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

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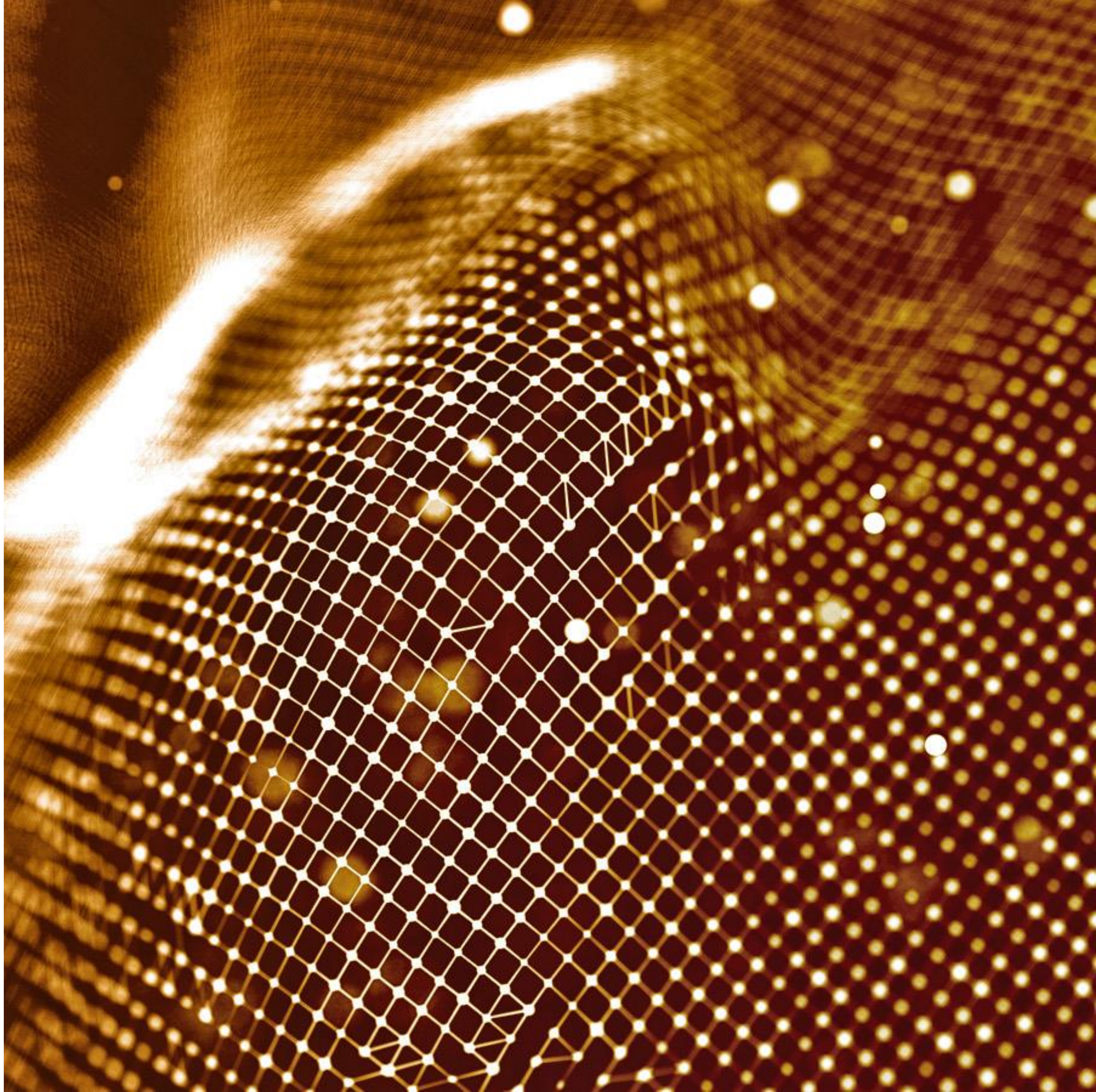


