Engineering, Test & Technology

Cold Spray Development for Apache Mast Support

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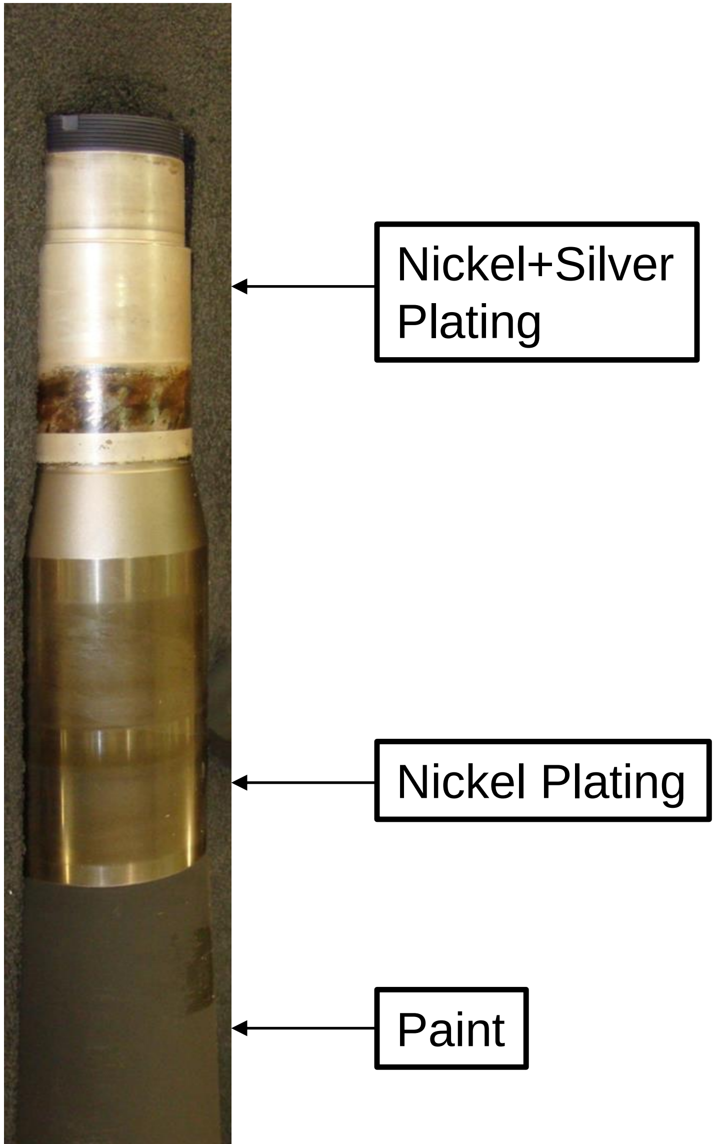
This research herein was performed under Contract W911W6-12-D-0006, Task Order 0001.

Agenda

- **Repair Development Background**
- **Test Approach and Results**
- **Destructive Test Results**
- **Process Improvement Opportunities**
- **Conclusion**

Driver for Repair Development

Unique Advantage – Localized Repairs



- **Current Process**
  - Strip everything
    - Very long process due to nickel removal rate
    - Part serviceability not known until after process is complete
  - Reapplication of all plating and coatings
  - Limitations on thickness buildup
- **Proposed Process**
  - Machine local area of damage until corrosion is removed
  - Locally mask area
  - Cold spray nickel powder on top of whatever is left
  - Part limits thickness as opposed to application process

Test Approach

Purpose:

- To develop a structural, cold-spray repair solution for corroded nickel plated main rotor support mast

Methodology:

- Utilize requirements from multiple sources to evaluate capability of technology
  - BAC5851 – Application of Thermal Spray Coatings
  - MIL-STD-3021 – Materials Deposition, Cold Spray
  - D6-51343 – Thermal Spray Repair of Exterior Clad Aluminum Skins

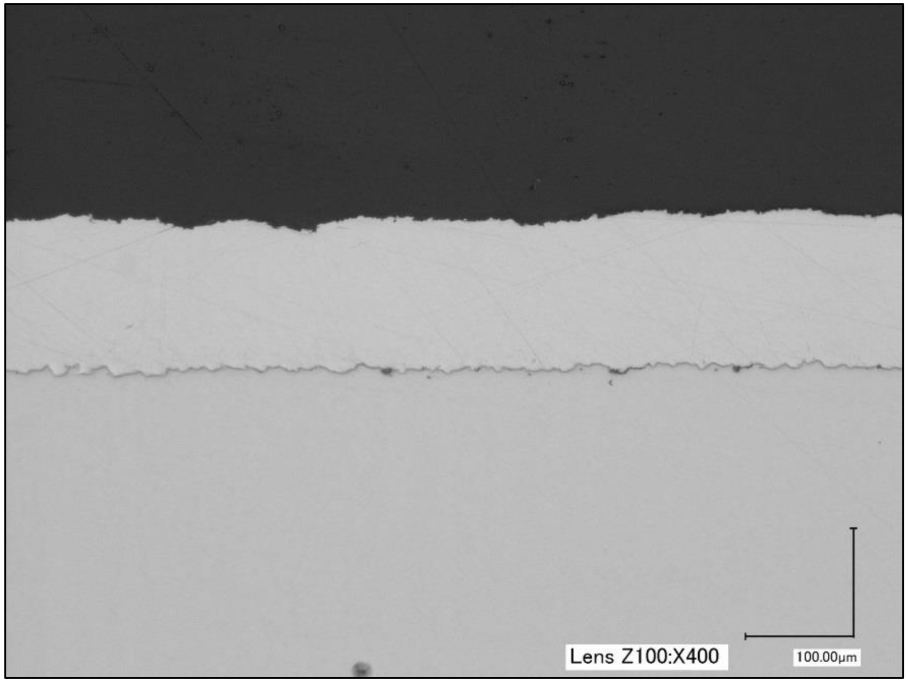
Goal:

- Leverage Technology Developed by ARL
- Validate Moog/Mid-American Aviation cold spray equipment and processing parameters for nickel on 4340 steel
- Demonstrate Cold Spray technology as a viable process for corrosion repair on structural part

