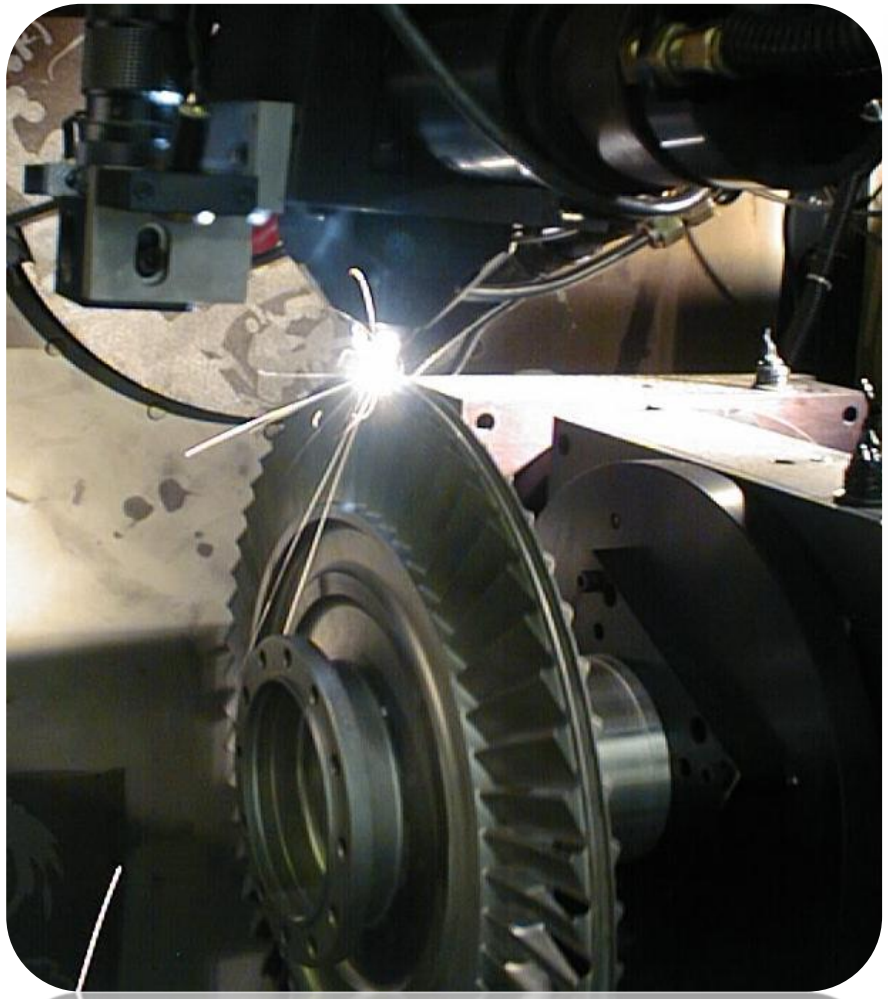
How 3D Metal Printing Saves Time and Lowers Costs: DED for Repair of Industrial Components



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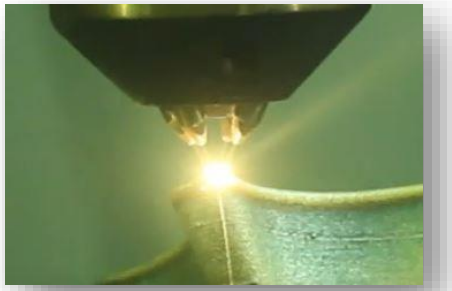
Agenda



- What is DED?- Basics of the process
- What separates the DED process from traditional manufacturing processes or other AM processes
- How 3D metal printing saves time and lowers costs- DED for repair of industrial components- Examples of the DED process being used to repair specific parts from various industries

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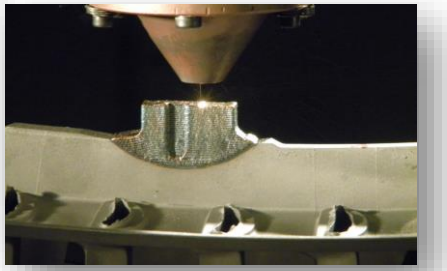
About Optomec

- Located in Albuquerque, New Mexico (Aerosol Jet in St. Paul, Minnesota).
- 20+ years experience in DED/LENS metal additive manufacturing.
- World renowned for DED technological advancements, systems, and software.
- About 100 Optomec LENS DED systems installed and operating around the globe today.
- Excellent customer service support-service contracts available.
- Sales reps available in US, EU, and Asia-Pacific regions.



