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Low Energy Welding for Ni-based Superalloy Repair

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ASETS DEFENSE
ADVANCED SURFACE ENGINEERING TECHNOLOGIES FOR A SUSTAINABLE DEFENSE

Outline

- Low energy welding system
- Introduction
- LEW repair of Ni-superalloy
- Performance analysis
  - Heat affected zone
  - Tensile strength
  - Oxidation test
- Turbine blade repair example

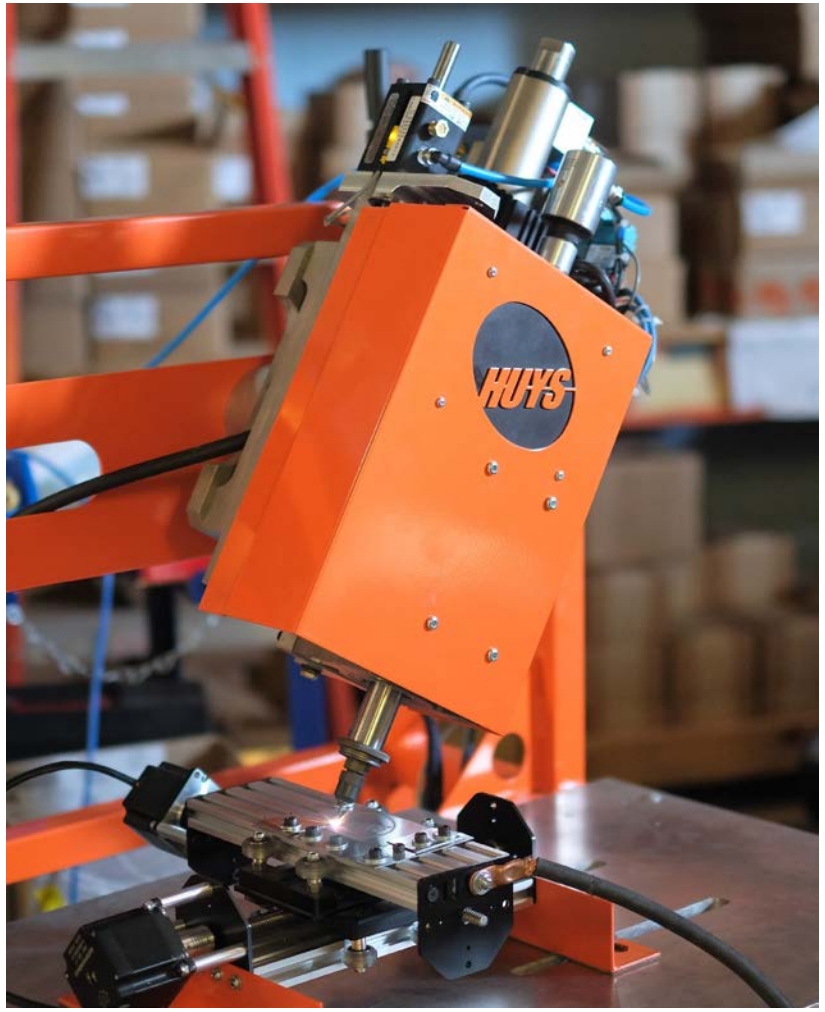
Low Energy Welding System

ESD Power Supply

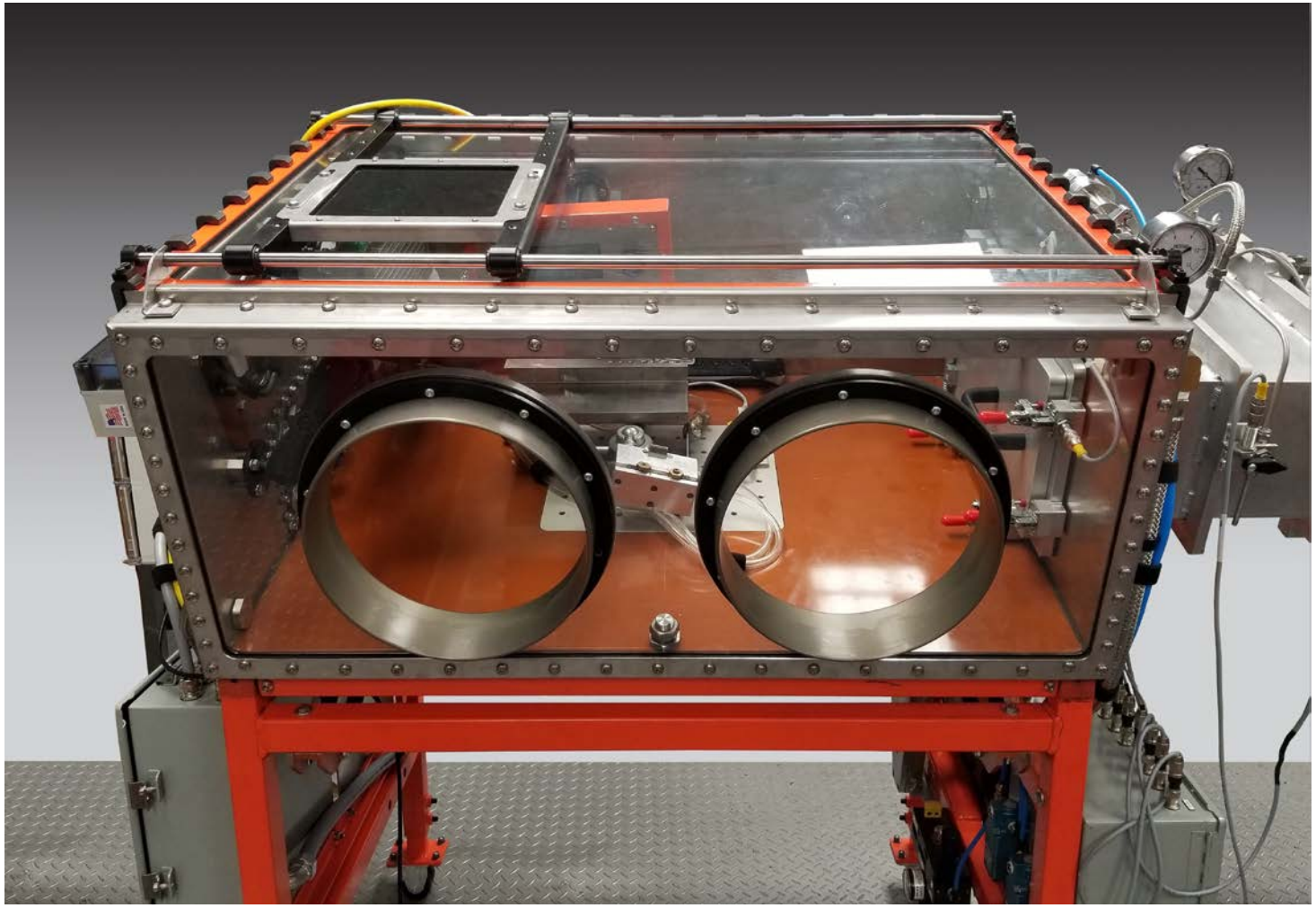
Rotating Applicator

Vibrating Applicator

Low Energy Welding System



Automated LEW system



LEW Integrated Glovebox

LEW Process Demo

Beneficial Properties of Ni-superalloys

01 Mechanical Properties

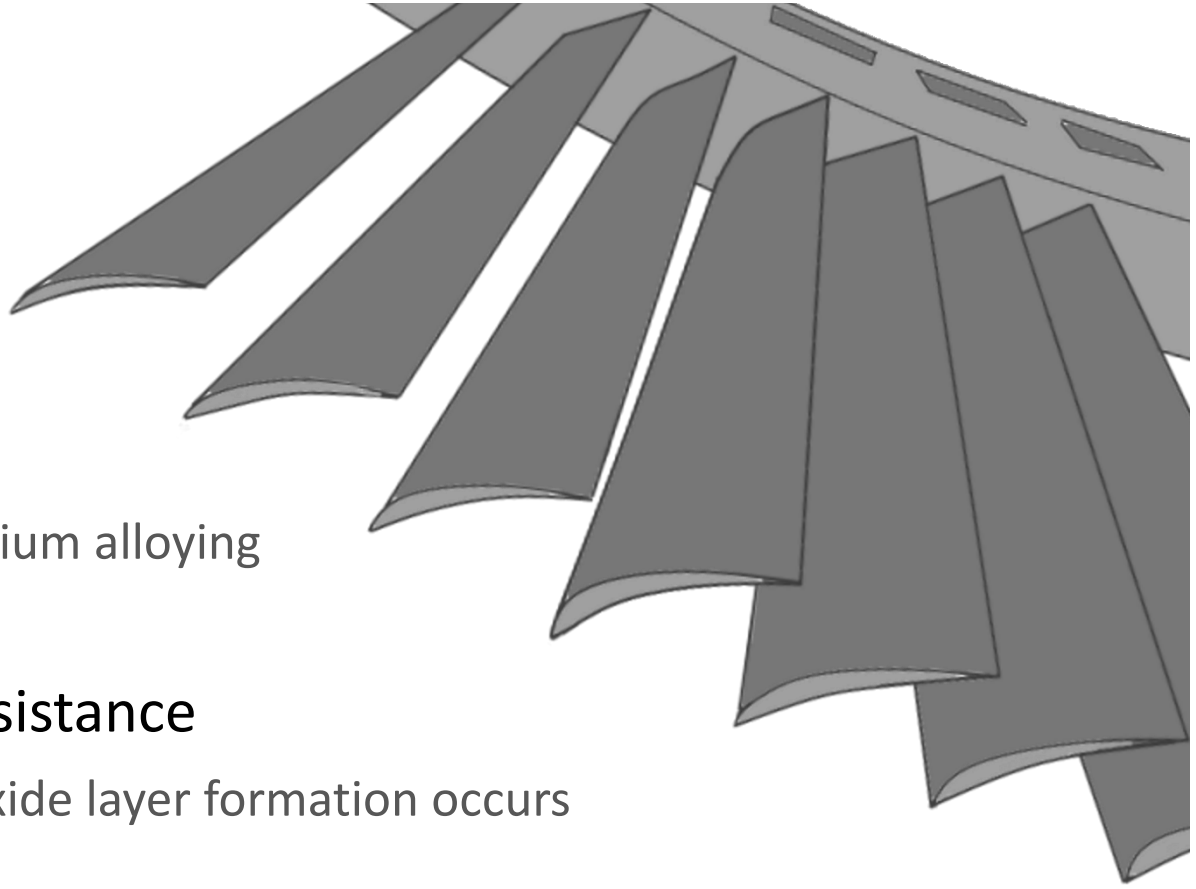
Retains high strength and creep deformation resistance at high temperatures

02 Corrosion Resistance

Addition of molybdenum and chromium alloying elements

03 Oxidation Resistance