Coating Quality

Coating quality test results:

Cold Spray Equipment	CGT Kinetics 4000
Powder	AAE Ni-110, 99.9% (4-8 micron)
Carrier Gas	Helium
Sample #	B-13
Spray Date	10/1/15
Coating Thickness	0.008 inches
Interface contamination (particles greater than 0.002")	0 abrasive particles/inch
Porosity/Oxide Content Normal	Average value: 0.083 % Standard deviation: 0.039 % Minimum: 0.022% Maximum: 0.323 % Number of fields examined: 20
Cracks or interface zone separation	Non observed
Micro Hardness (10 sample average)	394 HV (0.2kg)



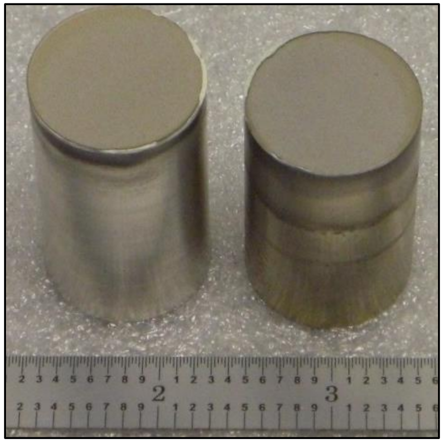
Adhesion Testing

Testing was in accordance with ASTM C633 with modifications -

Specimen #	Spray Date	Coating Thickness (inches)	Test Result (psi)	Failure Mode
A-2	9/29/15	.010 to .011	11,906	Glue
A-3	9/29/15	.011 to .012	11,064	Coating Adhesion
A-4	9/29/15	.012	11,334	Coating Adhesion
A-5	9/29/15	.013	10,968	Glue
B-11	10/1/15	.009	11,484	Glue
B-12	10/1/15	.009	11,698	Glue
B-14	10/1/15	.009	12,048	Glue
B-15	10/1/15	.009	11,268	50% Glue/50%Coating

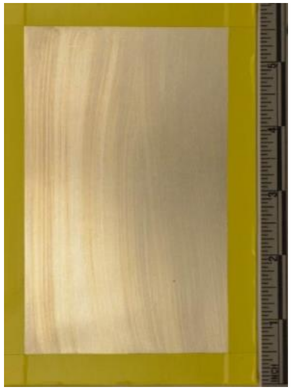
Requirement: 10,000 psi min.

Average: 11,471 psi



Corrosion Testing- ASTM B117

EL Ni + Ag



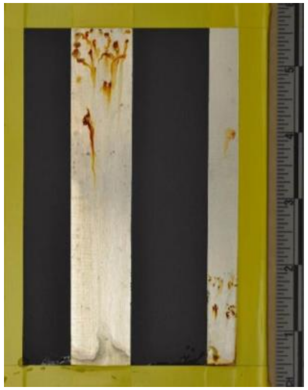
Combo

CS Ni

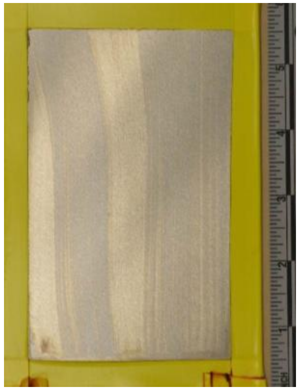
CS Ni + Dry Film

24 Hours

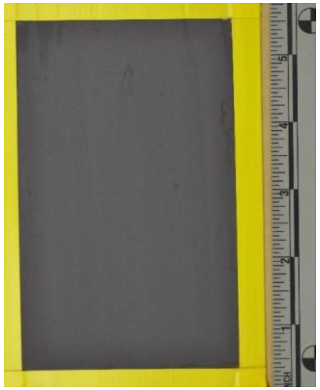
24 Hours



360 Hours

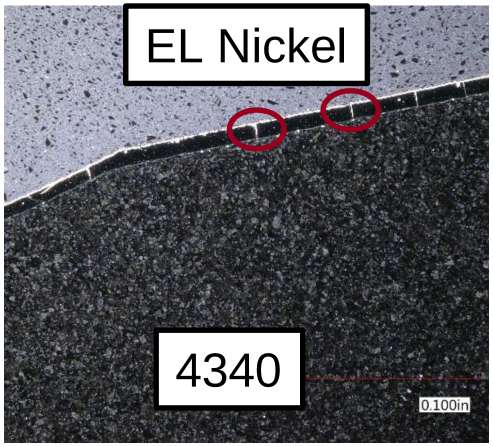


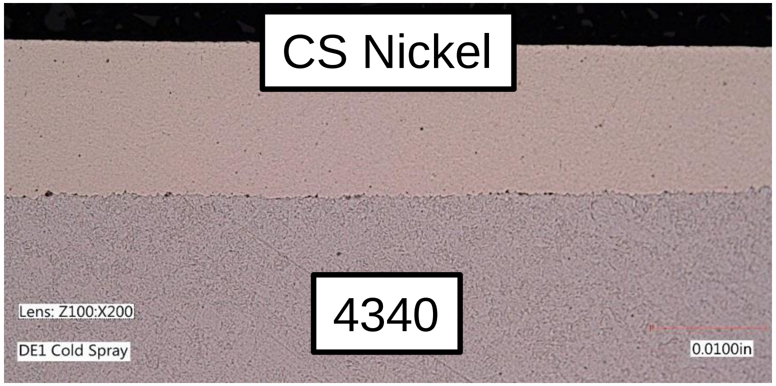
360 Hours



Corrosion Testing- Discussion

- **Two reasons for improved corrosion performance**
  1. Cold spray coating much more uniform than electroless nickel plating
  2. Removing silver reduces some galvanic potential from the system
     1. Silver
     2. Electroless Nickel
     3. 4340 Steel





