Advanced Materials and Manufacturing Technologies Workshop
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Oak Ridge, Tennessee

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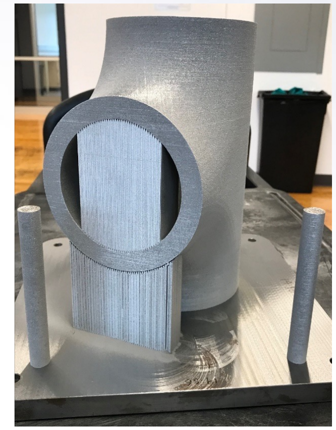
SETTING THE STANDARD

ASME Codification of Additive Manufacturing

- The ASME Special Committee on AM has drafted the technical requirements for two Additive Manufacturing. Code Cases
  - AM Construction of Pressure Equipment using the Direct Energy Deposition Process with Wire Feedstock.
    - Includes Gas Metal Arc and Electron Beam Welding Processes.
    - Limited to temperatures below the creep regime.
  - AM Construction of Pressure Equipment using the Powder Bed Fusion AM Process.
    - Includes Laser and Electron Beam Energy Sources.
    - The “Criteria for PBF Pressure Retaining Metallic Components Using Additive Manufacturing” was published in Pressure Technology Book-13 in May 2021.
    - Limited to temperatures below the creep regime.
    - Limited to austenitic and nonferrous material.



Tee Built using PBF
4” Diameter x 8” Tall ≅ 50 lbs.
(Rolls-Royce)

Valve Built Using Gas Metal Arc DED
8” Valve ≅ 1000 lbs.
(EPRI/ Lincoln Electric)

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- **Code Case Criteria**
- The ASME PBF and DED criteria provide the needed requirements for the materials, design, fabrication, examination, inspection, testing and quality control for integration into the ASME Construction Codes.

    - **Powder Bed Fusion**
    - Scope
    - Additive Manufacturing Specification
    - Materials
    - Thermal Treatment
    - Powder Requirements
    - Design Requirements
    - PBF Procedure
    - Procedure Qualification Builds
    - Production Builds
    - Chemical Composition Testing
    - Mechanical Property Testing
    - Metallographic Evaluation
    - Referenced Standards
    - Definitions
    - Records
    - Quality Program

    - **Direct Energy Deposition**
    - Scope
    - Additive Manufacturing Specification
    - Materials
    - Thermal Treatment
    - Design Requirements
    - Welding Qualification
    - Procedure Qualification Builds
    - Production Builds
    - Chemical Composition Testing
    - Mechanical Property Testing
    - Metallographic Evaluation
    - Referenced Standards
    - Definitions
    - Records
    - Quality Program

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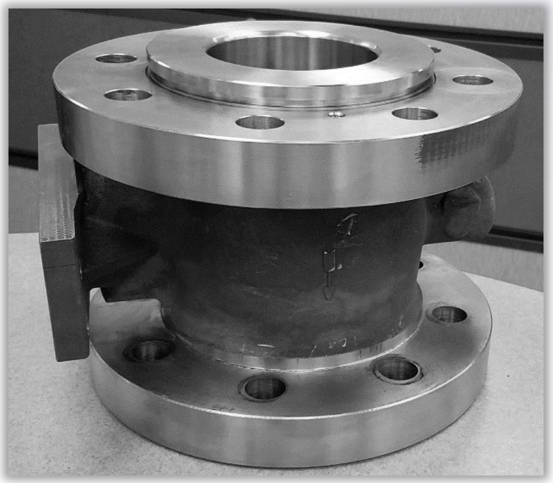
- **Materials**
  - Material is defined as the additively manufactured component.
  - Tensile properties for AM material shall conform to the ASME material specification.
  - ASME Section II Part D – Allowable Stress for Design



Valve Body using PBF AM
Courtesy of Emerson

- **Powder Bed Fusion**
  - ASME material specification is required for the component material.
  - Powder particles shall individually represent the final alloy composition.
  - Component chemical composition shall conform to the requirements of the ASME material specification.

- **Direct Energy Deposition**
  - ASME filler material specification and targeted material specification.
  - Component chemical composition shall conform to the filler material specification.

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- **Allowable Stress Values for DED AM Weld Metal**
- The ASME AM Committee and Section II are working on how to specify allowable stress values for DED AM Weld Metal.
  - What criteria and verification testing is needed to enter the allowable stress tables in ASME Section II Part D and use base metal property data for the allowable stress values for AM deposited weld metal?
    - Tensile data for deposited weld metal needs to show the same trends with temperature for properties between the deposited metal and base metal.
    - Verification testing to address heat input and cooling rates for the AM deposited weld metal.
    - ASME BPVC has an extensive successful experience with welding in a wide verity of materials and services.

- Heat input and cooling rate, which are Additive Manufacturer process dependent, and PWHT control the final tensile properties.
  - Different criteria are needed for acceptance of AM material because of the variability in tensile properties heat input and cooling rate.
  - The current Section II Appendix 5 process for new materials is impractical for AM because of the variability in heat input and cooling rate.

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- **AM Procedure Qualification.**
  - Capture the range of heat input and cooling rates on tensile properties.
  - ASME Section IX - QW-600 Bracket Weld Qualification for DED.
  - High temperature tension test.
- **Additive Material Manufacturing Qualification Builds**
  - Capture the geometric features in the component being manufactured to account for the thermal effects that provides the limiting material properties. (e.g., thick wall sections, thin wall sections, tilted wall sections, overhangs, thickness transitions, and required joints, etc.).
  - Requires 15 room temperature tension tests or statistical analysis to support with 95% confidence that 99% of the produced material comply with tensile properties.
- **Additive Material Manufacturing Production Builds**
  - Witness Sample Testing is required for all production builds.
  - Capture each heat of filler material for the DED process.

