Robust Dissimilar Metal Friction Welded Spool for Enhanced Capability for Steam Power Components

FY22 FECM Spring R&D Project Review Meeting

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Robust Dissimilar Metal Friction Welded spool for enhanced capability for steam power components

DOE DMW

Team

GE Research, GE Gas Power & GE Steam Power

Program impact

3 year, $6.25MM DOE program to improve dissimilar metal weld (DMW) durability to reduce maintenance costs and provide enhanced cycling capability

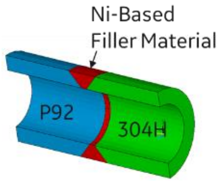
Key Innovations

- Demonstrate **friction welded** dissimilar metal spool w/superior properties
- Mature GE developed **nanostructure ferritic alloy (NFA)** tech for steam cycle applications
- Enhanced durability through **oxidation protective coatings** on DMW joint
- GE **lifing methodology** to predict joint life & durability

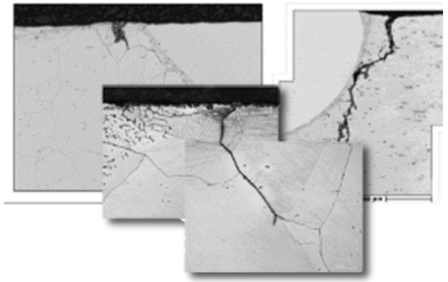
Anticipated Benefits

- 5x increase in cold starts & cycling behavior of steam turbine fleet
- Reduced DMW repair frequency
- Improved DMW creep & fatigue behavior
- Advance NFAs from TRL4 to TRL6