Passivating surface oxide layer formation occurs at high temperatures



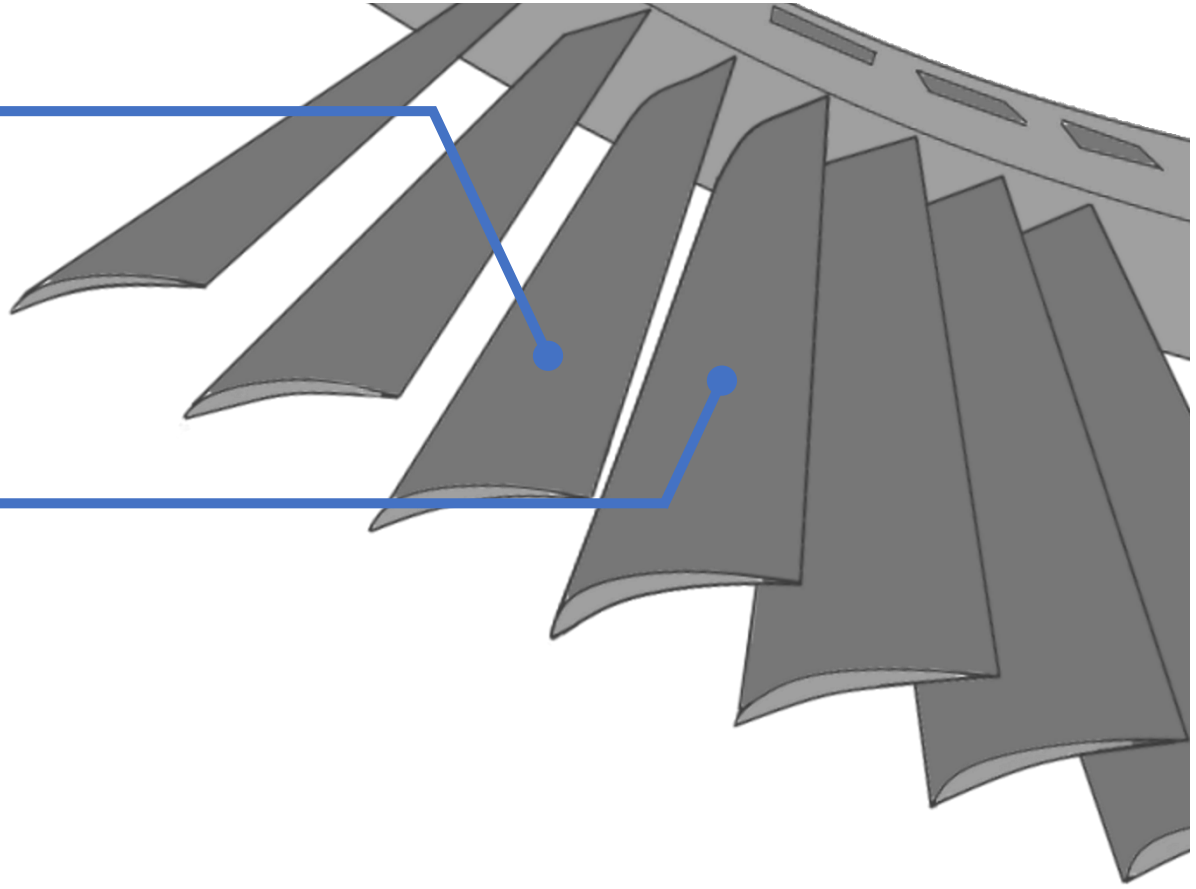
Working Environment

Thermal Stress

Higher temperatures due to advances in cooling efficiency

Mechanical Stress

Cycles of centrifugal loading and aerodynamic forces



Repair Process for Surface Crack

01 Crack Formation

Crack formation occurs from a surface defect

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02 Crack Detection

Crack is detected with the use of liquid penetrant, ultrasonic or radiograph techniques

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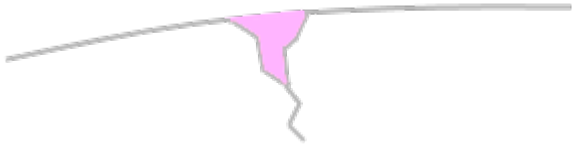

03 Replace Turbine Blade

Throw away old turbine blade and get a new one

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02 Crack Removal

Crack is detected, and removed by excavating material from the surrounding area

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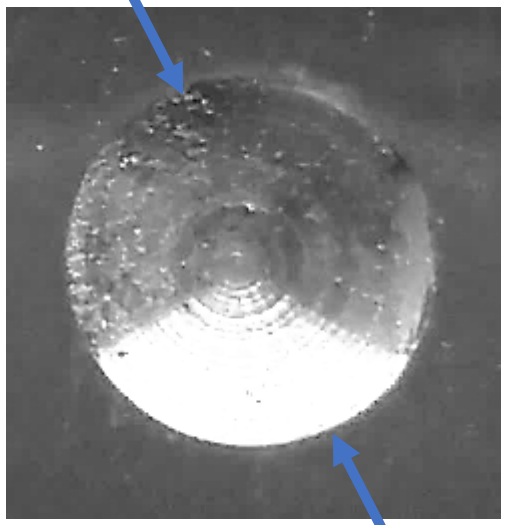
03 Cavity repair