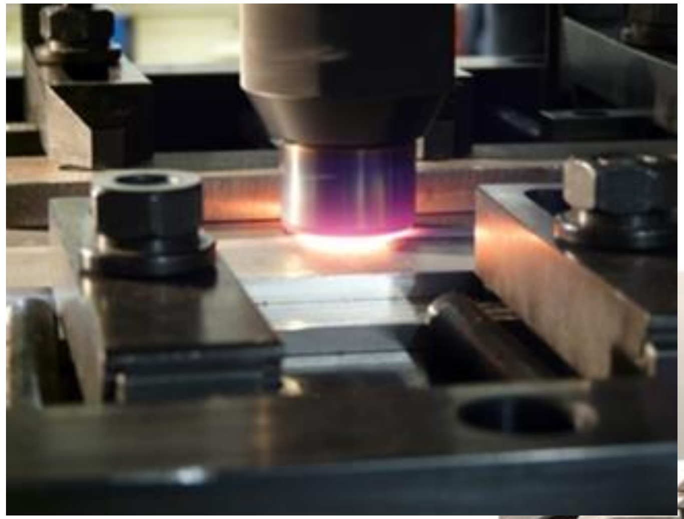
Vision

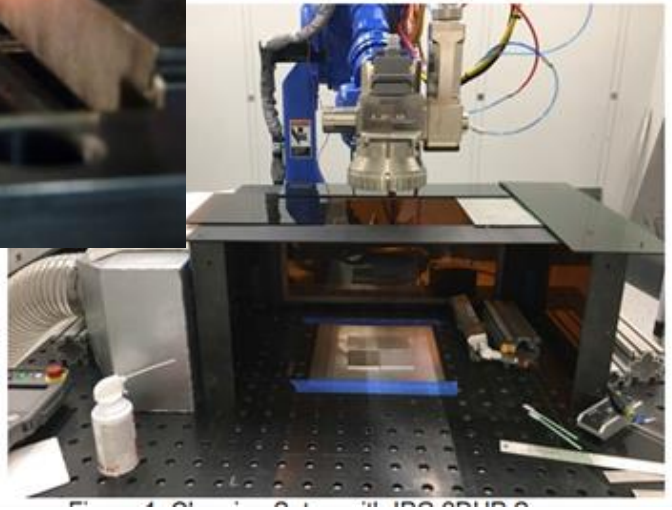
We need new advanced manufacturing processes to reach higher efficiency and lower cost in power generation systems

We need new methodologies for repair, refurbishment and return-to-service to improve existing fleet reliability and extend the life of the existing infrastructure

Project 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 alloy castings and wrought products used in Fossil Power Systems

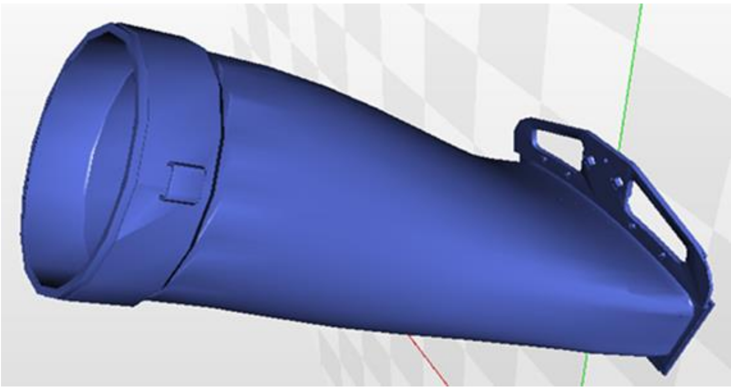




Motivation

- Fabrication challenges for Ni alloy components.
  - 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 when fusion welding is used in fabrication
  - For large, expensive Ni alloy castings, near surface casting defects can influence casting integrity and fatigue performance.

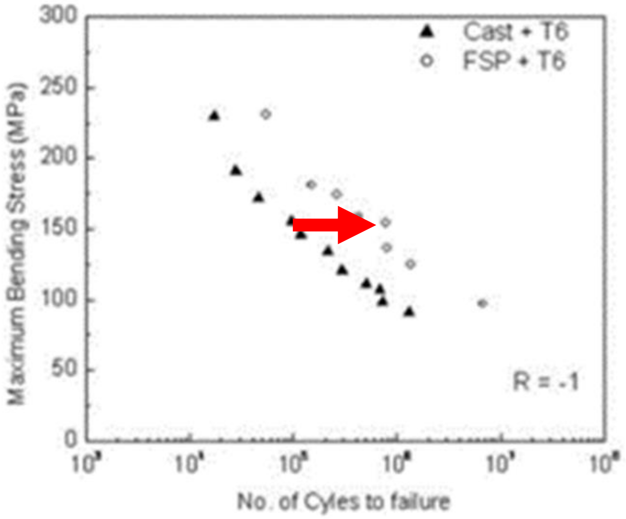
- Challenges also exist in repair and return-to-service environments.
  - In-service degradation of Thermal Barrier Coatings (TBC) requires time consuming stripping/ cleaning of the TBC prior to recoating.
  - Crack or damage repair by fusion welding or overlay processing leads to hot cracking during weld repair

