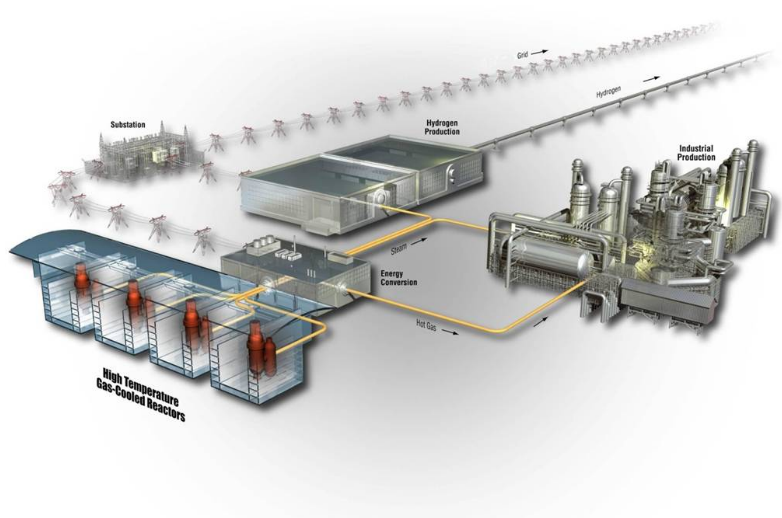
INL-EXT-21-63328

Assessment of Overmatched Filler (Alloy 617) to Improve Alloy 800H Stress Rupture Factors

July 2021

Changing the World's Energy Future

Ryann Rupp
Idaho National Laboratory



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INL ART Program

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Technical Reviewer: (Confirmation of mathematical accuracy, and correctness of data and appropriateness of assumptions.)

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SUMMARY

Section III, Division 5 of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (BPVC) specifies rules for elevated-temperature nuclear reactors. Currently, only six metals are qualified in Section III, Division 5 for construction of Class A metallic pressure boundary components for elevated-temperature service, one of these being Alloy 800H. Alloy 800H is qualified to be welded with only two permissible filler metals: Alloy A and Alloy 82. At the upper extremity of Alloy 800H's qualified temperature and service life, the stress rupture factors for these two filler metals are low. This may preclude vendors from being able to use Alloy 800H for elevated-temperature nuclear construction. In this work, an overmatched filler metal, Alloy 617 is assessed to determine its potential to offer improved stress rupture factors. Scoping creep-rupture tests of cross-welds with Alloy 800H base metal and Alloy 617 filler metal were conducted. Preliminary results do not indicate that Alloy 617 will offer significantly improved stress rupture factors. Consequently, a matching filler metal, UTP A 2133, is now being investigated.

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- Todd Morris and Wesley Jones, characterization
- Mike McMurtrey, Richard Wright, and Sam Sham, project development and guidance.

Thomas Lillo conducted most of the INL cross-weld creep-rupture tests with Alloy 800HT base metal and Alloy 82 filler metal.

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ACRONYMS

ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
AWS	American Welding Society
BPVC	Boiler and Pressure Vessel Code
CRBRP	Clinch River Breeder Reactor Plant
CTE	Coefficient of thermal expansion
GTAW	Gas tungsten arc welding
INL	Idaho National Laboratory
LMP	Larson-Miller parameter
NRC	Nuclear Regulatory Commission
SRF	Stress rupture factor

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Assessment of Overmatched Filler (Alloy 617) to Improve Alloy 800H Stress Rupture Factors

1. MOTIVATION

Section III, Division 5 of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (BPVC) provides rules for elevated-temperature nuclear reactors. The rules cover a variety of topics including design and construction for metallic materials, graphite, and composite materials. Currently, Alloy 800H is one of six metallic materials qualified in Section III, Division 5 of the ASME BPVC. Alloy 800H is permitted for temperatures up to 760°C and design lives up to 300,000 hours. ENiCrFe-2 (i.e., Alloy A) and ERNiCr-3 (i.e., Alloy 82) are two permissible weld metals for Alloy 800H base metal specified in Division 5. The ASME BPVC specifies SFA-5.11, "Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding," for Alloy A. SFA-5.14, "Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods," is specified for Alloy 82. This specification permits any welding process for which an SFA-5.14 classified filler metal is suitable. However, it is intended for gas metal arc, gas tungsten arc, plasma arc, and submerged arc welding processes. For the temperatures and service lives qualified, the stress rupture factor (SRF) values range from 1.00 to 0.59 and 0.54 for welds comprised of Alloy A and Alloy 82, respectively (ASME, 2019). Low SRF values may impede elevated-temperature nuclear construction with Alloy 800H.

Consequently, an alternative weld metal is desired to improve the SRF values for the qualified temperatures and service lives. In this work, the impact of an overmatched weld on elevated-temperature creep-rupture properties was investigated, specifically, Alloy 800H welds with Alloy 617 filler metal fabricated by gas tungsten arc welding (GTAW). An overmatched, matching, and undermatched weld has strength greater than, equivalent to, or less than the base metal, respectively. The stress-rupture properties of Alloy 82 filler metal are considered to be slightly undermatched compared to Alloy 800H at temperatures above approximately 760°C (Marshall & Farrar).

