Fatigue Testing of Coke Drum Plates Reinforced With Weld Overlay: Summary of Results

Fábio de Castro Marangone, Petrobras,

Ediberto Bastos Tinoco, Petrobras,

Julian J. Bedoya, P.E., Stress Engineering Services, Inc.,

Luiz Carlos Largura Jr., Stress Engineering Services, Inc.

Taking on your toughest technical challenges.

REFCOMM

RIO DE JANEIRO

29 Sept – 3 Oct 2014

Coking.com

STRESS ENGINEERING SERVICES INC.

an employee-owned company

Presentation Outline

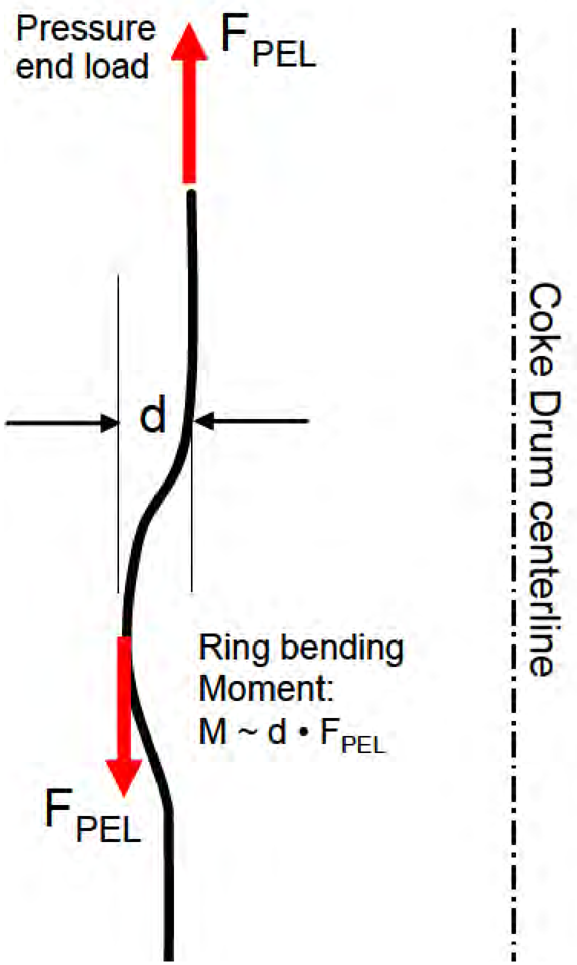
- Project Objective – Effects and Consequences of Bulging
- Questions That Need Answers
- Testing Methodology
  - Low Cycle Fatigue (WOL material only)
  - Bending Thermo-Mechanical Fatigue – BTMF – (WOL, base metal, clad)
- Results
  - Low Cycle Fatigue Results of Inconel 625
  - Fully Reversed Bending Fatigue Testing
- Discussion

Project Objective

- To determine the viability of using weld overlay to reinforce coke drums that have experienced bulging, or similar material degradation.
- Weld overlay (WOL) works by adding layer(s) of Inconel 625 (or Inconel 600) to the area to be reinforced. While theoretically this is a viable repair option, practical aspects of how the repair is executed can differentiate whether or not the repair is successful.
- Ultimately, the WOL works by increasing the second moment of area (and cross-sectional area) to a bulged region in the drum, and retarding the growth of bulging by a reduction in stresses.

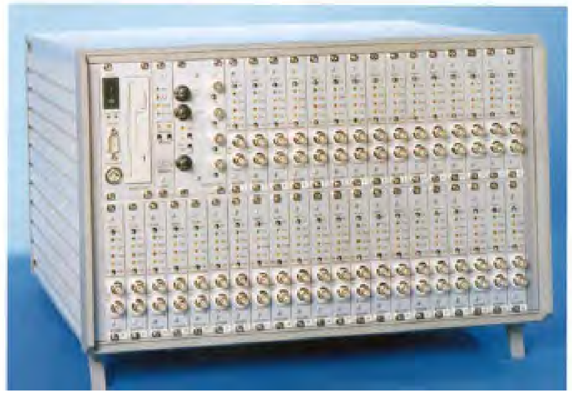
Effects and Consequences of Bulging

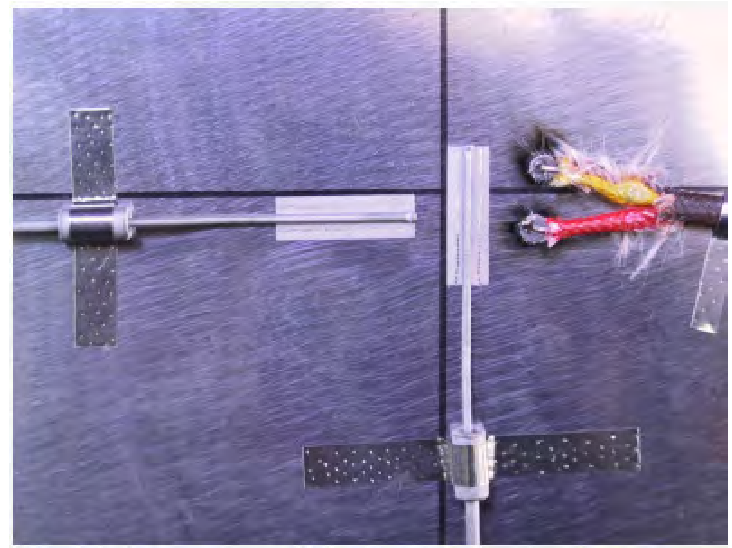
- Coke drum bulging effects cause variation in the stress field
- Bulge severity illustrated with bulge severity assessment
- Encourages low cycle fatigue from bending stress amplification
- Relationship to seam is critical
- Bulge severity reduced with designed structural weld overlay



How is Bulging Assessed?

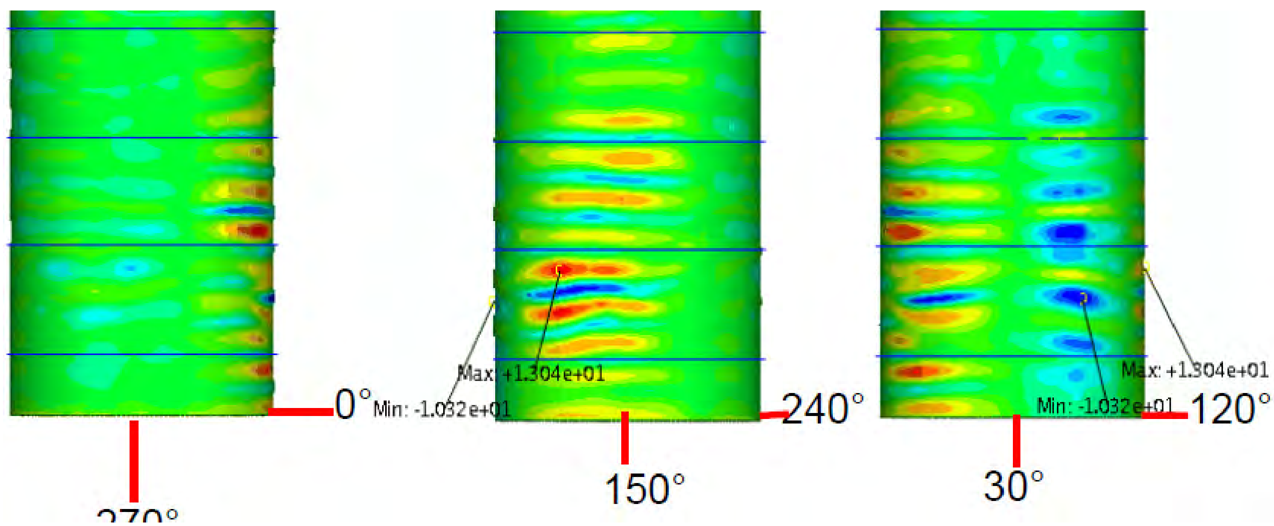
- A bulge severity analysis is performed
- Ranks bulges based on stress amplification factor
- Method to identify and track specific characteristics of each bulge during life of drum
- Useful in choosing strain gauge and thermocouple locations and interpreting their results
- The stress amplification factor obtained from this analysis can also be used in fracture mechanics assessments