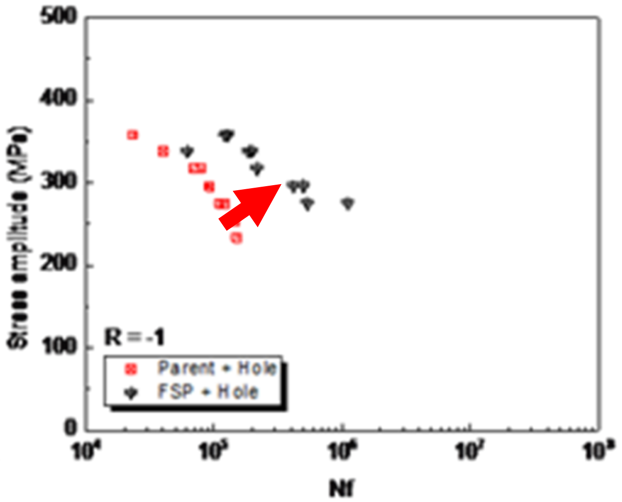


Solid Phase (SP) Welding/Processing

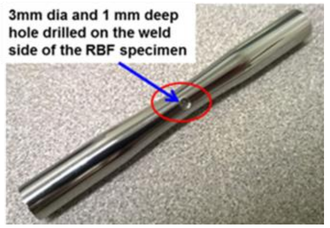
SP welding/processing has potential to address these challenges. Lesson learned from other materials systems…

Fatigue

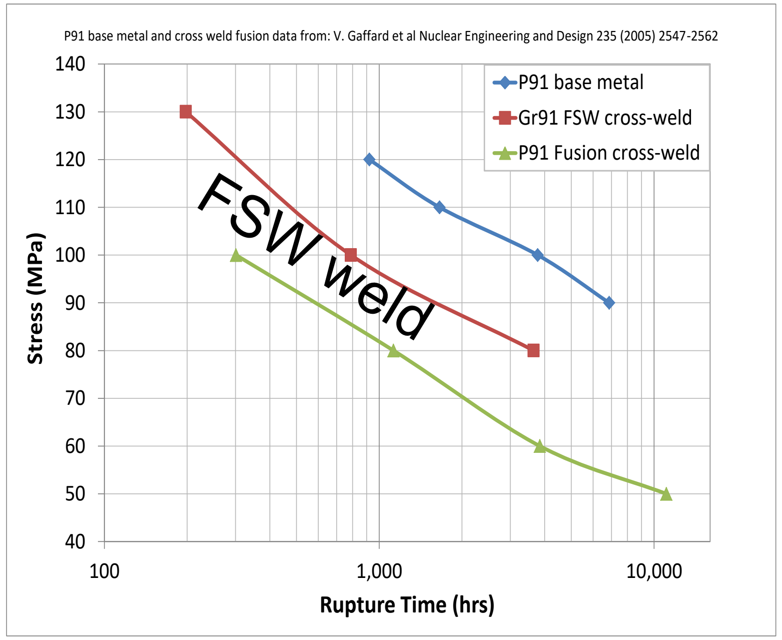




- 10x improvements in fatigue performance can be achieved when applying Friction Stir Processing to cast aluminum alloys
- FS Processed Crankshaft steels fully recover the fatigue performance around a drilled oil hole

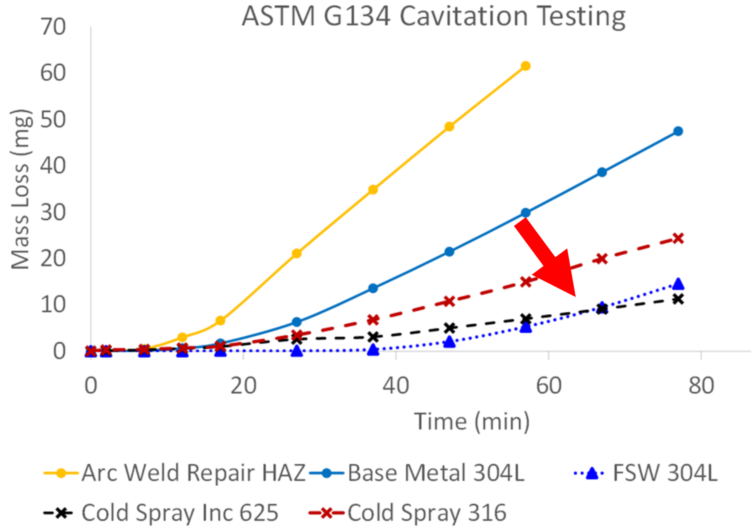


Creep



- FSP microstructures are dramatically better in elevated temperature creep (Fe-based alloys)