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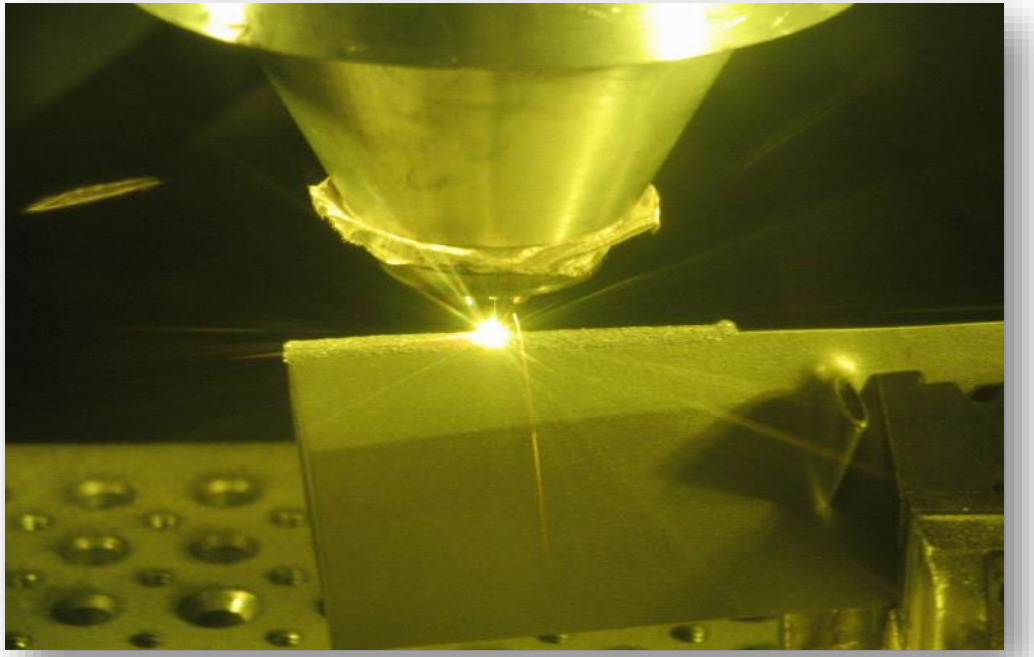
Why a webinar on DED?

Feedback in the market place-

- General comments from AMUG and IMTS-
  - "What is this?"
  - "What CNC process is this?"
  - "What percent does the end product shrink?"
  - "Where's the powder bed?"
  - "How much post-processing is involved?"
  - "How long does the HIP'ing take?"

- Recent AM symposium presentation topic title- "DED- it's not PBF"-

- A need to inform-



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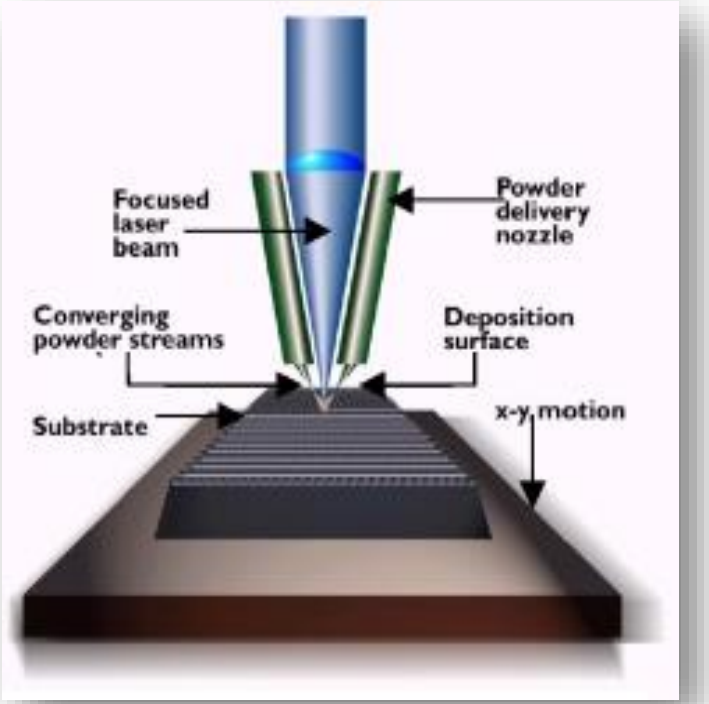
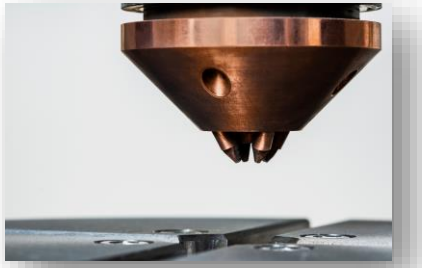
What is DED?- Basics of the Process