Low Energy Welding (LEW) used to fill the cavity

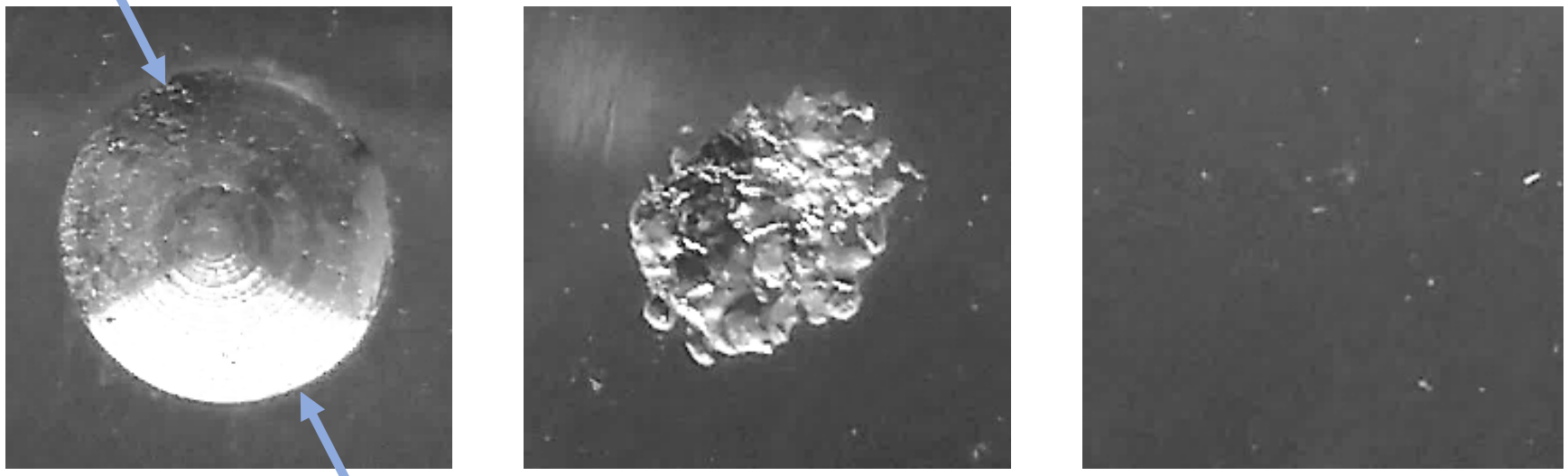
LEW Repair of Ni-Superalloy



5 mm ø cavity, 1 mm depth

LEW Repair of Ni-Superalloy

Repair Progression



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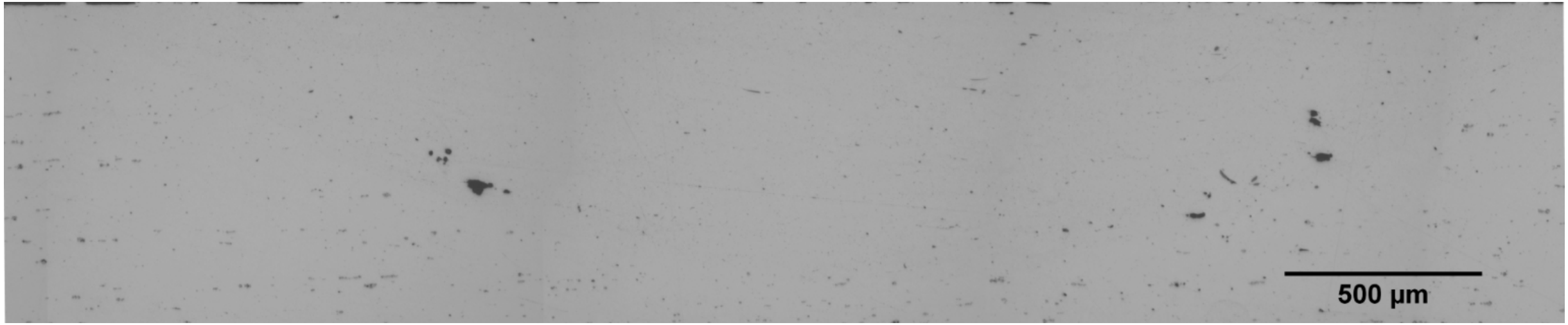
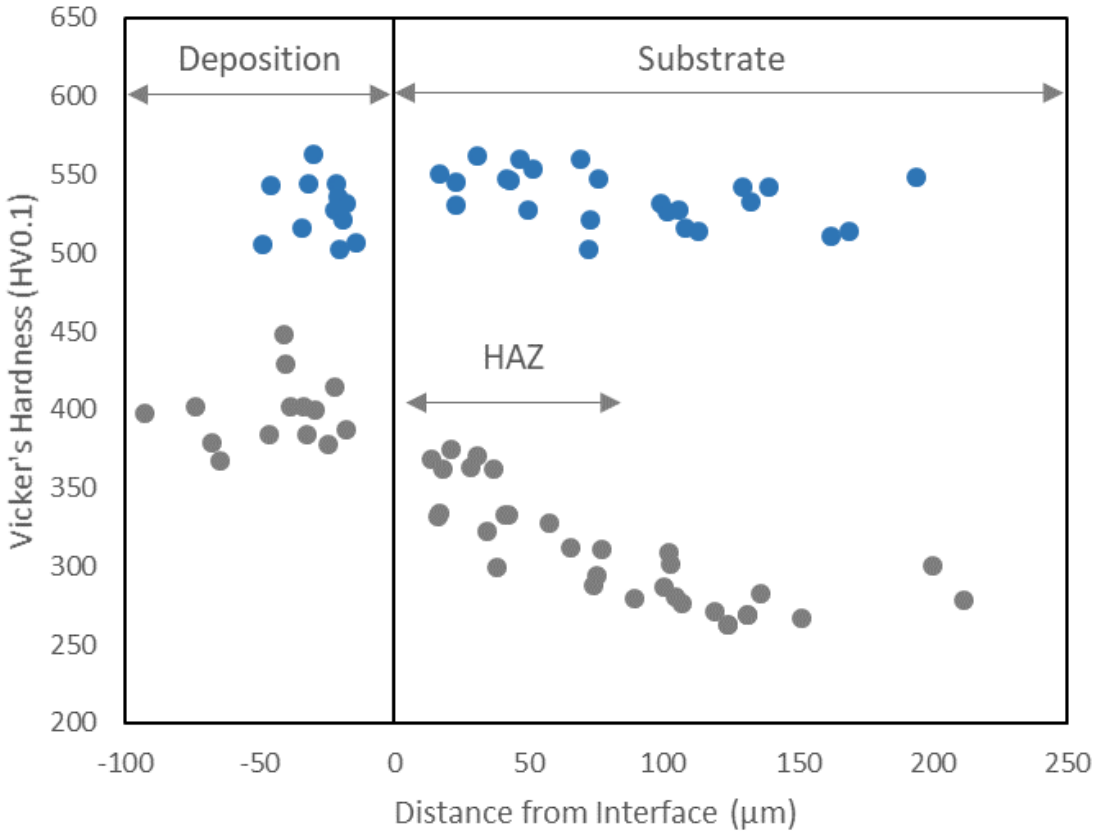
LEW Repair of Ni-Superalloy



Minimal Heat Affected Zone



01 Repair of Annealed Inconel 718

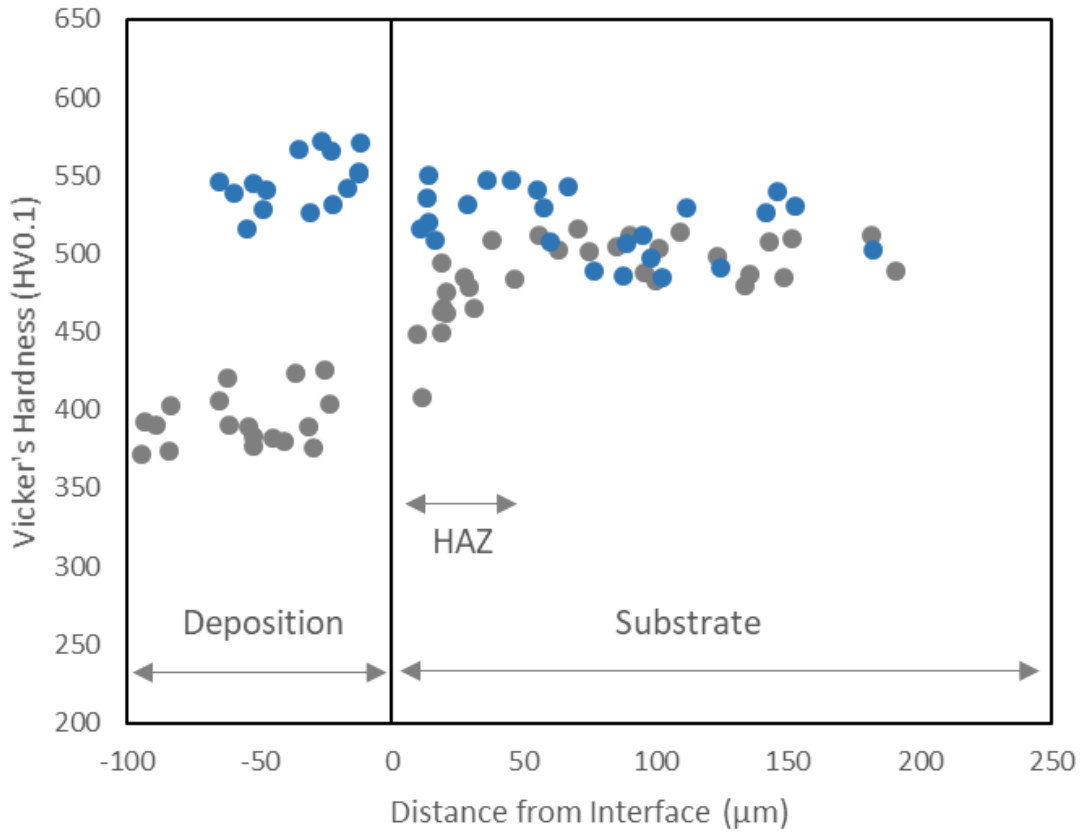
Low energy input and fast cooling rates limit the welding damage that occurs to the substrate