Cavitation



- FSP can produce surfaces that show 3 to 10x improvement in cavitation resistance in austenitic stainless steel

Solid Phase Joining gives us a new tool to increase the performance of Ni based alloys in service

Approach

Investigate two new approaches to fabrication, repair, return to service

- Laser stripping of TBC bond coat for repair/return to service (Siemens)
- Laser ablation as a surface treatment to enhance diffusion bonding (Siemens)
- Friction Stir Welding (FSW) as an alternative joining method to fusion welding and diffusion bonding (PNNL)
  - Optimize FSW welding parameters to achieve high performance joints in superalloys (Haynes 282, 233 and Inconel 617)
  - Develop a scalable and manufacturing friendly FSW process for joining Ni based alloys (induction preheat, closed loop temperature control, in-process defect detection, etc)
  - Discover the effect of FSW parameters (and PWHT) on creep and creep fatigue
- Friction Stir Processing (FSP) as a surface treatment or repair
  - Demonstrate the ability for FSP to repair defected or damaged Ni alloy Castings
  - Demonstrate FSP as a method to produce local improvements in fatigue and creep
  - Demonstrate FSP to prepare a surface for bond coat/TBC, Break up surface oxides

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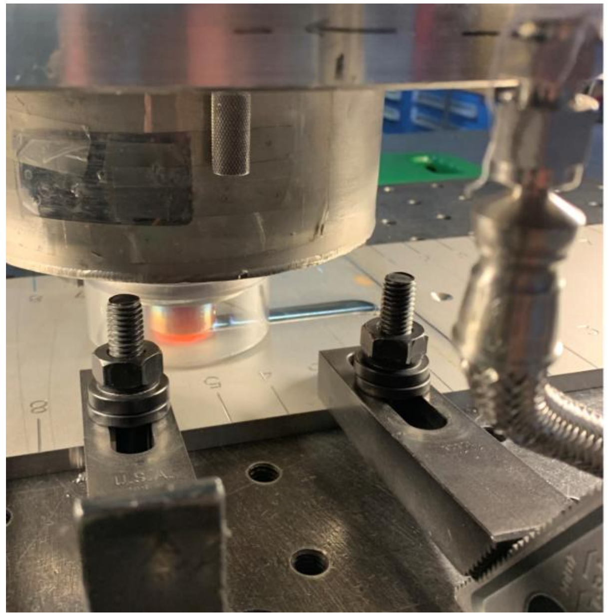
Major Tasks during FY19-20

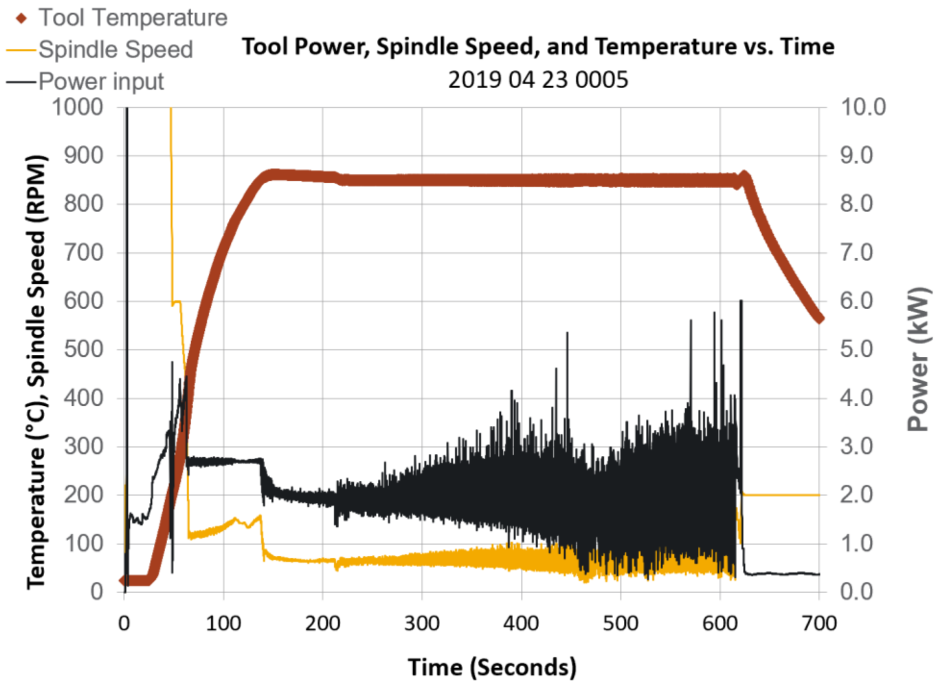
- Teaming with Siemens Energy
  - Siemens leading laser ablation task
- Friction Stir Welding/Processing (FSW/P)
  - Literature review
    - ✓ Limited success in FSW of Ni alloys
    - ✓ Trend of lower rotation speeds providing better quality welds
    - ✓ Trend of lower temperatures providing better quality welds
  - Haynes 282 and Inconel 617 Nickel based super alloys
  - Dissimilar alloy welding – Haynes 282 to 233
  - Friction stir process of casting for repair and property improvemtn
  - Employ PNNL temperature control