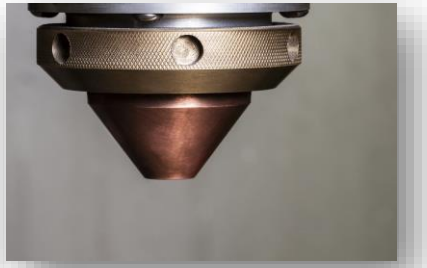
- **Directed Energy Deposition, an AM process**
- Other names include LENS, LMD, DMD, LB-DED

A working definition of DED-

- **ISO/ASTM** definition- "an additive manufacturing process in which focused thermal energy is used to fuse materials by melting as they are being deposited."







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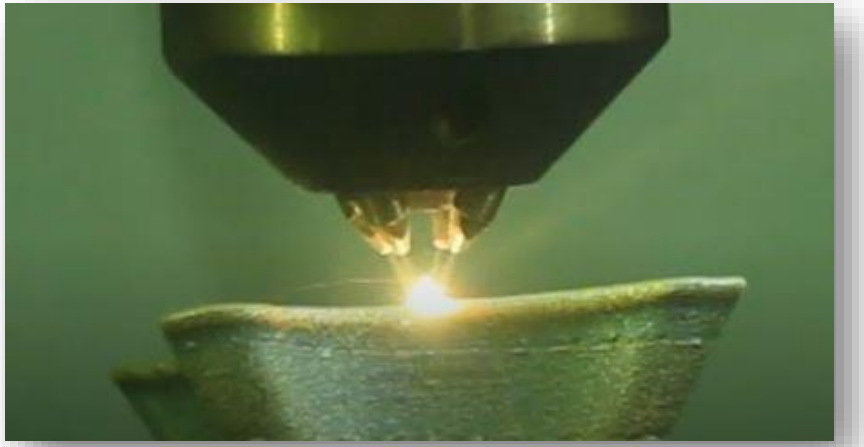
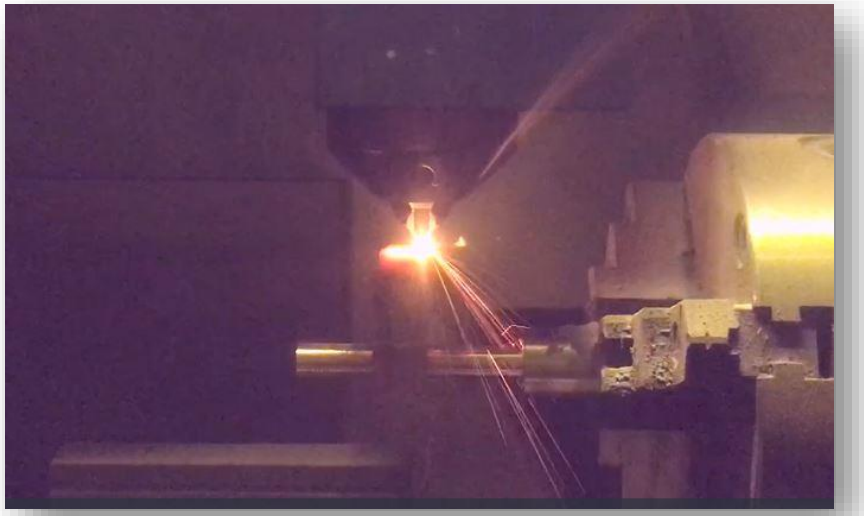
Basics of the DED Process

- The DED process is a metallurgically bonding process- not an adhesive or mechanical bonding process i.e. thermal/cold spray. Mechanical properties achieved are near wrought material properties.
- The process forms fully dense parts- the material (powder or wire) does not include plastics, composites, or any bond-assisting type materials- not a sintering process. Does not require post-processing to remove non-metallic or bonding agents.
- It allows free form building with multi-axis capabilities. It typically does not require support structures that later have to be removed.
- It allows for start/stops, in-situ adjustments to parameters with closed loop feedback capabilities.





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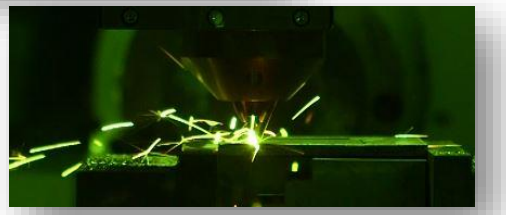
Basics of the DED Process

- A wide range of materials can be processed, including reactive materials.
  - Steels
  - Tool steels
  - Stainless steels
  - Nickel base alloys
  - Co/wear resistant steels
  - Reactives- Ti, Al, Mg
- Metal powders can be blended during building to create new alloys, change chemistry during building/functionally grade, apply dissimilar metals or coatings for property enhancement.
- It can be combined with other processes in a system- additive and subtractive from one machine.
- SW/controller easy adoption- SW packages and G&M codes that a machinist is already familiar with.