MAX BSF = 13.0

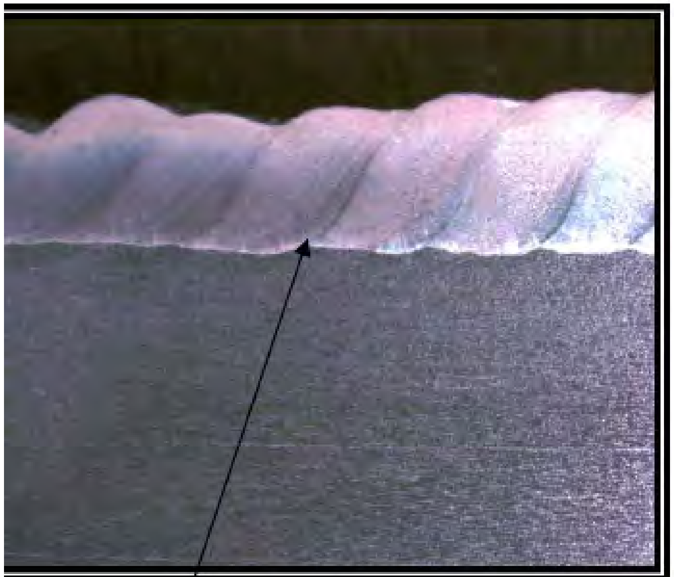
MIN BSF = -10.3



Shell, Cone, and Skirt Repair with Automated Temper Bead Technology

Pictures Courtesy of WSI

Temper Bead Welding



HAZ created by 1st weld layer

HAZ is tempered by deposition of successive layers

Pictures Courtesy of WSI

How is Bulging Mitigated?

- Weld overlay (WOL) for bulge reinforcement
  - Automated temper bead technology
  - Reduce outage time for repair
  - Full PWHT not required
  - Repair from inside and/or outside
- Window replacement
  - Material is too degraded and must be removed
  - Bulge is too severe for weld overlay
- Can replacement

Questions That Need Answers (1 of 2):

1. What are the low cycle fatigue characteristics of the WOL material?
2. Does the WOL material stay bonded to the base metal during the expected loading on coke drums?
3. Does the presence of the WOL in a repair encourage accelerated cracking?
4. What guidelines should be followed at the regions where the WOL reinforcement terminates, and interacts with the base metal and cladding?

Questions That Need Answers (2 of 2):

5. How do repairs that reinforce circumferential welds perform relative to mid-plate regions?
6. Does the WOL in a reinforcement need to be ground smooth for it to be effective?
7. Can effective WOL reinforcements be applied directly on the cladding instead of the base metal?
8. What are the consequences of providing a WOL reinforcement directly over a crack, without removing it?

Testing Methodology

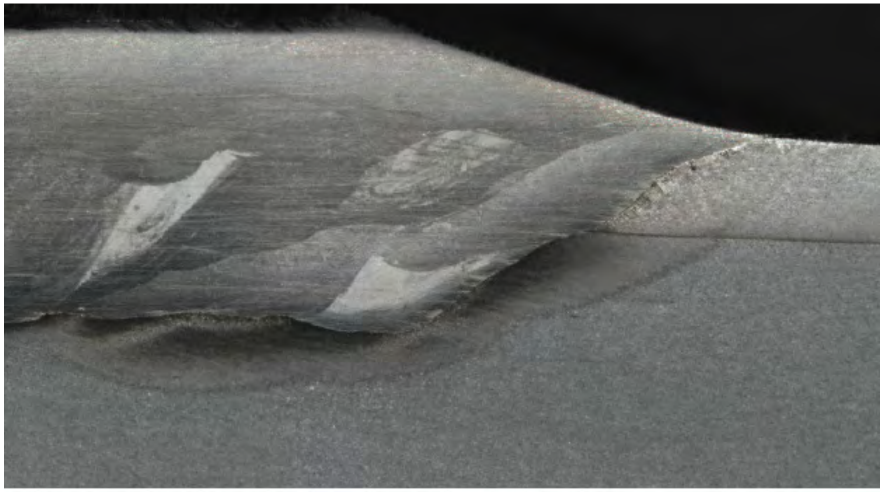
- Low cycle fatigue testing of WOL material
  - Stresses beyond the yield strength of the material
  - Inconel 625 only (base metal machined off)
  - Ambient temperature
  - Strain, or displacement controlled
- Bending Thermo-Mechanical Fatigue Testing
  - Stresses beyond the yield strength of the material
  - Samples were a combination of base metal, WOL, cladding, transitions, butter pass, circumferential welds and simulated cracks.
  - Elevated temperature
  - Force controlled
  - 4 Point Bending Tests

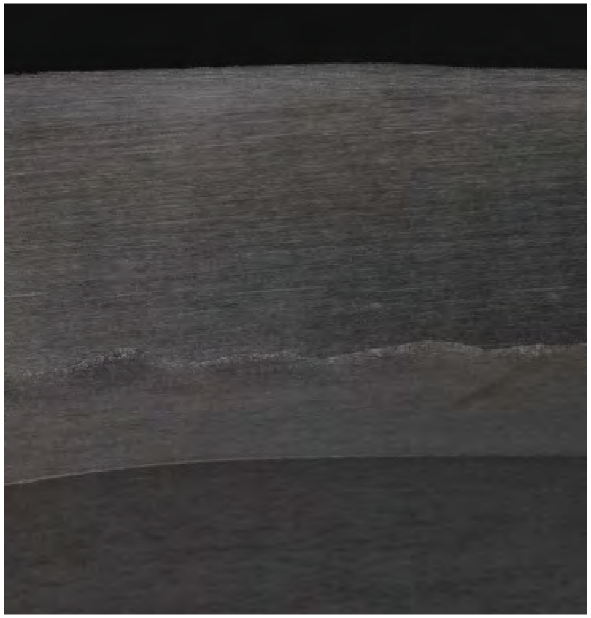
Testing Program

- Welding Services Incorporated (WSI) performed the reinforcements on the cones per the test and welding specifications
- A UT inspection was performed to document the wall thicknesses of the cones before and after repair
- A certified material test report was made available
- Required equipment and fixtures were designed and purchased

