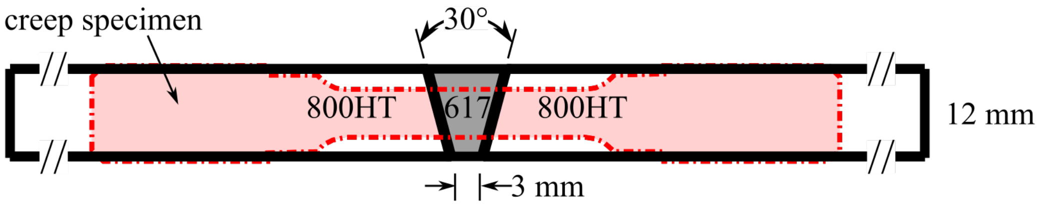
Purpose

An alterative filler metal is desired to improve the creep-rupture strengths of Alloy 800H weldments for the qualified temperatures and services lives.

U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Alloy 617 Filler Metal

Experimental Methodology



Chemistry of the Alloy 800HT base metal and Alloy 800H chemistry requirements specified in Division 5 in weight percent

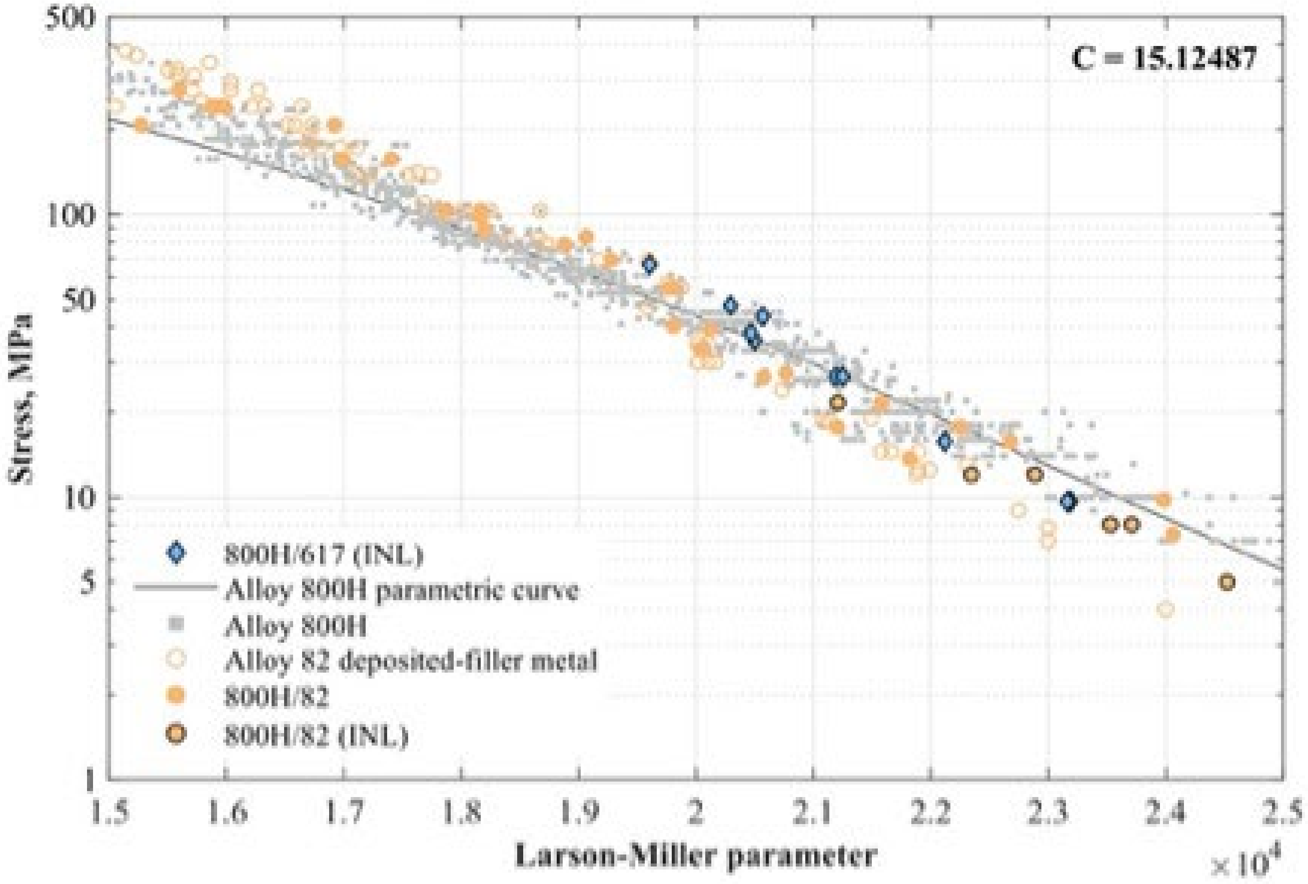
		Ni	Cr	Fe	Mn	C	Cu	Si	S	Al	Ti	Mo	Co
800HT base metal		30.45	19.30	47.05	1.31	0.063	0.21	0.37	0.001	0.43	0.45	0.21	0.11
Division 5 requirements	minimum	30.0	19.0	39.5	-	0.05	-	-	-	0.15*	0.15*	-	-
	maximum	35.0	23.0	-	1.5	0.10	0.75	1.0	0.015	0.60*	0.60*	-	-