Residual Stress

Residual stress testing –

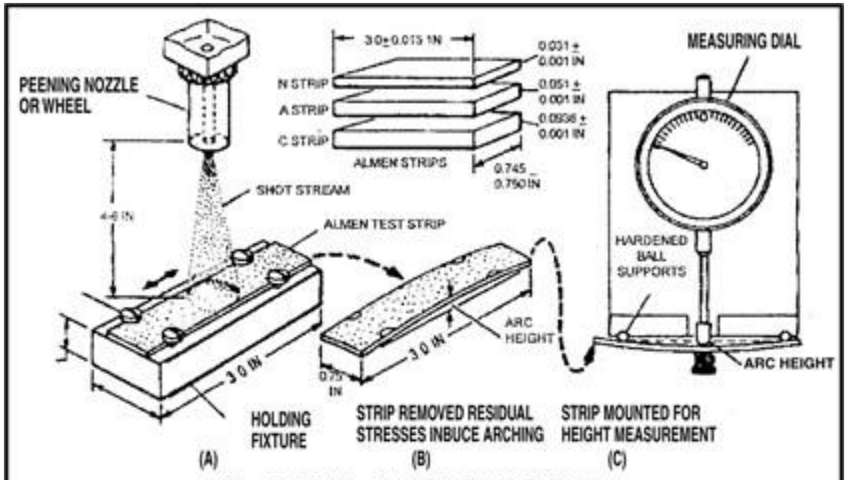


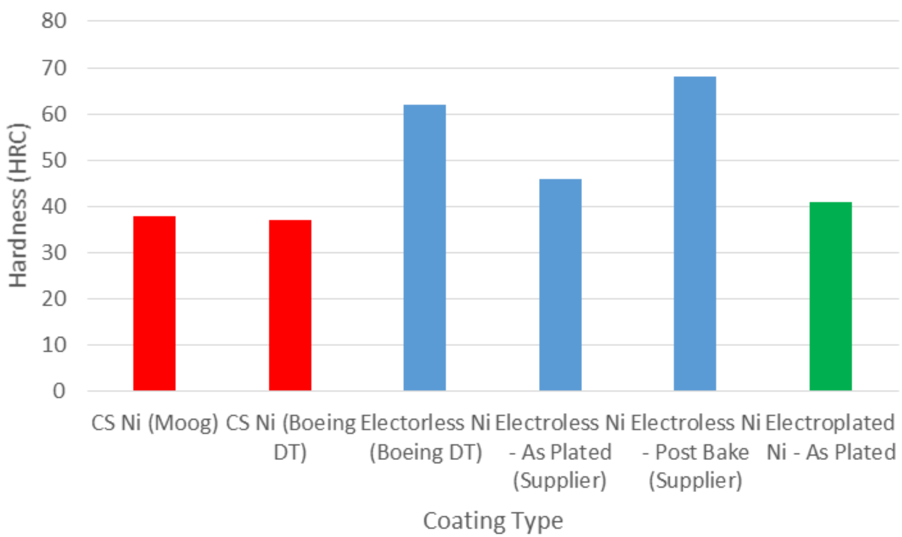
Fig-14 THE ALMEN STRIPSYSTEM

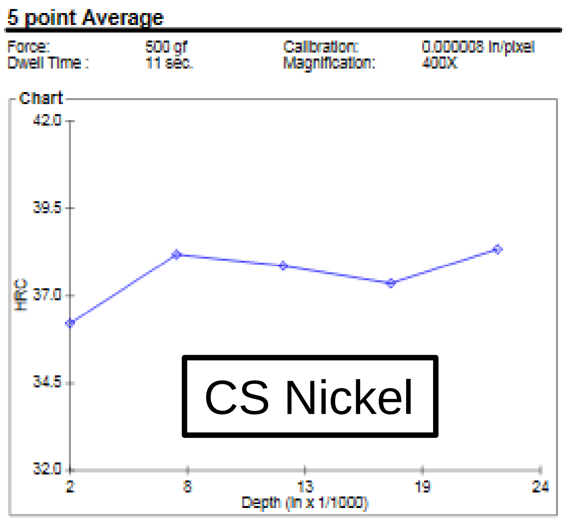
Specimen #	Cold Spray Thickness	As-Received Deflection	As-Grit Blasted Deflection	As-Coated Deflection	Deflection Difference	Residual Stress Type
1	0.004	-0.0004	-0.0003	+0.0024	+0.0027	compressive
2	0.004	+0.0001	0.0000	+0.0019	+0.0019	compressive
3	0.005	+0.0001	+0.0002	+0.0014	+0.0012	compressive
4	N/A	+0.0000	+0.0034	N/A	+0.0034	compressive
5	N/A	-0.0003	+0.0034	N/A	+0.0037	compressive

Microhardness Testing

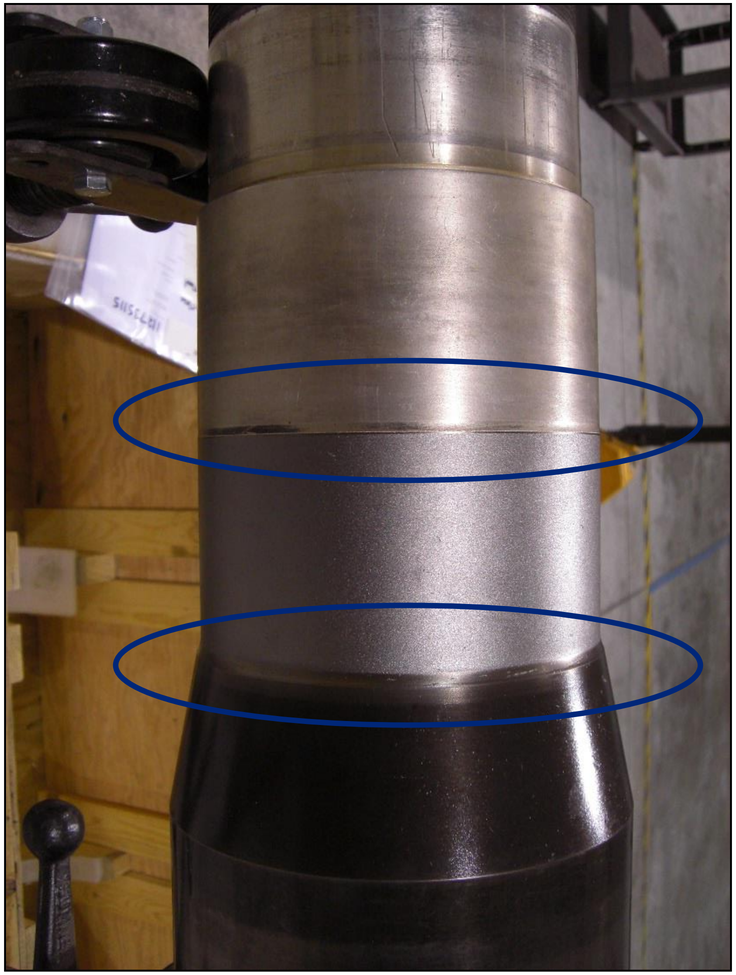
Hardness testing results from various sources:

- Cold spray hardness lower then expected (38 HRC)
  - Hardness consistent through thickness
- Electroless Ni hardness increased due to hydrogen embrittlement bake
- Plan to simulate multiple installations prior to fatigue testing

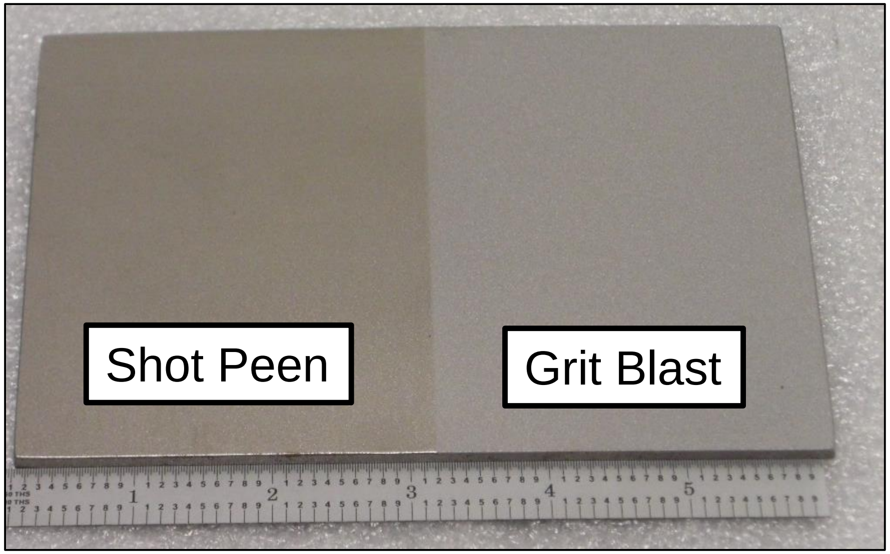


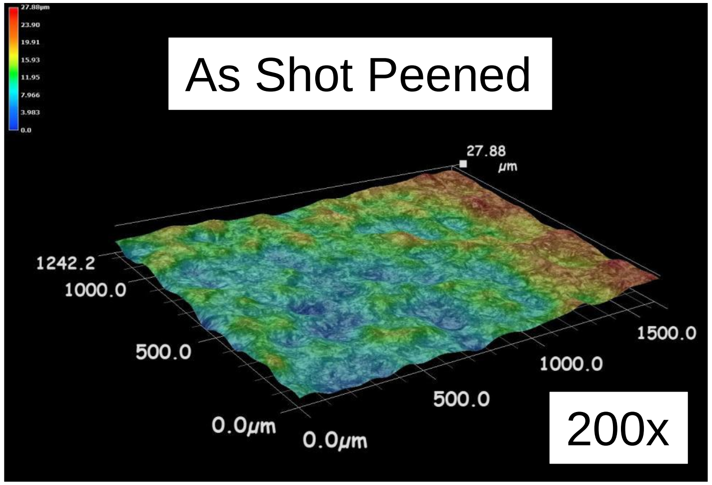


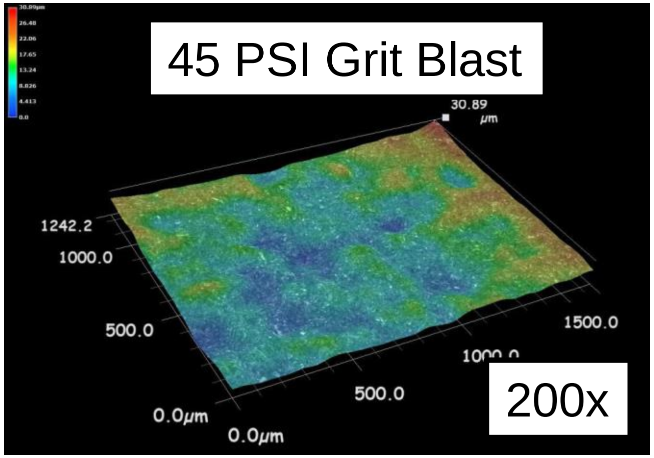