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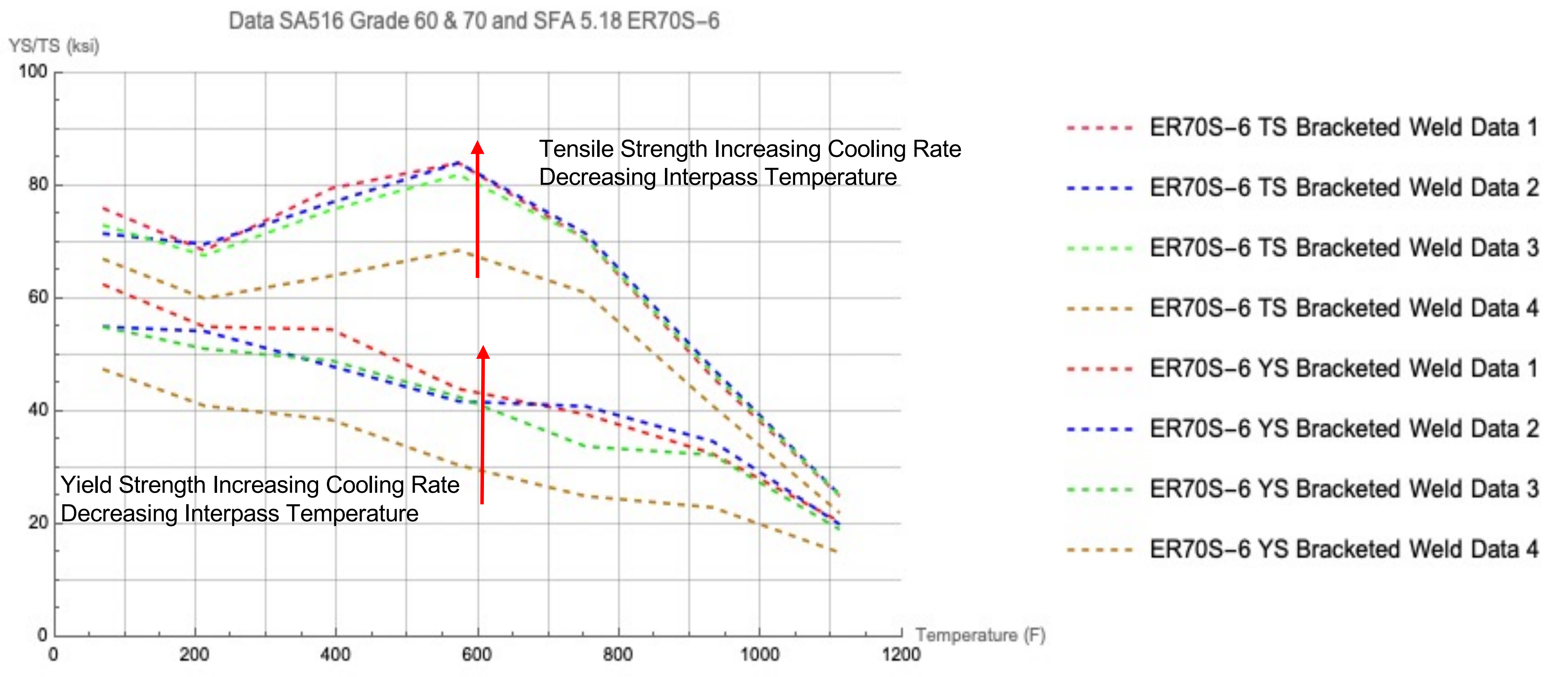
- **Tensile Properties for Weld Metal and DED Sample Builds**
  - Data for ER70S-6 Filler - Variability in material properties for a given filler material with heat input and cooling rate.
  - Lincoln Electric Design of Experiments Project.



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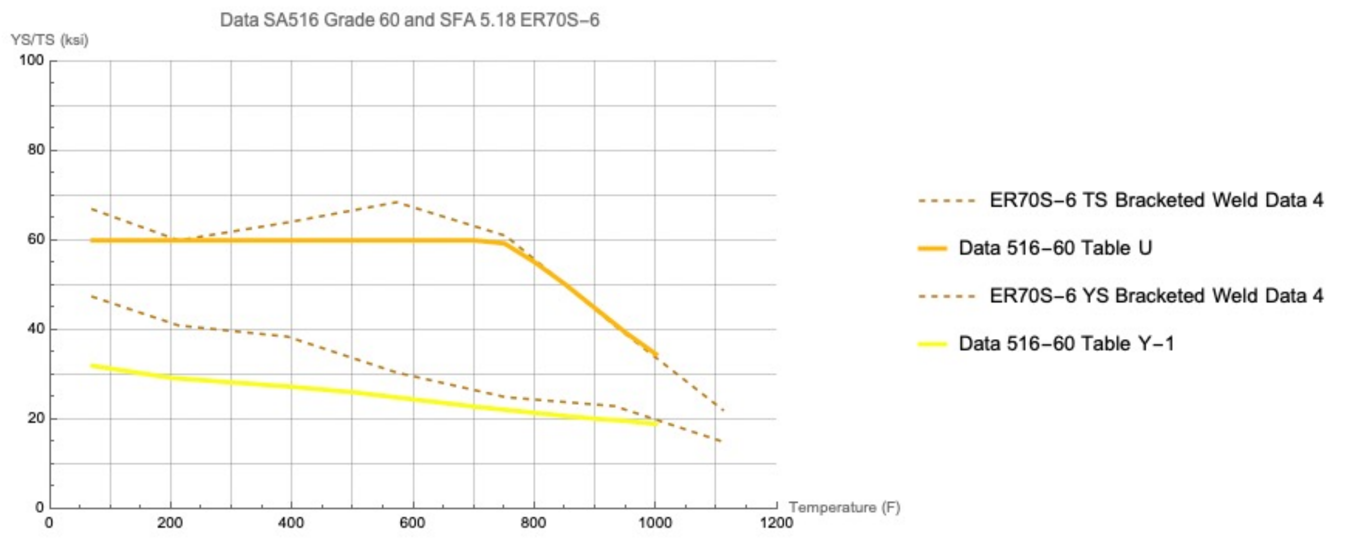
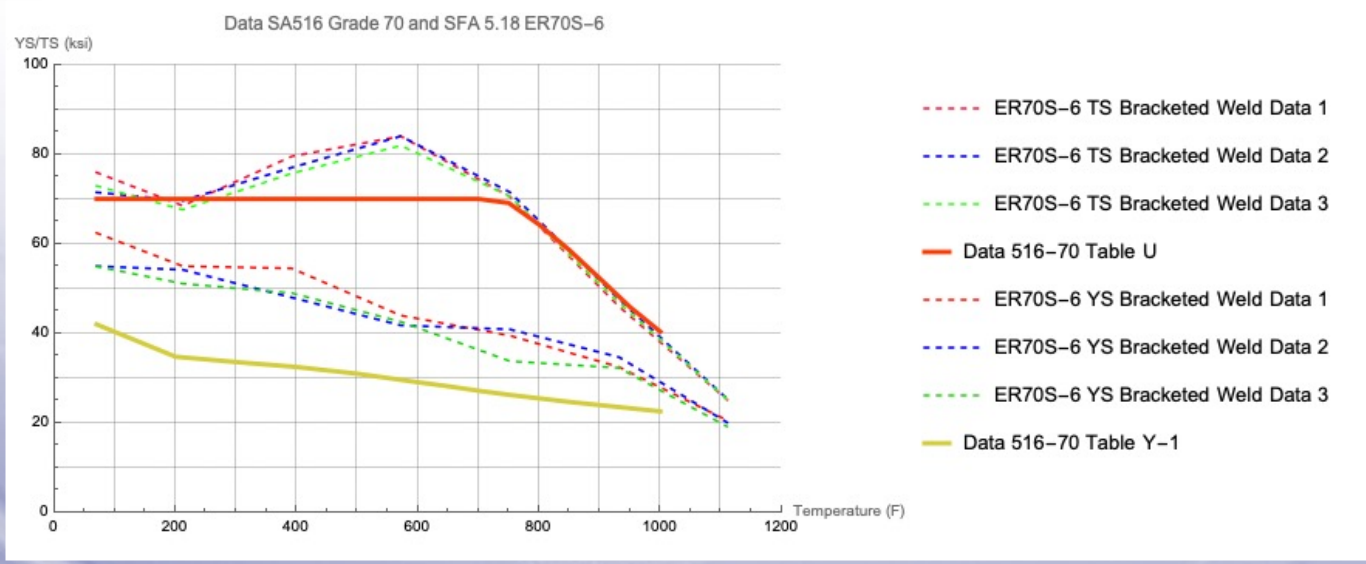
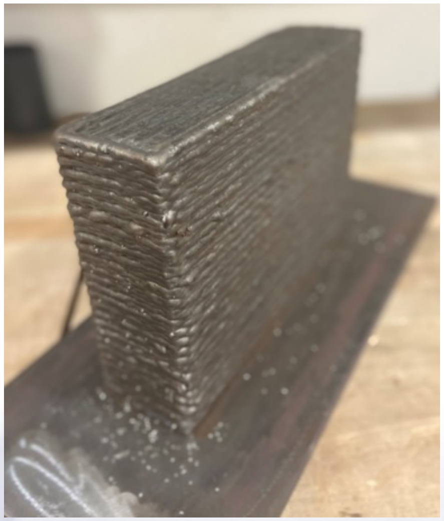
- **ER70S-6 can be qualified for either SA516-60 or SA516-70.**
- **Verification testing and controls are required at the Additive manufacturing facility.**