Traditional DMWs

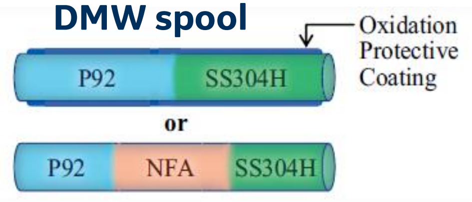


Oxide notching and cracking near fusion line and HAZ

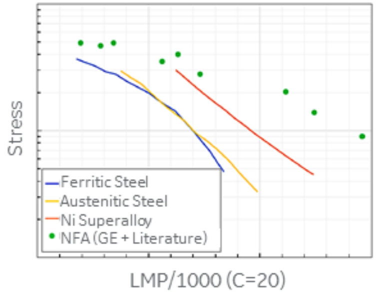


Proposed Solution

Friction Welded DMW spool

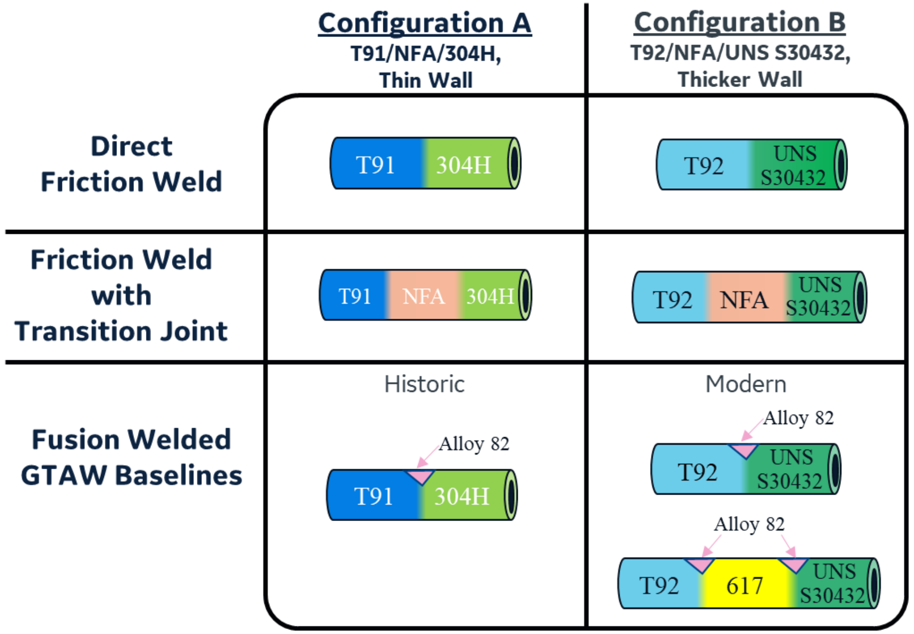


NFA superior creep resistance



Deliverable Update

Task	Deliverable Title	Due Date	Current Status
1.1	Project Management Plan (PMP)	11/30/2020	Completed
1.3	Technology Maturation Plan (TMP)	5/31/2021	Version 1 completed
4.1	**Initial NFA material for friction welding trials**	**5/31/2021**	**Completed**
3.1	**Optimal coating down-selection**	**6/30/2021**	**Completed**
1.2	Workforce Readiness Plan (WRP)	8/31/2021	Completed
2.1	**Crack free friction-welded tubes of *T91/304H - Config A***	**10/15/2021**	**Completed**
2.1	Crack free Rotary friction-welded tubes of *T91/NFA/304H - Config A*	3/31/2022	Preliminary trial resulting in crack free weld
3.2	Coating process optimization	3/31/2022	Completed – Q1 report
1.3	Technology Maturation Plan (TMP)	4/30/2022	In progress - on track
2.1	Crack free friction-welded tubes of *T92/UNS S30432 - Config B*	4/29/2022	Currently on track
4.2	Report on NFA tube demonstration - Config A (thin wall)	4/30/2022	Modified to Config A - on track

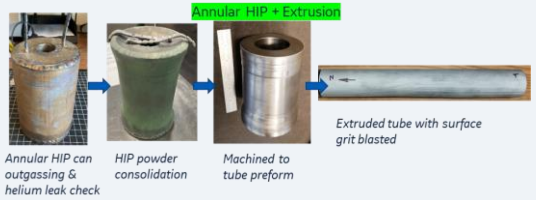


- Dissimilar Metal Weld (DMW)
- Nanostructured Ferritic Alloy (NFA)
- 2 Configurations:
  - Config A: thin wall
  - Config B: thick wall
- Friction welds
  - Rotary friction weld (RFW)
  - Low force friction weld (LFFW)

Major Technical Achievement – 2021
Capability

NFA Tube Demonstration

- **(4.1)** Completed mechanical alloying and **produced 1000 lbs** of NFA materials
- Successfully produced **defect-free**, pilot-scale thin wall NFA tubes (Config A) via 2 processing routes
- Produced **thin wall (Config A) NFA tubes** for friction weld development
- Successfully produced **defect-free thick wall tubes** (Config B)

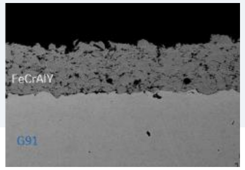


Rotary Friction Weld

- **(2.1)** Successfully produced **crack free** rotary friction weld of thin wall (Config A) **T91/304H tubes**
- Identified **optimal processing parameter** for friction weld of thin wall **T91/304H tubes**
- **(2.1)** Successfully produced **crack free** rotary friction weld of thin wall (Config A) **T91/NFA tubes**
- Preliminary tensile, LCF, and creep assessment of **thick wall (Config B) T92/UNS30432** underway

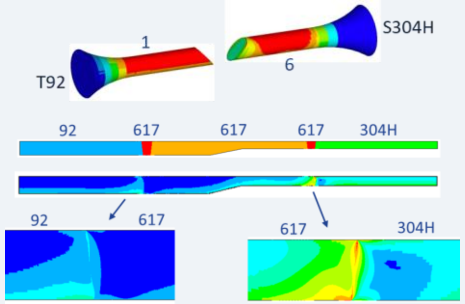
Coating Materials and Process

- **(3.1)** Identified **oxidation resistance coating chemistry** capable of forming protective oxide on the surface at temperature **up to 700C**
- Produced coating **meeting thickness requirements** using **industry standard** thermal spray process
- Assessment of **phase stability** due to long term exposure via diffusion multiple underway



Lifing Methodology

- **Implemented DMW lifing methodology** for fatigue and creep –tubes and solid bars/test coupons
- **Completed life prediction** of several baseline and **NFA DMW** tubes for industrial application (Boiler and HRSG)
- Defined **DMW coupon design and test conditions** for LCF and creep tests – coupon manufacturing underway



Field design example: DMW Spool
(Effective strain range contour plots for Hot Start)

NFA Tube Demonstration

Deliverable 4.1

- Completed mechanical alloying and **produced 1000 lbs** of NFA materials

Technical Progress

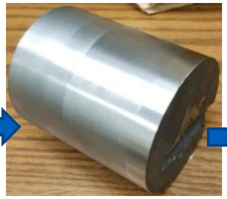
- Thin wall (Config A) tube manufacturing (4.2)
  - Successfully produced **defect-free**, pilot-scale NFA tubes via 2 processing routes
  - Produced **over 30” of thin wall (Config A) NFA tubes** for friction weld development
- Thick wall (Config B) tube manufacturing
  - Successfully produced pilot-scale **defect-free thick wall tubes**