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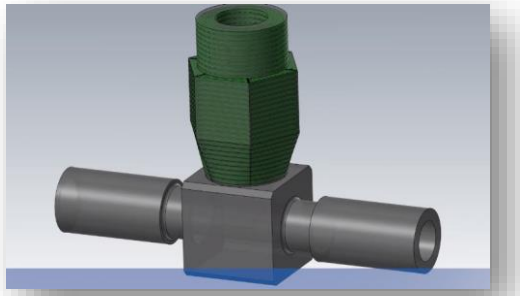
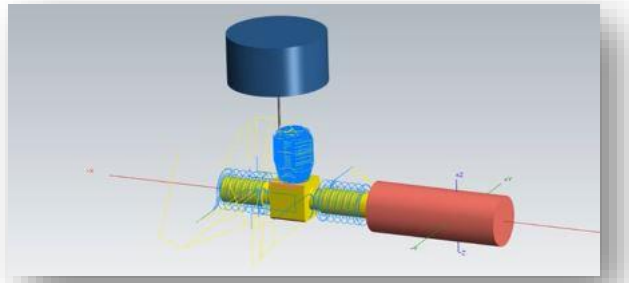
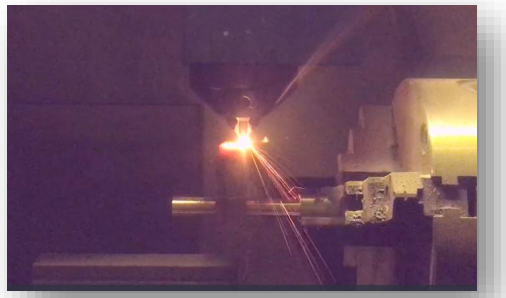
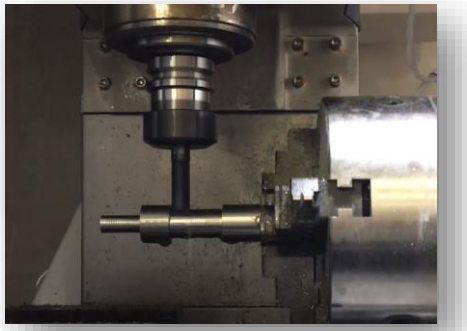
DED- “Art to Part”-

- CAD file
- Tool path generation
- Controller (G&M code)
- Building-
  - Motion control
  - Laser power
  - Powder feed
  - Scan rate
  - Inert gas (Argon)
  - Closed loop feedback controls









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Examples of LENS Fully Printed Samples

Nozzle
Inconel 718
7 hours

Cooling Channels
Stainless steel
4.5 hours

Venturi
Stainless steel
5.5 hours

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DED Building Example-

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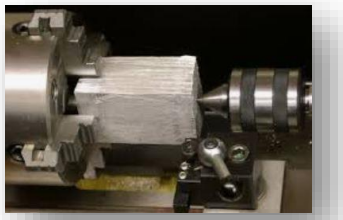
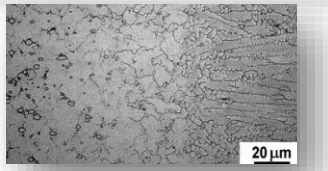
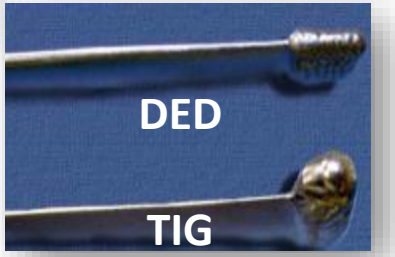
What separates DED from traditional manufacturing processes:

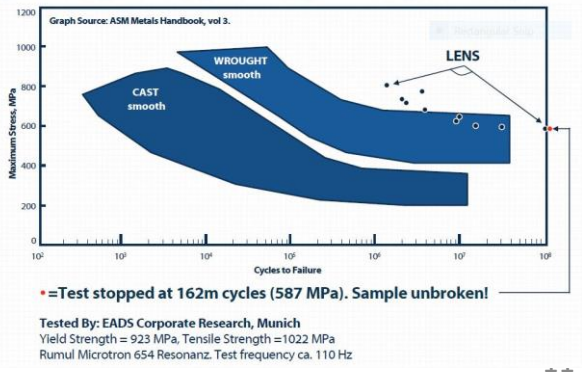
- Addition instead of removing.
- Design considerations.
- Removal of steps in build process.
- DED vs. traditional arc fusion welding processes:
  - **heat input-** lower, more precise heat input, fine grain structure, less base metal dilution, less residual stresses or distortion.
  - **travel speeds-** TIG- typical 9-14 IPM, laser welding typical 10 to 60+ IPM.
  - **HAZ-** much smaller heat affected zone, less detrimental effects to material/mechanical properties.
  - **near net shape-** little to no finishing requirements.
  - **material properties-** near wrought material, excellent tensile and fatigue properties.







