FWP 71843

Pacific Northwest NATIONAL LABORATORY

Integrated Process Improvement Using Laser/Friction Stir Processes for Manufacturing of Nickel Super alloy Fabrications

Glenn Grant and Chris Smith
Saumyadeep Jana, Jens Darsell, Mageshwari Komarasamy, Woongjo Choi
Pacific Northwest National Laboratory

Anand Kulkarni and Kyle Stoodt
Siemens Corporation, Charlotte, NC

Paul Jablonski
NETL Albany

U.S. DEPARTMENT OF ENERGY BATTELLE

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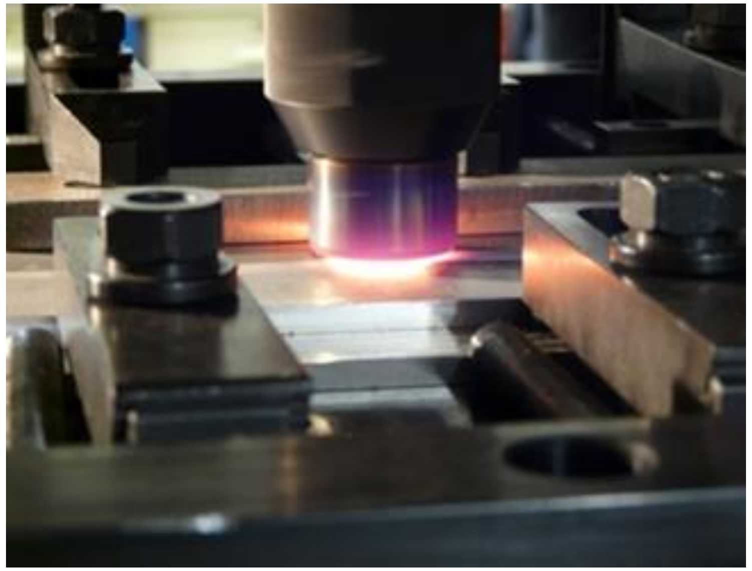
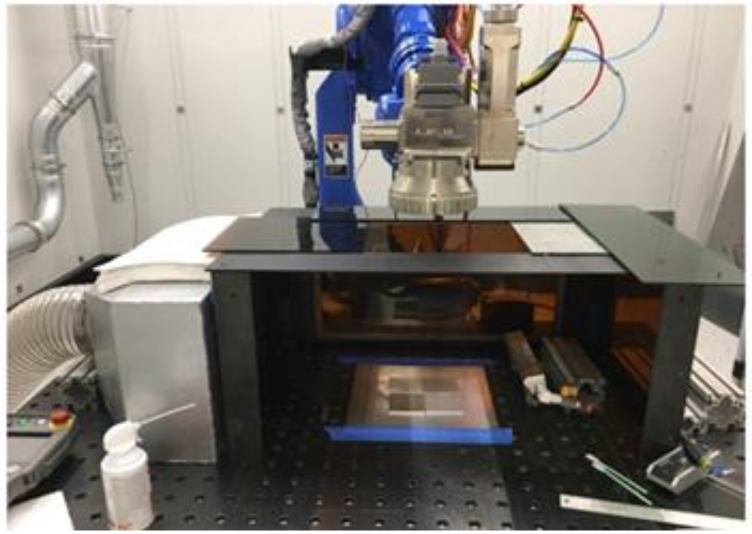
Vision and Project Objective

Vision: Development of new advanced manufacturing processes to reach higher efficiency and lower cost in power generation systems for OEM components, as well as for repair and refurbishment.



FSW of High Melting Point Material at PNNL

Objective: Investigate and demonstrate an integrated approach using both Laser Processing (LP) and Friction Stir Welding and Processing (FSW/P) to fabricate and repair Nickel based super alloys



Robotic Laser Ablation System
Courtesy: IPG Photonics

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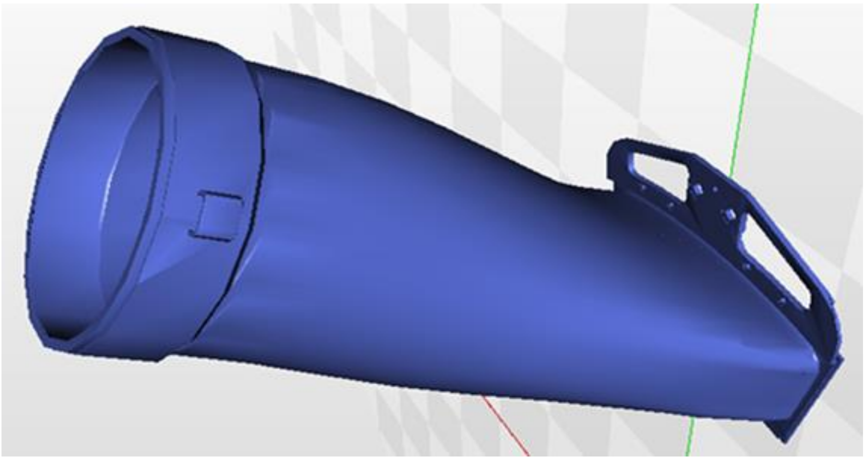
Background

- Fabrication challenges
  - Cycle time and cost of diffusion bonding (DB)
    - Surface preparation needed for DB (and for later application of thermal barrier coatings),
  - Hot cracking / liquation cracking with fusion welding
  - For large Ni alloy castings near surface casting defects.
- Repair challenges
  - In-service degradation of Thermal Barrier Coatings (TBC) requires time consuming stripping/ cleaning of the TBC prior to recoating.
  - Crack or damage repair by fusion welding or overlay processing leads to hot cracking during weld repair

Transition Duct
Courtesy: www.siemens.com/press



Transition Duct
Courtesy: Siemens

Approach & Major Taks

- Laser Processing - Siemens Lead
  - Investigate laser ablation (LA) of TBC bond coat for repair/return to service
  - Laser ablation as a surface treatment to enhance diffusion bonding

- Friction Stir Welding / Processing (FSW/P) - PNNL Lead
  - Compare FSW/P fusion welding & diffusion bonding
  - Investigate FSW to achieve high performance joints in superalloys
    - Haynes 282, 233 and Inconel 617
  - Develop FSW process for joining Ni based alloys
  - Discover the effect of FSW parameters and PWHT on creep

Approach & Major Tasks

- Friction Stir Processing (FSP) – PNNL Lead
  - For surface treatment or repair (PNNL)
  - Demonstrate ability to repair defected or damaged Ni alloy Castings
  - Demonstrate method to produce local improvements in creep
  - Demonstrate ability to prepare a surface for bond coat/TBC

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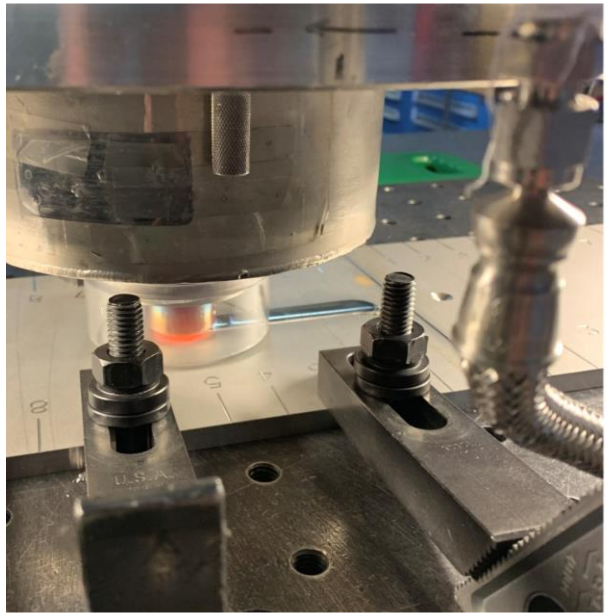
FSW/P Highlights

- Materials: Haynes 282, 233, and Inconel 617
- Acceptable visual and internal quality achievable
- Appreciable tool wear not observed
- Oscillatory behavior noted with 6 mm pin tool under temperature control,
  - Acceptable welds could still be generated
  - Controller tuning required .
- Some difference in process parameters required between alloys