* Al + Ti ≥ 0.50%

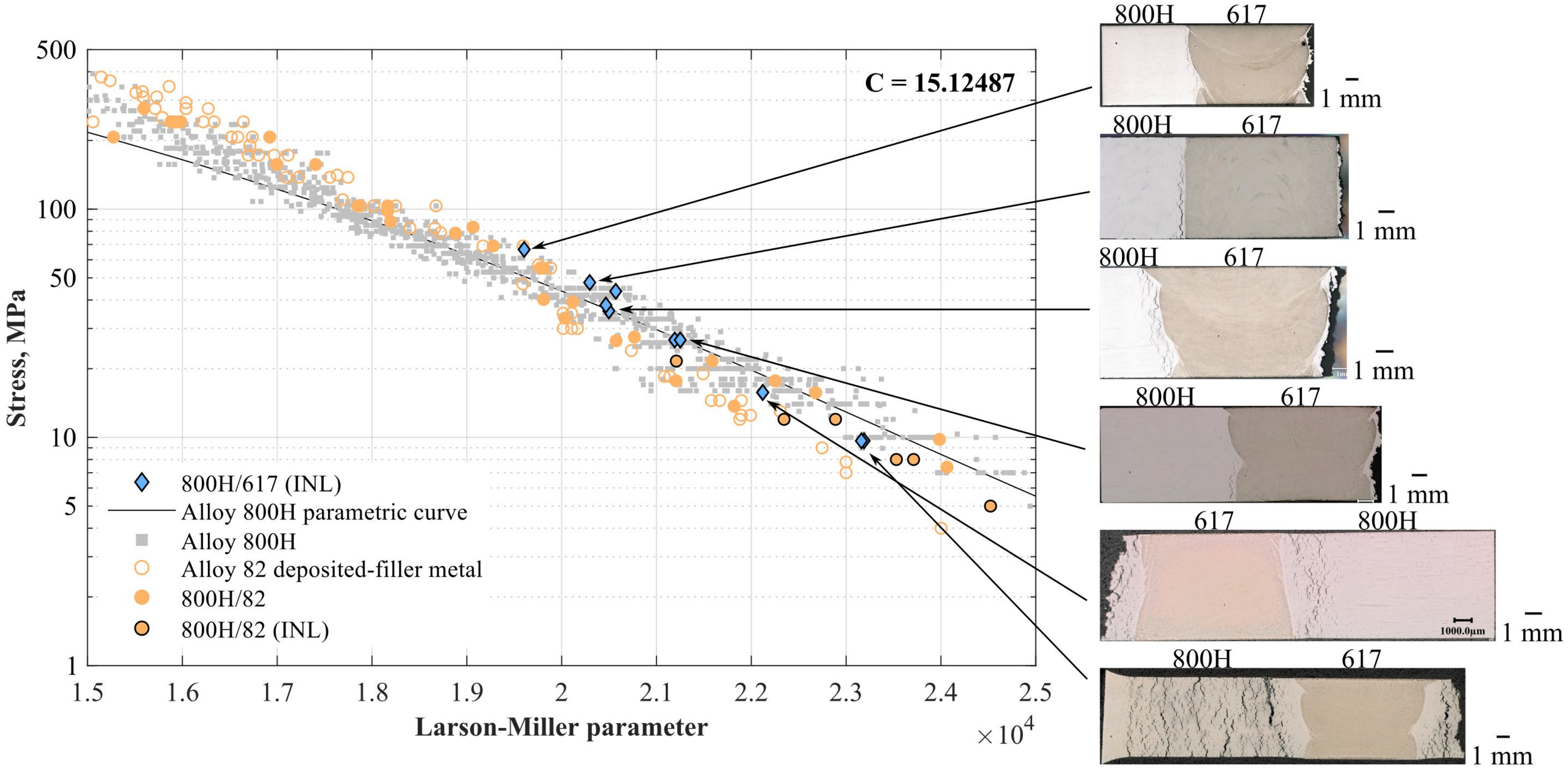
Chemistry of the Alloy 617 filler metal in weight percent

Ni	Cr	Co	Mo	Fe	Mn	Al	C	Cu	Si	S	Ti
53.91	22.41	11.49	8.98	1.37	0.11	1.10	0.89	0.04	0.04	0.001	0.34