Nanostructured Ferritic Alloy Tube Manufacturing Development (Config A)

Processing Routes

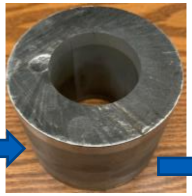
Compaction + Upset + Extrusion

outgassing & leak check



Compaction

Upset

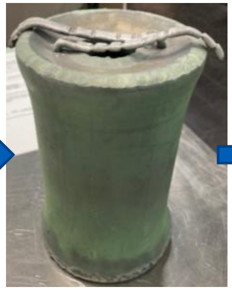


Hollowed by wire EDM to tube preform

Extruded tube with surface grit blasted

Annular HIP + Extrusion

Annular HIP can outgassing & leak check

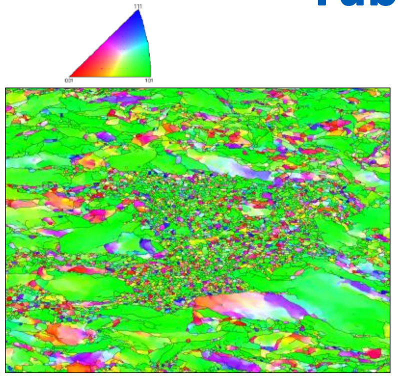


HIP powder consolidation

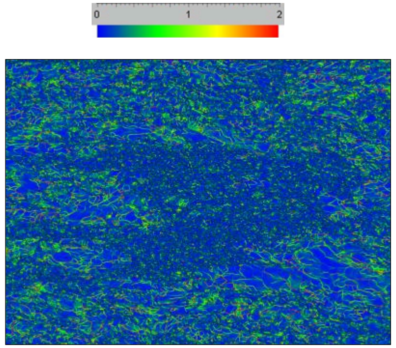
Machined to tube preform

Extruded tube with surface grit blasted

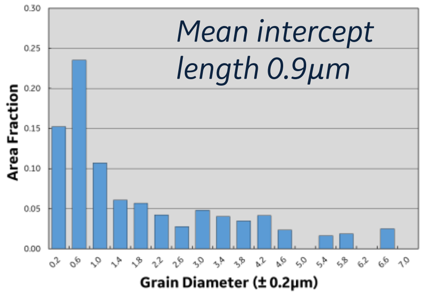
Tube Microstructure



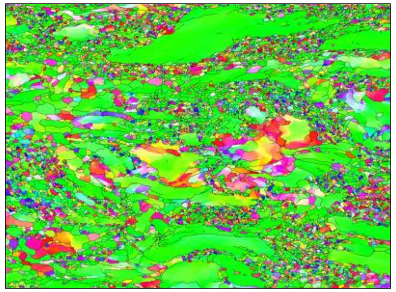
Orientation image map along axial direction

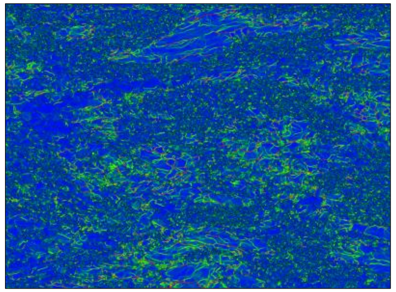


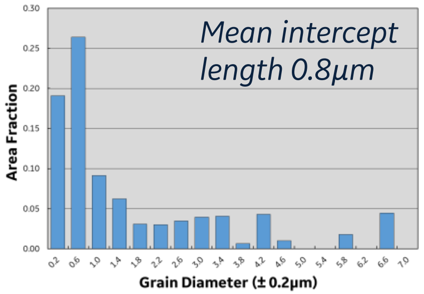
Kernel Average Misorientation Map



Grain size distribution







- Completed **mechanical alloying of 1,000 lbs NFA powder** with good chemistry control
- Demonstrated **pilot-scale thin wall (Config A) tubing** by 2 processing routes
  - Similar bimodal grain size distribution and preferred texture along axial direction
- Produced **over 30" of thin wall (Config A) NFA tubes** for friction weld development
- Confirmed **process parameters unaffected by powder chemistry variation** for thick wall (Config B) full-scale tube manufacturing