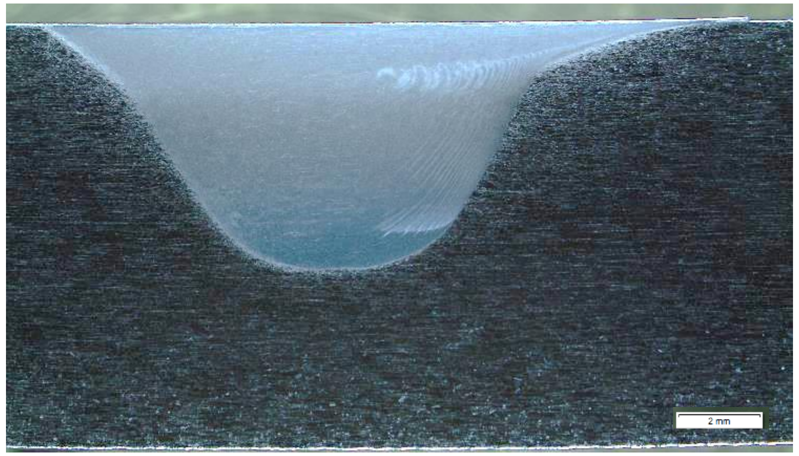
FS Tool w/ 6 mm Pin Length

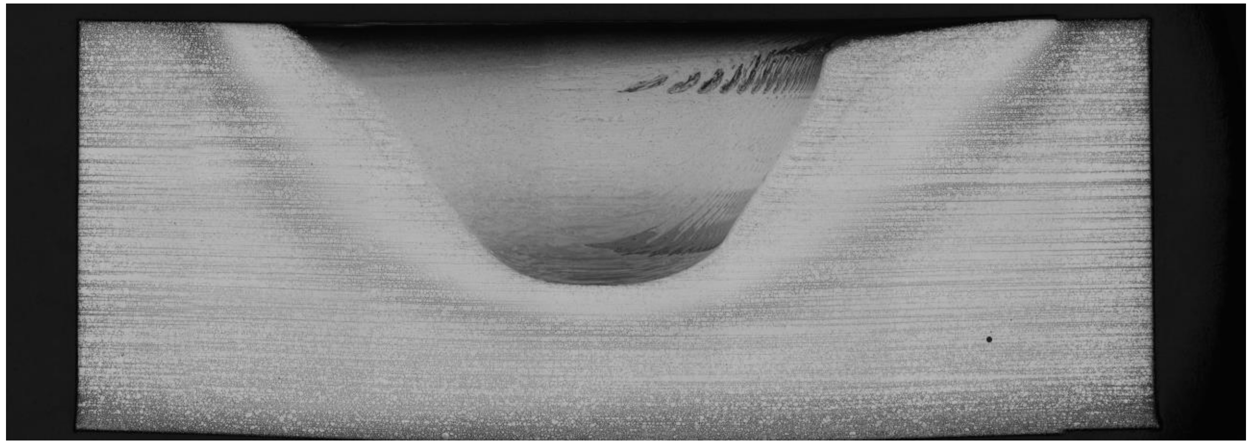


FSP in Progress

Haynes 282 FSP Face Surface

Inconel 617 FSP @ 850°C

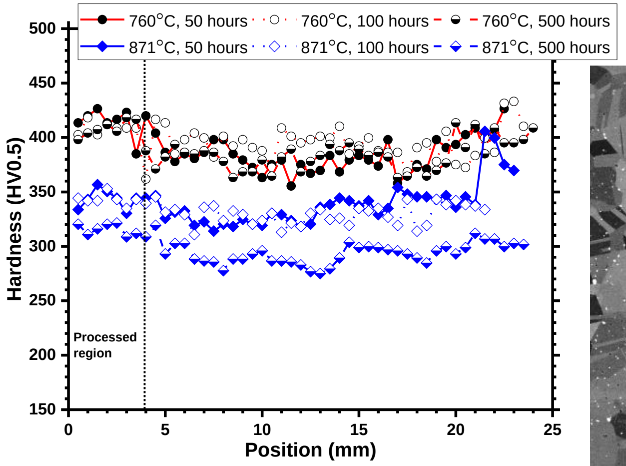




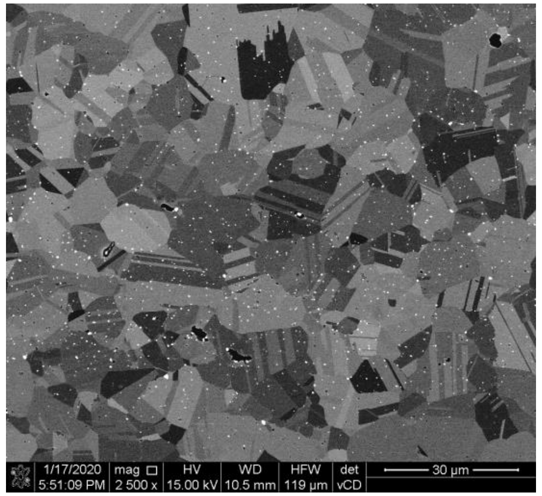
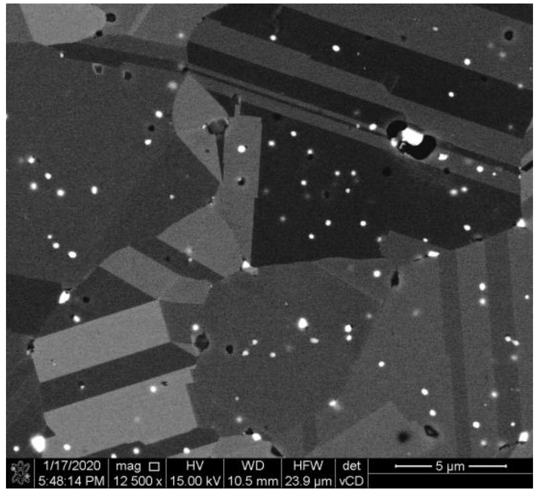
Haynes 282 FSP @ 800°C

Post Weld Heat Tx & Simulated Service Effect

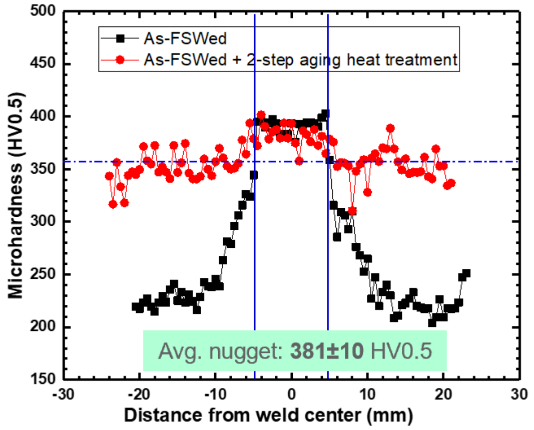
- Grain refinement was observed in nugget and grain growth was noted in the aged condition.
- FSW nugget, HAZ & Base Material Similar Hardness after Heat Tx
- Both in-grain and grain boundary carbide phases were observed.