Testing Program

- Specific samples were then fabricated



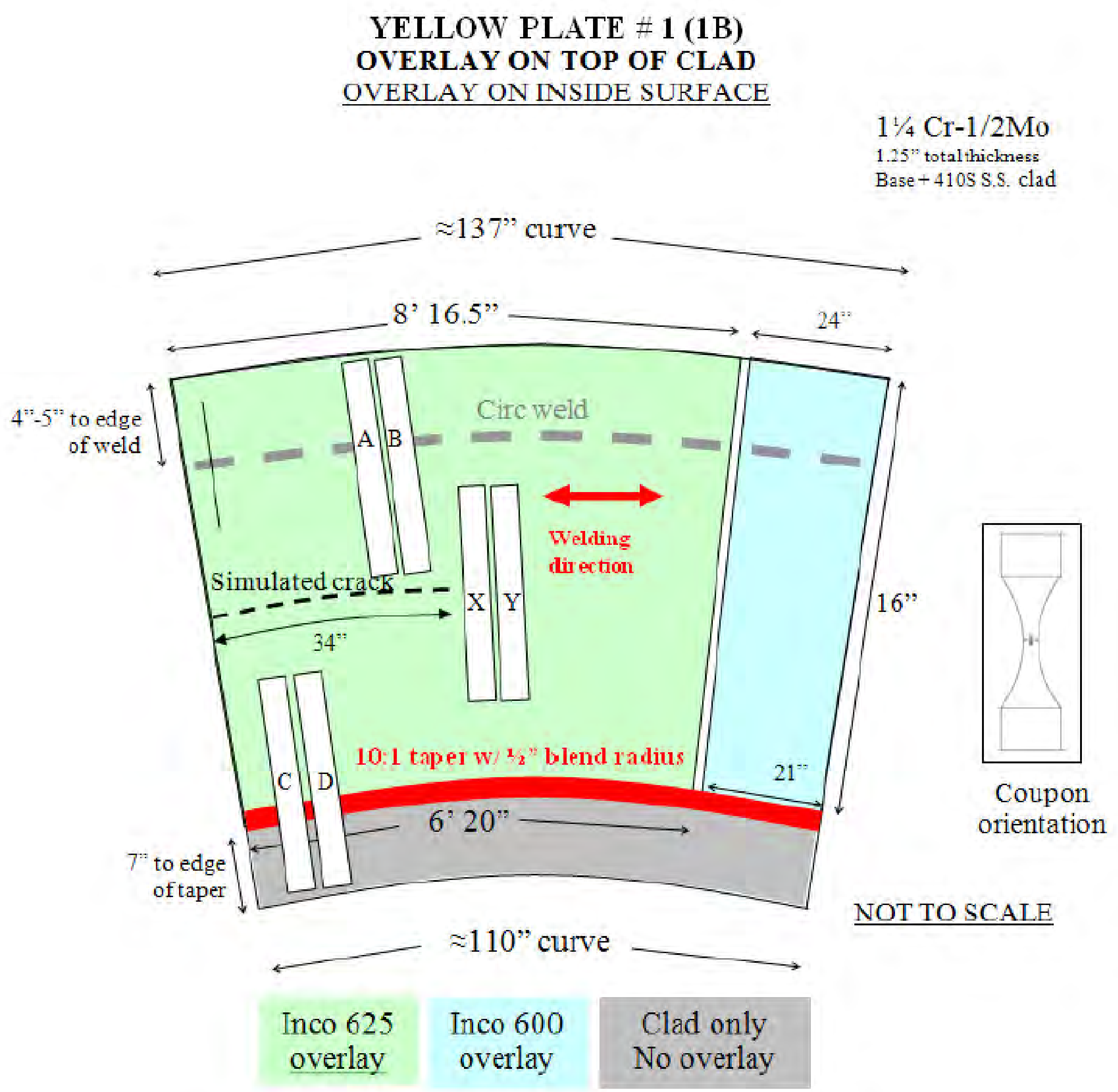


STRESS ENGINEERING SERVICES INC.