2. BACKGROUND

In 1983, the Nuclear Regulatory Commission (NRC) released a safety evaluation report on the construction of the Clinch River Breeder Reactor Plant (CRBRP). In this report, weldment cracking in elevated-temperature nuclear components from recurrent thermal transient loadings was noted as a structural integrity concern. At this time, weldments were only minimally addressed in the ASME BPVC. Cancellation of the CRBRP halted a planned test program to address concerns flagged by the NRC. In 1987, Code Case N-47-26 introduced weld factors into the ASME BPVC to improve the design methodology for elevated-temperature construction. This code case was a product of combined efforts from the Department of Energy structural materials programs and ASME BPVC committees (Sham, 2021; Corum, 1990).

The SRF (defined as R in Section III, Division 5 of the ASME BPVC) is a knockdown factor to account for the potential detrimental effect of weldments on the time-dependent allowable stresses (ASME, 2019). Code Case N-47-26 defined the SRF as the ratio of the average rupture strength of the deposited-filler metal to the base metal (Shingledecker, et al., 2017). R equals one if the rupture strength of the weldment is equivalent to or better than base metal. R is between zero and one if the weldment rupture strength is less than the base metal. The SRF values were validated or adjusted with cross-weld and component-weld creep-rupture data (Sham, 2021). Cross-weld specimens are comprised of both the base and weld metal (Corum, 1990). Cross-weld specimens enable the impact of the heat-affected zone as well as nonuniform stresses and strains induced by the weld to be captured. The current method for calculating SRF values is exclusively with cross-weld rupture data or a combination of cross-weld and deposited-filler-metal rupture data (Sham, 2021). The SRF values for Alloy 800H were calculated from a combination of cross-weld and deposited-filler-metal rupture data (Sham, 2021; Shingledecker, et al., 2017).

Section III, Division 5 of the ASME BPVC has not standardized a procedure to calculate creep-rupture strength (Swindeman, Swindeman, Roberts, Thurgood, & Marriott, 2007). One approach is with the Larson-Miller parametric correlation which combines temperature and time into a single parameter referred to as the Larson-Miller parameter (LMP) (Shingledecker, et al., 2017; Swindeman, Swindeman, Roberts, Thurgood, & Marriott, 2007). The LMP is defined in Equation 1 below:

$$\mathrm{LMP} = \mathrm{T}\,(\mathrm{C} + \log(\mathrm{t_r})) = \mathrm{a_0} + \mathrm{a_1}\log(\mathrm{S}) + \mathrm{a_2}\,(\log(\mathrm{S}))^2 + \mathrm{a_3}\,(\log(\mathrm{S}))^3 + \cdots \quad (1)$$

In Equation 1, T is the temperature in Kelvin, C is a material-dependent constant, t_r is the rupture time in hours, a_i are constants that depend on the number of polynomial terms, and S is the stress in megapascals (Swindeman, Swindeman, Roberts, Thurgood, & Marriott, 2007).

3. EXPERIMENTAL PROCEDURES

3.1 Characteristics of the Base and Filler Metal in this Work

3.1.1 Base Metal

A 12-mm thick Alloy 800HT, UNS 08811, plate from Jessop Steel, heat 37458, was used in this investigation. Alloy 800HT is within the specifications of Alloy 800H (Swindeman, Swindeman, Roberts, Thurgood, & Marriott, 2007). For this report, Alloy 800HT will be referred to as Alloy 800H. The chemistry of the plate is provided in Table 1. The Section III, Division 5 Alloy 800H chemistry requirements are included in Table 1.

3.1.2 Filler Metal

Alloy 617, UNS N06617, weld wire with a 1.14-mm (0.045”) diameter from Oxford Alloys, heat XX3703UK, was used in this investigation. This weld wire meets the American Welding Society (AWS)/ASME SFA 5.14 specification and belongs in the ERNiCrCoMo-1 class (ASME, 2019). The chemical composition of the weld wire is provided in Table 2.

Table 1. The chemical composition of the base metal, heat 37458, and Section III, Division 5 chemistry requirements for Alloy 800H in weight percent.

		Ni	**Cr**	**Fe**	**Mn**	**C**	**Cu**	**Si**	**S**	**Al**	**Ti**	**Mo**	**Co**
Heat 37458		30.45	19.30	47.05	1.31	0.063	0.21	0.37	0.001	0.43	0.45	0.21	0.11
Section III, Division 5 Requirements	min	30.0	19.0	39.5		.05				0.15*	0.15*		
	max	35.0	23.0		1.5	0.10	0.75	1.0	0.015	0.60*	0.60*		

* Al + Ti ≥ 0.50%

Table 2. The chemical composition of the Alloy 617 weld wire, heat XX3703UK, in weight percent.