Simulated Service Micro Hardness

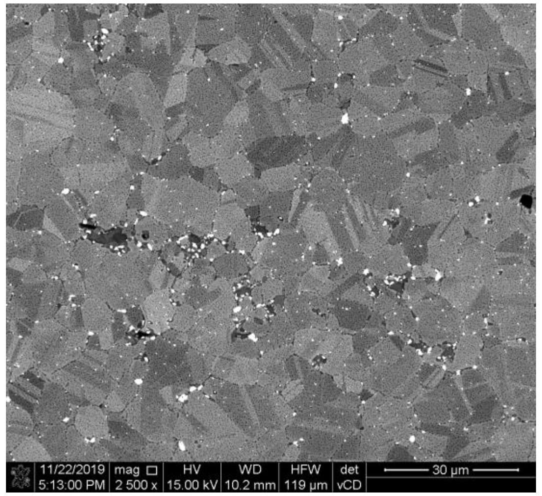
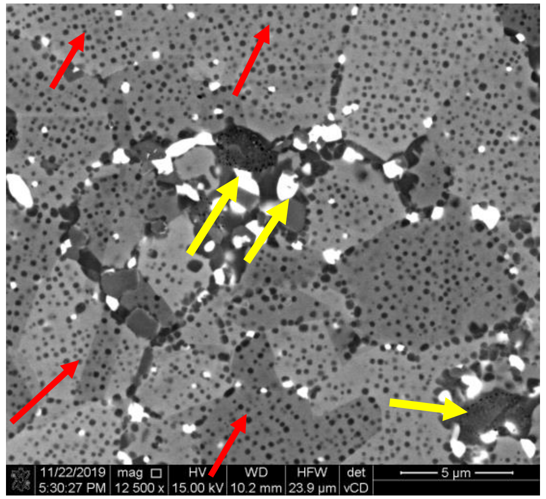
FSP + 2 step heat tx



Simulated Service

Temp (°C)	Time (hours)
760	50, 100, 500
871	50, 100, 500

- Microstructural Analysis: Processed Region
  - No change observed other than at 500 Hours at 871°C
  - Coarsening of γ' precipitates observed
    - ✓ Not observed before thermal exposure
    - ✓ Due mainly to the fine precipitate size in the as-heat treated sample.
    - ✓ γ' coarsening leads to reduced hardness observed
  - Precipitation of other phases observed

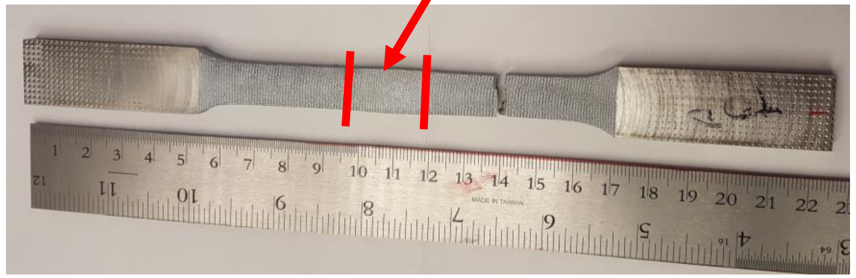
FSP + 2 step heat tx + 500 hrs @ 871°C

FSW Properties vs. Processing Conditions

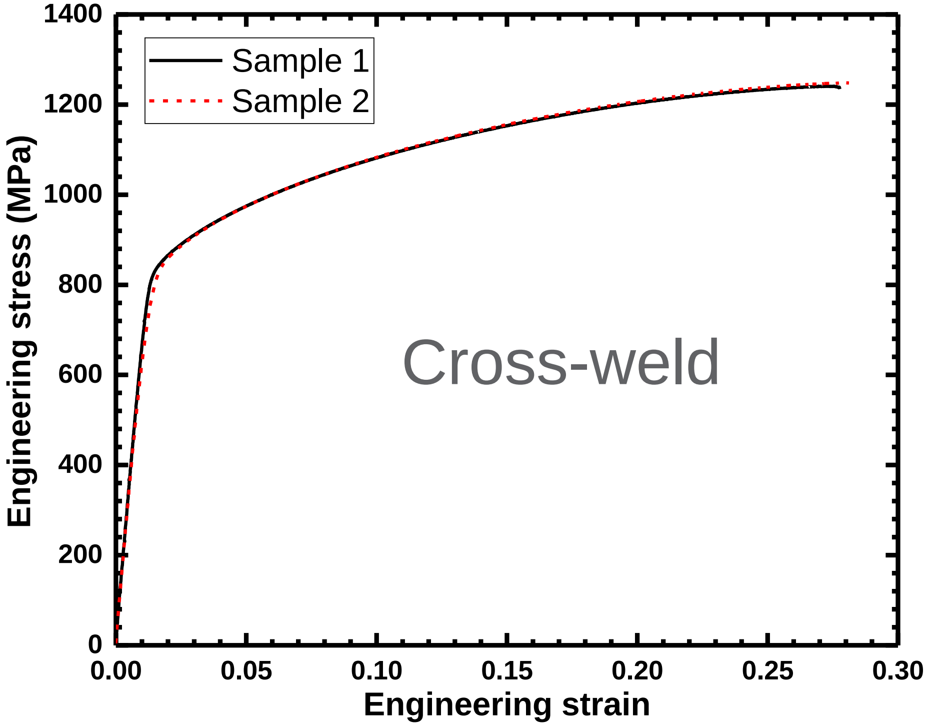
- Cross-Weld Tensile Test
  - After 2 Step Heat Treatment
  - Performed at Room Temperature
  - Test parallel to rolling direction
  - Plastic deformation initiated in base metal
  - Failure in base metal
  - Nugget deformation also present

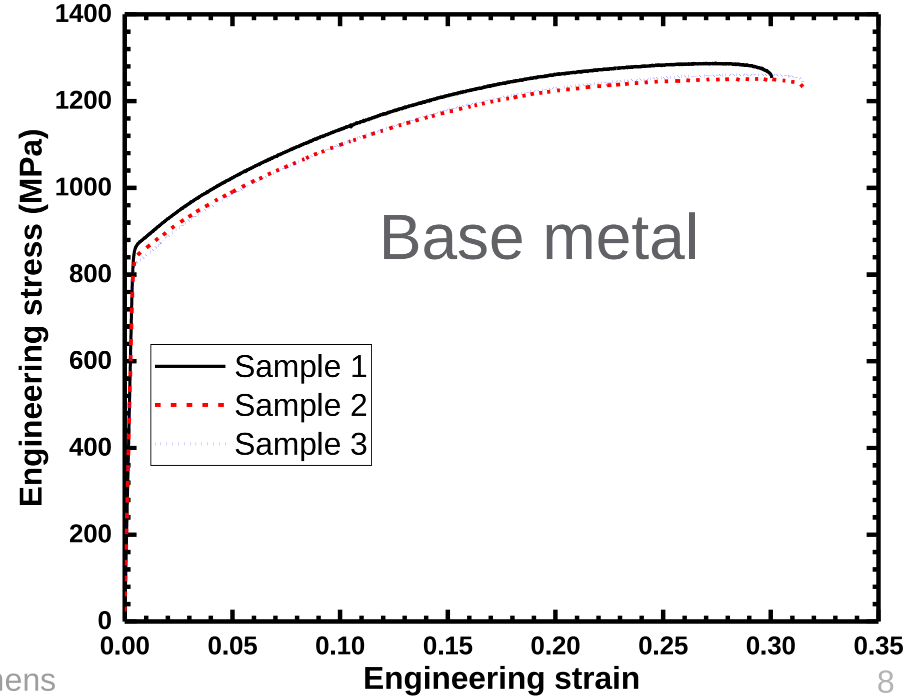
- Step 1:
  - 1010°C(1850°F) / 2 hours / Air Cooled
- Step 2:
  - 788°C(1450°F) / 8 hours / Air Cooled

FSP Region



Room Temperature Tensile Test Coupon

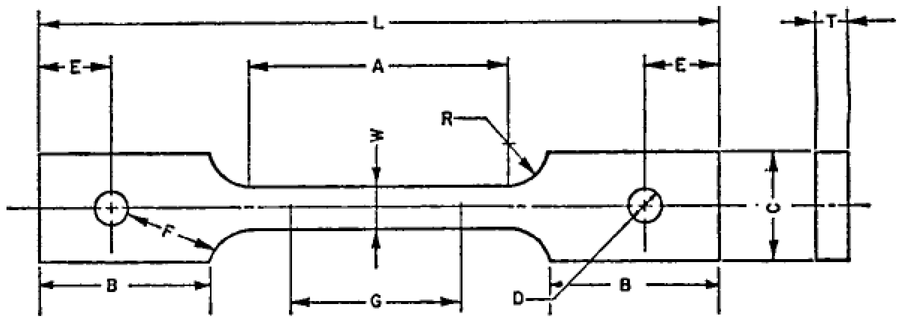




		YS (MPa)	UTS (MPa)	El%
Cross-weld	Sample 1	830	1240	26
	Sample 2	817	1247	26
	Avg.	**824±9**	**1244±5**	**26**
Base metal	Sample 1	869	1287	29.3
	Sample 2	847	1250	31
	Sample 3	833	1261	31
	Avg.	**850±18**	**1266±19**	**30±1**