- Investigate effect of post weld heat treatment
- Investigate effect of extended exposure to service temperatures
- FSW/P coupon Testing
  - Microscopy (Optical, Scanning and transmission electron microscopy)
  - Hardness testing
  - Tensile testing
  - Creep testing
- Test Regions
  - Base material
  - FSW nugget / StirZone
  - Heat affected zone
- Test Conditions
  - At room temperature and at service temperatures

FSW Highlights

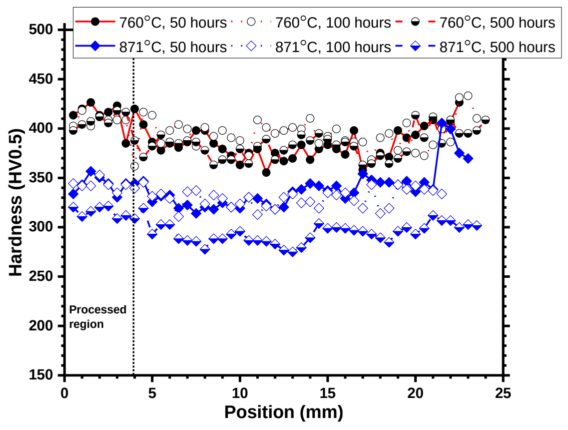
- Materials:
  - Haynes 282 Alloy and Inconel 617
  - 5 mm & 9.5 mm Thick
- Acceptable visual and internal quality achievable
- Appreciable tool wear not observed
- Oscillatory behavior noted with 6 mm pin tool under temperature control, but acceptable welds could still be generated
- Controller tuning required .
- Some difference in process parameters required between alloys



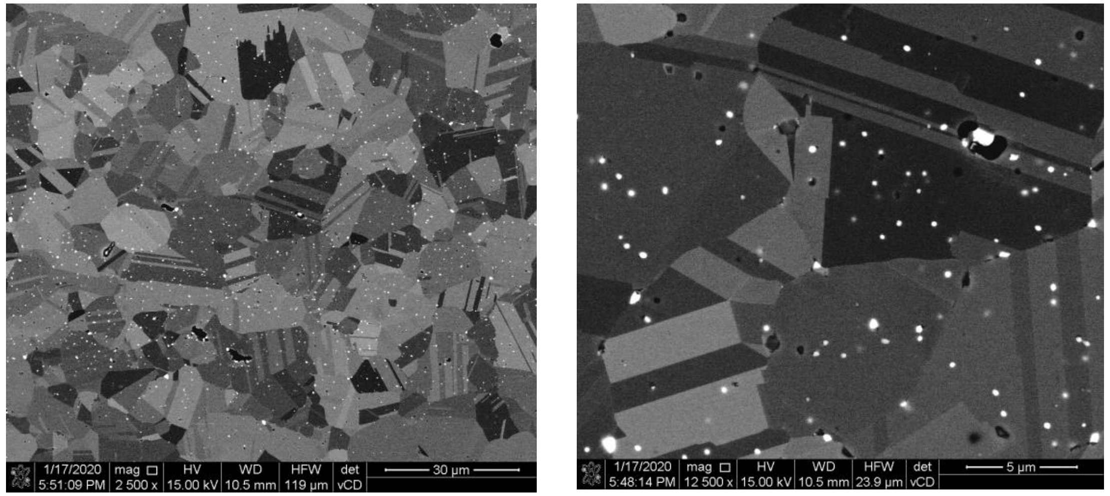


Post Weld Heat Tx & Simulated Service Effect

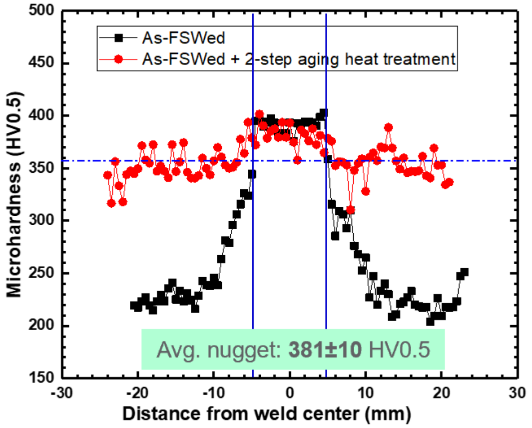
- Grain refinement was observed in nugget and grain growth was noted in the aged condition.
- FSW nugget, HAZ & Base Material Similar Hardness after Heat Tx
- Both in-grain and grain boundary carbide phases were observed.