Material	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)
LENS Ti 6-4	848	955
Wrought Ti 6-4 Typical	883	952
LENS 316 Stainless Steel	276	661
Wrought 316 Stainless Steel	289	578
LENS Ni Alloy 625	579	930
Wrought Ni Alloy 625	400	834



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What separates DED from other AM processes:

- A metal AM process (vs. plastics, polymers, composites, etc.).
- Laser heat source (vs. solid state extrusion, electron beam, etc.).
- Metallurgical bond (vs. binding, sintering, adhesive, or mechanical means).
- Powder fed, not powder bed.

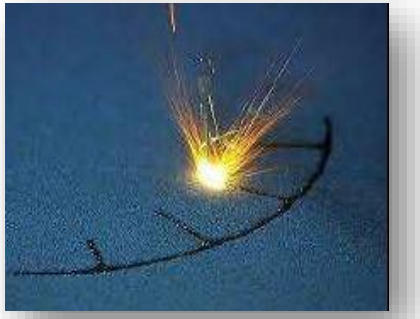
- There are two main metal AM processes for building parts from metal powder using a laser heat source:

DED- Directed Energy Deposition

"Powder Fed"

PBF- Powder Bed Fusion

"Powder Bed"



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Metal AM Processes- DED and PBF

DED

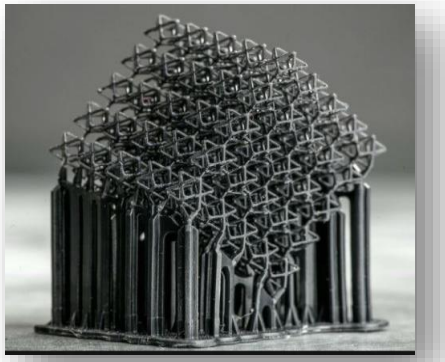
- Powder and focused laser energy are delivered simultaneously. Part is built up in free space.
- The part is visible during build- any powder not fused falls away from part/build area.
- For building larger features/ less complex shapes (when compared to PBF builds).

PBF

- Powder is laid out first, then selectively melted or sintered with a laser.
- Process is repeated layer by layer, and part is built up in a "powder cake"- the part is not visible during build.
- After post-processing, the excess powder is removed and the part revealed.
- For building smaller feature parts with more complex shapes/geometries.

DED Builds

PBF Builds



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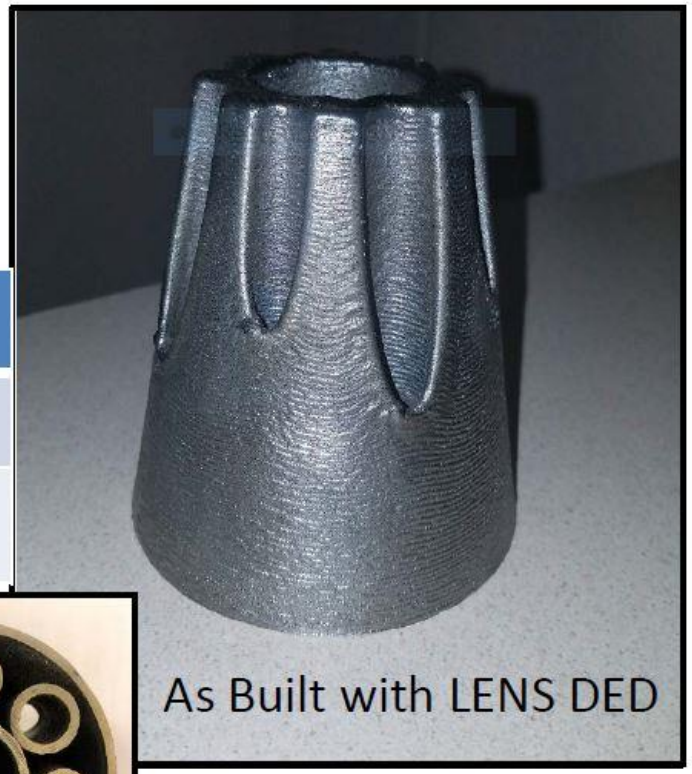
DED and PBF- Sample Build Comparison

Comparison of Powder AM Methods

- Part dimensions:(Ø x H) 100 mm x 200 mm,
- Wall thickness 2.5mm
- Material: Inconel 716

Metric	LENS DED*	PBF*
Build Time	10 hours	240 hours
Cost	$3,400	$16,800

* time/cost estimates provided by LENS & PBF service bureaus. Does not include post processing.