•an employee-owned company

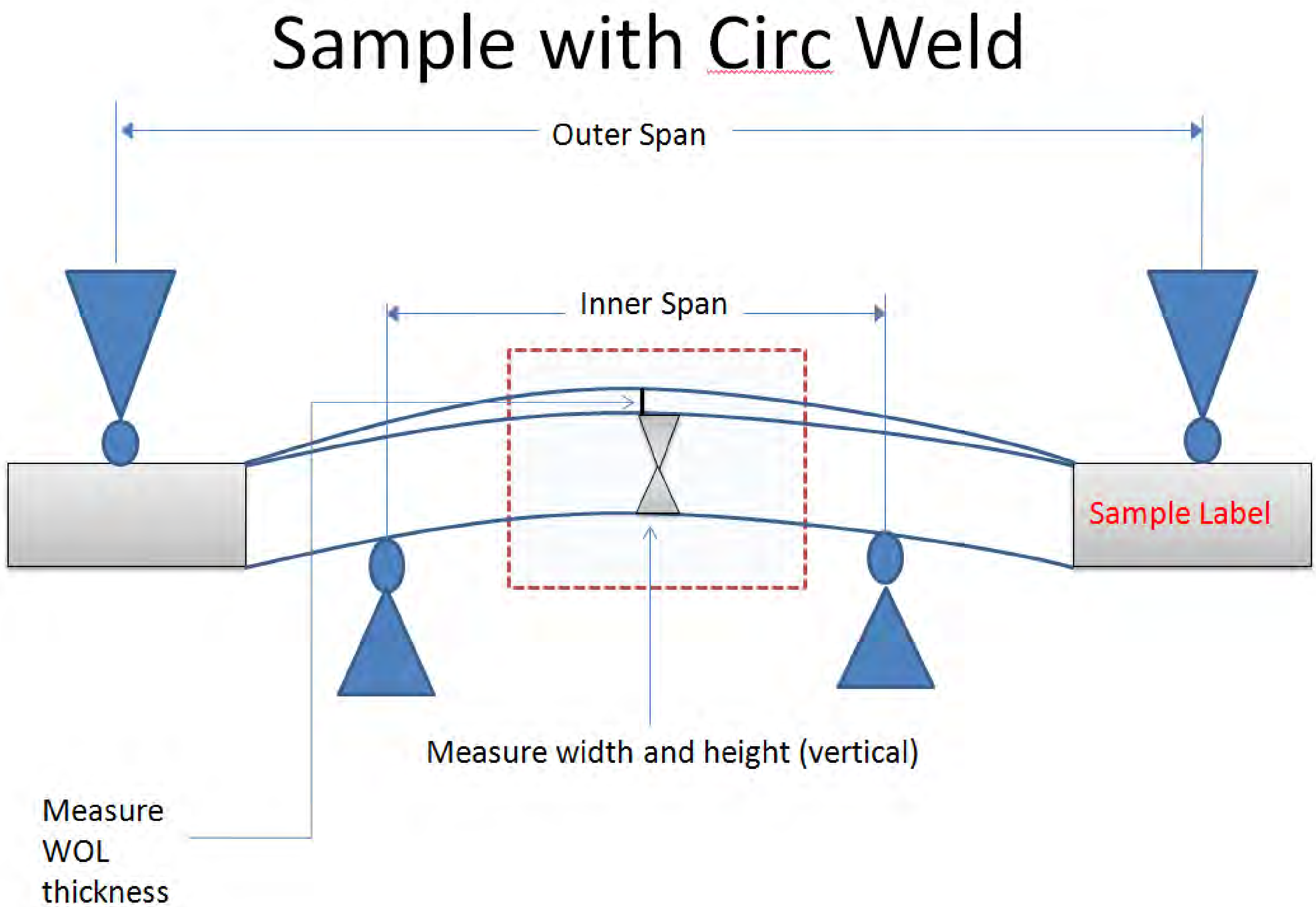
Testing Program

- Specific samples were then fabricated



Testing Program

- Loading of Samples



STRESS ENGINEERING SERVICES INC.