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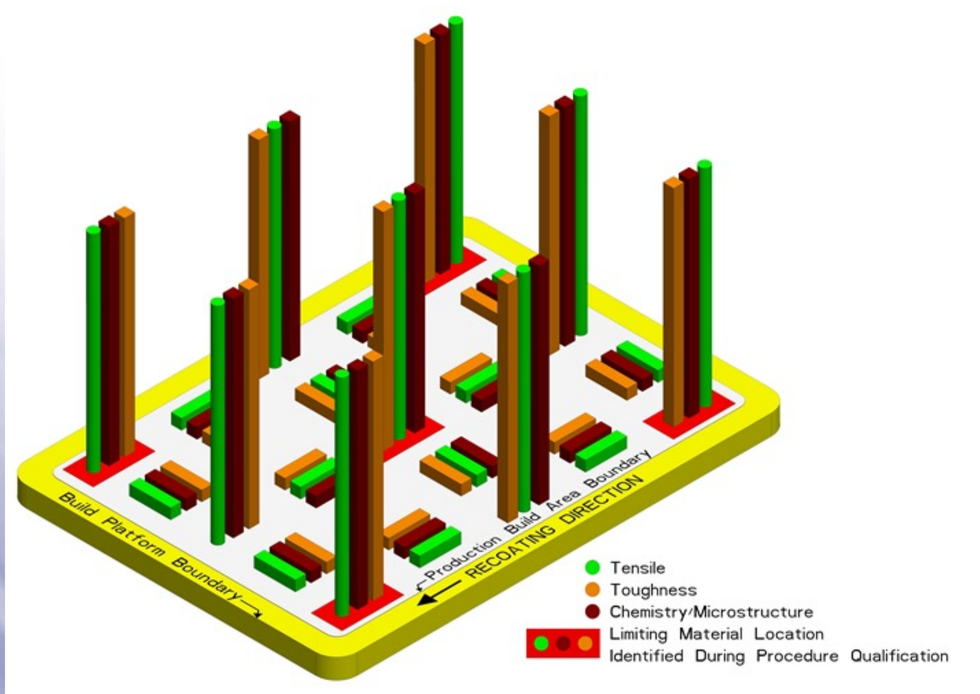
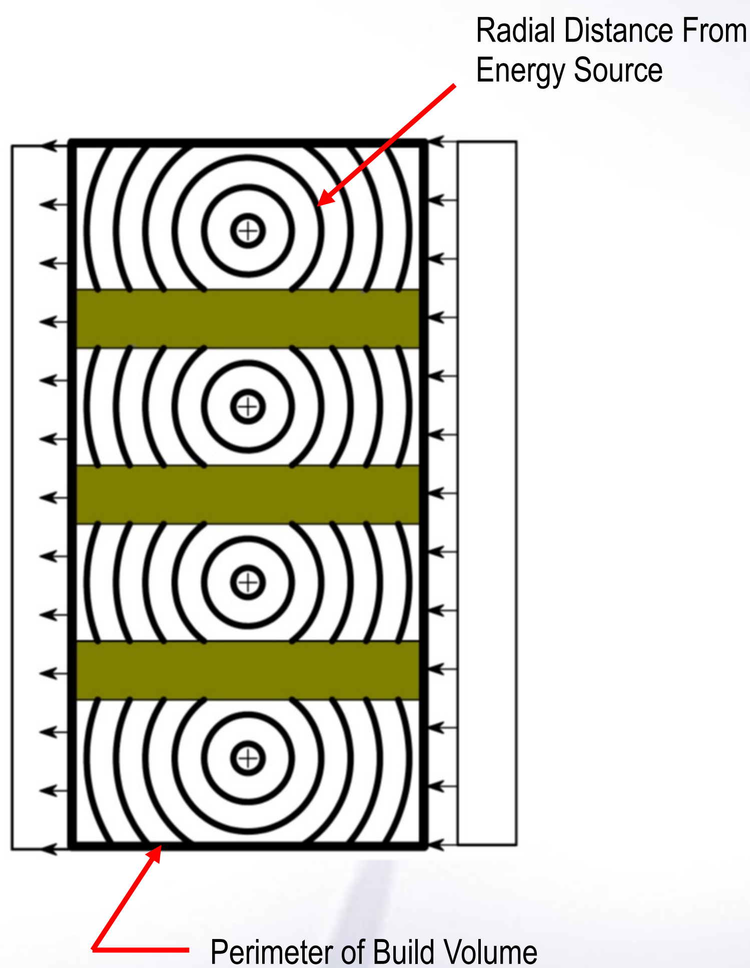
- **Additive Manufacturing Procedure**

- The Additive Manufacturer shall identify the locations of limiting material conditions for each energy source
- The qualification builds shall include a minimum of 3 powder lots.
- Understanding material cooling rates





Specimens for PBF Additive Manufacturing Procedure Qualification

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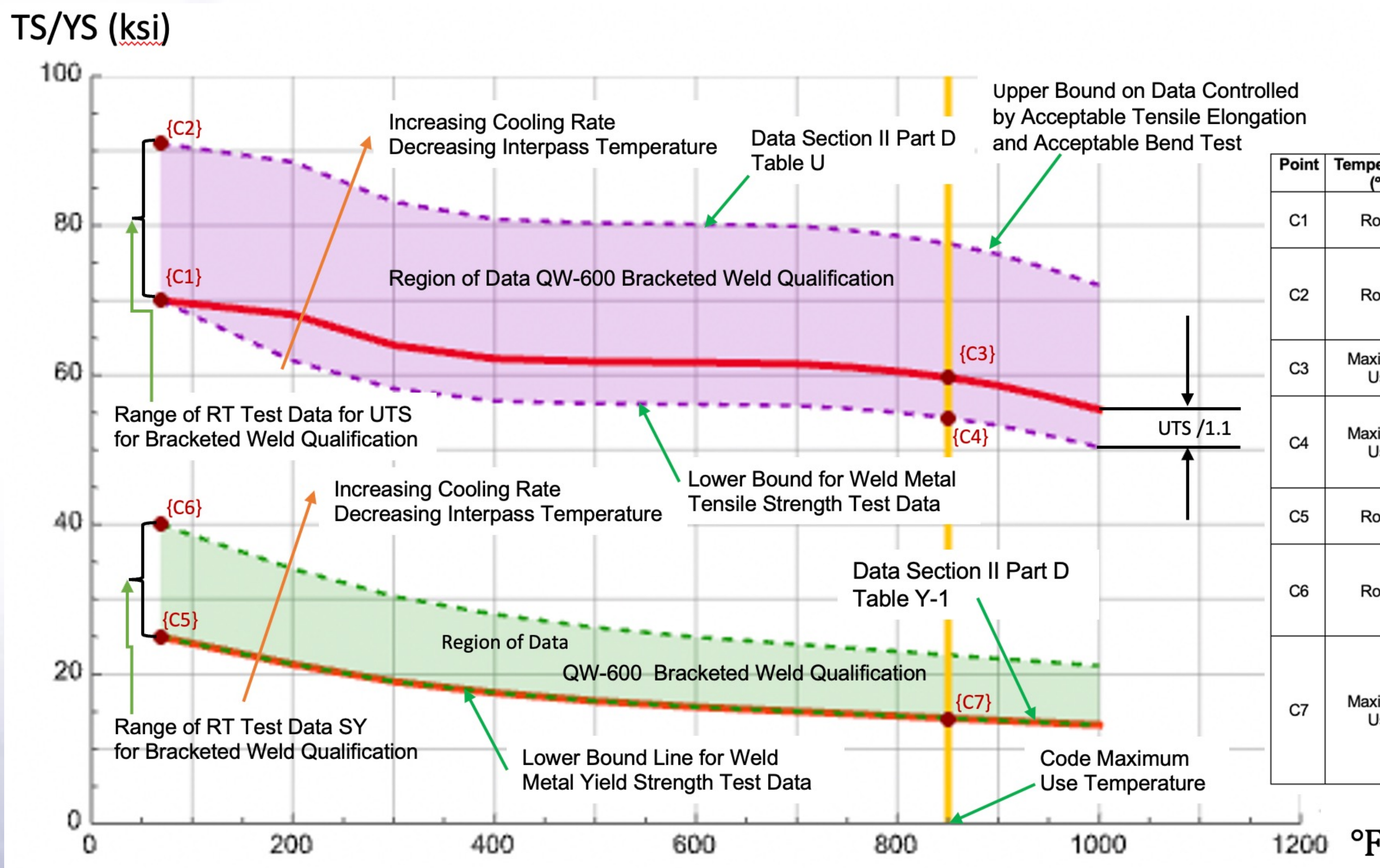
- **Bounding Criteria for DED Bracketed Weld Qualification**