Destructive Test – Shot Peen

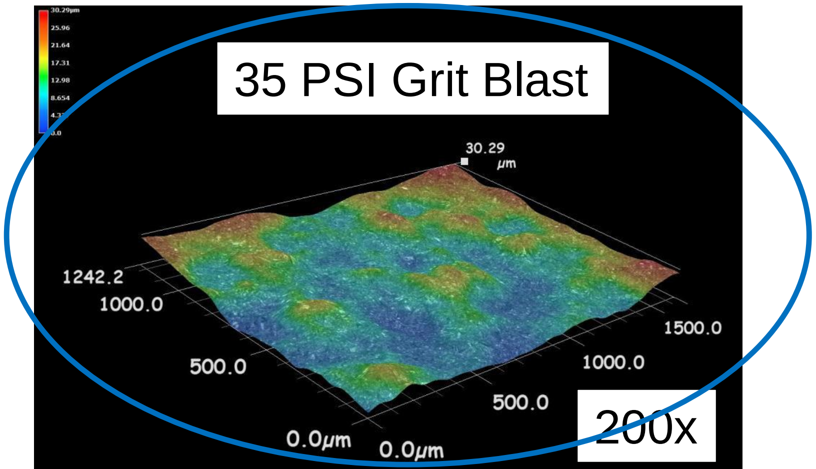


Determining Grit Blast Parameters

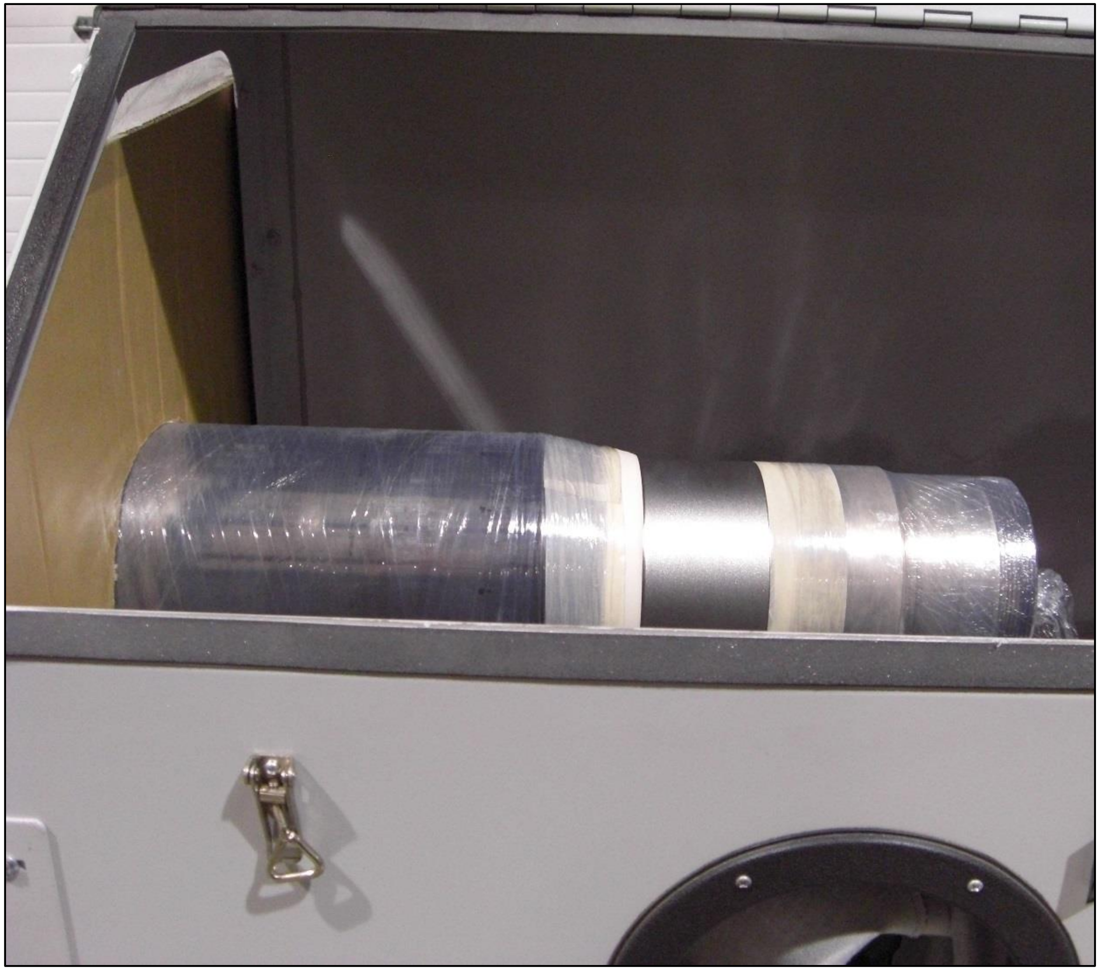




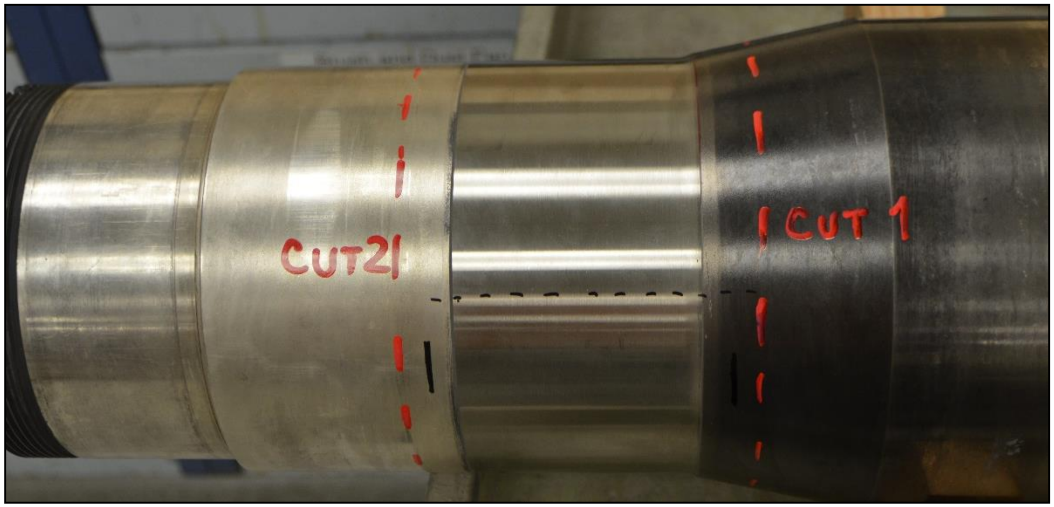




Destructive Test – Grit Blast



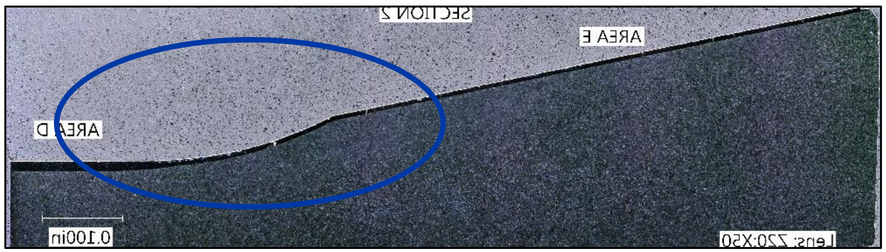
Destructive Test Results

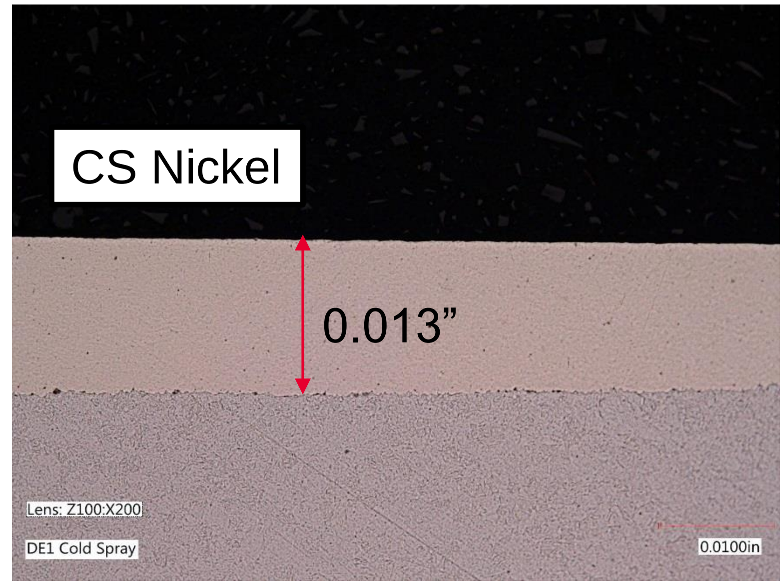