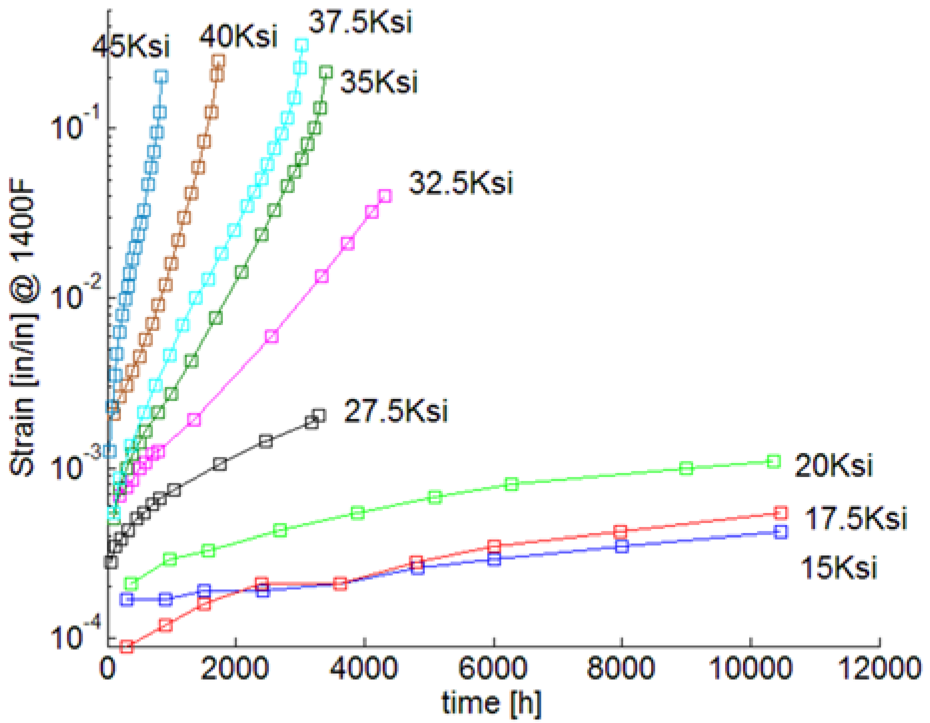
FSW Properties vs Processing Conditions

- Creep Testing of FSW 282
  - Screening Study: Full Creep Test Study Not Viable with Planned Project Schedule
  - Shorter Term / Higher Stress Levels
    - ✓ 310 MPa (45 ksi)
    - ✓ 190 MPa (27.5 ksi)



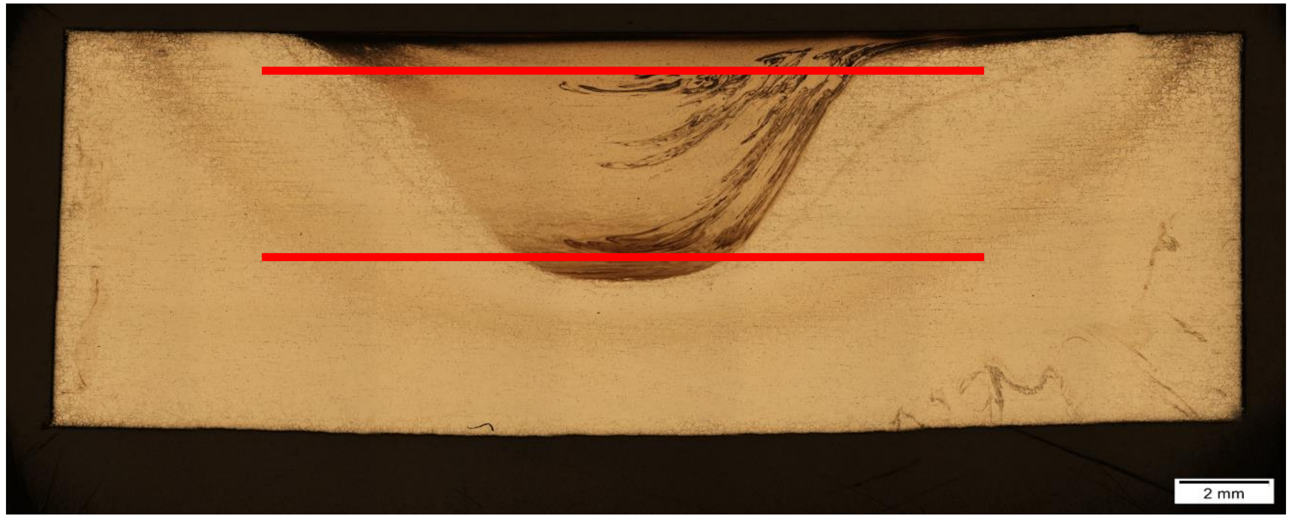
Dimensions, mm [in.]	
G—Gage length	50.0 ± 0.1 [2.000 ± 0.005]
W—Width (Note 1)	12.5 ± 0.2 [0.500 ± 0.010]
T—Thickness, max (Note 2)	16 [0.625]
R—Radius of fillet, min (Note 3)	13 [0.5]
L—Overall length, min	200 [8]
A—Length of reduced section, min	57 [2.25]
B—Length of grip section, min	50 [2]
C—Width of grip section, approximate	50 [2]
D—Diameter of hole for pin, min (Note 4)	13 [0.5]
E—Edge distance from pin, approximate	40 [1.5]
F—Distance from hole to fillet, min	13 [0.5]

Creep Testing Coupon Geometry



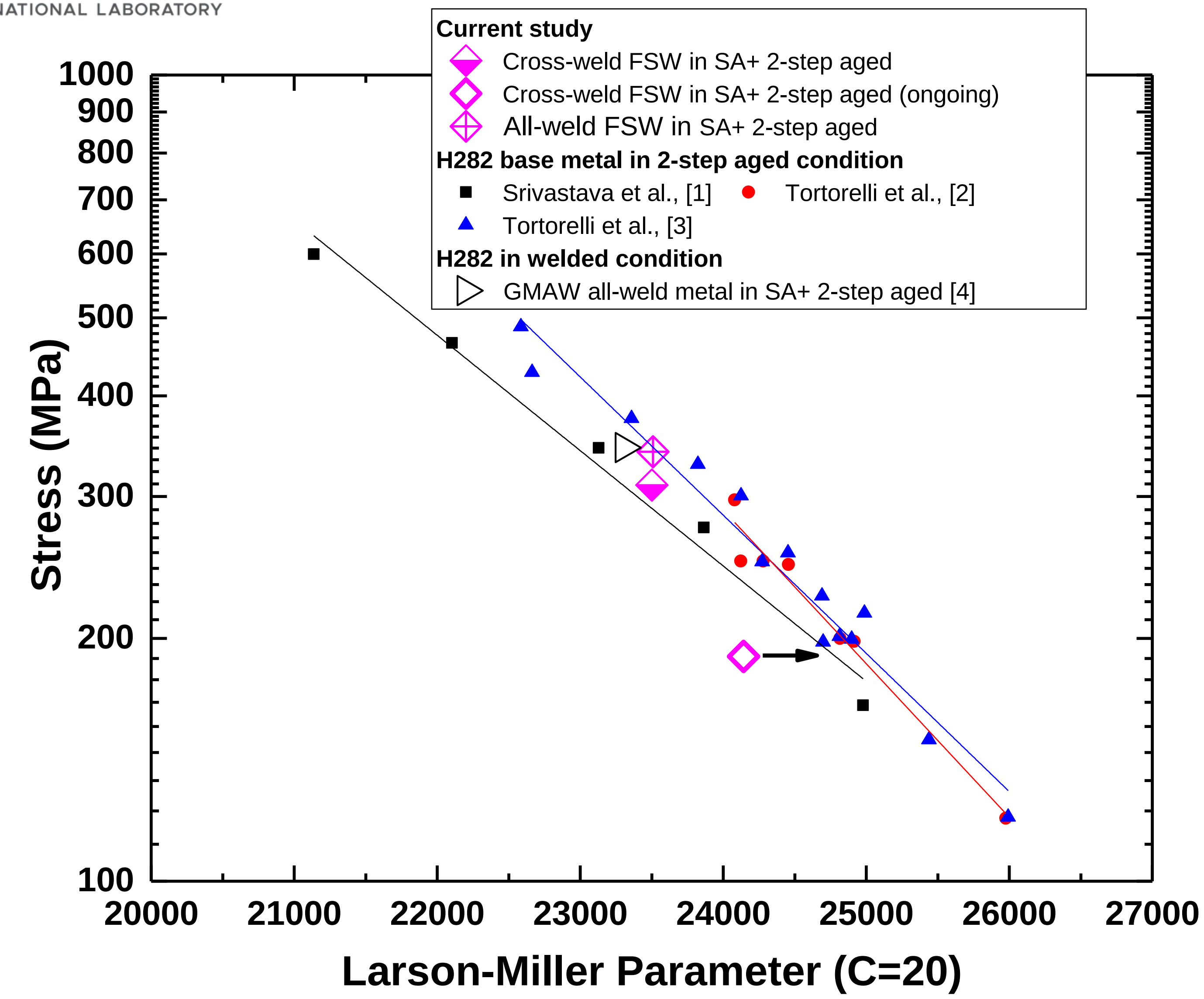
Creep Data for Haynes 282 Base Material*