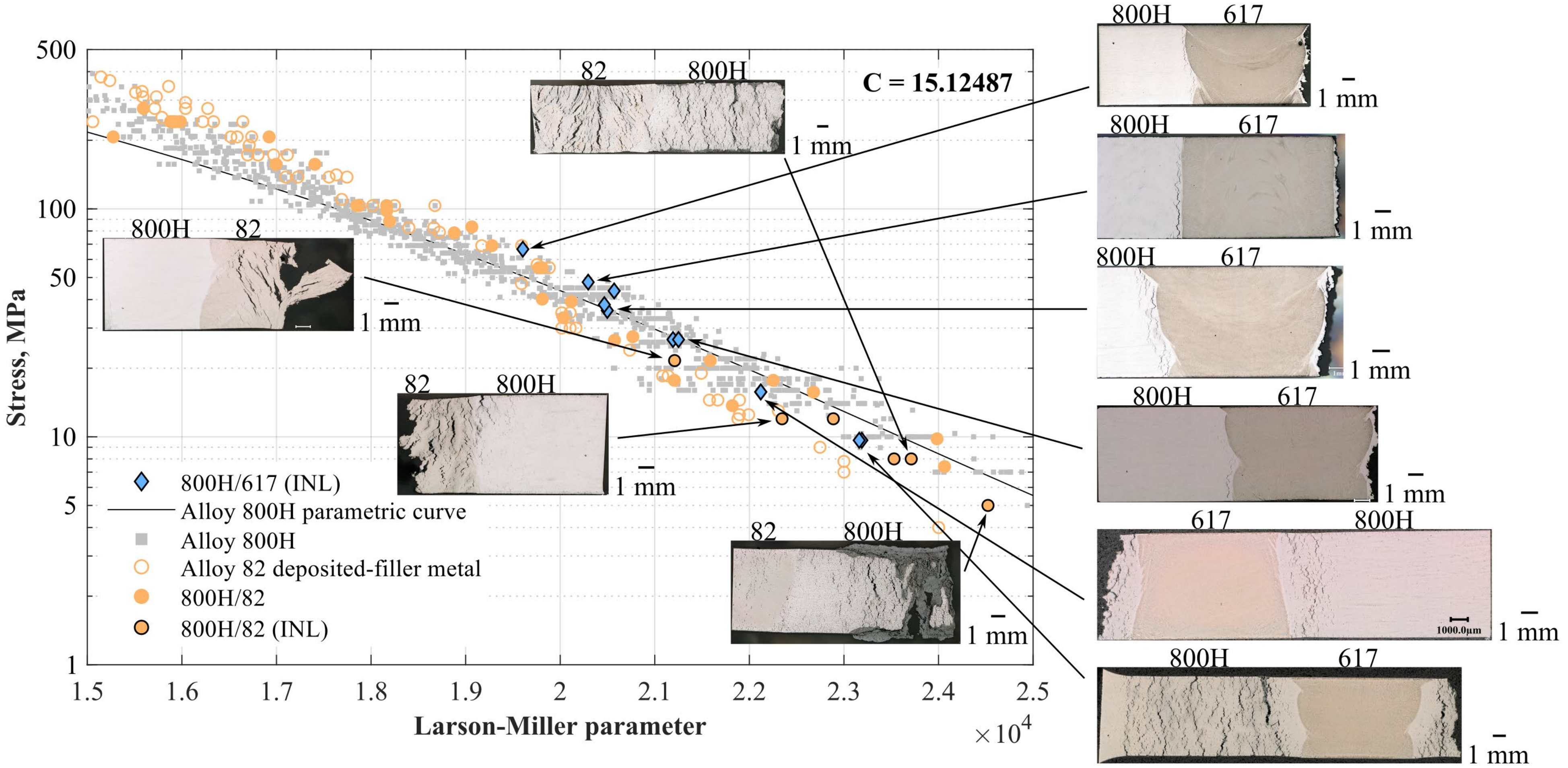
Results and Discussion



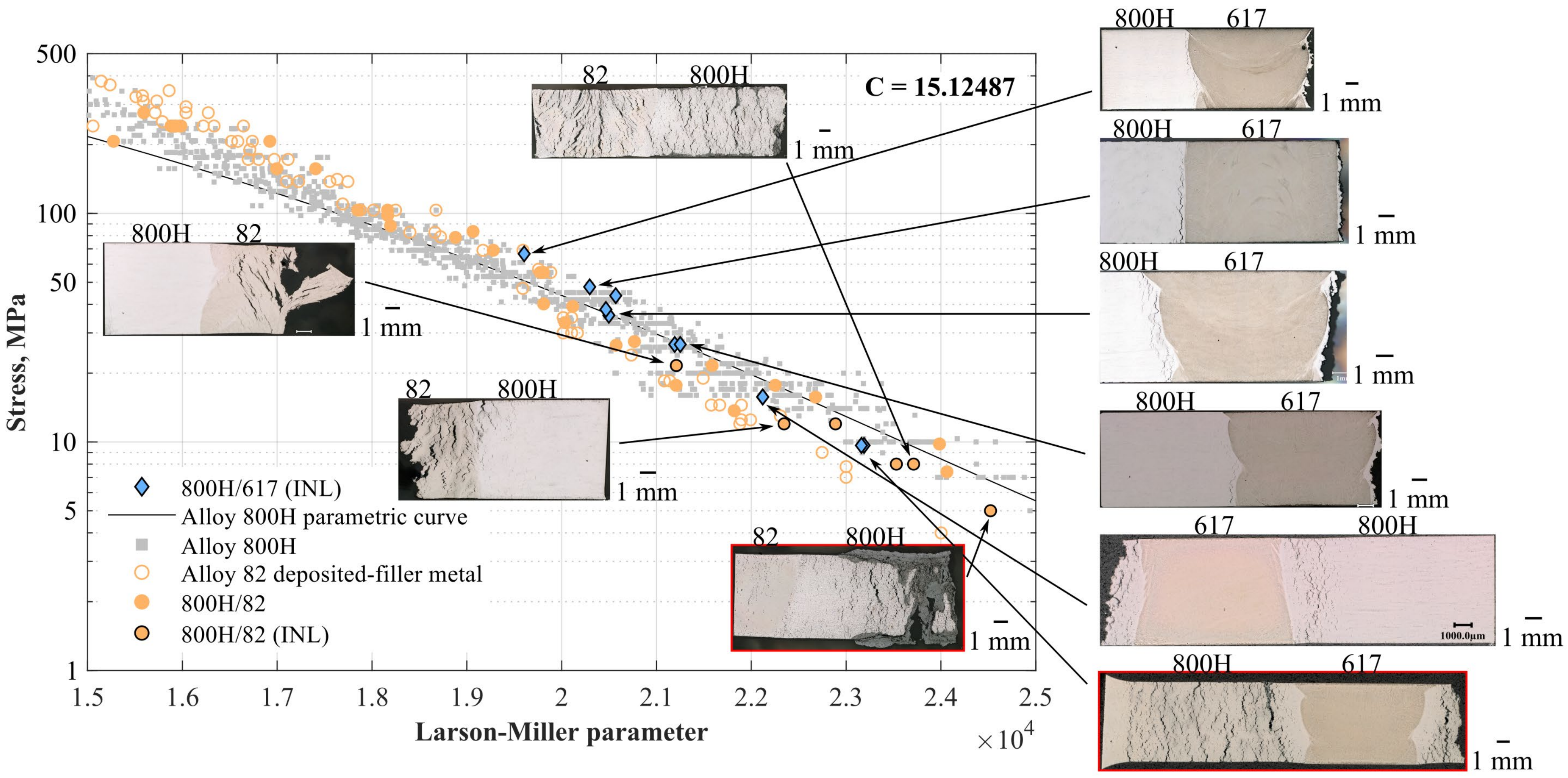
Results and Discussion



Results and Discussion



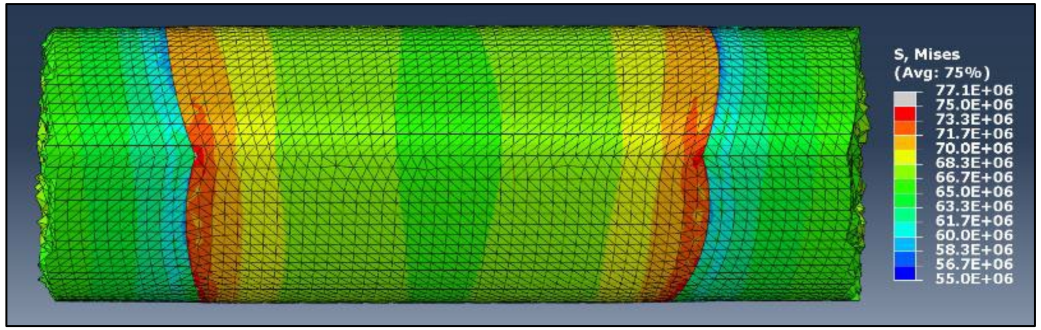