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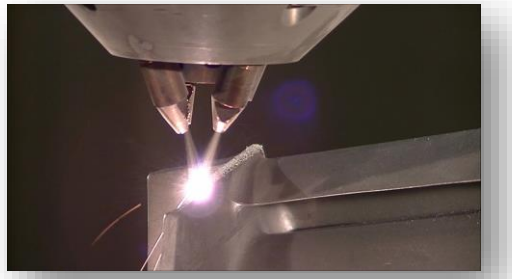
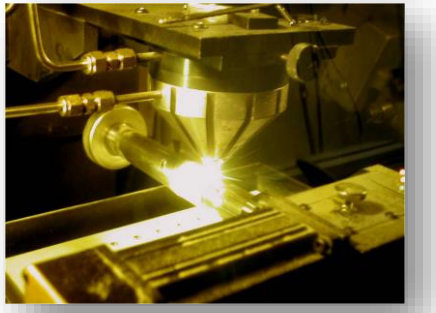
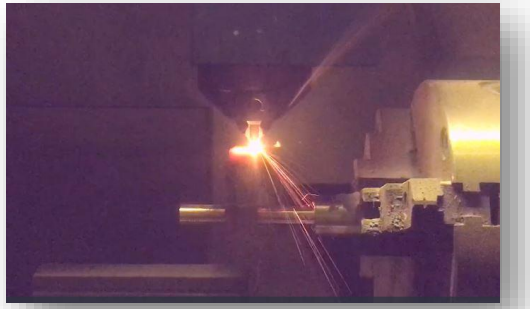
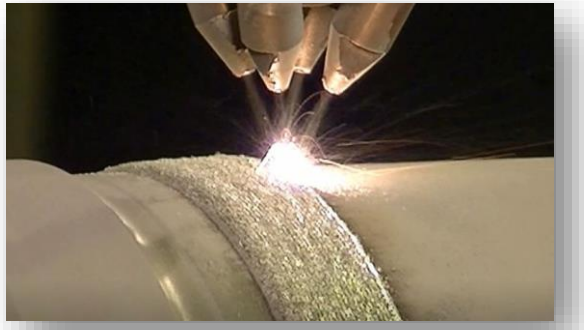
DED is well suited for a number of industry applications:

- Rapid mid-large size new builds
- ***Repairs***
- Rework
- Remanufacturing
- Feature addition/part modification
- Functional grading
- Coatings/property enhancements

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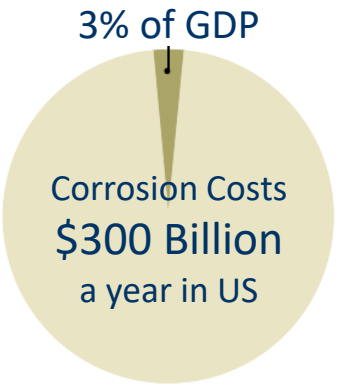
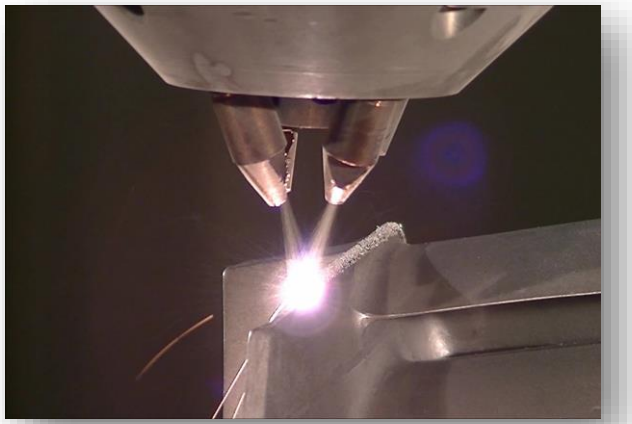
The Need for Repair in Industry:

- Corrosion or wear costs- $300B/yr in US-
- $100B's/yr spent on spares and overhaul
  - Commercial aviation spends >$100B per year.
  - US DOD spends >$50B per year.
- **More cost effective/time saving to restore vs. replace**
  - DED repairs can be more wear resistant than original part.
- There can be significant ROI for DED repair solutions