No post-deposition heat treatment

- Mismatch Ratio: 1.46
- HAZ: 80µm

With direct aging heat treatment

Minimal Heat Affected Zone



02 Repair of Aged Inconel 718

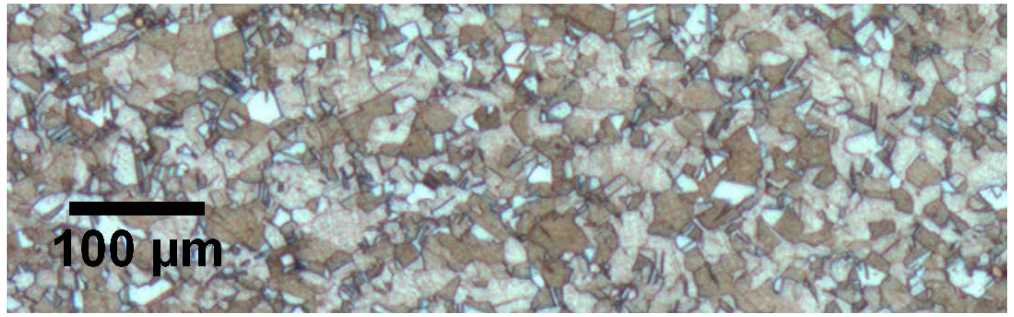
Low energy input and fast cooling rates limit the welding damage that occurs to the substrate

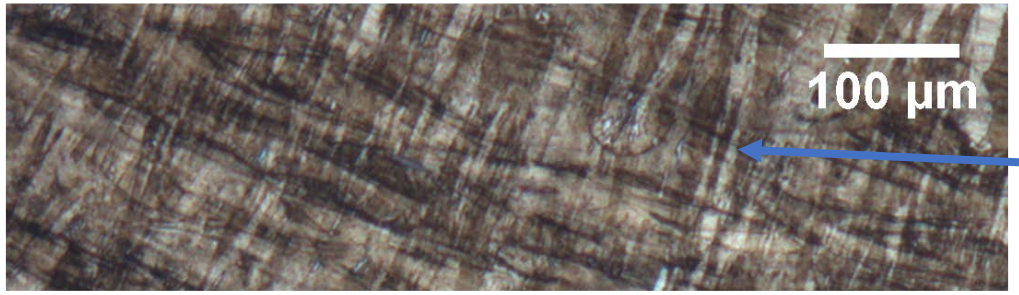
No post-deposition heat treatment

- HAZ: 40µm

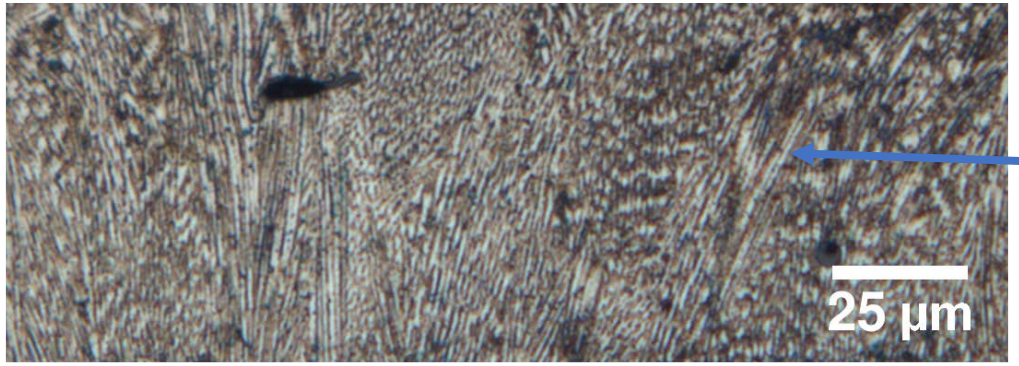
With direct aging heat treatment

Small Grain Sizes and Segregation





Elongated grains in the deposited material

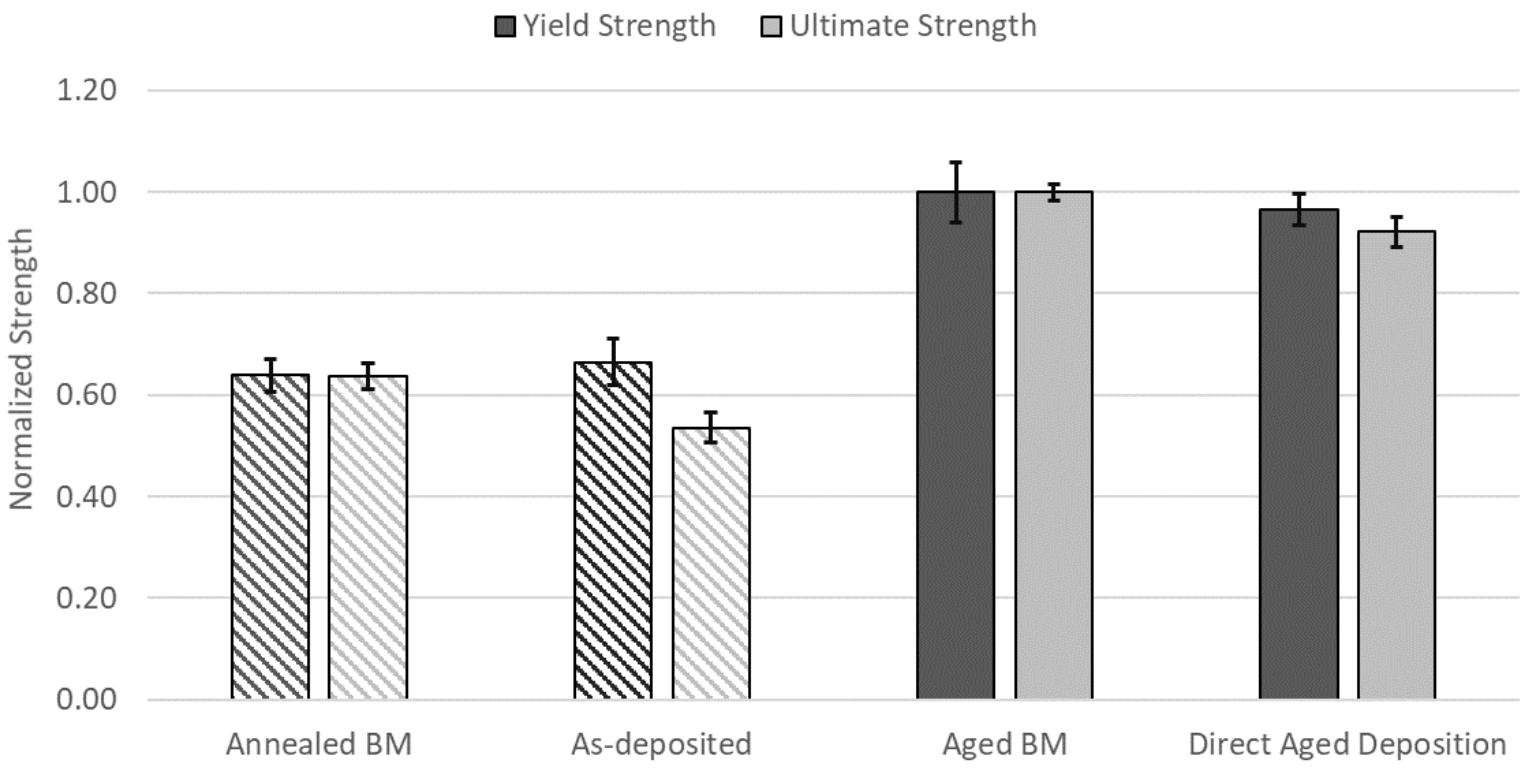


Fine cellular dendritic solidification microstructure

03 Fast Cooling Rates

Fast cooling rates result in small grain sizes, high strength/hardness and lower segregation in alloys

Yield and Ultimate Strength Recovery



04 Tensile Properties

Yield strength of deposited material is similar to base metal, while tensile strength is hampered by interdendritic Laves phase