Results and Discussion



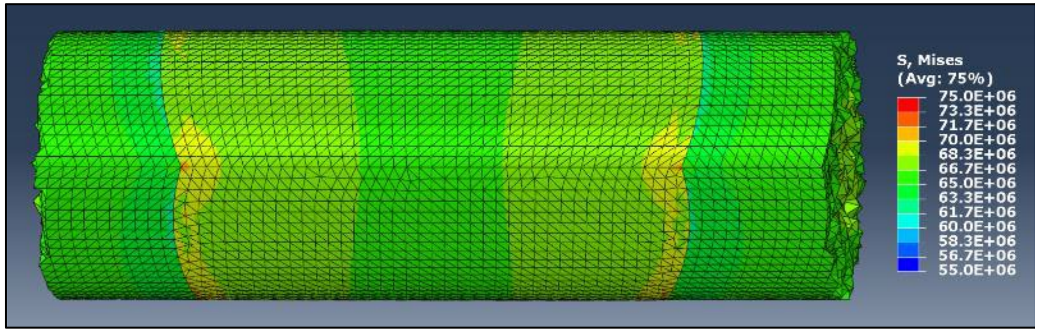
Cross-weld Creep – Stress Models

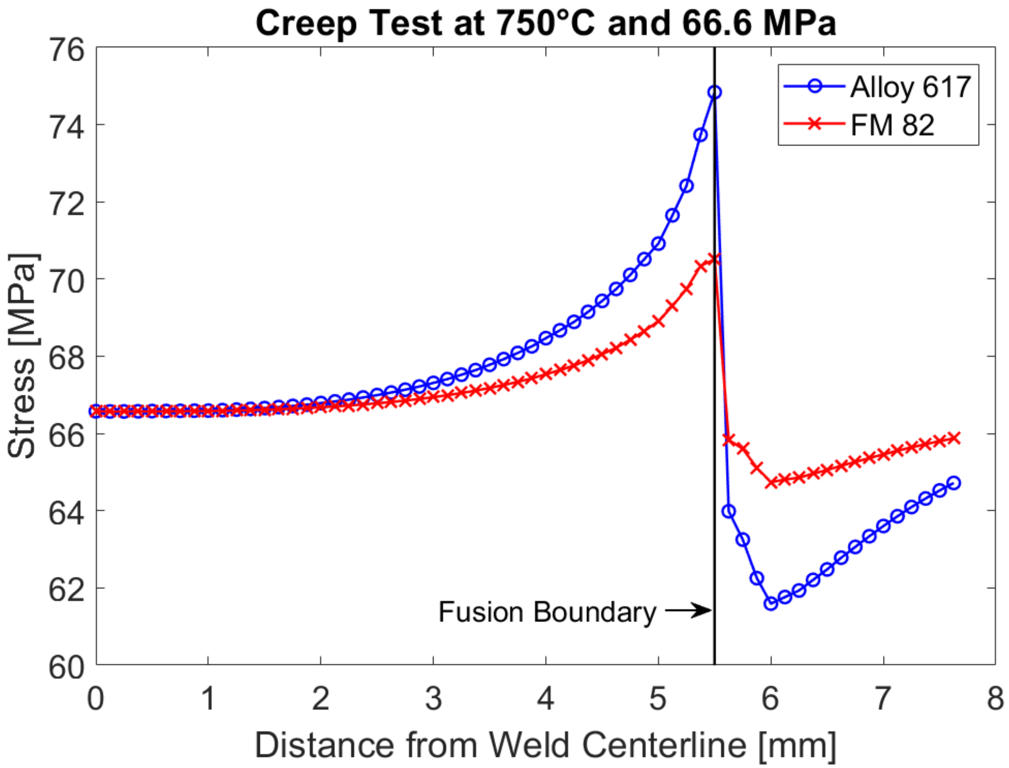
Abaqus® 3D Modeling based on the Creep Sample Geometry