* C. Shen, Modeling Creep-Fatigue-Environment Interactions in Steam Turbine Rotor Materials for Advanced Ultra-Supercritical Coal Power Plants: Final Report, DOE/NETL Cooperative Agreement DE-FE0005859, April 2014



Creep Testing Coupon Material Area

FSW Properties vs Processing Conditions

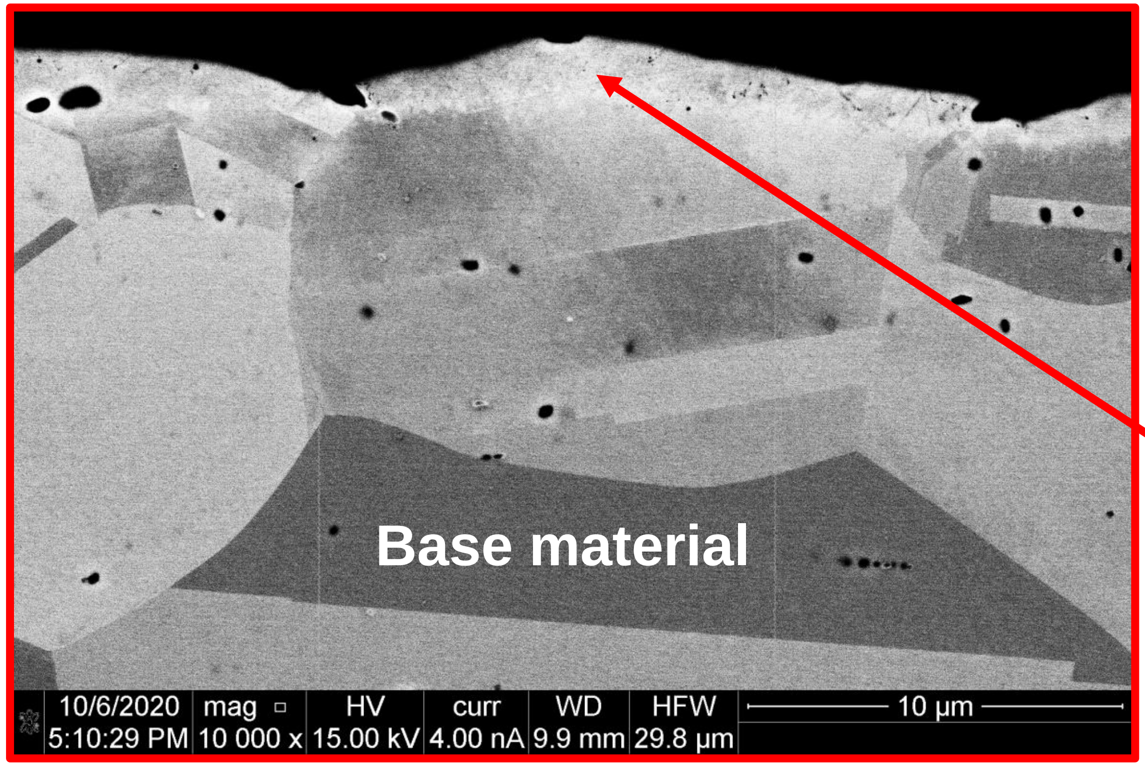


- FSP
  - Processing temperature: 850°C
- Post FSP Heat Treatment:
  - Solution annealing +
  - Two-step aging heat treatment
- Creep test conditions:
  - 760°C and 310 MPa (Completed)
  - 760°C and 190 MPa (Ongoing)
    - In the secondary creep regime

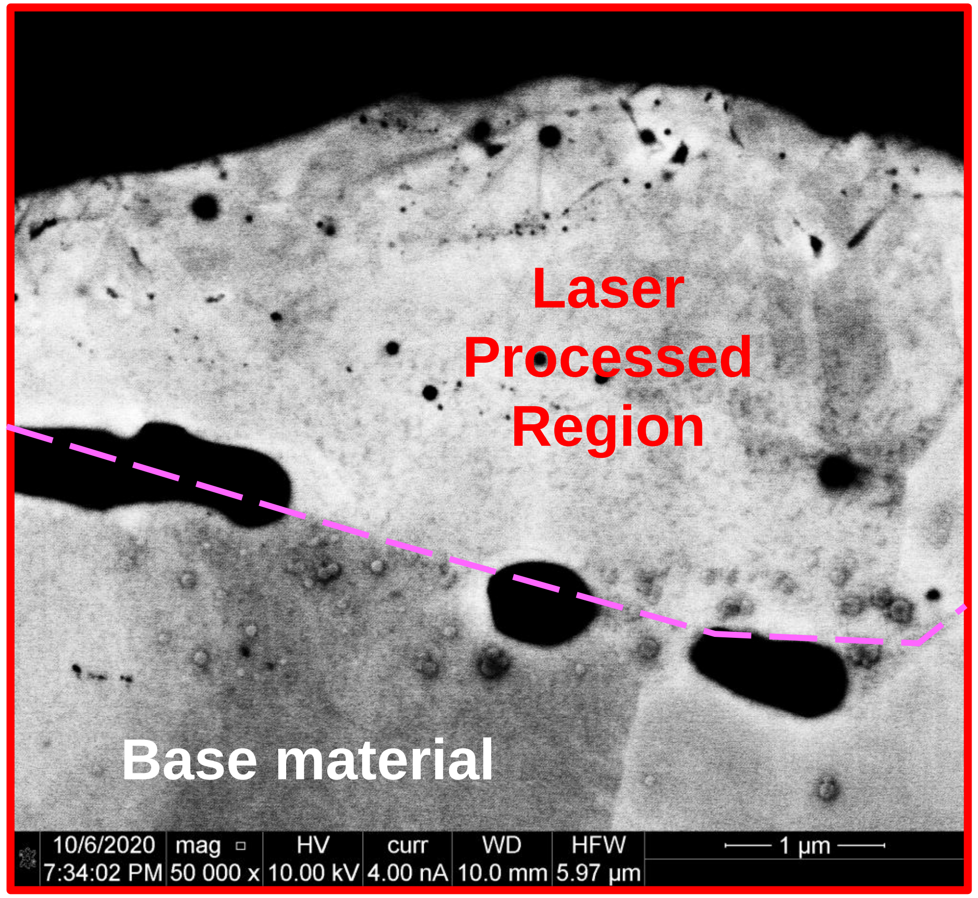
1. S. Srivastava, J. Caron, L. Pike, Recent developments in the characteristics of HAYNES 282 alloy for use in A-USC applications, in: Proceedings From the 7th International Conference on Advances in Materials Technology for Fossil Power Plants October 22–25, 2013, pp. 120–130
2. P. Tortorelli, K. Unocic, H. Wang, M. Santella, J. Shingledecker, Ni-based alloys for advanced Ultrasupercritical steam boilers, in: Fossil Energy Crosscutting Research Program Review, April 25, 2015, Pittsburgh, Pennsylvania, 2015.
3. P. Tortorelli, K. Unocic, H. Wang, M. Santella, J. Shingledecker, V. Cedro, III, Long-term creep-rupture behavior of Inconel® 740 AND Haynes® 282, Proceedings of the ASME Symposium on Elevated Temperature Application of Materials for Fossil, Nuclear, and Petrochemical Industries March 25-27, 2014.
4. Haynes 282, Haynes international