Point	Temperature (°F)	Strength (ksi)	Description	Criteria
C1	Room	TS	Specified Minimum Tensile Strength	Specified Minimum Tensile from Material Specification
C2	Room	TS	Upper Bound of Tensile Strength	Elongation from Tension Test data is Equal to the Specified Minimum Value in the Material Specification
C3	Maximum Use	TS	Value from Table U at Maximum Use Temperature	From Section II Part D Table U
C4	Maximum Use	TS	Minimum Acceptable Value of Tensile Strength for High Temperature Test	Point 3/1.1 Value from Table U at Maximum Use Temperature Divided by 1.1
C5	Room	YS	Specified Minimum Yield Strength	Specified Minimum Tensile from Material Specification
C6	Room	YS	Upper Bound of Yield Strength	Elongation from Tension Test data is Equal to the Specified Minimum Value in the Material Specification
C7	Maximum Use	TS	Value from Table Y-1 at Maximum Use Temperature Minimum Acceptable Value of Yield Strength for High Temperature Test	From Section II Part D Table Y-1

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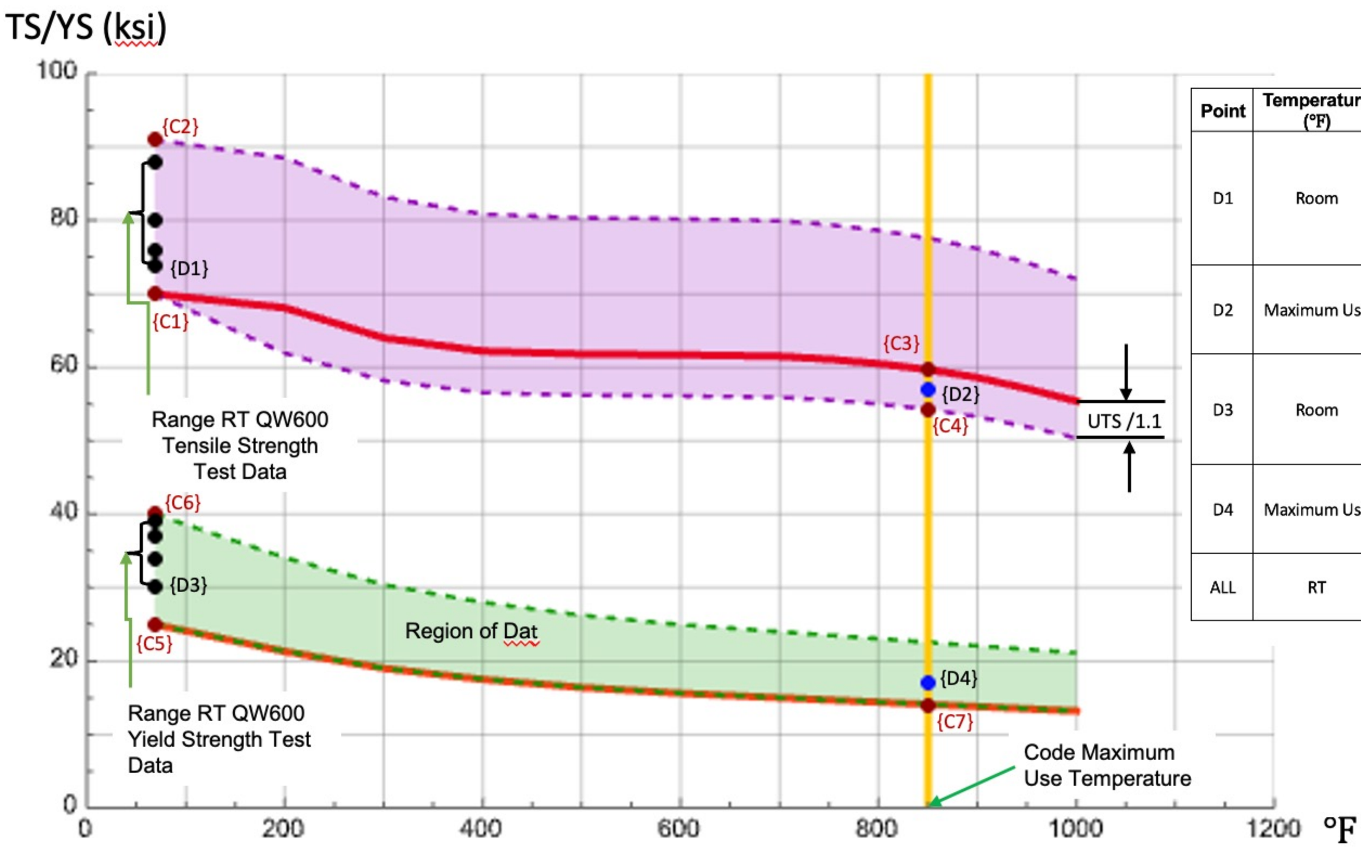
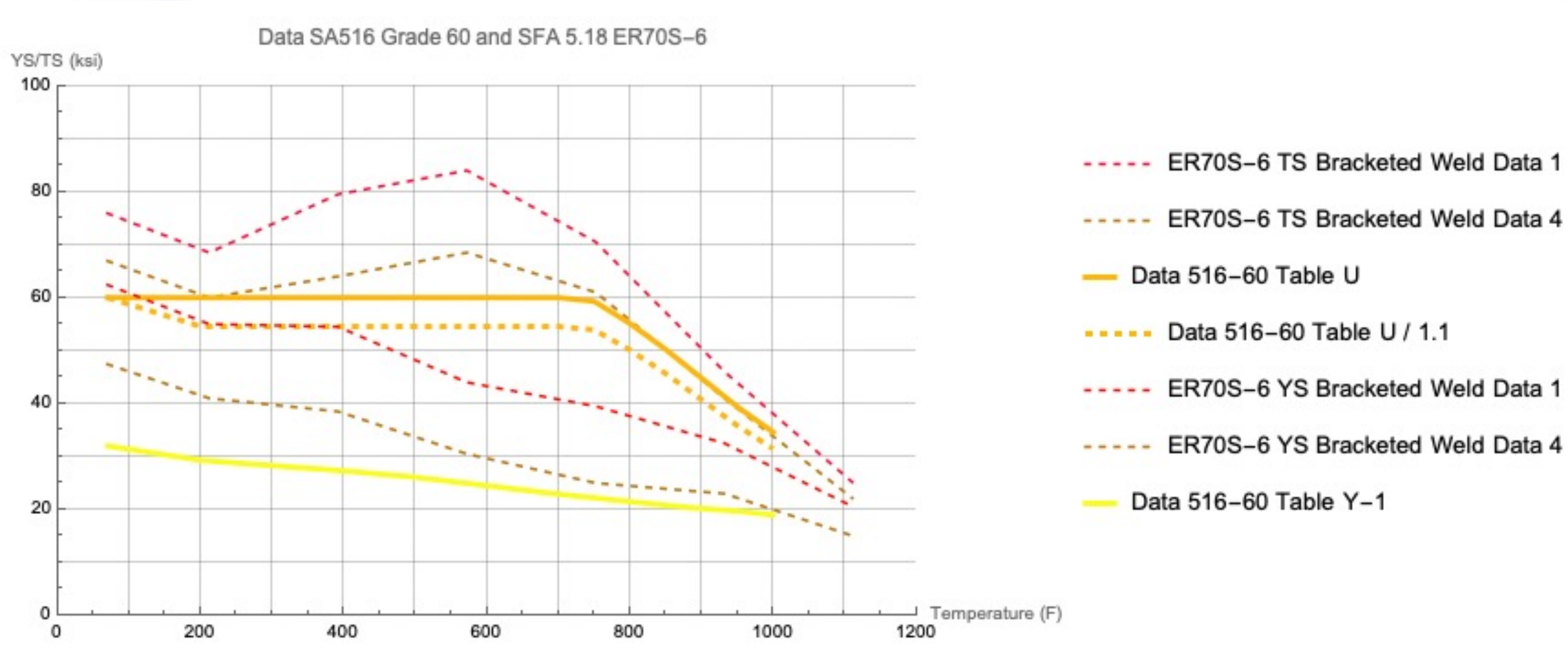
- **Bounding Criteria for DED Bracketed Weld Qualification**
  - Showing Example Test Data