Simulated Service



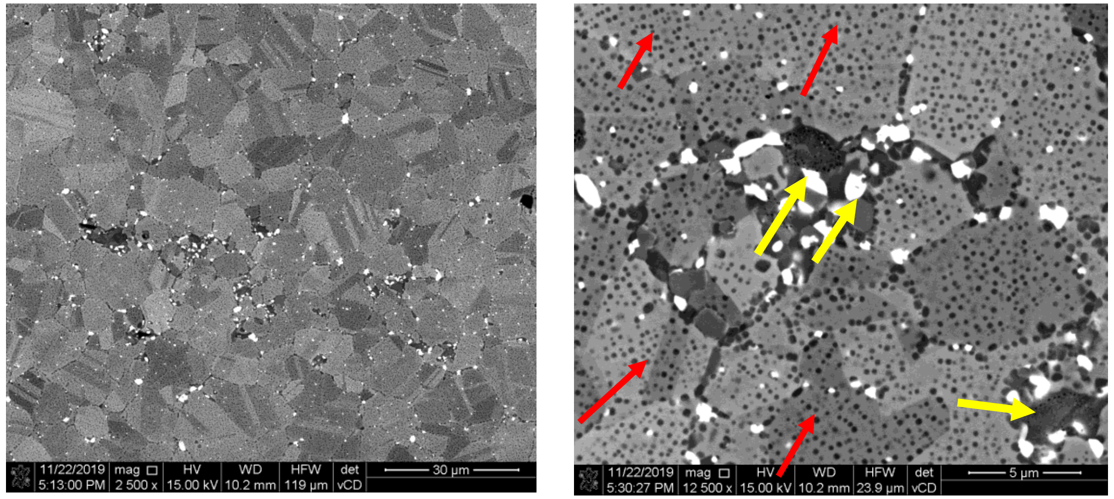
FSP + 2 step heat tx



- 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

Simulated Service

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

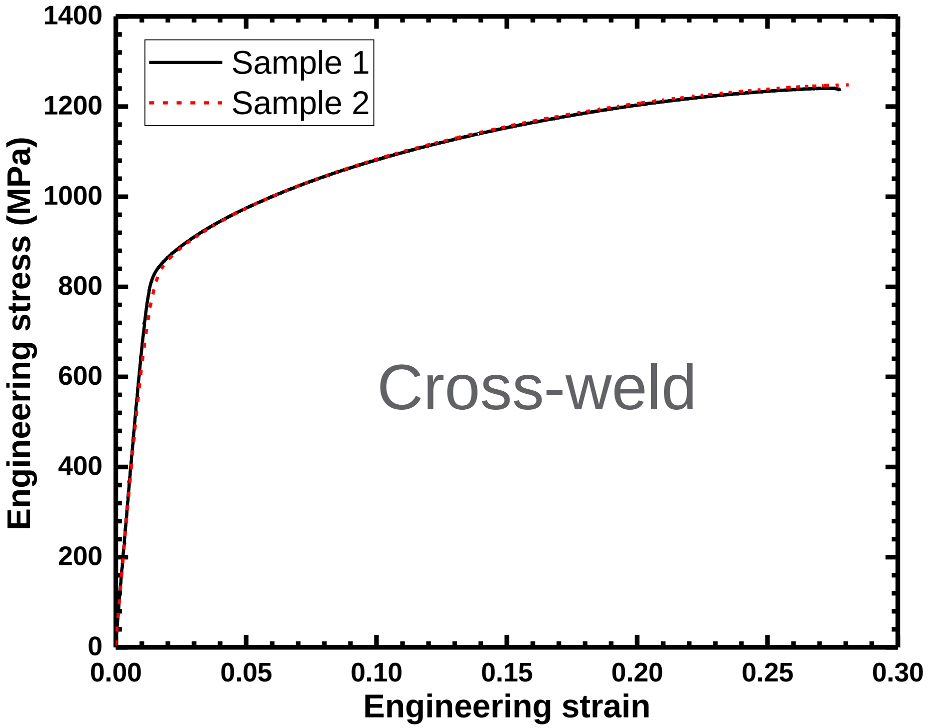


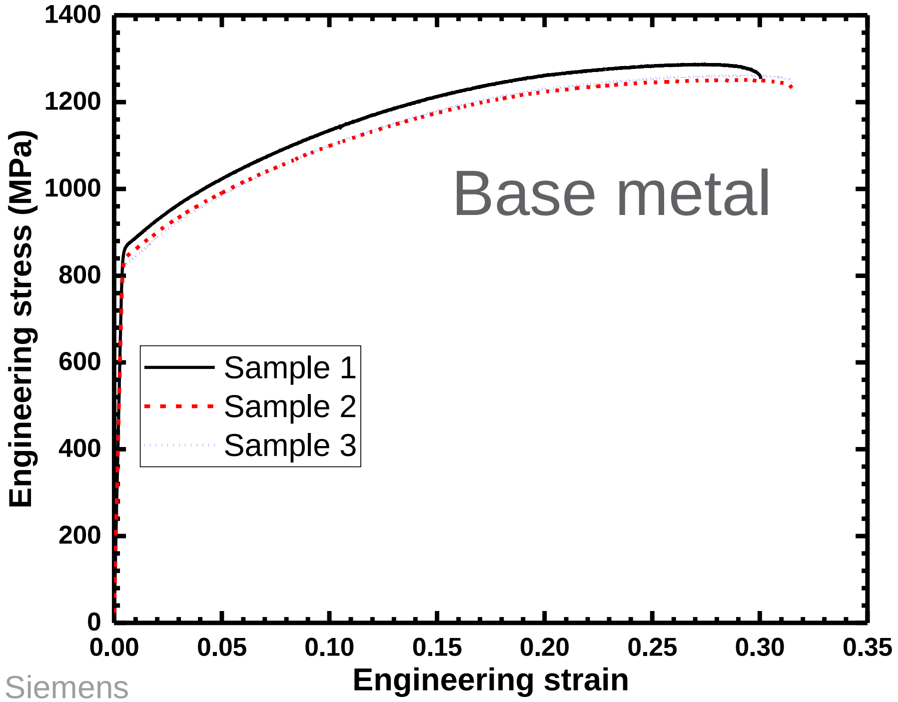
FSP + 2 step heat tx + 500 hrs @ 871°C

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

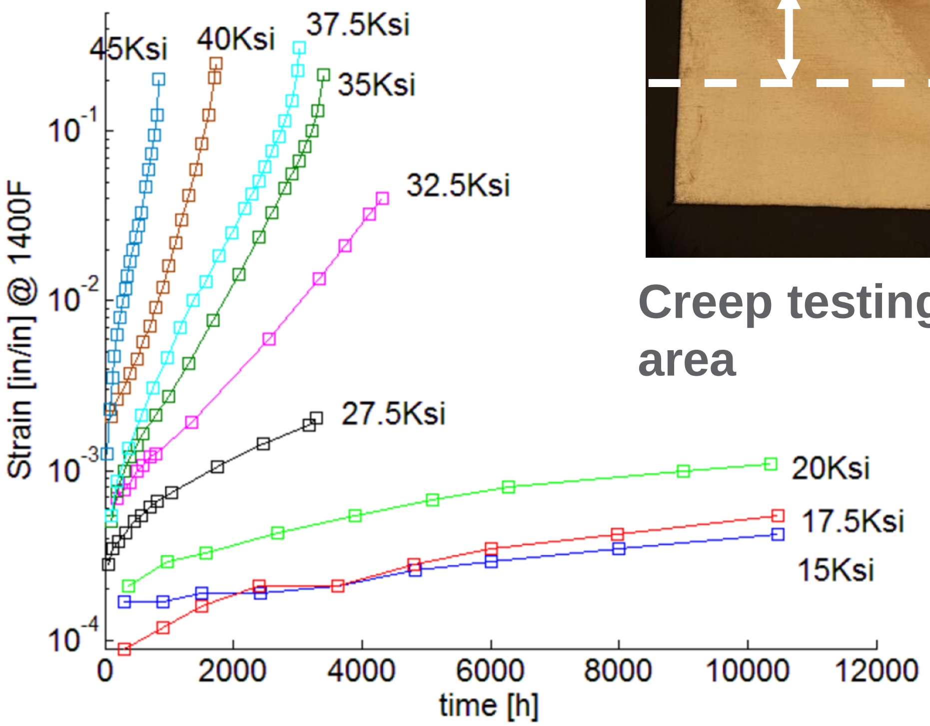


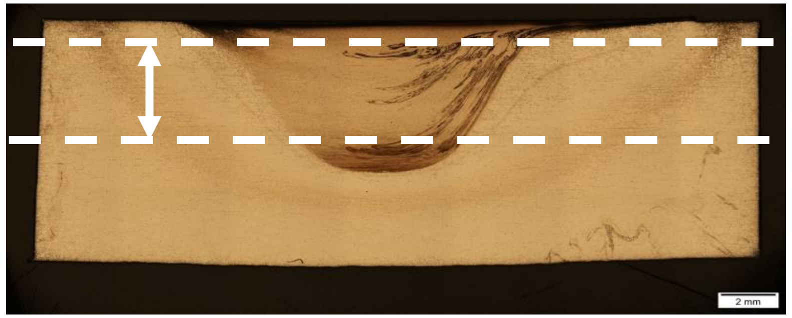


		YS (MPa)	UTS (MPa)	El%
Cross-weld	Sample 1	830	1240	26
	Sample 2	817	1247	26
	Avg.	**824±9**	**1244±5**	**26**
Base metal	Sample 1	869	1287	29.3
	Sample 2	847	1250	31
	Sample 3	833	1261	31
	Avg.	**850±18**	**1266±19**	**30±1**

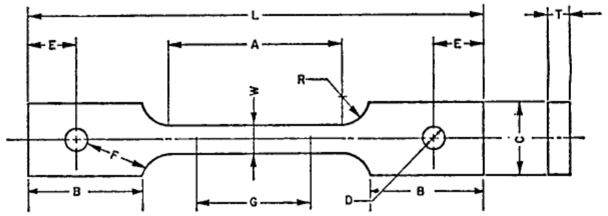
Future Tasks

- Creep Testing of FSW 282