	Ni	**Cr**	**Co**	**Mo**	**Fe**	**Mn**	**Al**	**C**	**Cu**	**Si**	**S**	**Ti**
Heat XX3703UK	53.91	22.41	11.49	8.98	1.37	0.11	1.10	0.089	0.04	0.04	0.001	0.34

3.2 Gas Tungsten Arc Welding (GTAW)

An Alloy 800H welded plate with Alloy 617 filler metal was fabricated by GTAW. Welding was in accordance with the Idaho National Laboratory (INL) Welding Procedure Specification I5.1 and Section IX of the ASME BPVC (Idaho National Laboratory Welding Procedure Specification; ASME, 2019). The weld geometry was a 30° V-groove with a 3-mm gap at the bottom of the weld. The weld was sealed with a tacked-on Alloy 800H backing bar. More information on the welding of Alloy 800H plates with Alloy 617 filler metal at INL and the resulting mechanical properties can be found in Engineering Calculations and Analysis Report (ECAR)-1041 (Wright, 2007). A post-weld heat treatment was not conducted.

3.3 Mechanical Test Methods

3.3.1 Hardness Testing

A Leco LM-310AT was used to measure Vickers hardness. The force was 300 gf. The dwell time was 13 seconds.

3.3.2 Creep-Rupture Testing

Elevated-temperature, uniaxial, cross-weld creep-rupture tests were conducted in air. The temperature and load remained constant throughout the test. The weld was transverse to the longitudinal direction of the specimen and centered with respect to reduced section. In other words, the center of the specimen's reduced section was weld metal with base metal located on both sides of the weld metal. Testing was conducted in accordance with PLN-3386, "Creep Testing," and American Society for Testing and Materials (ASTM) standard E139-06, "Standard Test Methods for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials" (Idaho National Laboratory, 2016; ASTM E139-06, 2006). The following paragraphs describe creep-rupture testing in more detail.

Testing was conducted using creep frames from Applied Test Systems. Load was applied directly, indirectly with a 20:1 lever arm, or indirectly with a 3:1 lever arm. Temperature was monitored with two thermocouples in contact with the top and bottom of the specimen's reduced section. Prior to the test's start, which occurred when the load was applied, the specimen was heated up to the target temperature and soaked. The heat-up and soak were set for two and three hours, respectively. Typically, R-type thermocouples were used for testing above 750°C. Otherwise, K-type thermocouples were used. Strain was measured with either dual averaging linear variable differential transformers displacement transducers or HEIDENHAIN linear encoded photoelectric gauges. The resolution of the strain measurements was greater than 0.01%. Strain was calculated using the test specimen's adjusted length of the reduced section. The test specimens had a cylindrical geometry with a 32-mm-long reduced section that was 6.4-mm in diameter. Prior to testing, critical dimensions were measured with an optical comparator set at 50 ×. Post-test, calipers were used to measure important dimensions. Pre- and post-test measurements were measured at room-temperature.

Testing was conducted at temperatures ranging from 750 to 1000°C. These temperatures are at and exceed the maximum temperature Alloy 800H is qualified for in Section III, Division 5 of the ASME BPVC. The reason for testing at these temperatures is to accelerate testing. The low SRF values coincide with large LMPs which corresponds to high temperatures, low stresses, and long rupture lives. To evaluate the potential for Alloy 617 filler metal to offer improved SRF values, the tests need to be at conditions that result in a large LMP. The fastest way to achieve this is with higher temperatures. This is a legitimate approach since Alloy 800H is nominally a solid-solution strengthened material and the creep behavior is not expected to change at these higher temperatures. The applied stress for all tests was below the yield stress for Alloy 800H according to a vendor data sheet (Special Metals, 2004). The specimens' rupture lives ranged from approximately 250 to 11,000 hours.

3.4 Microstructure Characterization

3.4.1 Grain Size Measurements

Grain size measurements were in accordance with ASTM E112-13 (ASTM E112-13, 2013). The comparison procedure was followed using Plate II.

3.4.2 Optical Microscopy

A Keyence VHX-6000 microscope was used for optical microscopy. Specimens were prepared using standard grinding and polishing procedures. The specimens were electroetched. A 10% oxalic acid solution with a voltage of 2.2 V for 20 to 30 seconds yielded good results.

4. RESULTS

4.1 Welded Plate

The grain size and hardness of the welded plate was characterized as a function of distance from the weld. The base-metal grain size was an ASTM grain size of 2 and remained constant. The hardness did vary with the distance from the weld which is apparent by the results shown in Figure 1. The hardness of the weld metal and the base metal are represented by the dashed lines. These values were determined from the average of six measurements. These base-metal measurements were from an area far from the weld. This was to ensure the measurements represented the base metal and were not affected by the weld. The hardness as a function of the approximate distance from the weld edge was measured three times. The first measurement was taken at the fusion line. The hardness was then measured every 640-µm until the hardness measurements were equivalent to the unaffected base metal. The square represents the average of these three measurements although a couple of these data points are the average of only two measurements. The maximum and minimum error bars correlate to the maximum and minimum measured hardness, respectively. The gap in the data is a consequence of the cross-weld being sectioned for mounting in an epoxy puck. The size of this gap is approximate as the sectioning kerf is unknown. It is apparent from Figure 1 that the hardness of the weld metal is greater than the unaffected base metal. In the base metal the fusion line is the hardest. From the fusion line, the hardness of the base metal decreases in a linear manner for approximately 25-mm before reaching the hardness of the unaffected base metal.