Alloy 617



Alloy 82





Summary

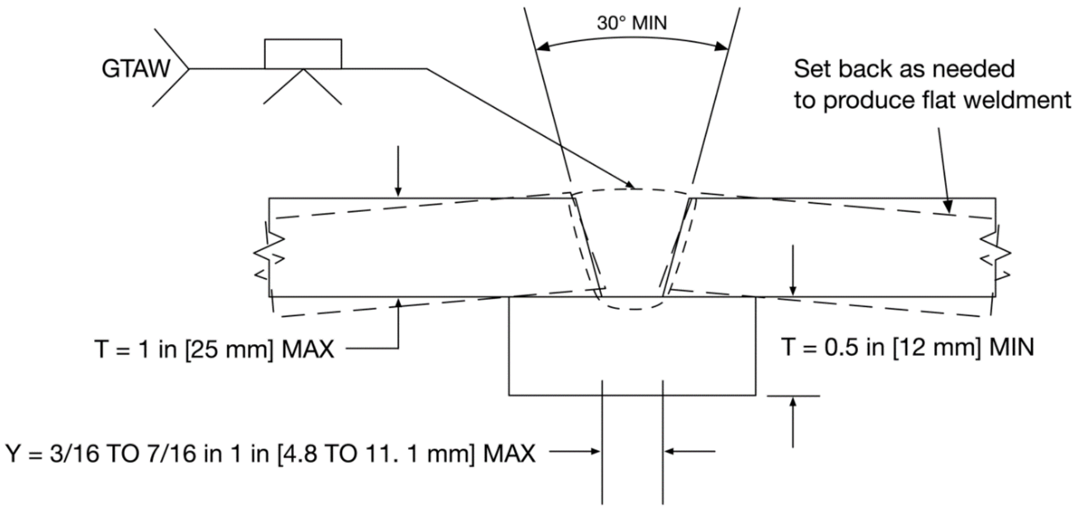
- Preliminary creep-rupture data of the Alloy 800H weldment with Alloy 617 filler metal do not show significant improvement compared to the filler metals currently permitted in Division 5 for Alloy 800H weldments.
- Therefore, Alloy 617 filler metal is unlikely to offer significantly improved stress rupture factor values for Alloy 800H weldments.

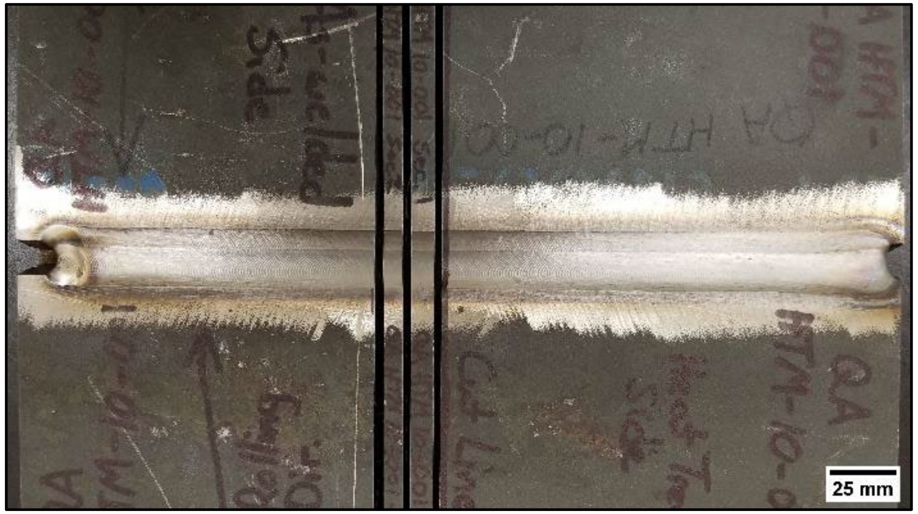
U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

UTP A 2133 Mn Filler Metal

UTP 2133 Mn Filler Metal

Chemical Compositions (wt%)														
	Fe	Ni	Cr	Mo	Nb	Ti	Al	Co	Cu	Si	Mn	C	P	S
800HT	46.2	30.6	19.7	-	-	0.54	0.56	0.10	0.20	0.42	1.27	0.061	0.024	0.001
UTP 2133Mn	Bal.	32.1	21.6	<0.1	1.23	-	-	-	<0.1	0.2	4.8	0.16	0.006	0.001