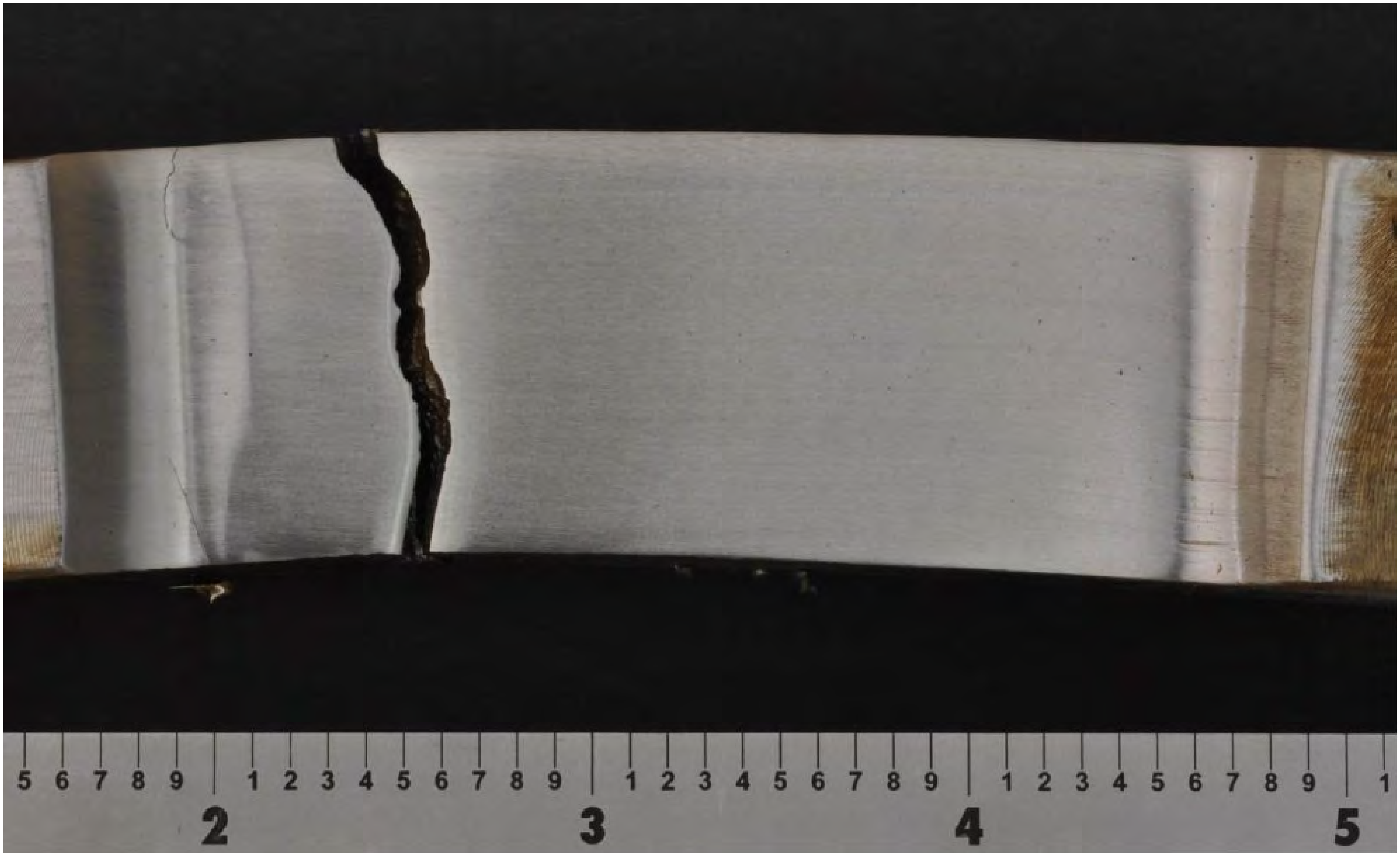
•an employee-owned company

Testing Program

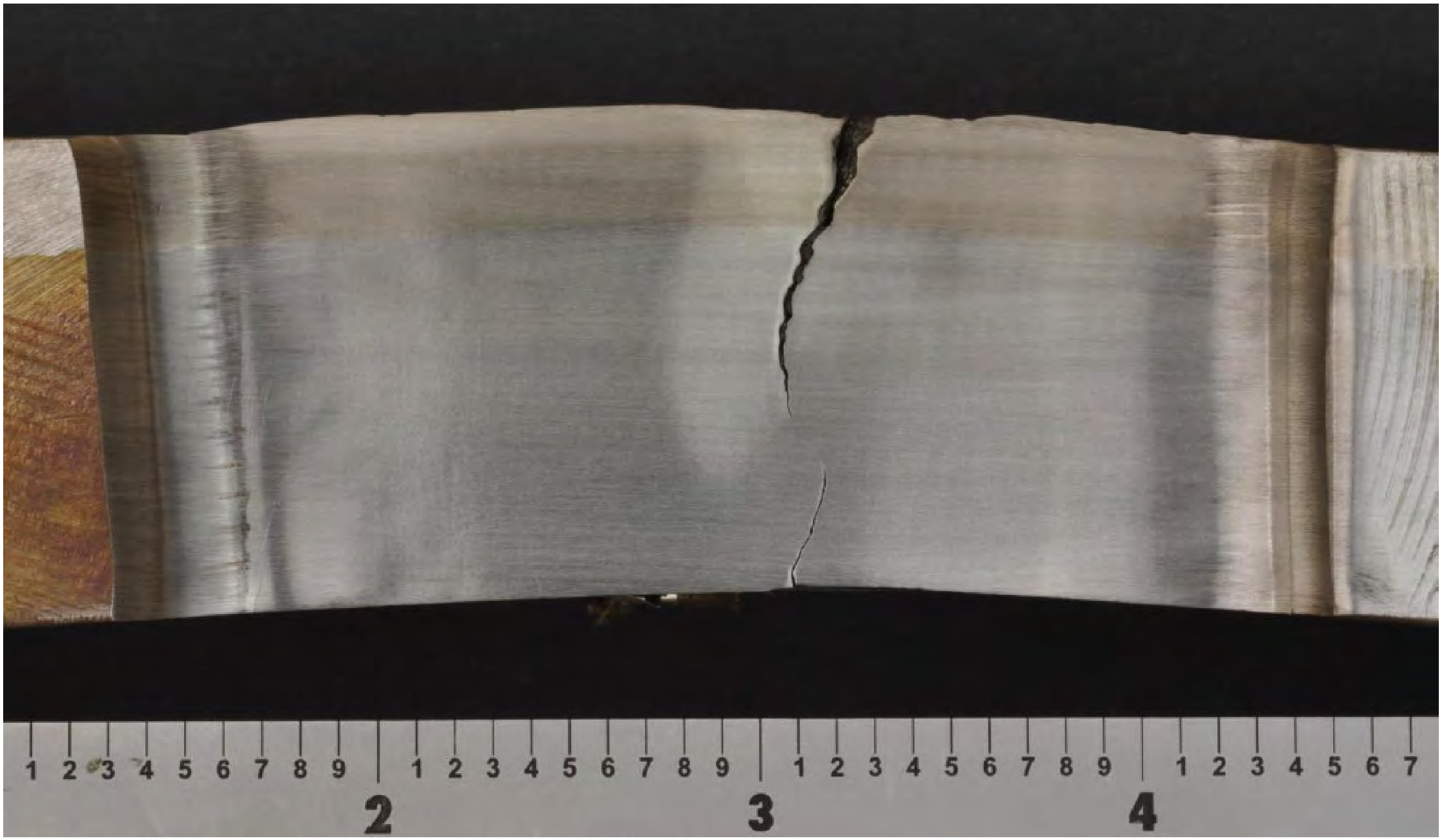
SAMPLE	Description	Approximate (Total) Moment of Inertia	Temperature Range
		in^4	°F
G2X	Base metal, mid-plate	0.2235	150°F-850°F
G2Y	Base metal, mid-plate	0.2099	300°-600°
G4X	Base metal, mid-plate	0.1890	450°F
G4Y	Base metal, mid-plate	0.1911	450°F
R2N2X	Red plate, mid-plate	0.2940	Ambient
R2N2Y	Red plate, mid-plate	0.2762	Ambient
R2N3X	Red plate, mid-plate	0.2533	450°F
R2N3Y	Red plate, mid-plate	0.2500	450°F
R15621A	Red plate, circ weld	0.1829	450°F
R15621B	Red plate, circ weld	0.1873	450°F
R2N1A	Red plate, circ weld	0.1945	150°F-850°F
R2N1B	Red plate, circ weld	0.2059	150°F-850°F
R15621C	Red plate, 5:1	0.2449	150°F-850°F
R15621D	Red plate, 5:1	0.2348	150°F-850°F
R110621C	Red plate, 10:1	0.2407	450°F
R110625C	Red plate, 10:1	0.2014	450°F
R110621D	Red plate, 10:1	0.2085	450°F
Y2N6X	WOL on clad, mid plate	0.3627	450°F
Y2N6Y	WOL on clad, mid plate	0.3635	450°F

Results – Bending Fatigue Testing

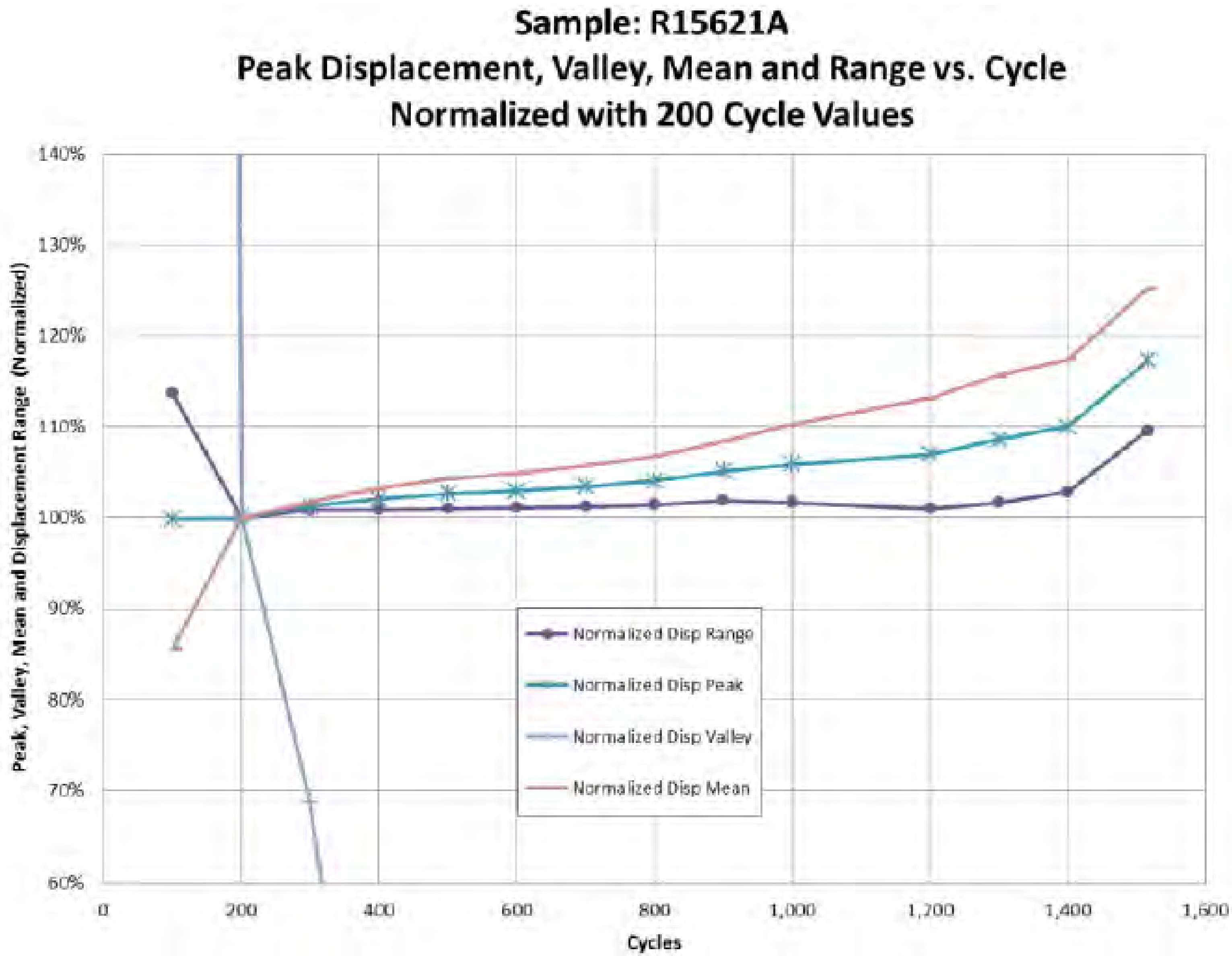
Results: Bending Fatigue Testing – Base Metal