The main takeaway from this analysis is that the welded plate does not have a traditional heat-affected zone. In the base metal, the hardness is highest near the weld and lowest in the unaffected base metal. This variation in hardness is not a consequence of the Hall-Petch effect since the grain size does not vary in the base metal. The variation in hardness is suspected to be the result of carbide precipitation, though transmission electron microscopy to confirm this was not performed.

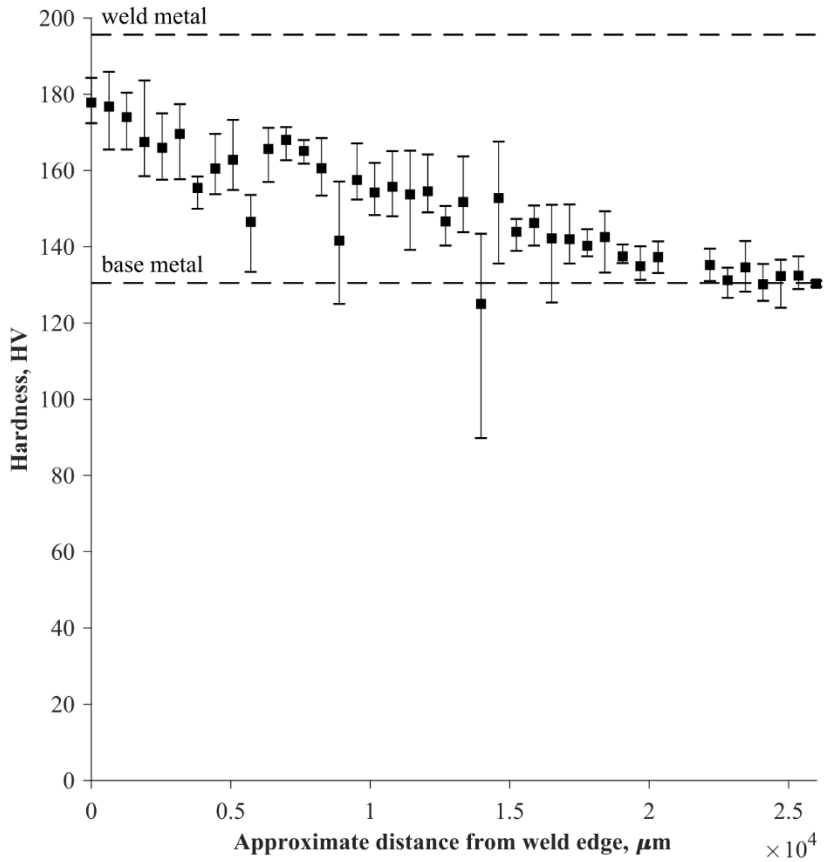


Figure 1. Base-metal hardness as a function of approximate distance from the weld.

4.2 Creep Tests

The results from the cross-weld creep-rupture tests with Alloy 800H base metal and Alloy 617 filler metal are shown on the Larson-Miller Plot in Figure 2. The C value is 15.12 and came from a report by Swindeman and colleagues, "A review of available tensile and creep-rupture data sources and data analysis procedures for deposited weld metal and weldments of Alloy 800H" (Swindeman, Swindeman, Roberts, Thurgood, & Marriott, 2007). Included in Figure 2 are the Alloy 800H Larson-Miller curve, Alloy 800H data, Alloy 82 deposited-filler-metal data, and cross-weld data with Alloy 800H base metal and Alloy 82 filler metal. The Alloy 800H parametric curve, Alloy 82 deposited-filler-metal data, and the majority of the cross-weld data with Alloy 800H base metal and Alloy 82 filler metal came from the report by Swindeman and colleagues (Swindeman, Swindeman, Roberts, Thurgood, & Marriott, 2007). The other cross-weld data with Alloy 800H base metal and Alloy 82 filler metal came from testing performed at INL. The Alloy 800H data came from the ASME BPVC Section II committee.