Ablation via Laser Processing: Microscopy

- Summary
  - Depth of affected region ~0.5 to 3.3 µm
  - Evidence of melting
  - Cracking not observed
  - Dark particles along boundary with base material
  - Some porosity observed

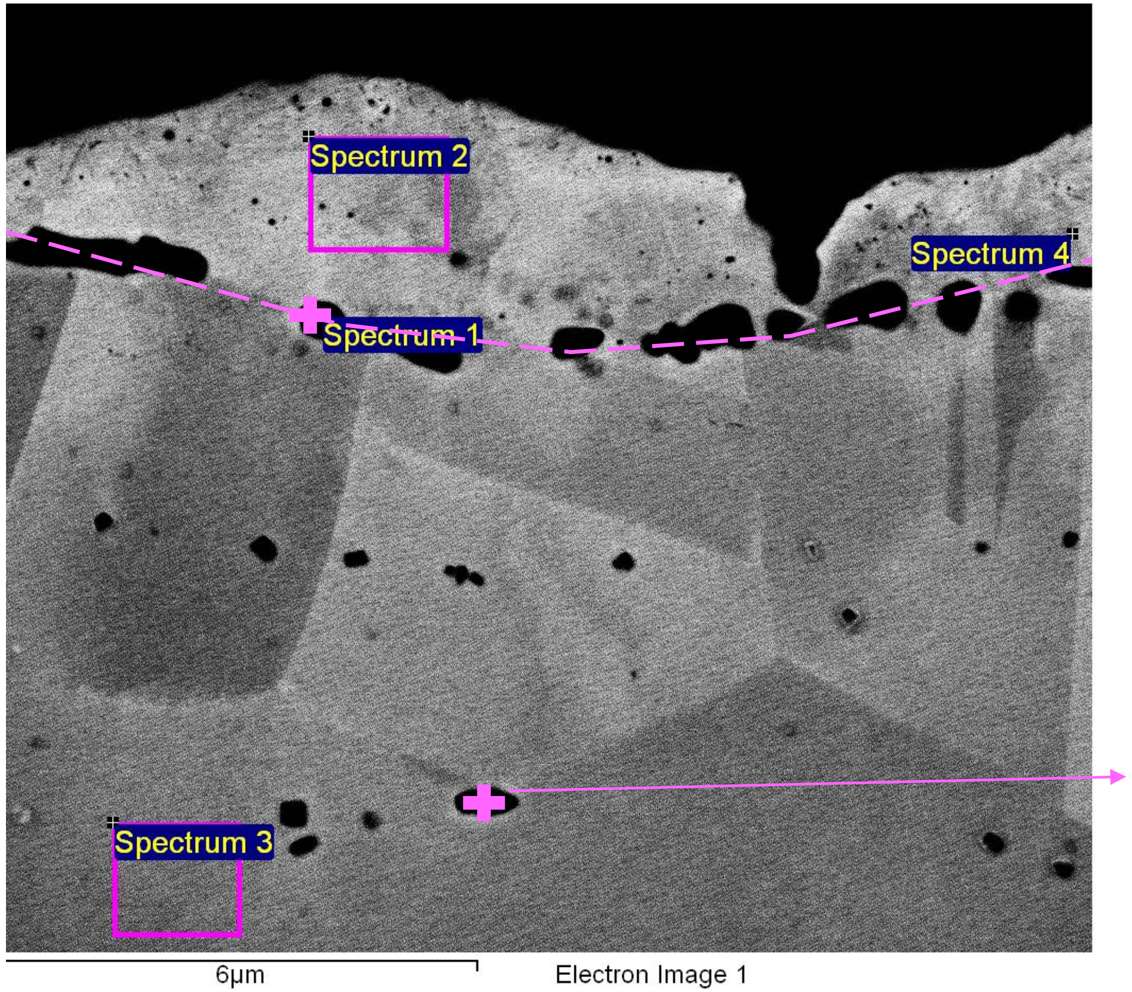


Laser processed region



Laser Ablation Compositional Analysis

- Analysis Summary
  - In LA processed region, Al, Ti and Cr fraction reduce while Fe and Mo fraction increased
  - Dark particles in boundary are rich in Al and O
    - ✓ Aluminum oxide
  - Dark particles in base material are rich in Mo and Ti
    - ✓ Ti and Mo carbides