  - Screening Study
  - Shorter Term / Higher Stress Levels
    - ✓ 310 MPa (45 ksi)
    - ✓ 241 Mpa (35 ksi)
    - ✓ 190 Mpa (27.5 ksi)
- Continue Inconel 617 FSW Development
  - FSW Trials
  - Metallography
  - Mechanical Testing
- Dissimilar Material FSW - Haynes 282 to Haynes 233
  - DSM 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 <u>Castings</u>
  - Demonstrate the ability to heal casting defects or in-service casting damage (work with NETL Albany)
  - Demonstrate the ability to improve local material properties in castings through selective FSP





Creep testing coupon material area



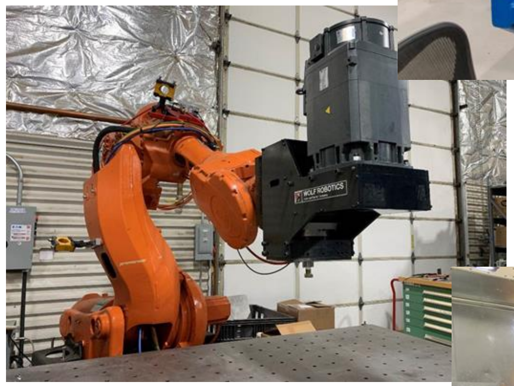
Dimensions, mm [in.]	
G—Gage length	50.0 ± 0.1 [2.000 ± 0.005]
W—Width (Note 1)	12.5 ± 0.2 [0.500 ± 0.010]
T—Thickness, max (Note 2)	16 [0.625]