Oxidation Testing

Inconel 718 is typically only used up to 650°C

- Experiences rapid loss of strength above this point

However, most oxidation testing is performed at 800°C or 850°C

- Oxidation rate would be too slow to easily study at 650°C

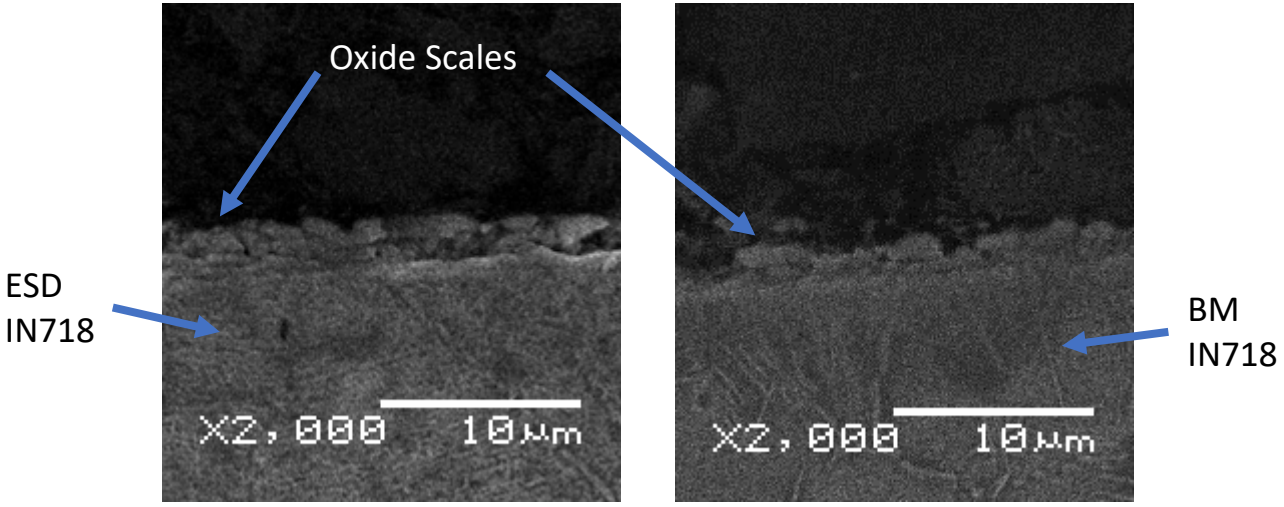
Oxidation testing details:

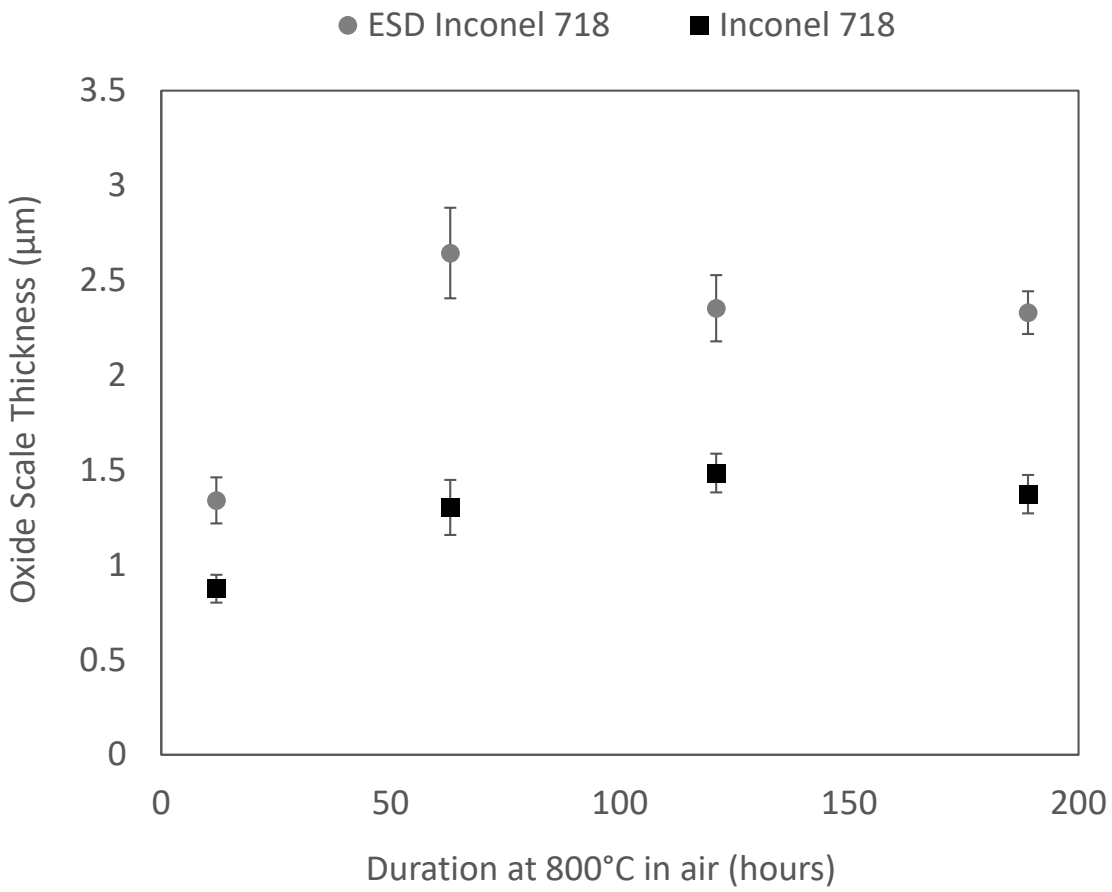
- Inconel 718 coating on all faces (4 passes, 100V, 120uF, 170 Hz) compared to uncoated base metal 718. All samples aged.
- Conducted at 800°C in air
- Samples retrieved at 12h, 63h, 121h and 189h intervals
- Samples x-sectioned for oxide thickness measurements

Oxidation Testing

Protective oxide scale forms thicker and faster in ESD Inconel 718:

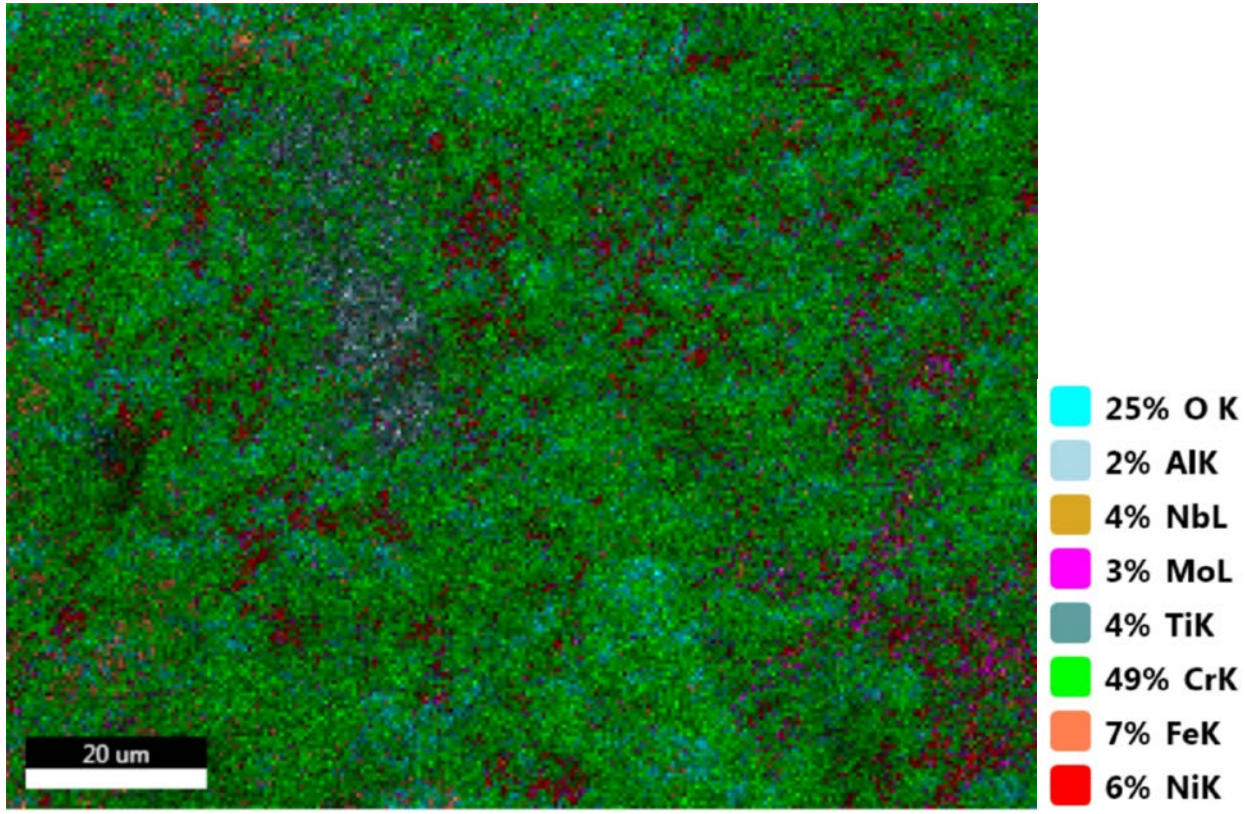
- Improved Cr diffusion due to smaller grain size
- More effective protection of component