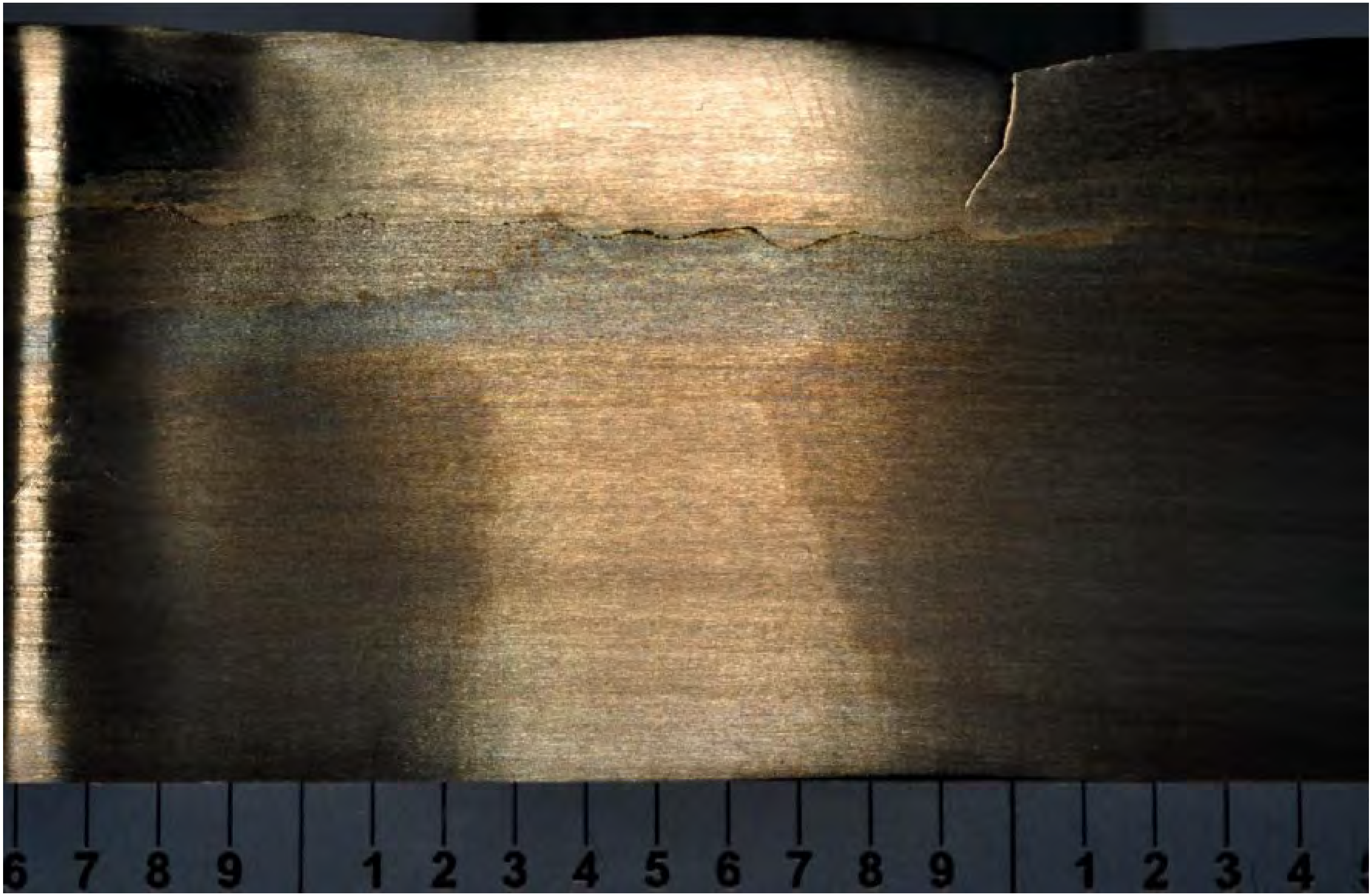
Results: Bending Fatigue Testing – WOL Mid



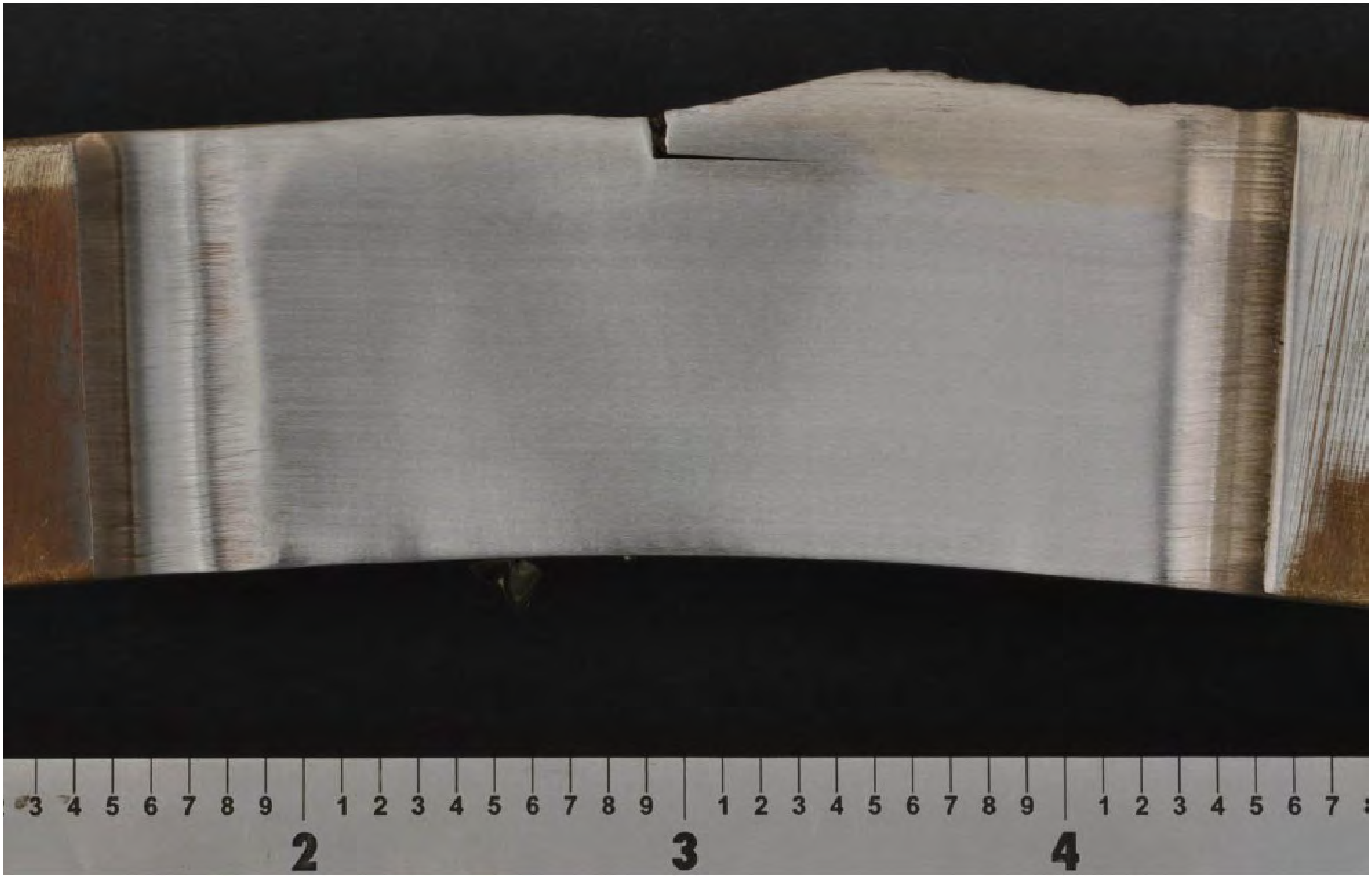
Results: Bending Fatigue Testing – WOL CW