Point	Temperature (°F)	Strength (ksi)	Description	Criteria
D1	Room	TS	Minimum Value of Tensile Strength from QW 600 Data	Minimum Tensile Strength and Elongation from the QW-600 Tests Shall Equal or Exceed the Specified Minimum Tensile Strength in the Material Specification (Point C1)
D2	Maximum Use	TS	High Temperature Tensile Strength Test Data Point	Minimum Tensile Strength Value from QW-600 Test Shall Equal or Exceed Value Calculated for Point C4
D3	Room	YS	Minimum Value of Yield Strength from QW 600 Data	Minimum Yield and Elongation from the QW-600 Tests Shall Equal or Exceed the Specified Minimum Yield Strength in the Material Specification (Point C5)
D4	Maximum Use	YS	High Temperature Yield Strength Test Data Point	Minimum Yield Strength and Elongation from QW-600 High Temperature Test Equal or Exceed Value of C7
ALL	RT	TS/YS	Range of QW 600 Tensile Data	Elongation from Tension Test is Below Specified Minimum in the Material Specification

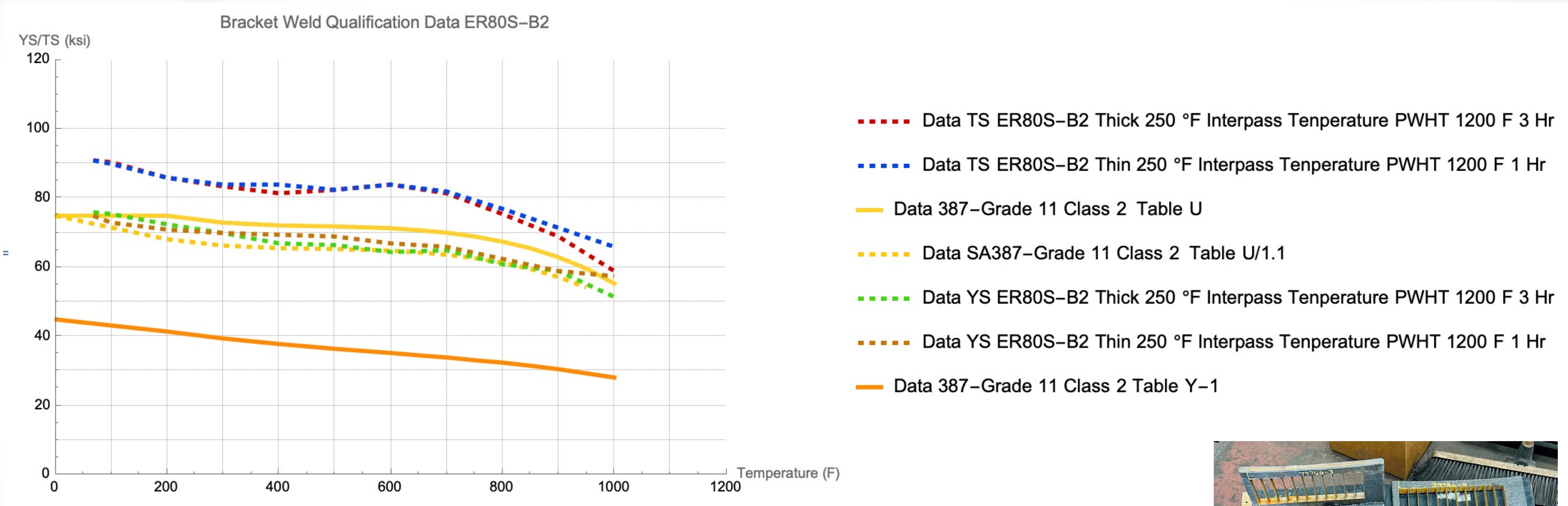
ASME Additive Manufacturing

- **Bracketed weld qualification data for ER70S-6 compared to proposed verification criteria for SA516-60.**



ASME Additive Manufacturing

- **ER80S-B2 compared to SA387 Grade 11 Class 2.**



SA 387 Elongation in 2 in. 22%

Temp (F)	Elongation Thick Sample (%)
68.	25.
100.	26.
200.	23.5
300.	22.5
400.	23.
500.	19.
600.	22.5
700.	24.5
800.	26.
900.	26.5
1000.	28.

Temp (F)	Elongation Thin Sample (%)
68.	29.
100.	28.
200.	23.5
300.	25.
400.	23.
500.	24.
600.	22.5
700.	25.
800.	26.
900.	27.
1000.	36.