Sector	# of Global Assets & Plants	"Big" things that spin
Transportation		
Rail: Diesel Electric Engines	120,000	2,160,000
Aircraft: Commercial Engines	43,000	129,000
Marine: Bulk Carriers	9,400	84,600
Oil and Gas		
Big Energy Processing Plants (1)	990	36,900
Midstream Systems (2)	16,300	63,000
Drilling Equipment: Drillships, Land Rigs etc.	4,100	29,200
Power Plants		
Thermal Turbines: Steam, CCGT, etc.	17,500	74,000
Other Plants: Hydro, Wind, Engines, etc. (3)	45,000	190,000
Industrial Facilities		
Steel Mills	1,600	47,000
Pulp and Paper Mills	3,900	176,000
Cement Plants	2,000	30,000
Sugar Plants	650	23,000
Ethanol Plants	450	16,000
Ammonia and Methanol Plants	1,300	45,000
Medical Machines		
	52,000	104,000
	Total	**3M**

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LENS Repair Examples- Recent Military Benefits/Cost Savings

Example: US Army repair of components from Honeywell AGT 1500 gas turbine engine

M1 Abrams Tank

3rd Stage Rotor

4th Stage Rotor

2nd Stage Nozzle

Compressor Stator

Material	Inconel 713	Inconel 713	Inconel 713	321 Stainless
New Cost	$ 8297	$ 5485	$ 6032	$ 910
Repair Cost	< $2,000	< $2,000	< 2,250	< $300
Savings/Part	**> 75%**	**> 60%**	**> 60%**	**> 60%**

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LENS Repair of Rotating Parts – Gears

CMn

- Line down due to broken teeth on a gear at a local NM food processing plant.
- Fully repaired and back in operation in <12 hours vs. 12-week lead time for new gear.

Broken Gear Teeth

After LENS Printed Repair

Machined to Spec

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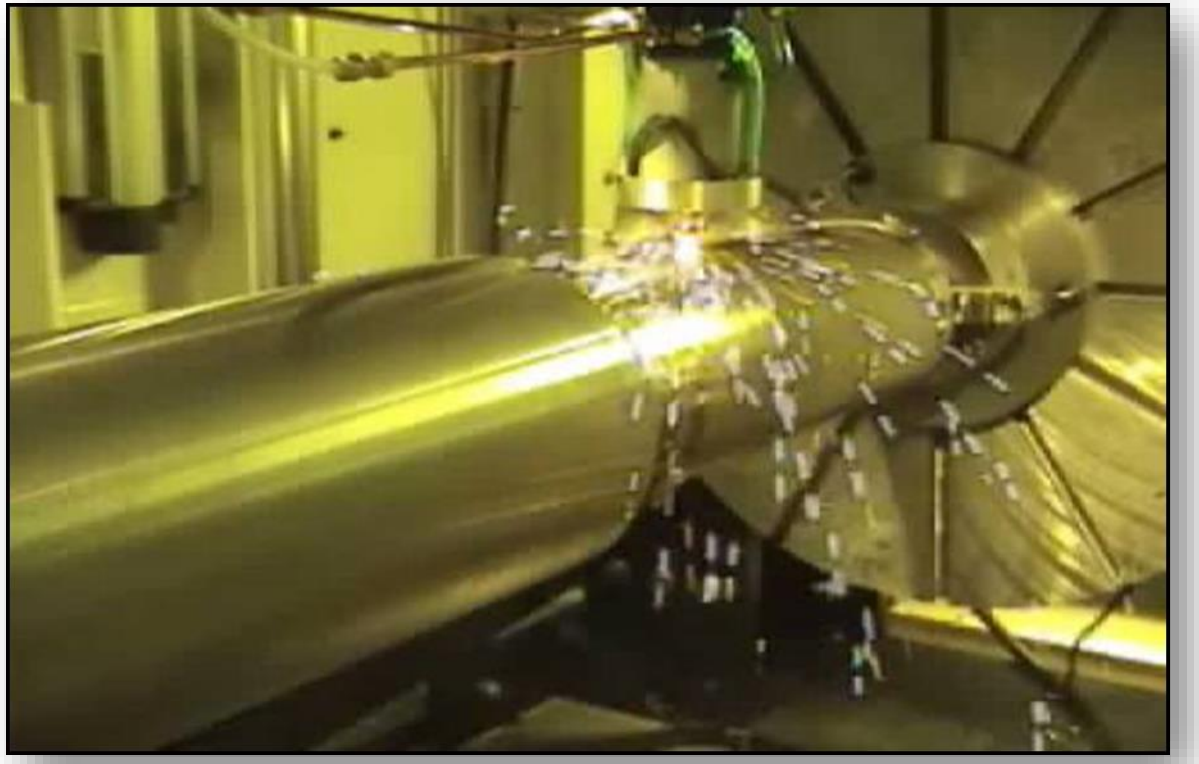
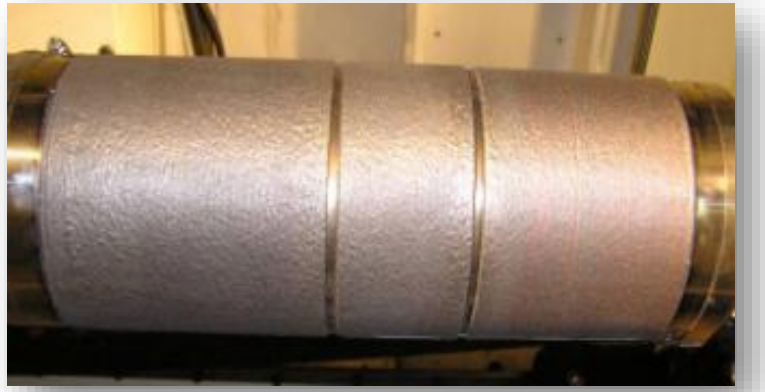
LENS Repair of Rotating Parts – Shafts