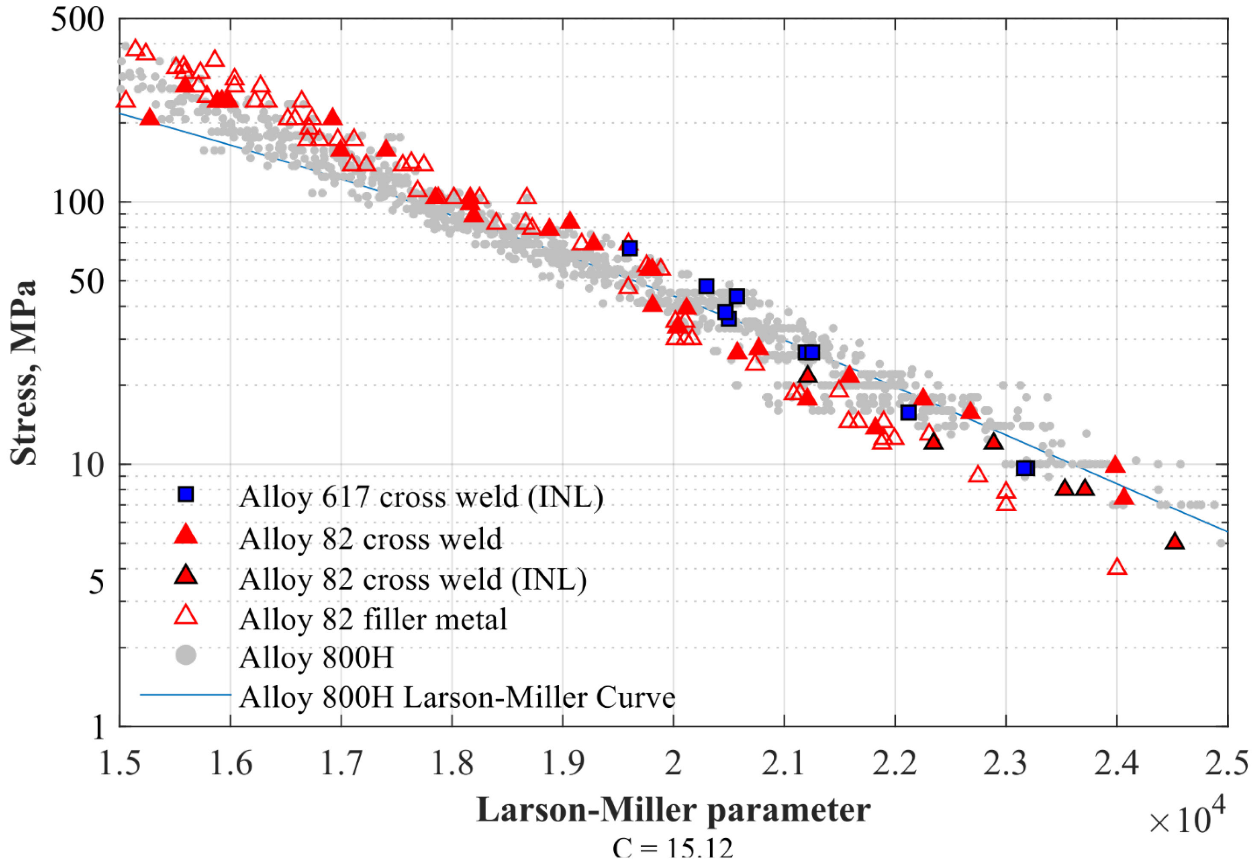


Figure 2. Stress as a function of the Larson-Miller parameter with a C value of 15.12 with the following creep-rupture data: 1) cross welds with Alloy 800H base metal and Alloy 617 filler metal, 2) cross welds with Alloy 800H base metal and Alloy 82 filler metal, 3) Alloy 82 deposited-filler metal, and 4) Alloy 800H. Also shown is the Alloy 800H parametric curve.

The following observations can be drawn from Figure 2. For small LMP values, cross-welds with Alloy 617 or Alloy 82 filler metal and deposited Alloy 82 filler metal typically have better creep-rupture properties compared to Alloy 800H. For large LMP values, the opposite behavior is observed. The Alloy 617 filler metal had better creep-rupture properties compared to the Alloy 82 filler metal for larger LMP values. Cross-welds with the Alloy 617 filler metal intersect the 800H parametric curve at LMP values ranging from approximately 20,500 to 21,250. The Alloy 82 filler metal for both the cross-weld and deposited-filler-metal specimens intersected the Alloy 800H parametric curve at an LMP value of 19,750. For large LMP values, the creep-rupture behavior of both filler metals appears to be similar.

4.3 Ruptured Specimens

Preliminary results indicate that rupture in the cross-weld specimens with Alloy 617 filler metal occurs in the base metal with minimal damage in the weld metal; see Figure 3. The exact location of the cavitation damage in the base metal varies with stress and temperature. For lower LMPs, cavitation damage is limited to a narrow region next to the fusion line. For higher LMPs, cavitation becomes more dispersed throughout the base metal with minimal damage in the area next to the fusion line.

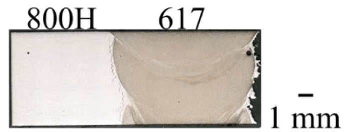
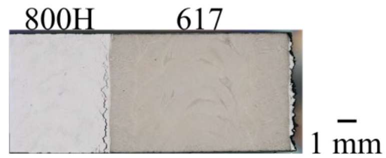
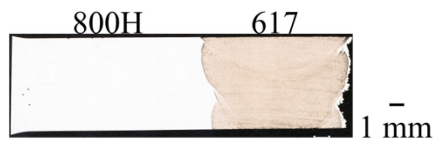
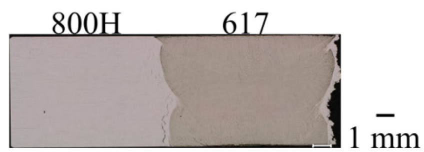
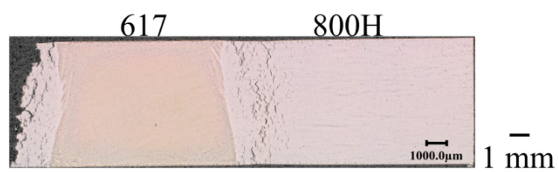
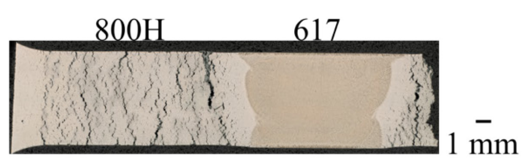
LMP	Location relative to Alloy 800H Larson-Miller Curve	Temperature °C	Stress MPa	
1.96×10^4	right	750	66.6	
2.03×10^4	right	800	47.7	
2.05×10^4	on	800	35.8	
2.06×10^4	right	900	43.7	
2.13×10^4	on	900	26.7	
2.21×10^4	left	950	15.7	
2.32×10^4	left	1,000	9.7	