Thick 9 Beads / Thin 2 Beads

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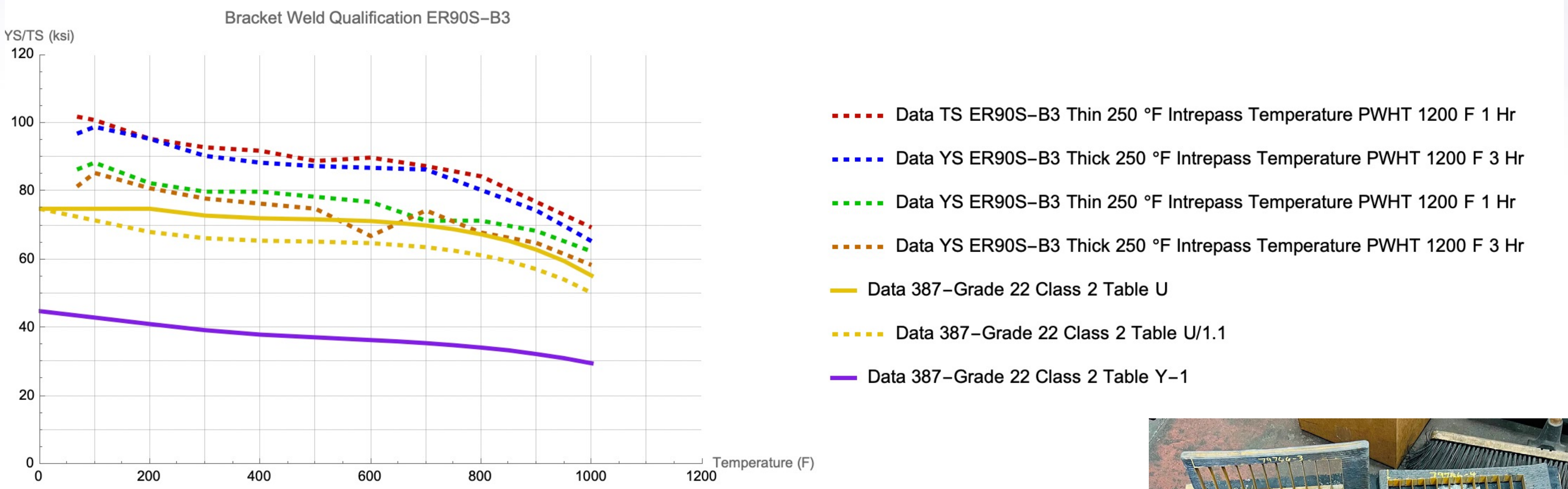
- **ER90S-B3 compared to SA387 Grade 22 Class 2.**



SA 387 Elongation in 2 in. 18 %

Temp (F)	Elongation Thick Sample (%)
68.	23.
100.	22.5
200.	22.5
300.	20.5
400.	20.
500.	19.5
600.	19.5
700.	18.
800.	20.5
900.	22.5
1000.	26.

Temp (F)	Elongation Thin Sample (%)
68.	24.
100.	23.
200.	23.5
300.	23.
400.	23.
500.	20.
600.	21.5
700.	20.5
800.	22.5
900.	25.
1000.	26.5

Thick 9 Beads / Thin 2 Beads

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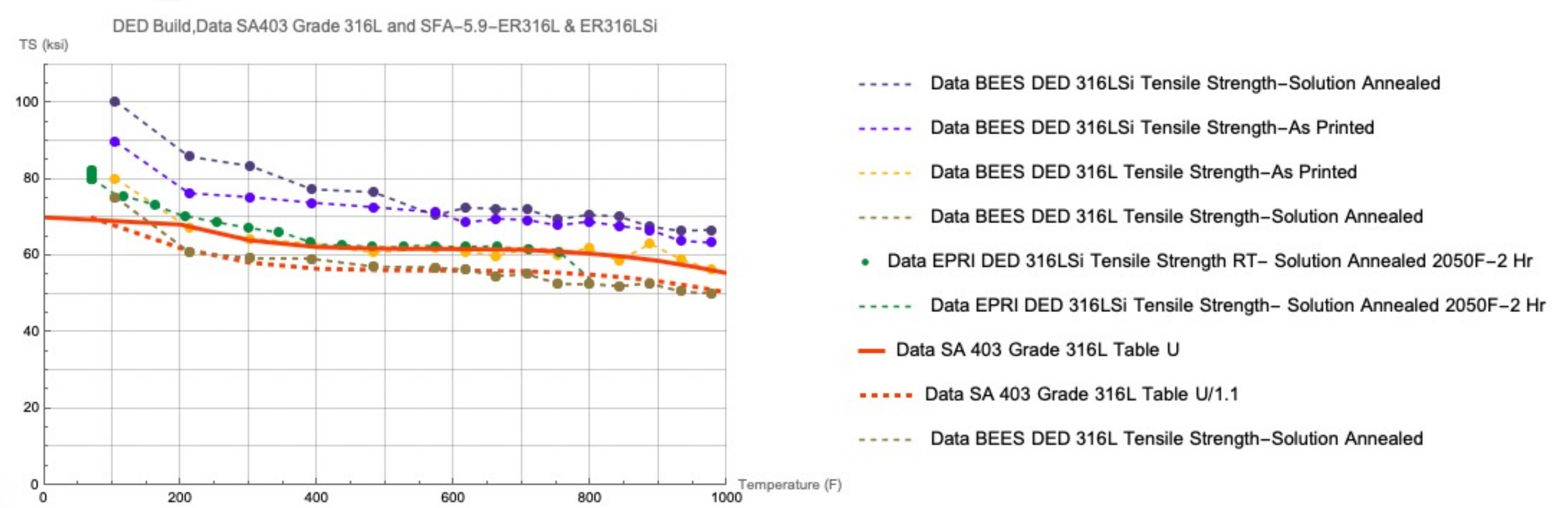
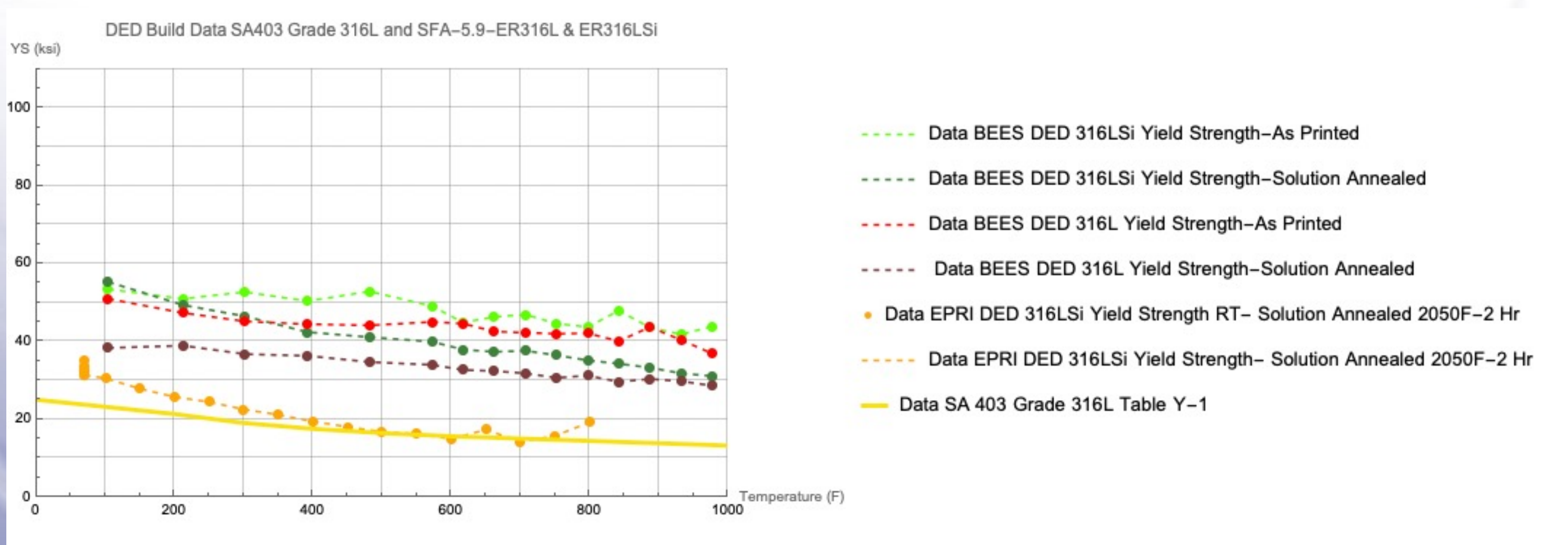
- **Tensile Properties for Weld Metal and DED Equipment Builds.**
  - **Data for 316L and 316LSi Filler Materials Shows the Variability in the AM Process.**