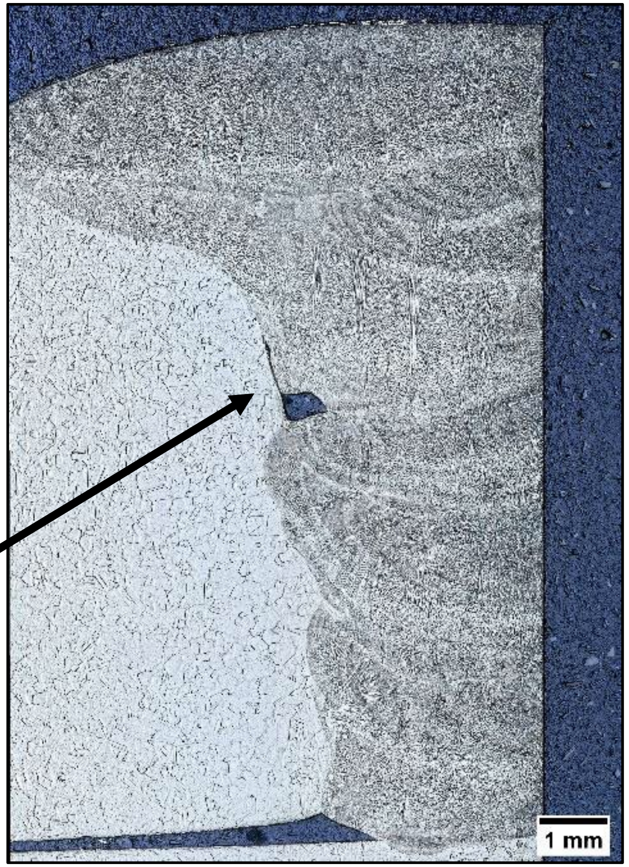


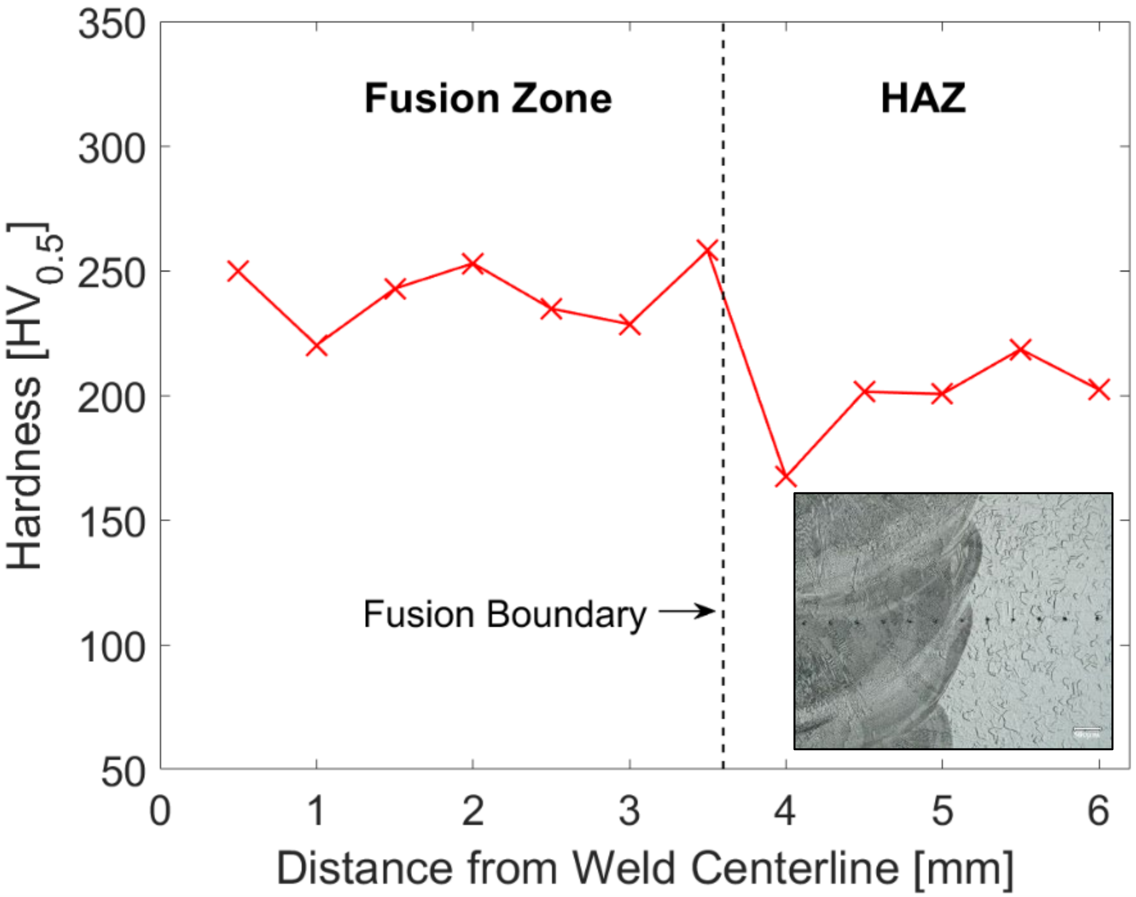


UTP 2133 Mn Weld Analysis

Low Heat Input
1.15 kJ/mm
(29.3 kJ/in)