Figure 3. Representative optical microscopy images of the ruptured cross-weld specimens with Alloy 800H base metal and Alloy 617 filler metal. The images are in order from smallest to largest LMP for a C value of 15.12. The location of the specimen on the Larson-Miller plot with respect to the Alloy 800H parametric curve is described. The temperature and initial applied stress of the test are provided.

These observations are in stark contrast with the creep damage observed in cross-weld specimens with Alloy 82 filler metal tested at INL (see Figure 4). The rupture location in these cross-weld specimens varied with stress and temperature. However, in all these specimens, regardless of rupture location, there was significant cavitation damage in the weld metal.

LMP	**Location relative to Alloy 800H Larson-Miller Curve**	**Temperature** °C	**Stress** MPa
2.12×10^4	left	900	21.6
2.23×10^4	left	925	12
2.29×10^4	left	900	12
2.35×10^4	left	975	8
2.37×10^4	left	950	8
2.45×10^4	left	1,000	5

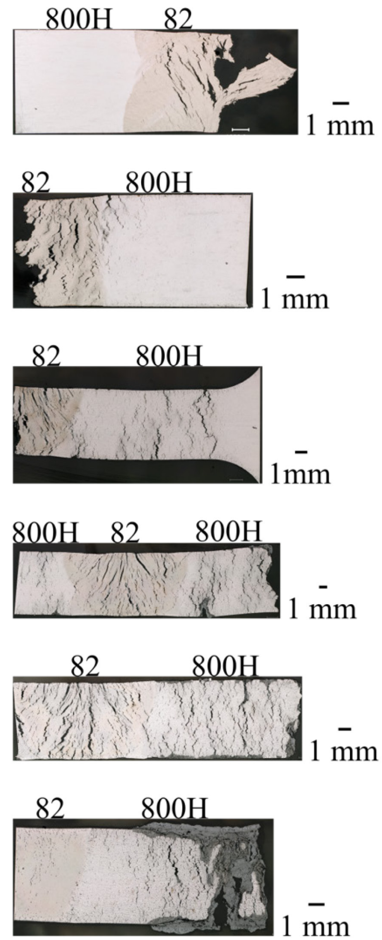


Figure 4. Optical microscopy images of the ruptured cross-weld specimens with Alloy 800H base metal and Alloy 82 filler metal tested at INL. The images are in order from smallest to largest LMP for a C value of 15.12. The location of the specimen on the Larson-Miller plot is described with respect to the Alloy 800H parametric curve. The temperature and initial applied stress of the test are provided.

5. DISCUSSION

Filler metal significantly impacts the location of creep damage and rupture. Although rupture always occurred in the base metal, preliminary data does not indicate Alloy 617 SRF values will be significantly improved compared to those for Alloy 82. Use of Alloy 617 is not likely to improve the SRF values that impede construction of Alloy 800H at elevated temperature for long service lives. This is demonstrated in

Figure 5, which shows the SRF values as a function of service life at 750°C for the following: 1) cross-weld data with Alloy 617 filler metal, 2) cross-weld data with Alloy 82 filler metal, and 3) values from Section III, Division 5 Table HBB-I-14.10C-2 (ASME, 2019).

At 750°C, the Alloy 82 SRF values drop below one at an earlier service life when compared to Alloy 617 SRF values. However, at the longest service life of 300,000 hours, the SRF values for both filler metals are essentially the same. Note the SRF values presented in Figure 5 calculated from cross-weld data are preliminary. They were calculated using the optimized Larson-Miler parametric correlations for Alloy 800H, Alloy 617 cross welds, and Alloy 82 cross welds. The Alloy 800H Larson-Miller parametric correlation came from the report by Swindeman and colleagues using data from tests conducted at temperatures greater than or equal to 732°C (Swindeman, Swindeman, Roberts, Thurgood, & Marriott, 2007).

The Larson-Miller parametric correlation for the two filler metals were calculated. For Alloy 617 filler metal, a_o, a_1, and C were determined from 11 data points and equal 23624.03, -3529.47, and 12.84, respectively. For Alloy 82 filler metal, a_o, a_1, and C were determined from 24 data points and equal 26428.61, -4662.11, and 14.05, respectively. These values were determined using data from the tests conducted at INL and the report by Swindeman and colleagues (Swindeman, Swindeman, Roberts, Thurgood, & Marriott, 2007). The data from Swindeman and colleagues was filtered to only include data equal to and greater than 732°C since this temperature cutoff was also used for Alloy 800H. The open markers indicate data extrapolation beyond the factor of five permitted in the ASME BPVC (ASME, 2019).