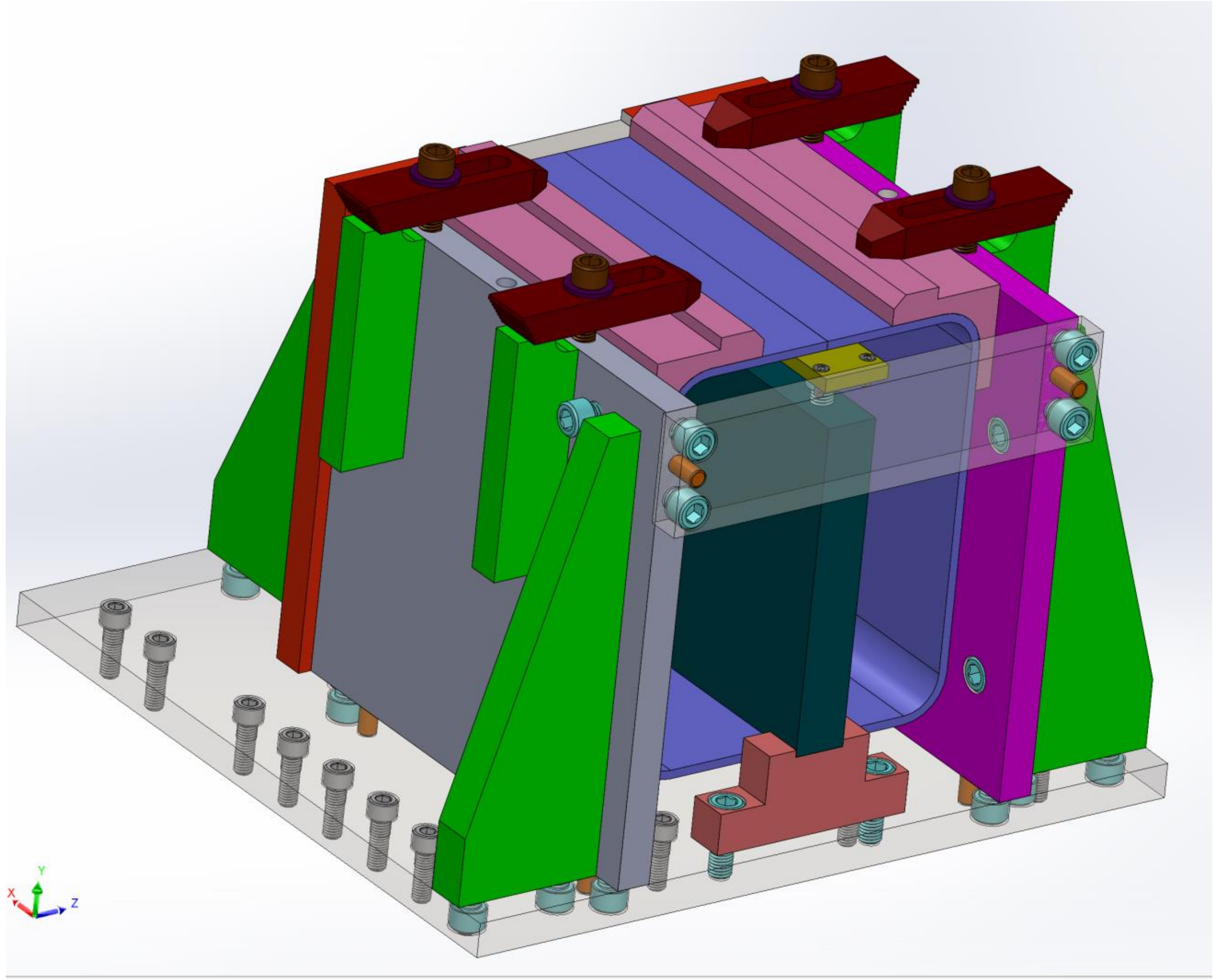


Spectrum	O	Al (↓)	Ti (↓)	Cr (↓)	Fe (↑)	Co	Ni	Mo (↑)	Total
Matrix (Spectrum 3)	0.26	1.13	1.27	15.70	0.76	10.25	62.33	8.29	100.00
Laser processed region (Spectrum 2)	0.36	0.33	0.58	10.80	2.12	11.06	63.54	11.20	100.00
Laser processed region (Spectrum 4)	0.37	0.22	0.60	10.73	2.86	10.60	63.92	10.70	100.00
Dark particles at the boundary (Spectrum 1)	43.00	38.25	0.81	4.22	0.00	1.48	6.52	5.72	100.00
Dark particles in the matrix	0.62	0.77	16.76	14.47	0.63	7.79	43.96	15.00	100.00

Chemical Composition in weight %

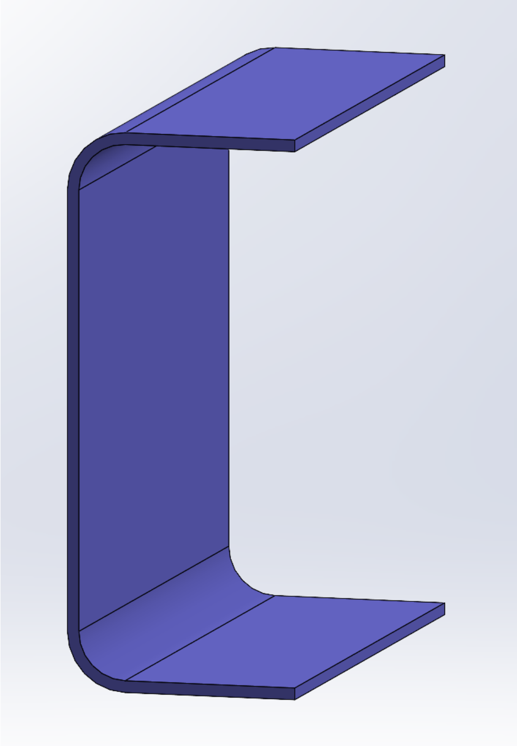
Prototypic Part Fabrication

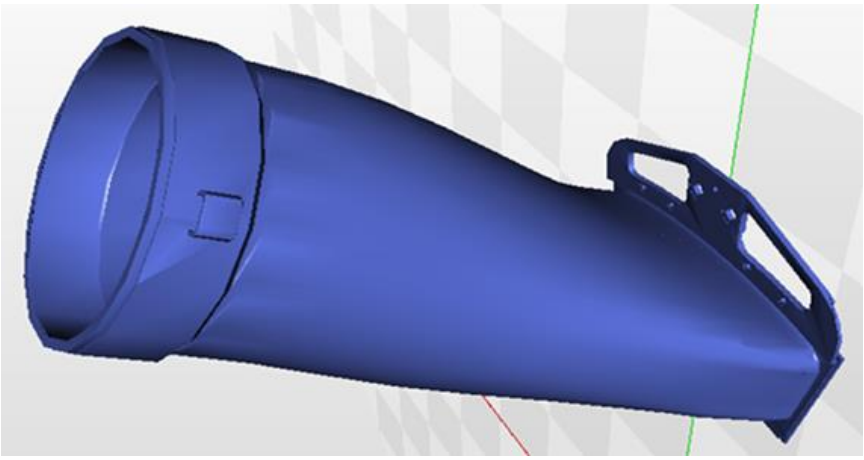
- Status
  - Fixture design complete
  - Fixture materials on order
  - Trials of forming Haynes 282 to right angle complete
  - Material for prototypic part on order



FSW Fixture with Prototypic Part

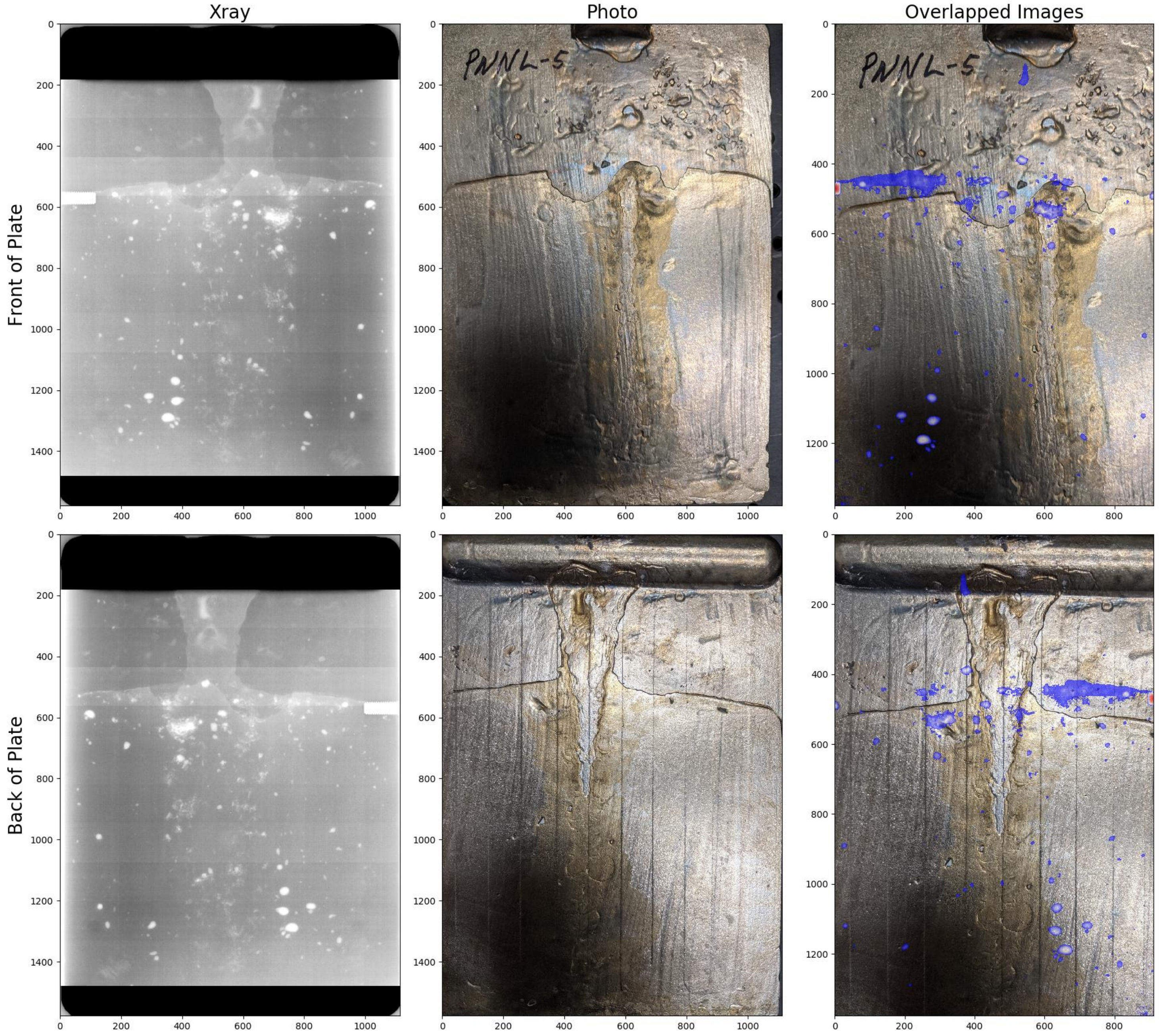
C-Channel Section via Joining 2 Sections Mimics Transition Duct