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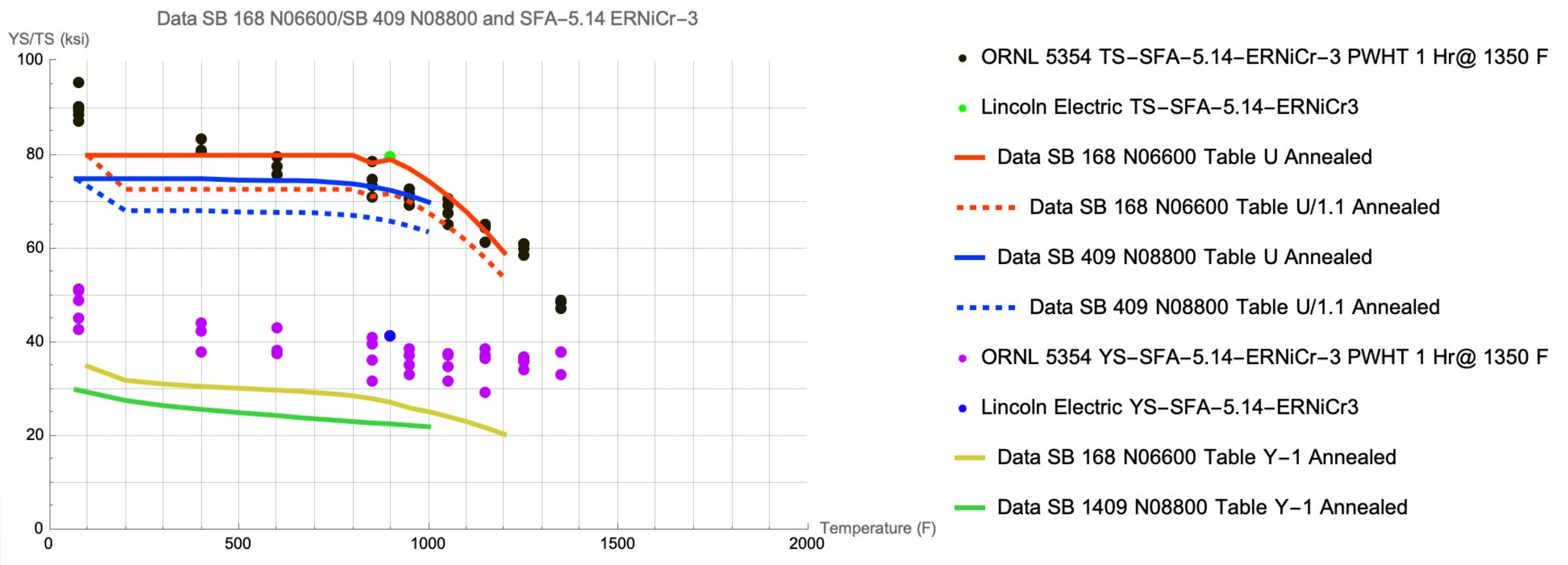
- **ERNiCr-3 compared to SB 168 N06600 and SB 409 N08800**



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- **Powder Bed Fusion Fatigue Evaluation**
  - Fatigue and flaw acceptance evaluation was developed under a DOE Funded Project with the Support of Savannah River National Lab.
  - The scope was performed by University of Michigan with Pingsha Dong as the principal investigator.
  - The Structural Stress Method and Welded Joint Fatigue Curve can be used for fatigue evaluation of PBF components. This is the current method adopted by the ASME Section VIII, Division 2 Code.
  - Code required examination of AM components can be guided using flaw acceptance criterion to identify fatigue-critical locations or hot spots resulting in cost effective NDE.

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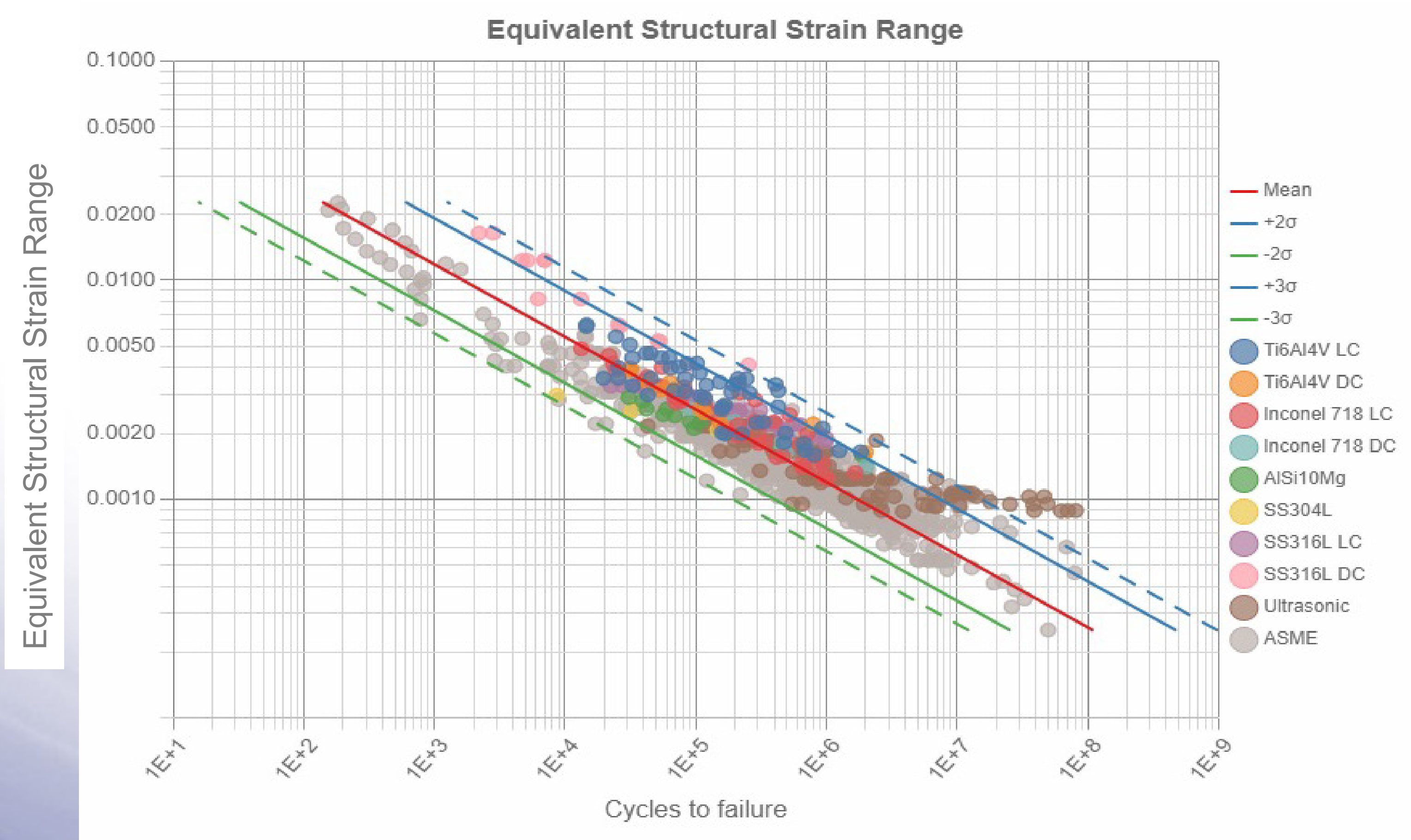
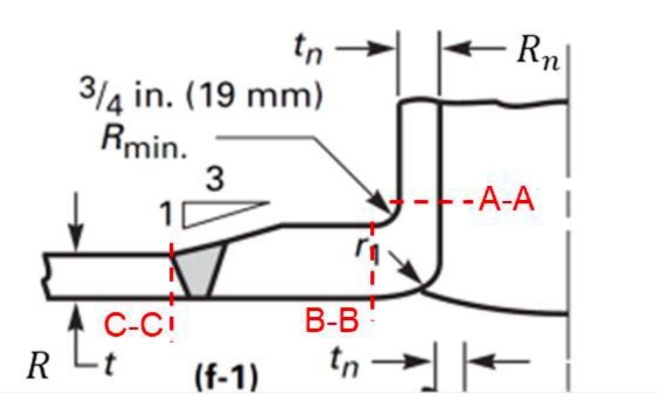
- **Powder Bed Fusion Fatigue Evaluation**
- Welded Joint Fatigue Curve Data for PBF Fatigue Evaluation
  - AM test data points considered: 295 load-controlled tests, 22 specimen types/geometries, over 400 data points were analyzed.