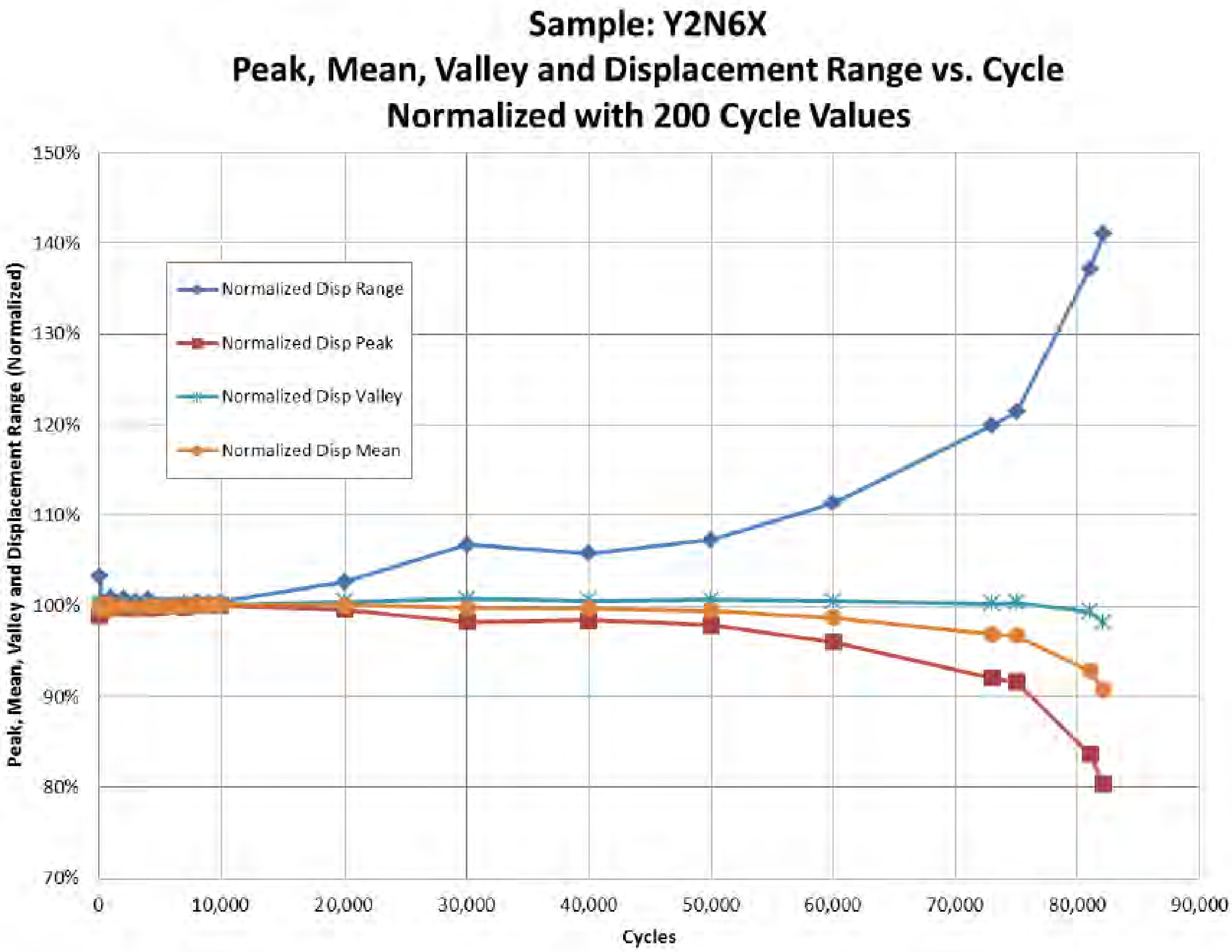
Results: Bending Fatigue Testing – WOL CW



Results: Bending Fatigue Testing – WOL Transition



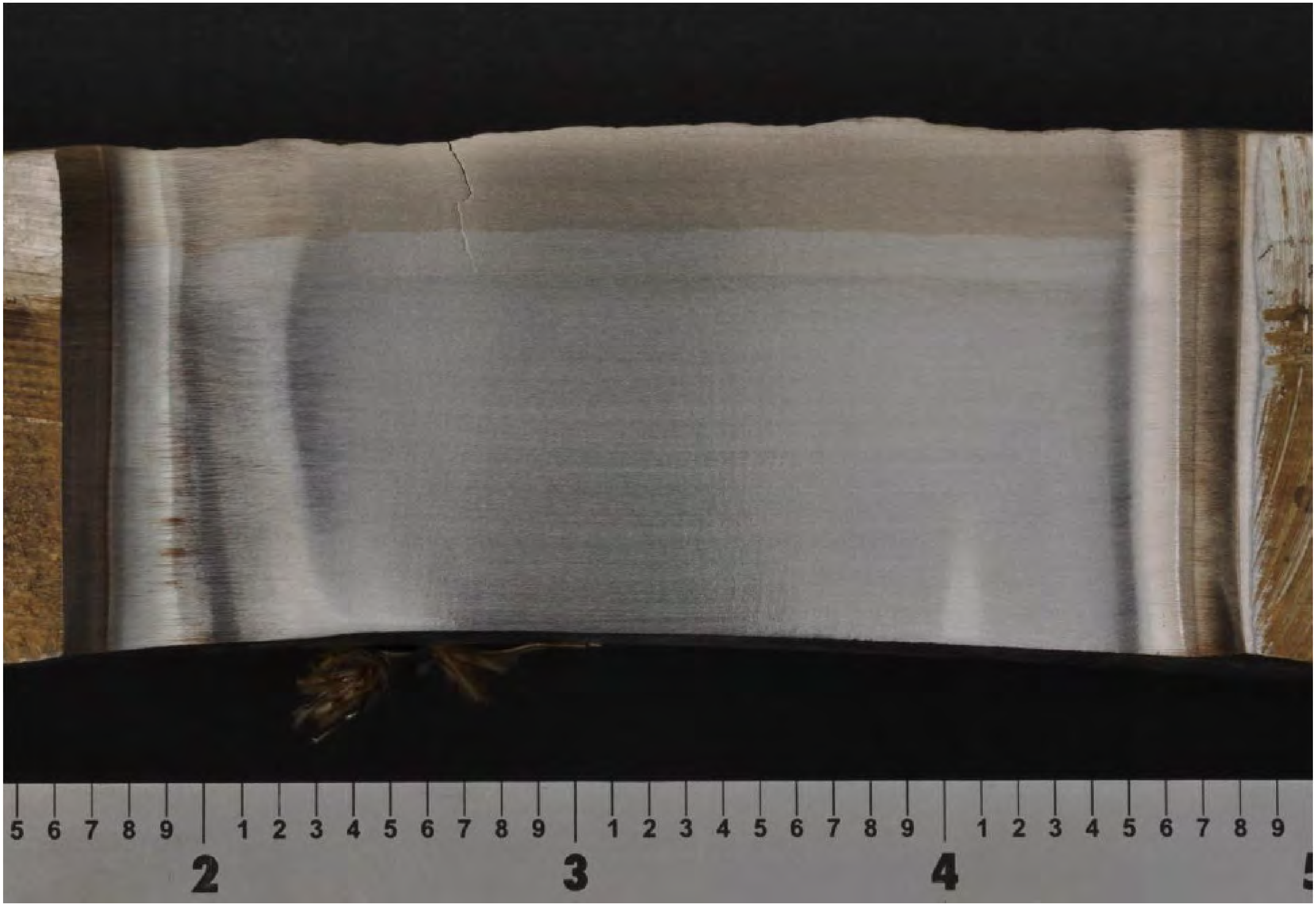
Results: Bending Fatigue Testing – WOL on Clad