Rotary Friction Weld

Deliverable 2.1

- Successfully produced **crack free** rotary friction weld of thin wall **T91/304H tubes**
- Successfully produced the first **crack free** rotary friction weld of thin wall **T91/NFA tubes**

Technical Progress

- Identified **key processing parameter** for rotary friction weld of thin wall (Config A) **T91/304H tubes**
- Preliminary tensile, LCF, and creep assessment of **thick wall (Config B) T92/UNS30432** underway

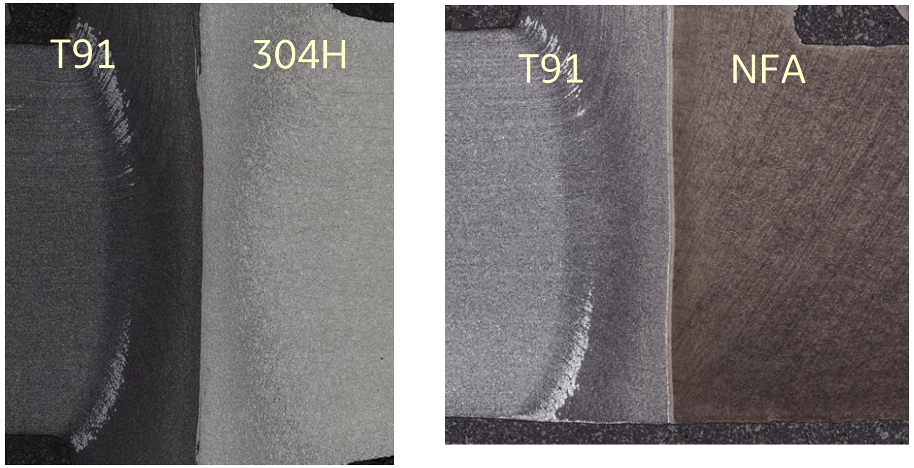
Friction Welding Progress

Friction weld

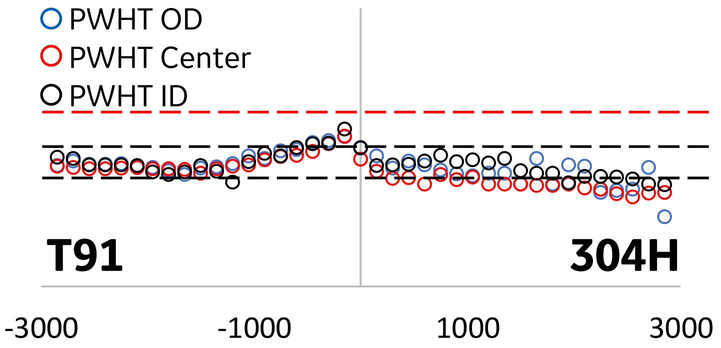
Baseline GTAW

- Produced the **first friction weld NFA tubes** (thin wall – Config A)
- Determined weld quality
    - CT scan of all welded tubes for defects
    - Microstructure evaluation
    - Microhardness across weld joints
- **Defined post weld heat treatment** necessary to temper T91/T92.

Microstructure across weld joins



Microhardness (HV) of PWHT T91-304H



Coating Materials and Process

Deliverable 3.1

- Identified **oxidation resistance coating chemistry** capable of forming protective oxide on the surface at temperature **up to 700C**
- Produced coating **meeting thickness requirements** using **industry standard** thermal spray process