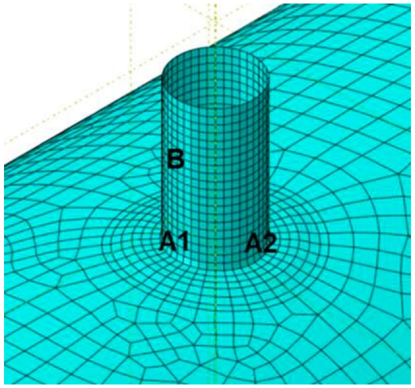


ASME Codification of Additive Manufacturing

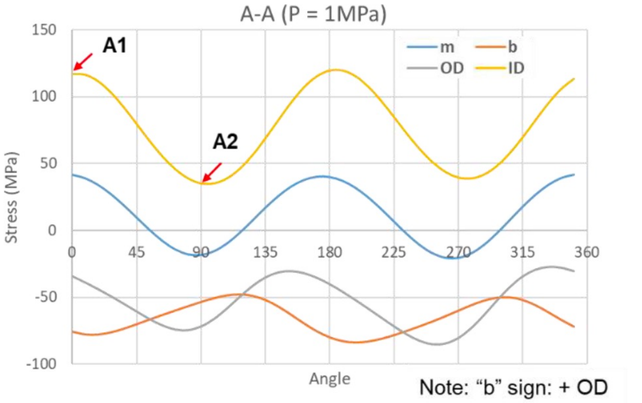
- **Component Specific Directed NDE**
  - Flaw acceptance criteria can be used to focus NDE to critical areas.
  - Using a component specific analysis would require code change in examination methodology.



Typical ASME Nozzle Detail

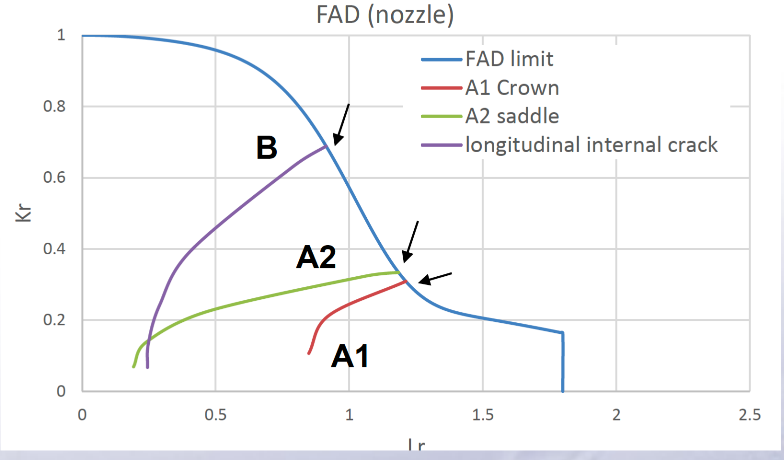


FEA Model



Stress Distribution from Pressure Loading

- A1: $\frac{a}{t} < 0.35$;
- A2: $\frac{a}{t} < 0.61$
- B: $\frac{a}{t} < 0.9$ (longitudinal internal surface crack:



Failure Assessment Diagram

ASME Codification of Additive Manufacturing

- **Integration of AM into ASME Codes and Standards**
- We would like to achieve consistent technical criteria for AM through ASME Codes and Standards.
- The goal is to have AM requirements in ASME Construction Codes and Product Standards with the 2025 Editions with Code Cases preceding the 2025 Edition.

Section I (Power Boilers) - presentation on AM during the May 2023 Code Week.

Section III (Nuclear Facility Components) - has formed Task Groups to begin incorporation of AM and has balloted code cases for review and comment.

Section VIII (Pressure Vessels) - has formed a Task Group to begin incorporation of AM.

B31 (Code for Pressure Piping) - B31 has issued a review and comment ballet for a code case for using direct energy deposition AM.

B16 (Standards for Pipes and Fittings) - has formed a Task Group to begin incorporation of AM.

ASME SETTING THE STANDARD

ASME Codification of Additive Manufacturing

- **Advanced Materials and Manufacturing Technologies Roadmap**
  - Technology to support ASME Codification of AM
- In situ process monitoring
  - Focus on NDE.
  - Codification would require criteria for the in-situ monitoring system.
  - Correlate defects to ASME existing relevant flaw sizes.
  - Data comparing situ monitoring to existing NDE techniques.
- Creep Behavior
  - Accelerated creep testing criteria needs to be initiated in ASME Section II.
  - Utilize existing creep data for weld metal for current materials.

Table 302.3.5
Weld Joint Strength Reduction Factor, *W*

Steel Group	Component Temperature, T_i, °C (°F)														
	≤427 (≤800)	454 (850)	482 (900)	510 (950)	538 (1,000)	566 (1,050)	593 (1,100)	621 (1,150)	649 (1,200)	677 (1,250)	704 (1,300)	732 (1,350)	760 (1,400)	788 (1,450)	816 (1,500)
Carbon Steel	1	1	1	1	1	1	1	...	...	...	...	...	...	...	...
CrMo [Notes (1)–(3)]	1	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64	...	...	...	...	...	...
CSEF (N + T) [Notes (3)–(5)]	...	...	...	1	0.95	0.91	0.86	0.82	0.77	...	...	...	...	...	...
CSEF [Notes (3), (4)] (Subcritical PWHT)	...	...	1	0.5	0.5	0.5	0.5	0.5	0.5	...	...	...	...	...	...
Autogenous welds in austenitic stainless grade 3xx, and N088xx and N066xx nickel alloys [Note (6)]	...	...	...	1	1	1	1	1	1	1	1	1	1	1	1
Austenitic stainless grade 3xx and N088xx nickel alloys [Notes (7), (8)]	...	...	...	1	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64	0.59	0.55	0.5
Other materials [Note (9)]	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

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- **ASME Codification of Additive Manufacturing**

Questions
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