R—Radius of fillet, min (Note 3)	13 [0.5]
L—Overall length, min	200 [8]
A—Length of reduced section, min	57 [2.25]
B—Length of grip section, min	50 [2]
C—Width 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]

Conclusion - Solid Phase Processing Advantages

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

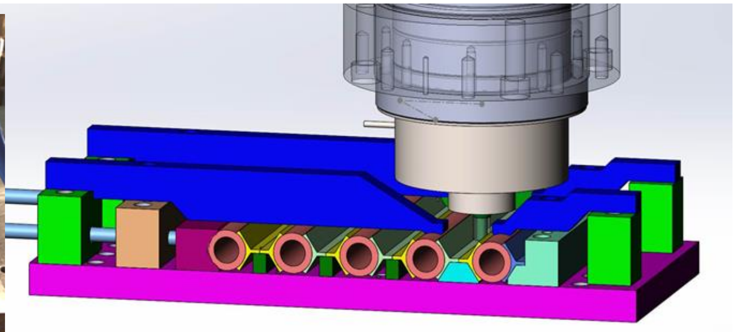
- Joining
  - Wrought microstructure
  - Minimized HAZ
  - No weld cracking during fabrication and repair
  - Better performance in fatigue and creep
- Processing
  - Selective property improvement - just where it is needed
  - In many metallurgical systems, fine grained microstructure shows improved 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

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Thank you