Haynes 282 Casting FSP

- Objective:
  - Can FSP heal casting indications or defects
    - ✓ Porosity
    - ✓ Cold shunts
- Castings Fabricated
  - Intentionally tried to make defects
- Pre-FSP Analysis in Progress
  - Radiography to help aid in determination of defect locations
  - Microscopy to correlate radiographic results with information regarding defects
    - ✓ Size
    - ✓ Location (depth)



Radiographic Images

As Cast Plate

Overlayed Images

Future Tasks

- Continue Inconel 617 FSW Development
  - Metallography
  - Mechanical Testing, Including Creep
- Dissimilar Material FSW - Haynes 282 to Haynes 233
  - Dissimilar material joint between a chromia former and an alumina former
  - Could be important joint in both gas turbine and AUSC plant applications
- Investigate Friction Stir Processing of Haynes 282 Castings
  - Demonstrate the ability to heal casting defects or in-service casting damage
    - ✓ NETL Albany fabricated castings with PNNL provided material
  - Demonstrate the ability to improve local material properties in castings through selective FSP

Future Tasks

- FSP over Laser Ablated Material
  - Laser ablated plates created for FSP
  - FSP step
  - Metallography will be performed to assess ability to disperse aluminum oxide pooling near surface
- Prototypic Heat Exchanger Joint with FSW
  - Complete fixture fabrication
  - Create / weld parts

- *Acknowledgment: This material is based upon work supported by the Department of Energy Award Number DE-FWP0071843.*

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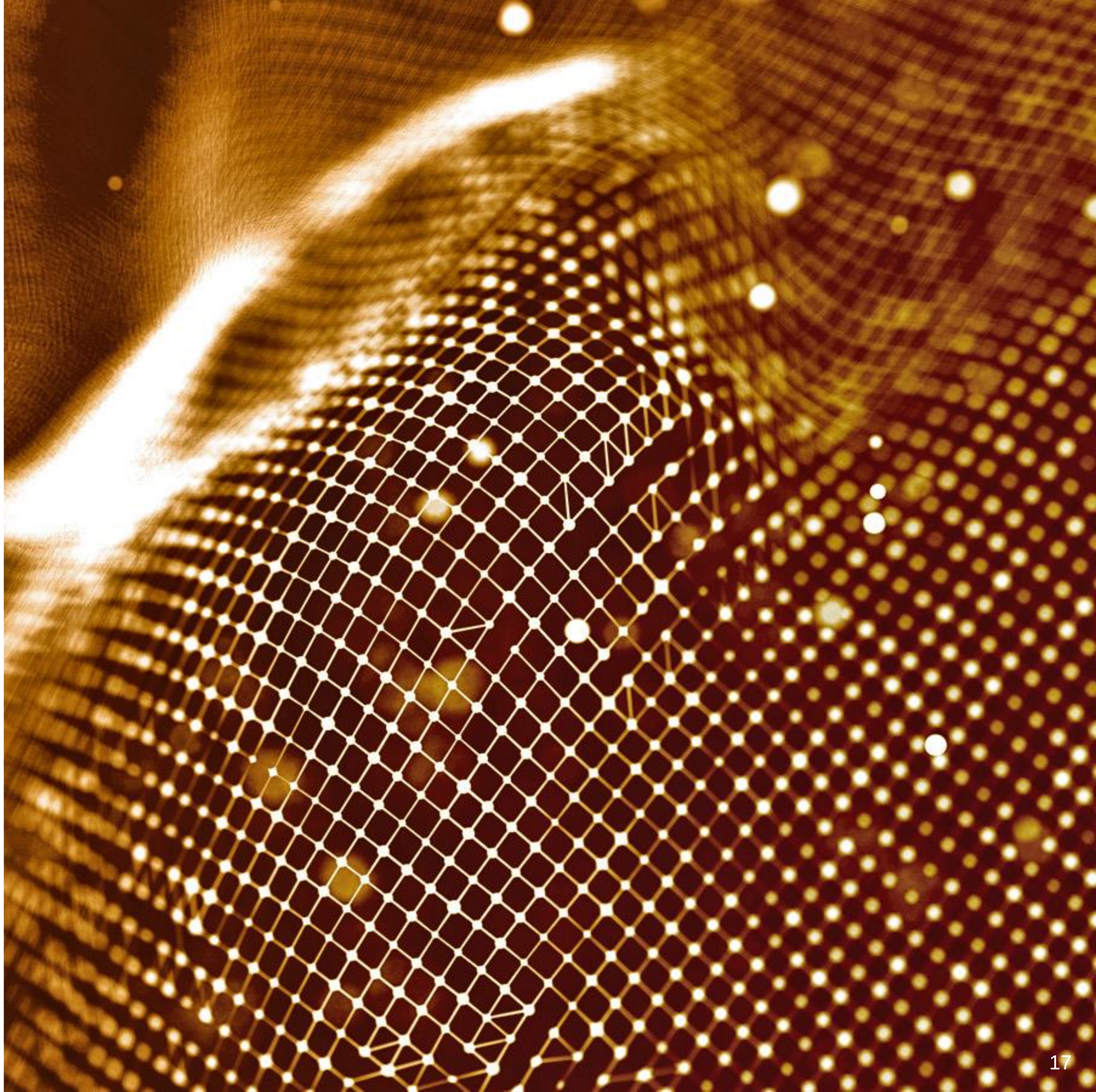
Thank you

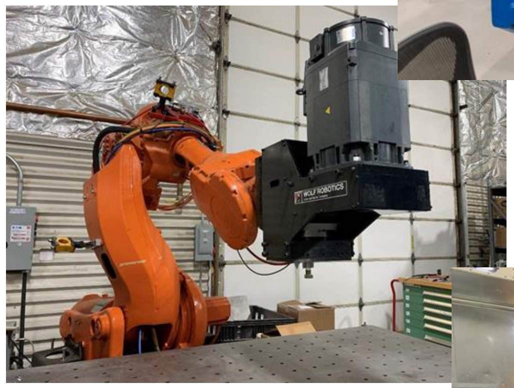


Background - Solid Phase Processing Advantages

Solid Phase Joining and Processing opens opportunities for improved performance in fabrication and synthesis of new High-Performance Alloys

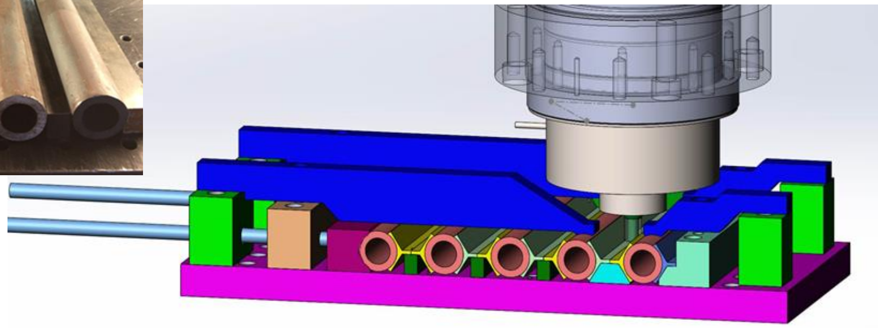
- Joining
  - Wrought microstructure
  - Minimized HAZ
  - No weld cracking during fabrication and repair
  - Better performance in fatigue and creep
- Processing
  - Selective property improvement - just where it is needed
  - In many metallurgical systems, fine grained microstructure shows improved corrosion resistance
- Repair and Return-to-Service
  - Crack repair or surface defect mitigation
- Solid Phase Processes can be additive (Friction Stir Additive or Cold Spray)

FSW



FSP

Cold Spray



Membrane Wall Friction Stir Welding