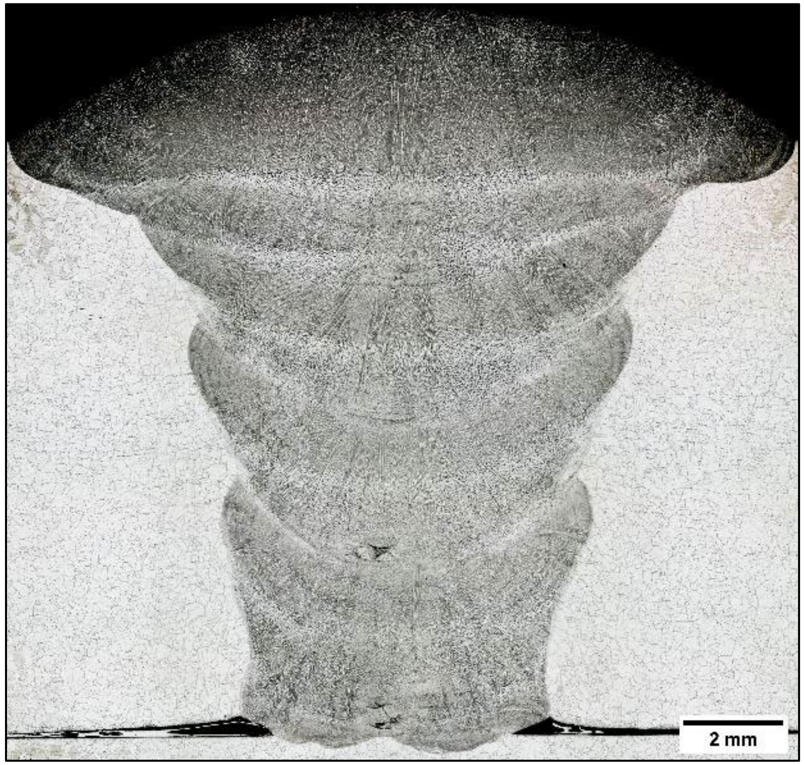
Issues with lack of fusion defects

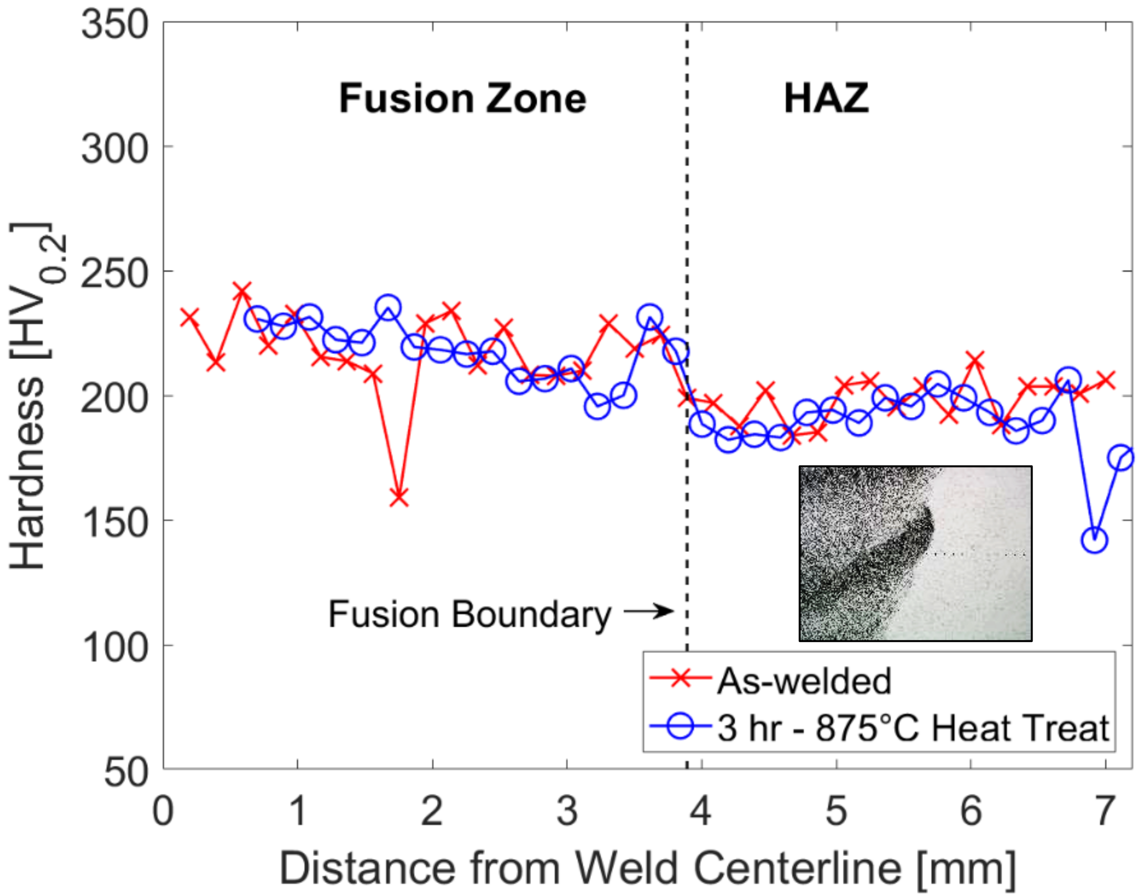




UTP 2133 Mn Weld Analysis

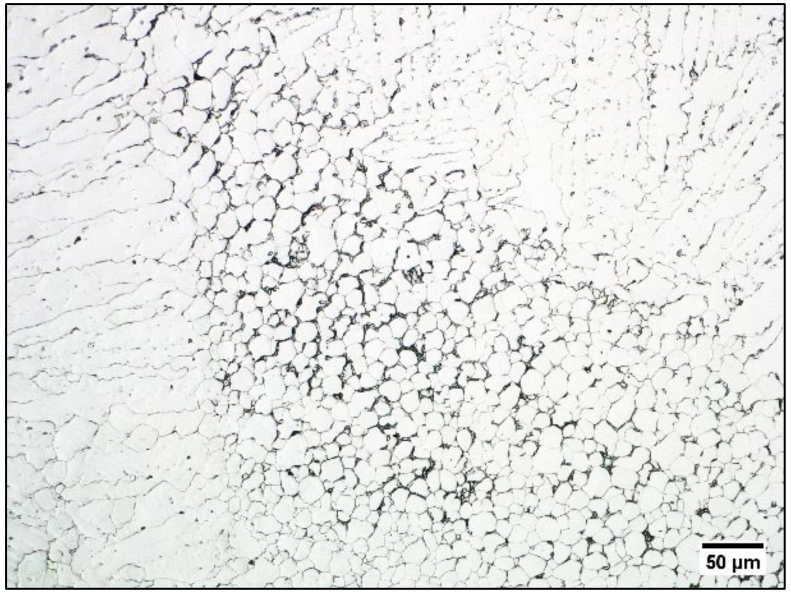
Higher Heat Input
1.31 kJ/mm (33.2 kJ/in)



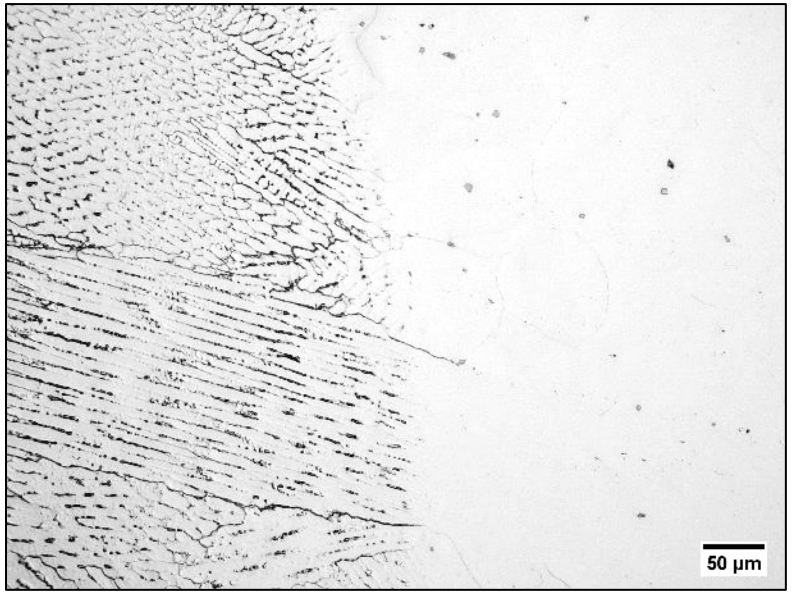


UTP 2133 Mn Weld Microstructures

1.15 kJ/mm

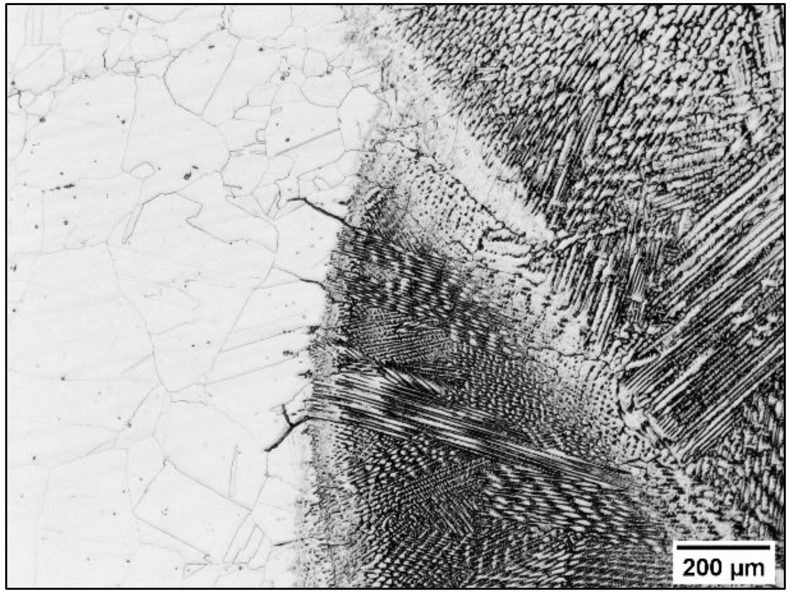


**As-Welded
Fusion Zone**



**As-Welded
Fusion Boundary**

1.31 kJ/mm



**As-Welded
Fusion Boundary**

Outlook

- **Optimize UTP 2133Mn welding parameters**
  - Explore buttering to eliminate lack of fusion and minimize liquation
- **Measure the material properties of UTP 2133Mn**
  - Laser ultrasonics at elevated temperatures
- **Use the measured properties to model the stress accumulation compared to the Alloy 617 and Alloy 82 welds**
- **Internally qualify Alloy 800H with UTP 2133Mn welds and perform creep testing once satisfactory welds are achieved**

U.S. DEPARTMENT OF
ENERGY

Office of
NUCLEAR ENERGY