Cut 2

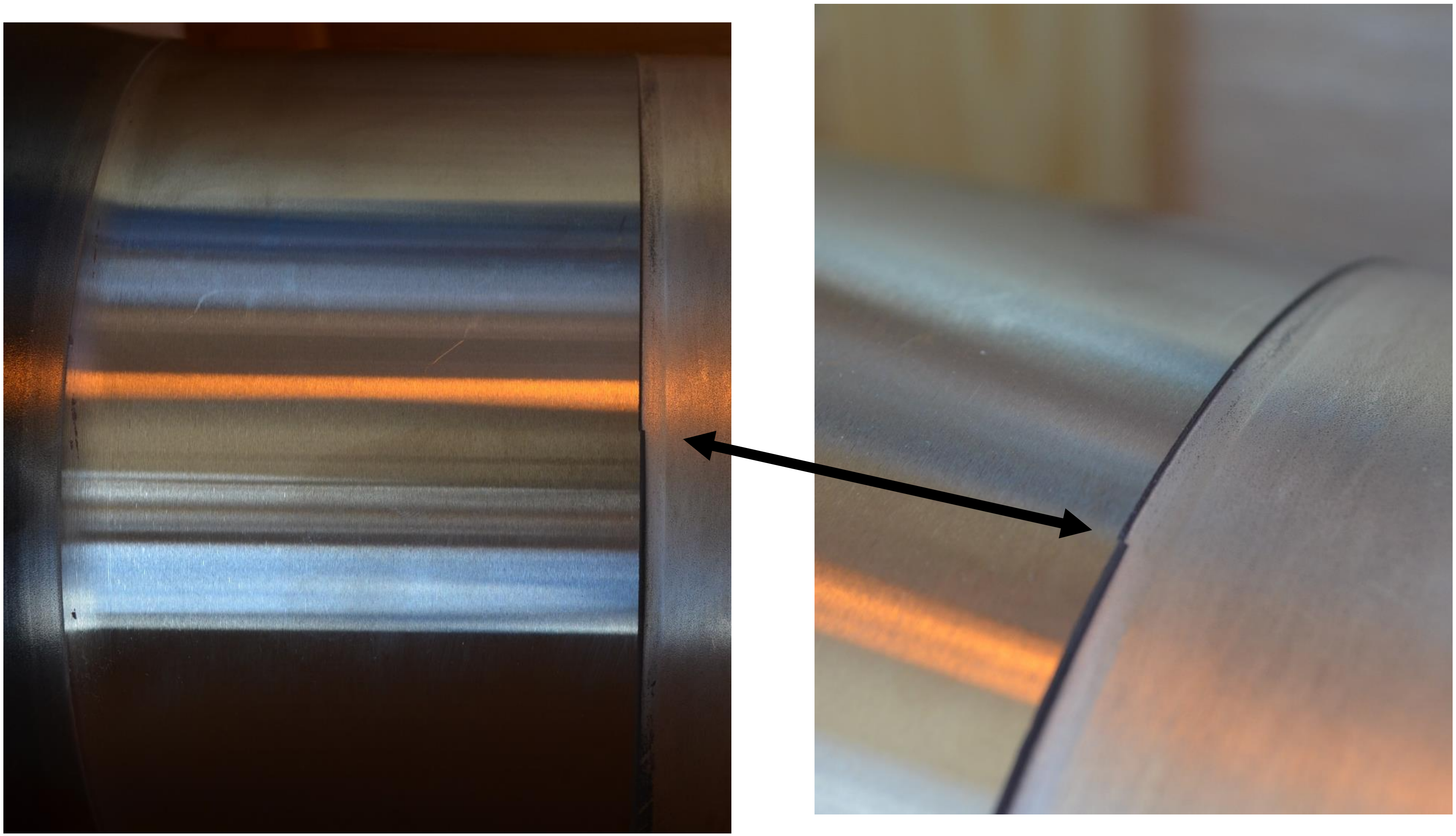
Cut 1

Destructive Test Microstructure

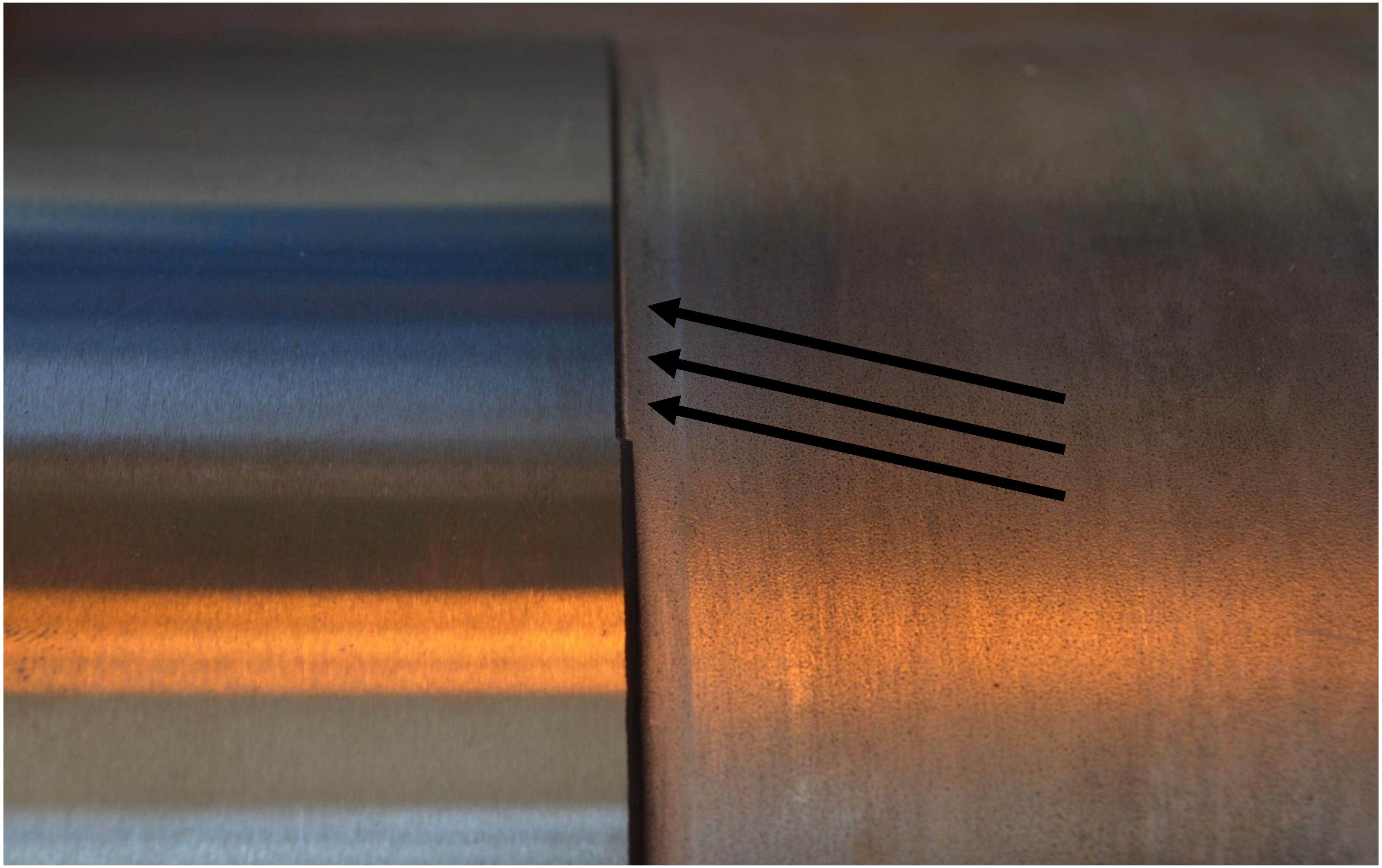




Real World Issues – Edge Irregularity

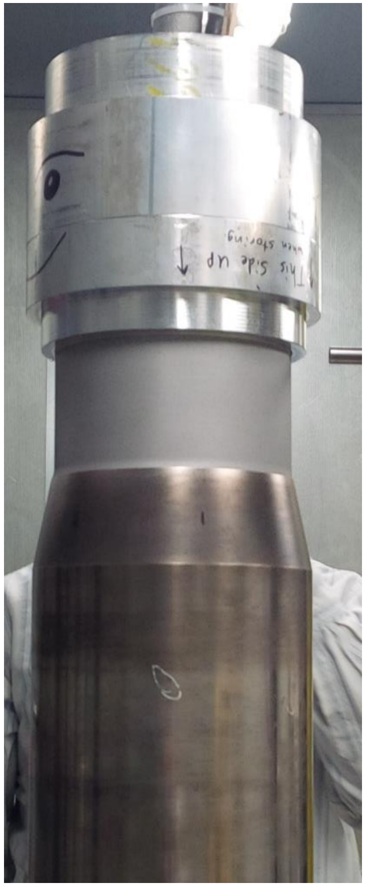


Real World Issues – Coverage

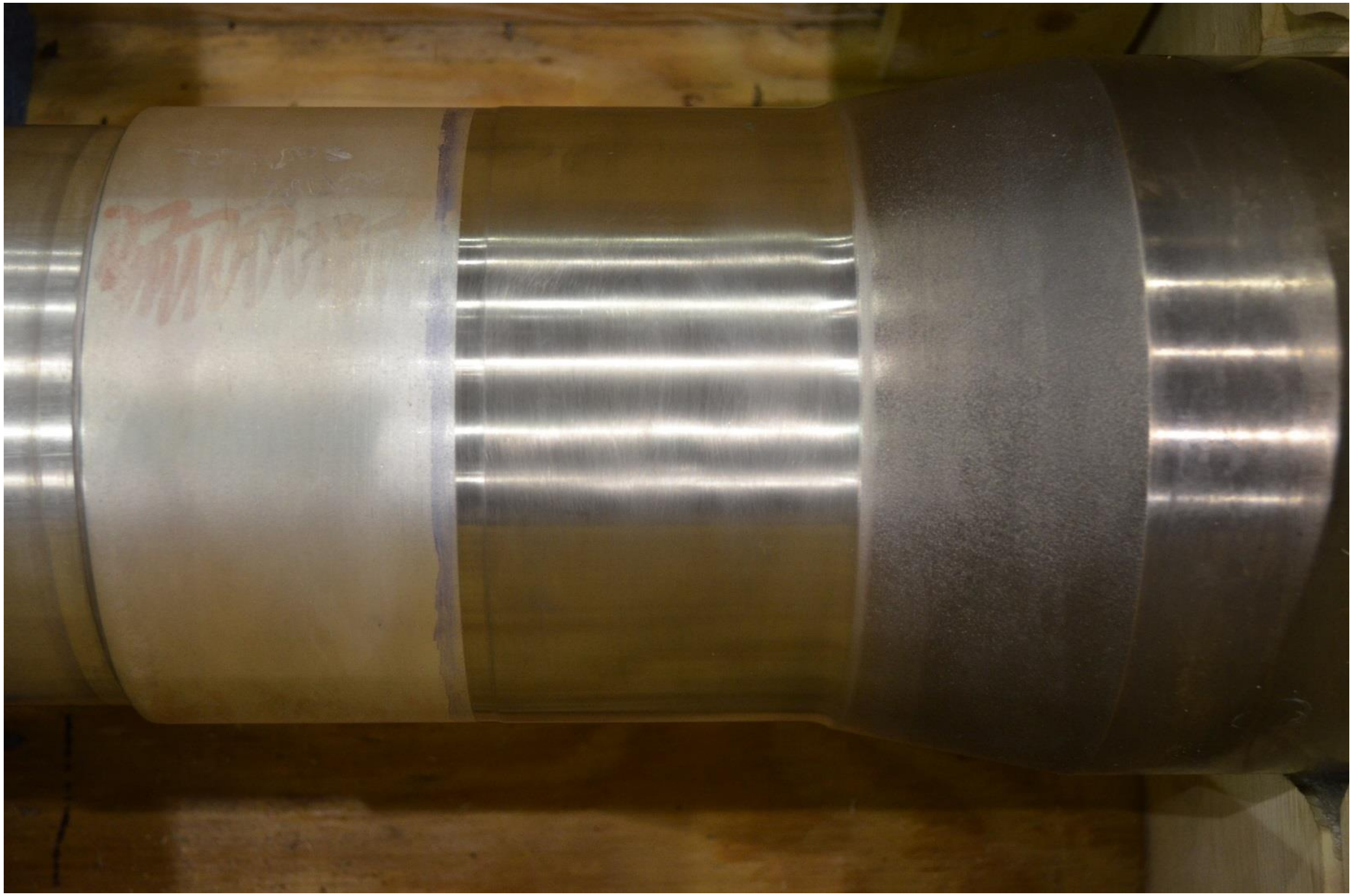


Real World Issues – Coverage Solution

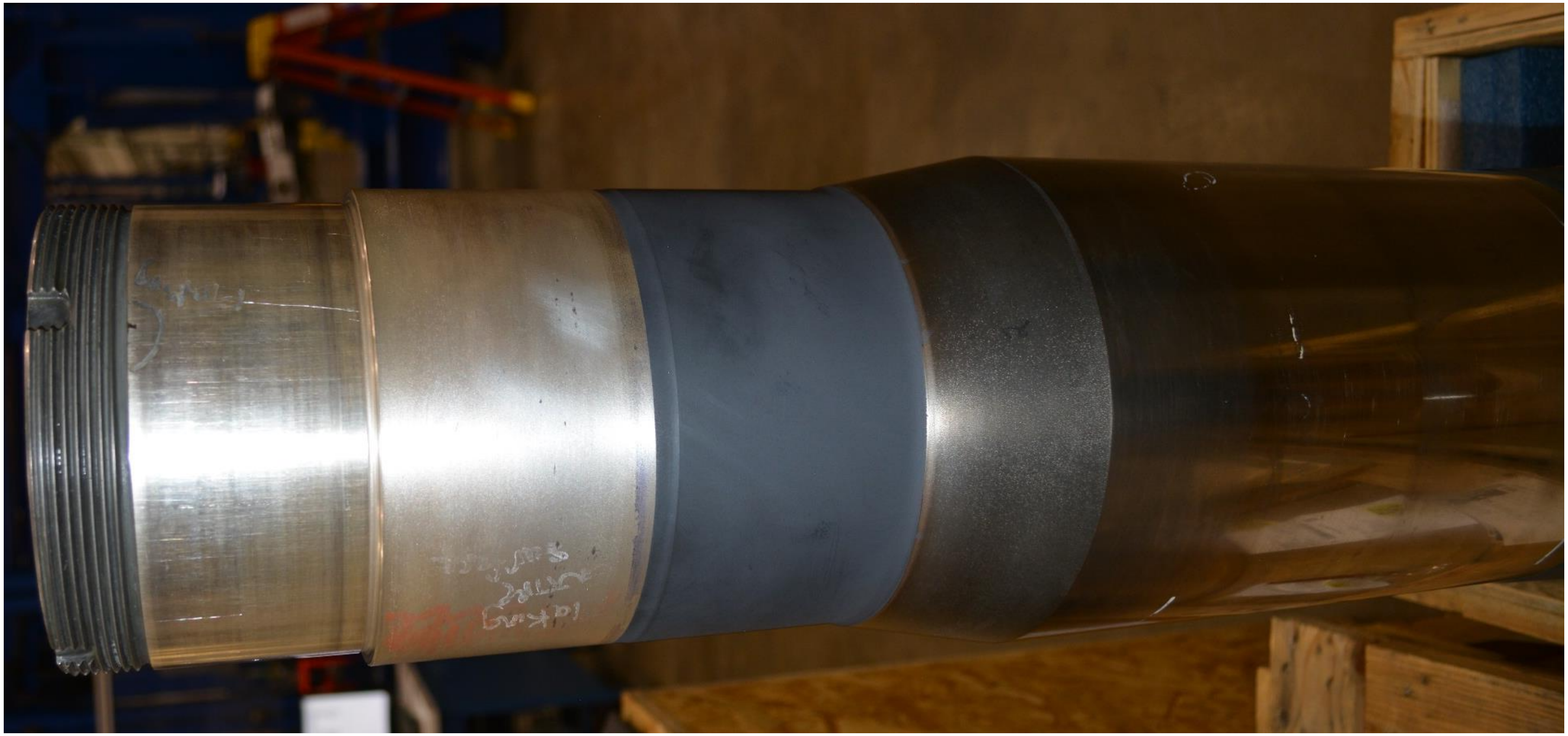
Massive Quality Improvement



Post Cold Spray Configuration



Final Part Configuration



Conclusion

- **All test objectives were successfully completed**
  - Hardness of cold spray nickel was lower than anticipated
  - Fatigue test used to verify system performance
- **Destructive test article did not find any significant issues**
  - Lessons learned were incorporated into processing fatigue test articles
    - More consistent masking technique
    - Improved approach to machining
- **Two full scale fatigue test masts were successfully repaired**
- **Fatigue testing revealed no significant change in performance**

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