The SRF values calculated from cross-welds with Alloy 82 filler metal are larger than those in Section III, Division 5 of the ASME BPVC. This is a consequence of the optimized Larson-Miller parametric correlations used in this work being calculated from different data than those used for the ASME BPVC. The Larson-Miller parametric correlations in this work were calculated from a very small data set and again should only be considered to be preliminary. The unimproved SRF values may be a consequence of the following: 1) stress relaxation cracking, 2) inadequate creep resistance of Alloy 800H at 1000°C, and 3) differences in the coefficient of thermal expansion (CTE) between Alloys 800H and 617. Each of these will be discussed in more detail in the following paragraphs.

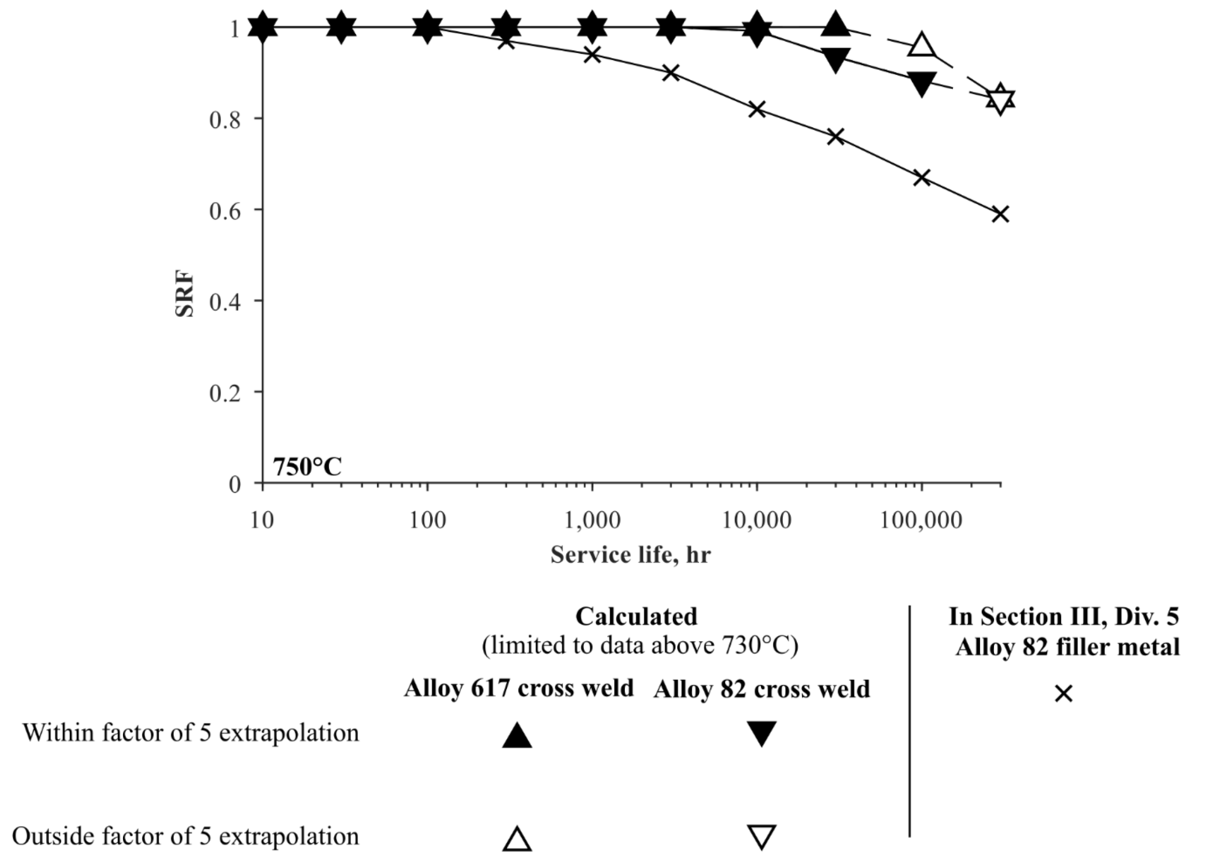


Figure 5. SRF values as a function of service life from the following: 1) cross-weld data with Alloy 617 filler metal, 2) cross-weld data with Alloy 82 filler metal, and 3) values from Section III, Division 5 Table HBB-I-14.10C-2 (ASME, 2019).

Stress relaxation cracking occurs as a result of reduced material ductility. This is observed when precipitation strengthening within the interior of the grain limits strain accommodation to the exterior of the grain. If the stress is unable to be relieved fast enough, stress relaxation cracking will occur (Colwell & Shargay, 2020; van Wortel, 2007; Shoemaker, Smith, Baker, & Poole, 2007; Siefert & David, 2014). Stress relaxation cracking is possible at temperatures ranging from 550°C to 750°C. Since most of the testing in this work was conducted at higher temperatures, stress relaxation cracking is not likely the cause of the unimproved SRF values.