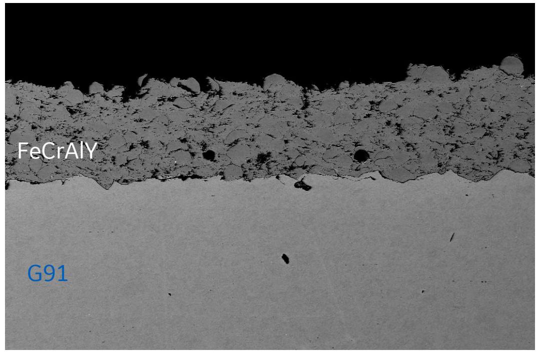
Technical Progress

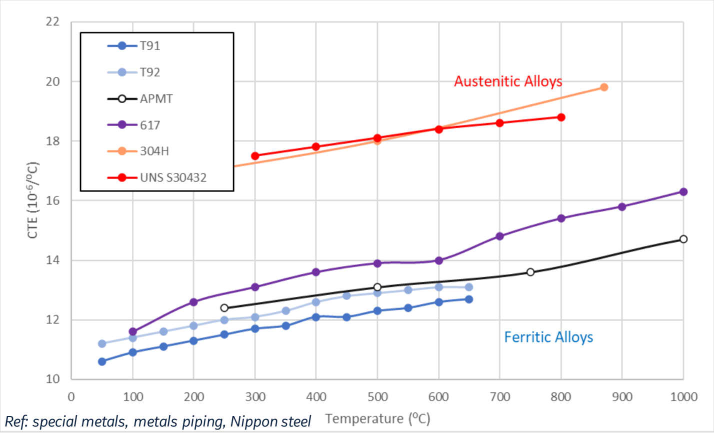
- Assessment of **phase stability** due to long term exposure via diffusion multiple underway
- Optimization of coating parameters for improved coating density

Oxidation Protective Coating Development

Oxidation Resistance Coating Development

FeCrAlY Coating
Down-selected for Coating Parameter Development





Ref: special metals, metals piping, Nippon steel

Microstructural Qualities:

- No delamination from interface
- Low porosity
- No vertical or horizontal cracking

Initial coating requirements:

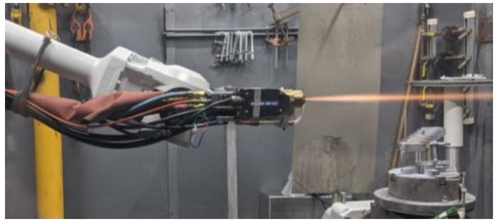
- ✓ Oxidation resistance in the temperature range
- ✓ Thermal expansion compatibility
- ✓ Commercially available coating process and compatible with current practice
- ❑ Phase stability (of coating as well as coating/substrate interdiffusion)

Oxidation results:

- FeCrAlY coating forms slow growing alumina oxide layer – provides good oxidation resistance

Coating Process Optimization

Method: Industry-standard Thermal Spray

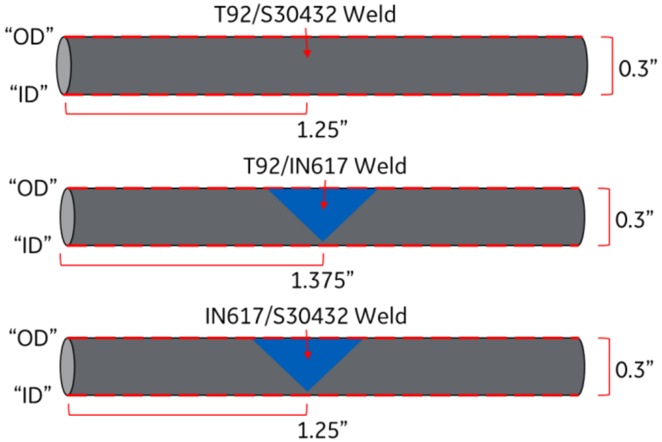


Go/No-Go Decisions:

- Coating Adherence at Target Thickness
- Visually Homogeneous Coverage
- Low Level of Porosity in Coating (cross-section)

Outcome:

- Down-selection to a set of parameters used on 12 pins for oxidation trials (4 of each of the following combinations)
- June 2022 spray coat on full tube