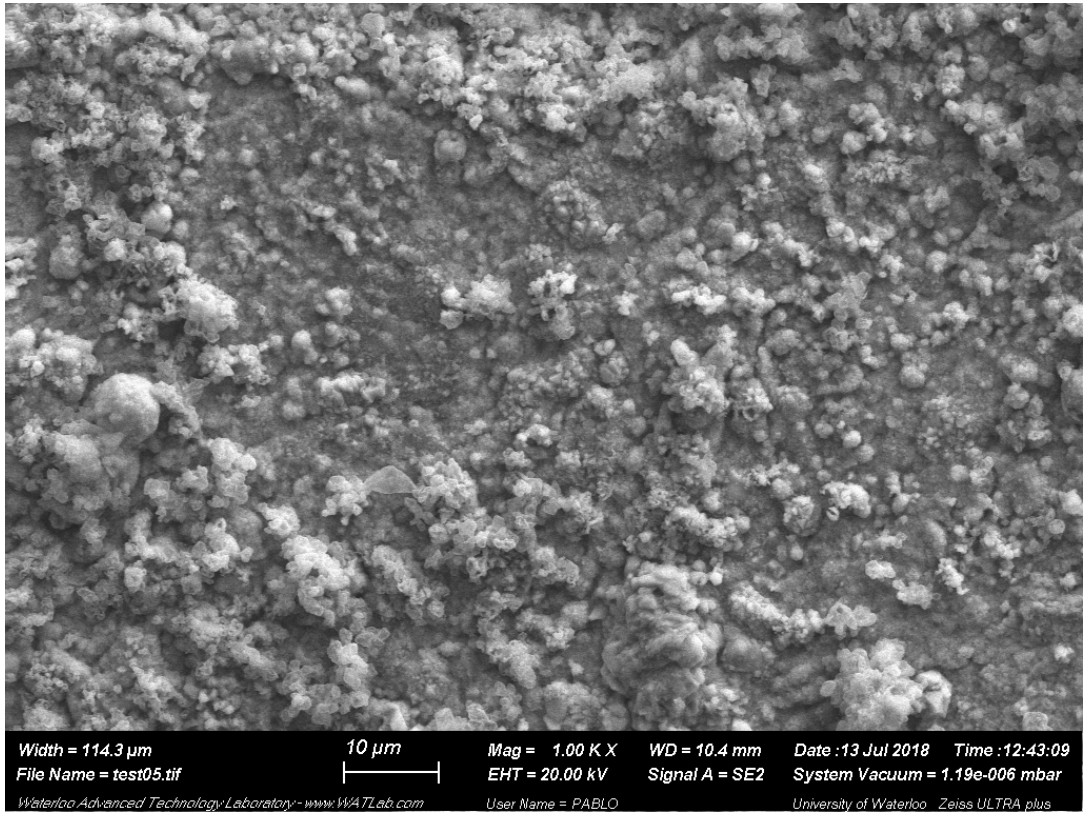




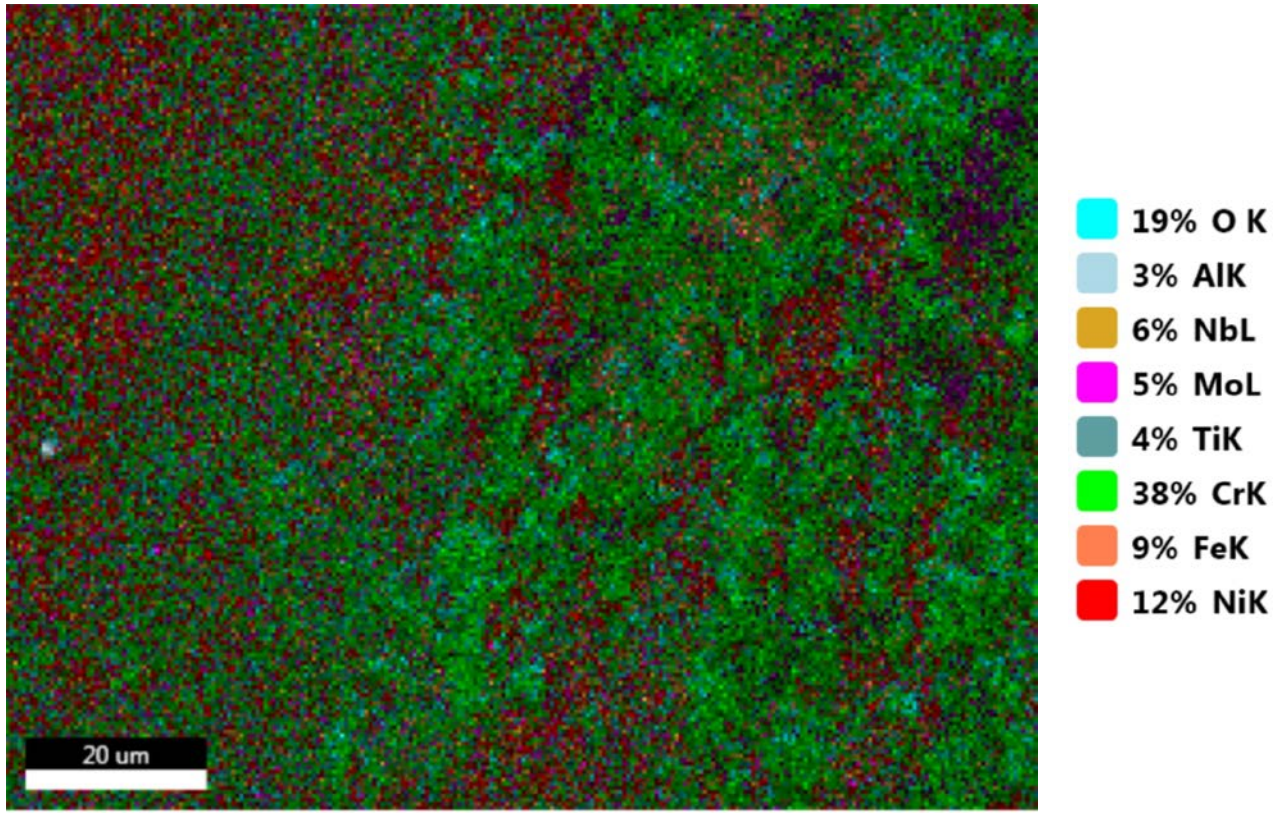
Surface Analysis

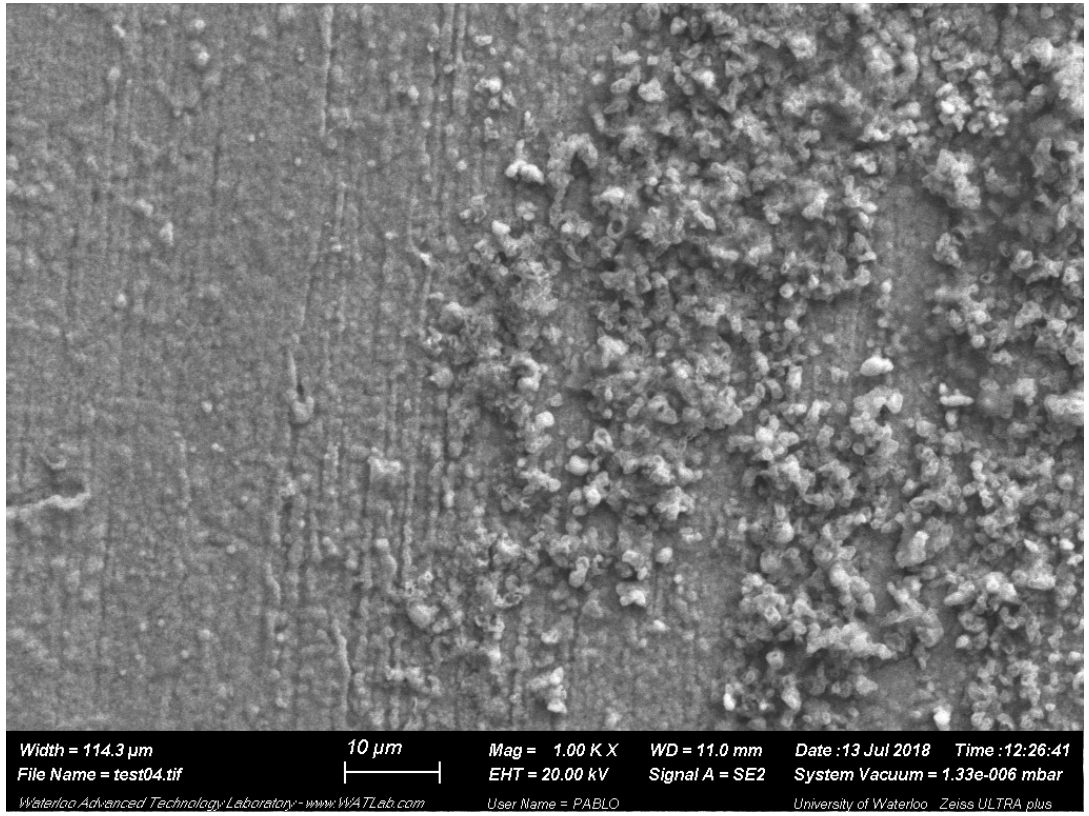
ESD Inconel 718 after 63h



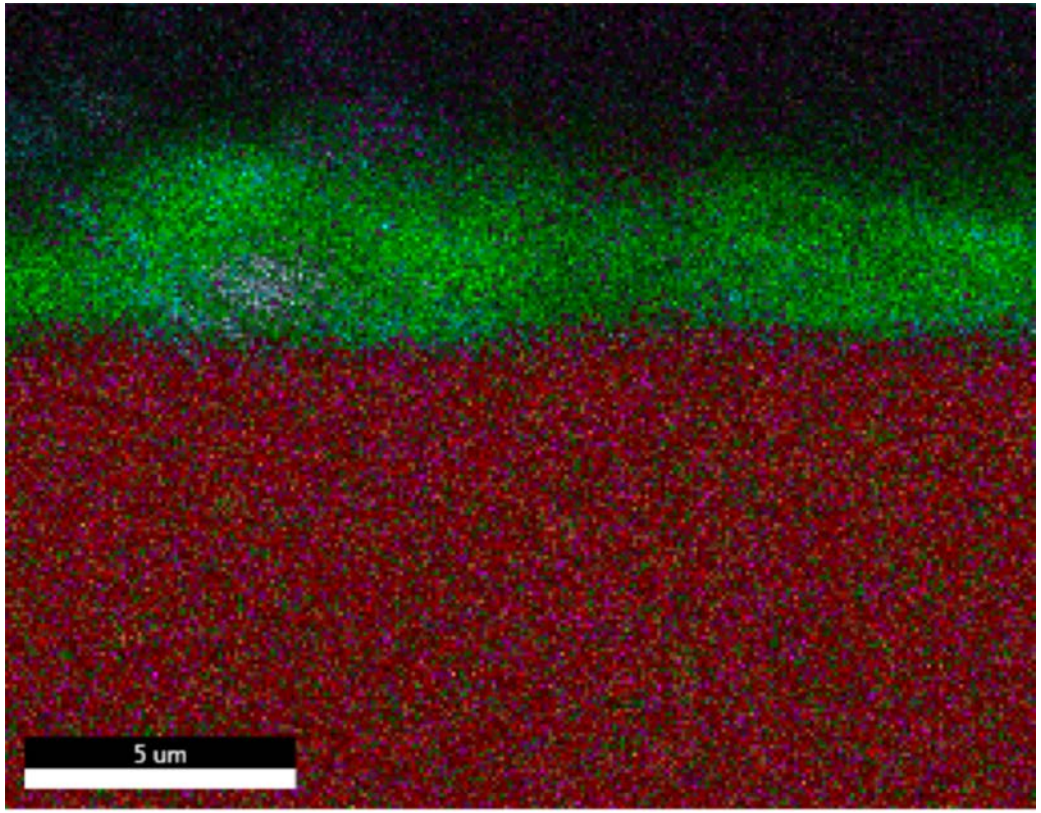


Surface Analysis



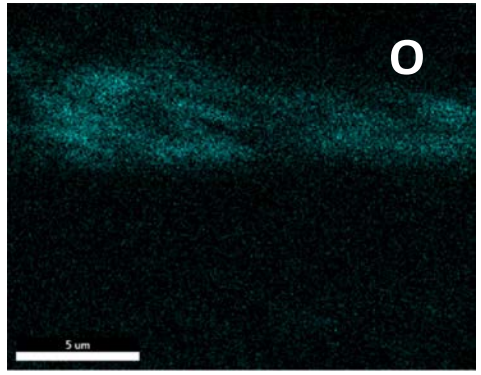


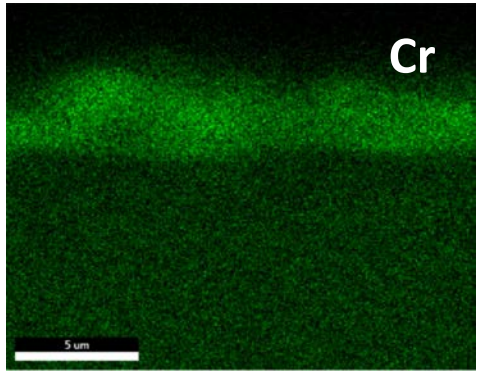
Cross-section Analysis

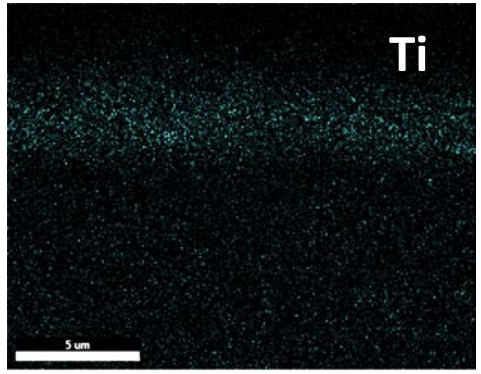


9% O K
6% AlK
7% NbL
8% MoL
4% TiK
29% CrK
13% FeK
23% NiK

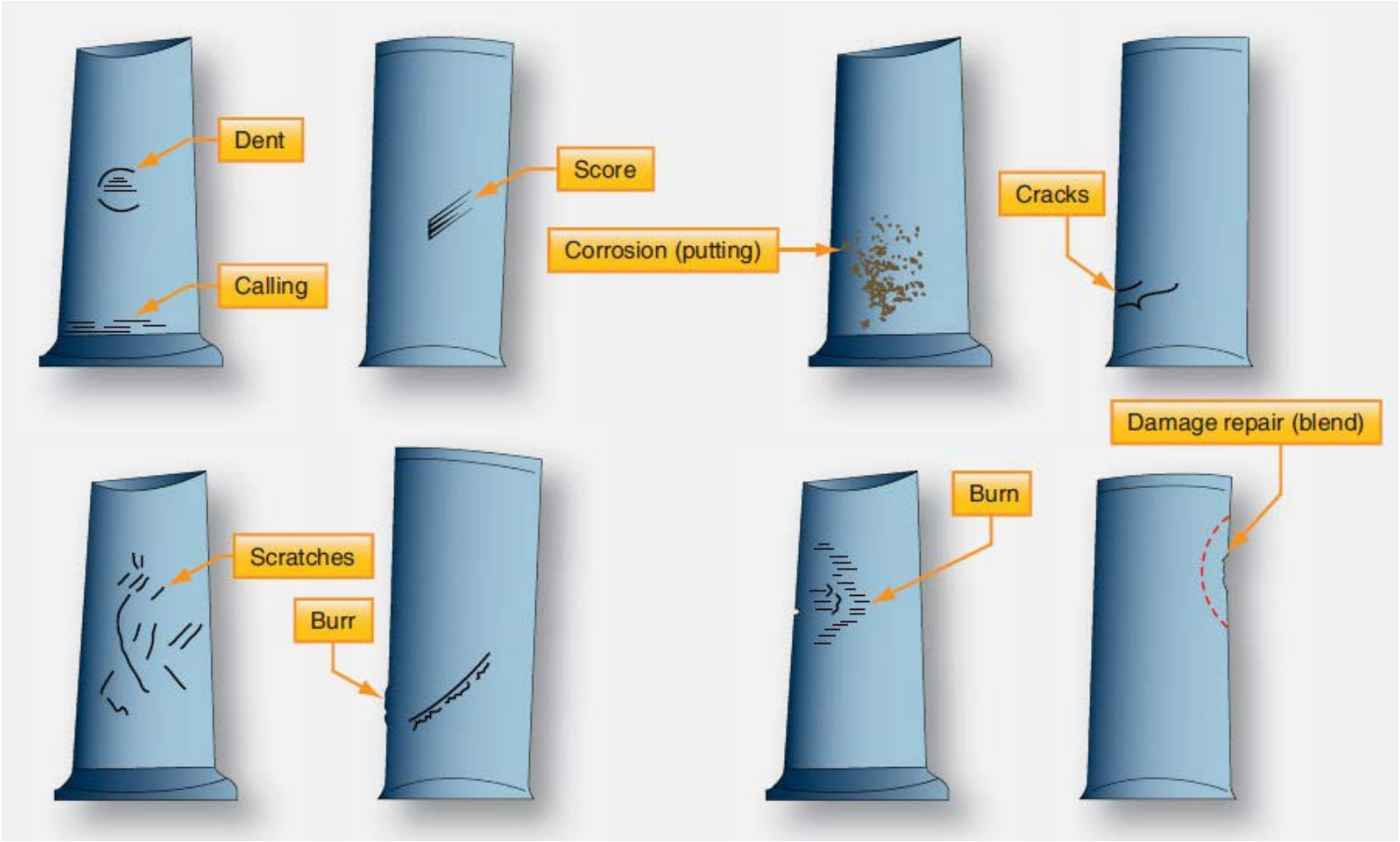