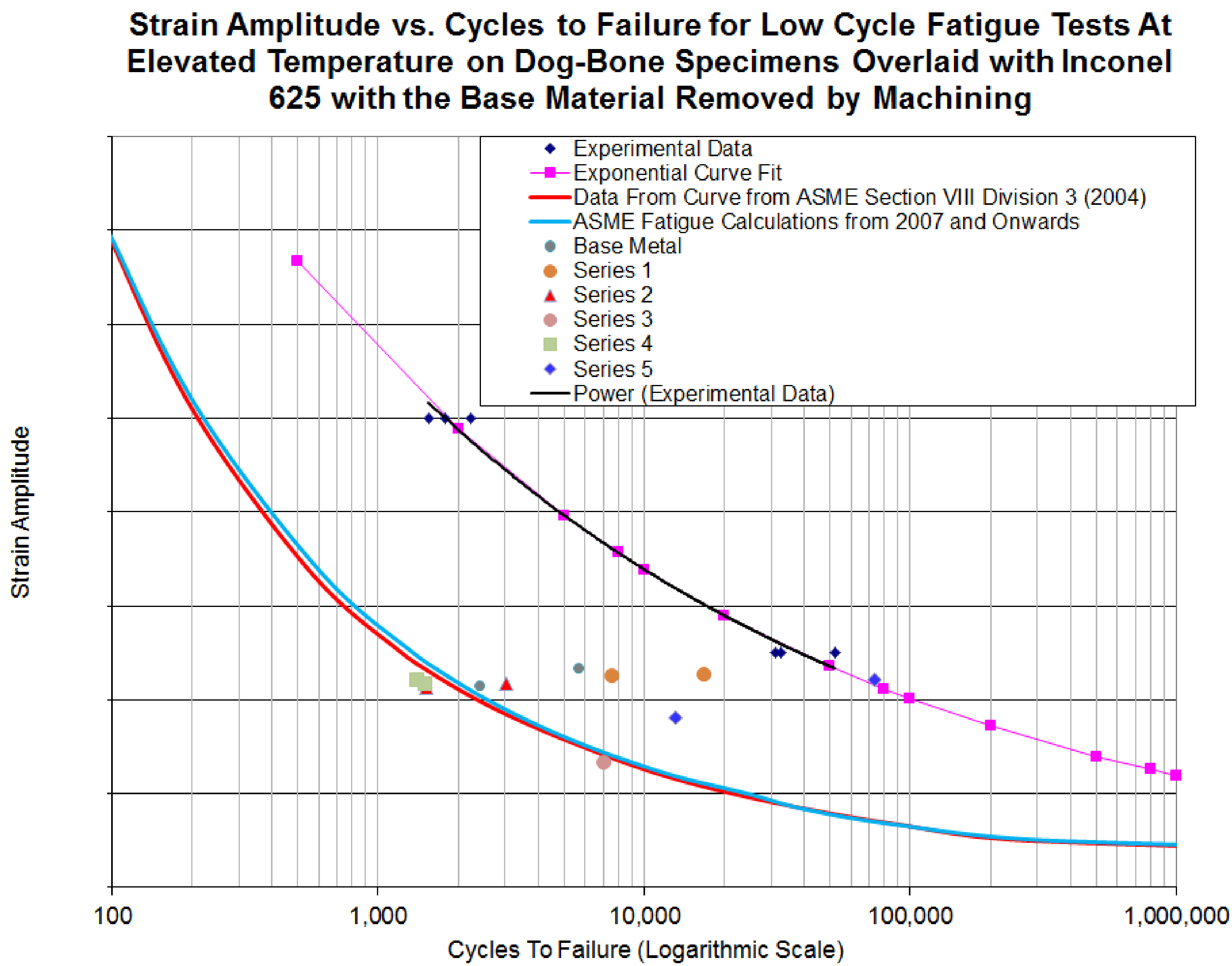
STRESS ENGINEERING SERVICES INC.

•an employee-owned company

Results: Bending Fatigue Testing – WOL on Clad



Results: Summary of All Tests (Failure)



Conclusions of Results To Date

- LCF testing of WOL material shows that Inconel 625 has a much higher degree of fatigue resistance than the base metal
- The material being tested is not virgin (10 year use). As such the previously accumulated damage is not readily quantified, and this may result in scatter in the results. However, results so far are very encouraging.
- All transitions are susceptible to cracking due to having a stress concentration factor. To maximize chance of success, transitions should be located in regions away from high stresses, or bending stresses.
- The ridges in the weld overlay reinforcements can create stress risers that are severe enough to precipitate the generation and propagation of cracks.
  - Less pronounced effect in mid-plate samples
  - Perhaps a significant contributing factor in circumferential weld samples
- Reinforcements in samples without the cladding removed, appear to be effective, so long as the bond strengths are sound, and any stress concentration factors caused by ridges are not significant enough to create problems.

Unknown Effects / Potential Improvements

- Samples with the WOL ground smooth
- Samples reinforced with an existing crack (without removal)
- Additional transitions
- Additional welds

Questions?

Julian J. Bedoya, P.E., Senior Associate

Julian.Bedoya@stress.com

Luiz C. Largura Jr., Associate

Luiz.Largura@stress.com

Stress Engineering Services, Inc.

281.955.2900