Testing at 1000°C may contribute to the unimproved SRF values. Significant oxidation was observed in the base metal for the cross-weld specimen with Alloy 82 filler metal tested at 1000°C (Figure 4). In the cross-weld specimen with Alloy 617 filler metal tested at 1000°C, extensive damage was observed in the base metal with minimal damage near or in the weld (Figure 3). However, the accelerated test temperatures are not expected to be solely at fault for the unimproved SRF values. Alloy 800HT is used by the syngas industry for temperatures up to 954°C (Colwell & Shargay, 2020). Cross-weld creep-rupture tests with Alloy 617 filler metal conducted at 950°C fell below the Alloy parametric curve.

The mismatch in the CTE between Alloys 800H and 617 introduces additional stresses that may be causing the unimproved SRF values. These stresses are localized to the weld interface. The magnitude of this stress, σ, is defined in Equation 2 below:

$$\sigma = E \left(T_{ns} - T_{op}\right) \Delta\alpha \tag{2}$$

where E is the Young's modulus, T is temperature, and $\Delta\alpha$ is the difference in CTE between the base and weld metal (Chilton, Price, & Wilshire, 1984). For this work, T_{ns} is assumed to be greater than 1,000°C and T_{op} is the temperature at which the creep test was conducted at. From Equation 2, it is apparent the localized stress at the interface increases as the operation temperature decreases. This stress will redistribute during the creep test. The location of the creep damage in the cross-weld specimens with Alloy 617 filler metal is consistent with Equation 2 (Figure 3). The creep-rupture test with the lowest temperature investigated in this study was conducted at 750°C. Of all the creep-rupture tests conducted, this test was expected to have the highest localized stress at the weld interface because of the mismatch in CTE. The cavitation damage was highly localized at the weld interface with rupture occurring next to the interface.

The highest temperature investigated in this study was 1000°C. These tests were expected to have the lowest localized stress at the interface. These specimens were observed to have significant creep damage throughout the weld metal. Rupture also occurred far from the weld. The mismatch in the CTE between base and weld metal was identified as the root cause for some premature component failures (Grooten, et al., 2019; van Zyl, Keltjens, & Al-Shawaf, 2017). There are two observations that preclude linking the mismatch in the CTE between base and weld metal to the unimproved SRF values. First, the directionality of the cavitation damage and cracks are opposite of what is expected if the CTE mismatch is at fault. The cavitation and ruptured direction of the cross-weld specimens with Alloy 617 filler metal are perpendicular to the applied stress (Figure 3). This indicates the creep damage was caused by the applied stress and not the localized stress from the CTE mismatch. Cracks perpendicular to the weld interface would be expected if the CTE mismatch caused the deformation. Second, this explanation does not match the Larson-Miller plot (Figure 2). At higher test temperatures, with a lower stress caused by the CTE mismatch, the Alloy 617 cross-welds had worse creep-rupture properties compared to Alloy 800H. At lower test temperatures, with a larger stress caused by the CTE mismatch, the specimens had equivalent or better creep-rupture properties compared to Alloy 800H.

Ultimately, the mechanism(s) responsible for the poor creep-rupture properties for the welded plates with Alloy 800H base metal and Alloy 617 filler metal are unknown. Regardless, preliminary data does not indicate that Alloy 617, an overmatched weld metal, will improve the SRF values compared to Alloy 82 filler metal. The next section of this report discusses ongoing work to identify an Alloy 800H filler metal with improved SRF values.

6. ONGOING WORK

A research and development program is in progress to investigate whether matching filler metal UTP A 2133 Mn offers improved SRF values. Since the late 1980s, the European syngas industry has used matching consumables which they prefer to the Ni-based filler metals. This is because of the additional stresses present in Ni-based welds because of the CTE mismatch between base and weld metal. A matching filler metal is commonly used for the cast variants of Alloy 800. Historically, the wrought Alloy 800 variants were welded with Ni-based filler metals. This was because matching consumables had hot cracking issues that have since been resolved. Currently, there is not a universal consensus on the best weld metal for the wrought variants of Alloy 800 (Marshall & Farrar). In literature, data on these matching consumables is limited. From the available data, these matching consumables show potential at improving the SRF values for Alloy 800H and are thus worth investigating (Swindeman, Swindeman, Roberts, Thurgood, & Marriott, 2007; Orbons, 1987).

INL has procured UTP A 2133 Mn. GTAW will be used to fabricate welds in accordance with Section IX and III of the ASME BPVC. Note that AWS standards for this filler metal do not exist. GTAW was selected because the technique is widely recognized to produce welds with the best mechanical properties. Creep-rupture scoping tests of cross-weld specimens will be conducted with Alloy 800H base metal and UTP A 2133 Mn filler metal.

7. CONCLUSIONS

The SRF values for filler metals qualified in Section III, Division 5 of the ASME BPVC are low at elevated temperatures and long service lives. This may prohibit elevated-temperature nuclear construction with Alloy 800H. An overmatched filler metal, Alloy 617, was investigated to determine its potential for improving SRF values. Preliminary data indicates Alloy 617 will not significantly improve the SRF values particularly at elevated temperatures for long service lives. Consequently, a matching filler metal, UTP A 2133 Mn, is now being investigated.

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