Diffusion of Cr and Ti to the surface



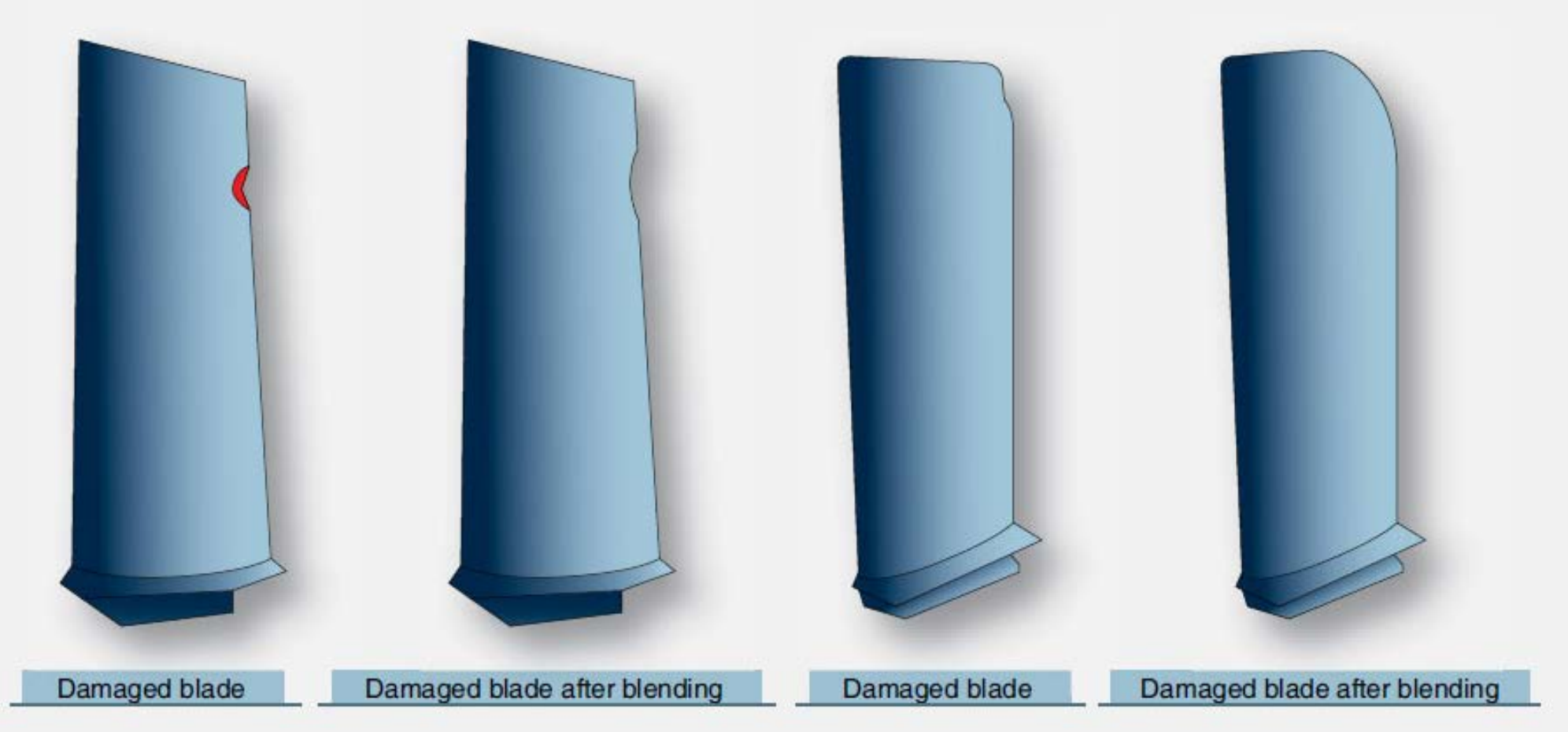




Turbine Blade Damage Types



Traditional Repair Methods for Edge Damage



Turbine Blade Repair Example– Face Damage

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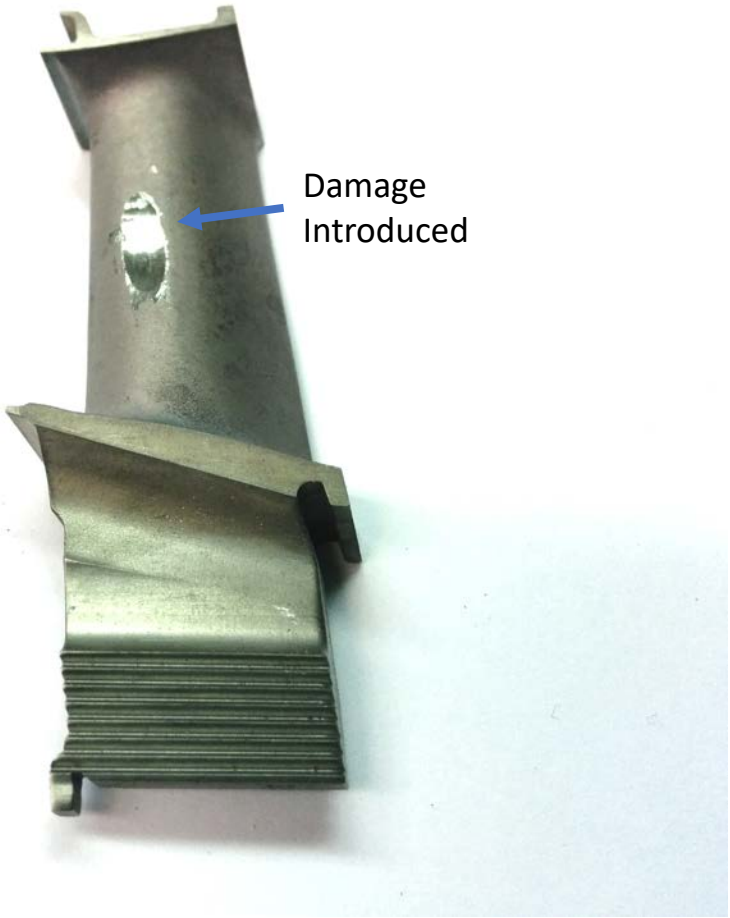
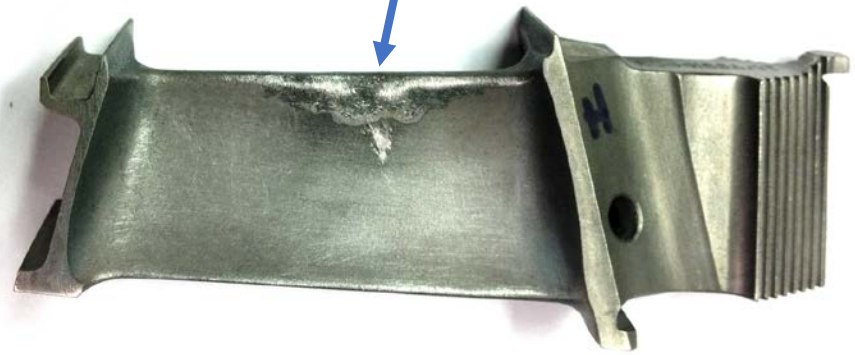


Turbine Blade Repair Example– Edge Damage

Damage
Introduced

Damage
Introduced

Repaired
After Polishing



Repaired
After Polishing

Closing Remarks

This LEW technique is beneficial for repairing thin geometries and applying functional coatings:

- Low heat input allows for repairing thin components with minimal effect on substrate properties
- Fast cooling rates result in smaller grains and subgrain features, which explain the high as-deposited hardness and good yield strength recovery
- Uniform oxidation layer of ESD coated Inconel 718 may serve as a protective layer for high temperature performance