Coated pin

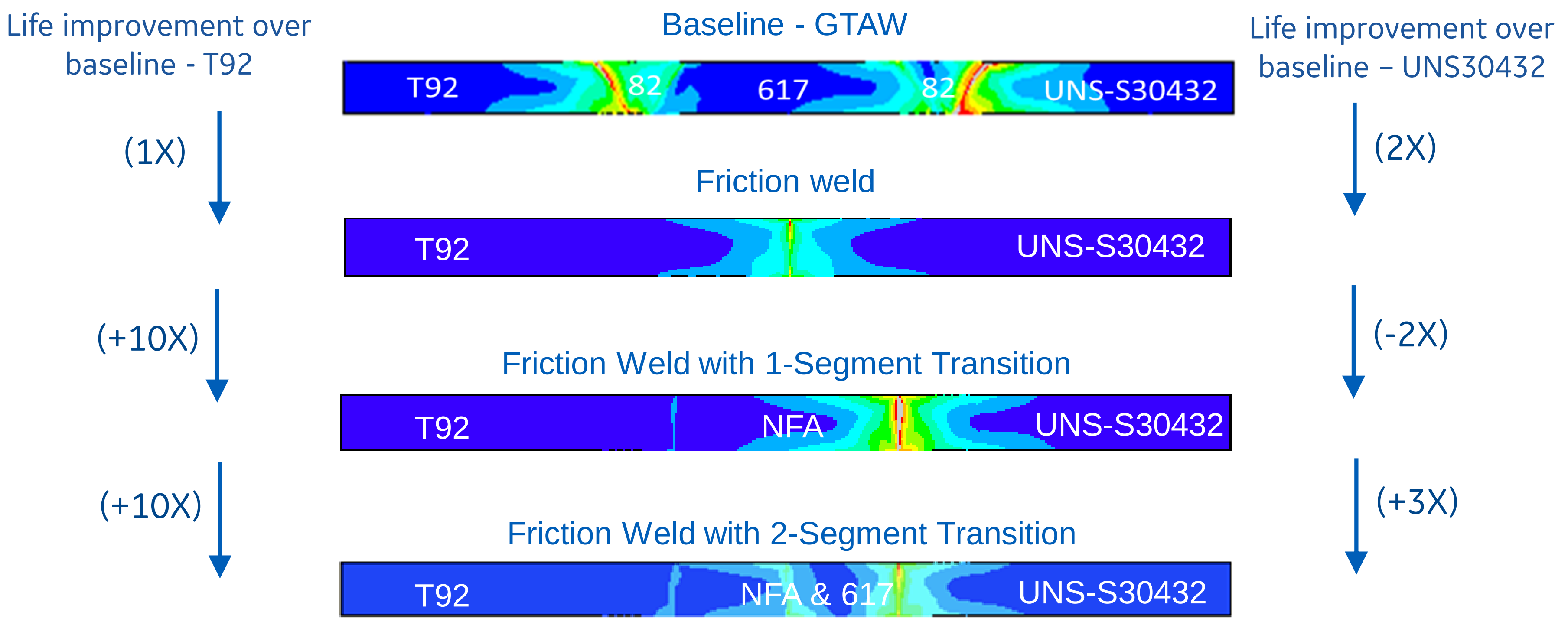
Lifing

Technical Progress

- **Implemented DMW lifing methodology** for fatigue and creep –tubes and solid bars/test coupons
- **Completed life prediction** of several baseline and **NFA DMW** tubes for industrial applications (Boiler and HRSG)
- Defined **DMW coupon design and test conditions** for LCF and creep tests – coupon manufacturing underway

Modeling & Lifing: *Durability-based design of DMW*

- Durability assessment is done using GE proprietary lifing methodology developed for DMW joints
- **Significant durability improvement** by using a two-segment transition design
- Required minimum transition piece length was calculated based on a nonlinear elastic-plastic parametric study



Calculated effective strain range contour plots – field condition

Going Forward Plan

<u>Q2-2022</u>

- (1.3) Technology maturation plan
- (3.2) Coating process optimization for improved density
- (4.2) Report on NFA tube demonstration – thin wall (Config A)

2022 Planned Tasks

Friction Welding – with Transition Pieces

- **Friction weld** parameter development of **T91 to 304H with NFA transition piece** by rotary friction welding – on going
- **(2.1)** Produce **crack-free** T91/NFA/304H thin wall tube (Config A) via rotary friction weld
- **(2.1) Friction weld** development for **thick wall** T92 & UNS30432 (Config B) tubes with and without **NFA transition pieces**
- Evaluation of **weld quality** in tensile, LCF, and creep under **industrial-relevant testing conditions**

NFA Tube Manufacturing – Scale up

- **(4.2) Documentation** of manufacturing demonstration for thin wall (Config A) NFA tube
- **Full-scale NFA thick-wall (config B) tube production**

Coating Process – Optimization & Phase Stability Assessment

- **(3.2)** Optimize **coating process parameters** for density and compliance
- **(3.3)** Evaluate **oxidation behavior** of **optimized coating on welds** and compare to uncoated substrate
- **Produce coated tubes** with thick wall (Config B) dimension
- Determine **risk of phase stability due to long term exposure** of coating on welds

Lifing – Validation & Fiction Weld Geometry

- **(5.2) Identify parameters** for accelerated thermal fatigue test for **durability evaluation**
- **Validate model prediction** with LCF and creep test data for solid bar/test coupon geometry
- Evaluate **configuration geometry and the effect of an NFA transition piece** on the strains produced during thermal cycling

ACKNOWLEDGMENT

This Technical Review Summary is based upon work supported by the Department of Energy under Award Number DE-FE0031907.

DISCLAIMER

Thank you!

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