SS

- Shafts rotated in 4th axis.
- LENS chosen for minimal distortion vs. traditional welding.
- No shaft warpage- successful restoration of worn surface.

Bulk Deposition





After Printing; Before Finishing

After Grinding and Polishing

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LENS Repair of Rotating Parts – Seals

Inco 718

- Second stage rotor disc seal repair for AGT 1500 M1 A1 Abrams Tank engine.
- Process: Machine back worn seal, LENS deposit Inco718, heat treat, machine finish.

Surface preparation (machining)

After LENS printed repair

Machined to spec

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LENS Repair of Seals – Ball Valve

Ti-6-4

- Scratch on Titanium ball valve causes leak; gas tungsten arc welding unsuccessful due to distortion from heat input.
- LENS conformal printing on surface successful, 15 minute repair. Cost/time greatly reduced vs. part replacement.

1” long scratch

After printing; before finishing

machined & polished

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LENS Repair of Tooling – Deep Draw Tool Cobalt/Carbides

Co / WC

- Substrate materials: nodular cast iron and various tool steels.
- LENS deposition of various hard facing steels (Co and WC alloys) and final machining.

Printed repair process

After printing; before finishing

Machined to spec

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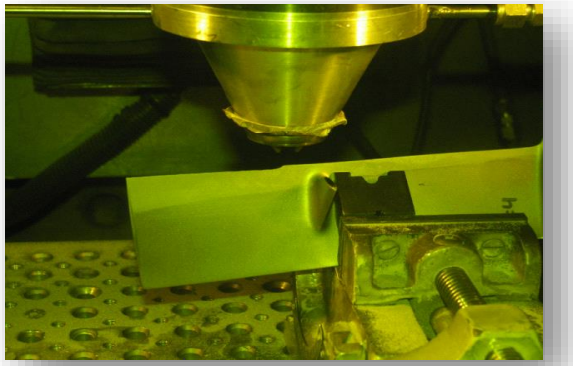
LENS Repair of Gas Turbines – Blade Tips, Edges, and FOD

Titanium

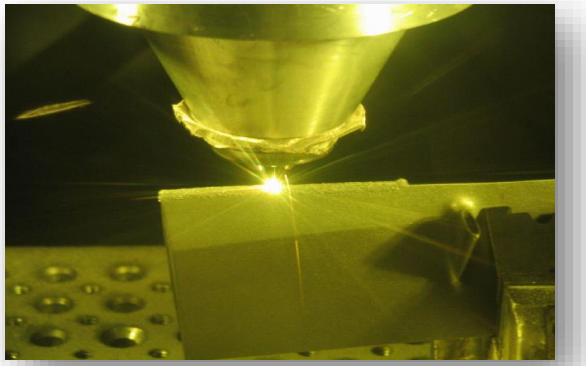
- Turbine blades wear over time and suffer damage from ‘foreign objects damage’ (“FOD”).
- New blades can be very expensive, and very long lead times for older units.
- LENS can be used to cost-effectively restore/resurface blades at a fraction of the cost.

Example: Using LENS to repair tips, leading edges, and scratches on Ti blades

Auto alignment



LENS restoration



As deposited

After finishing

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LENS Repair of Gas Turbine Blisks- Material Enhancement

Stellite 21

Example: Repair of leading edges for T-700 blisk (passes spin test requirements)

After printing; before finishing

- Base material: AM355 Steel
- Repair material: Stellite 21 (cobalt based, wear resistant)

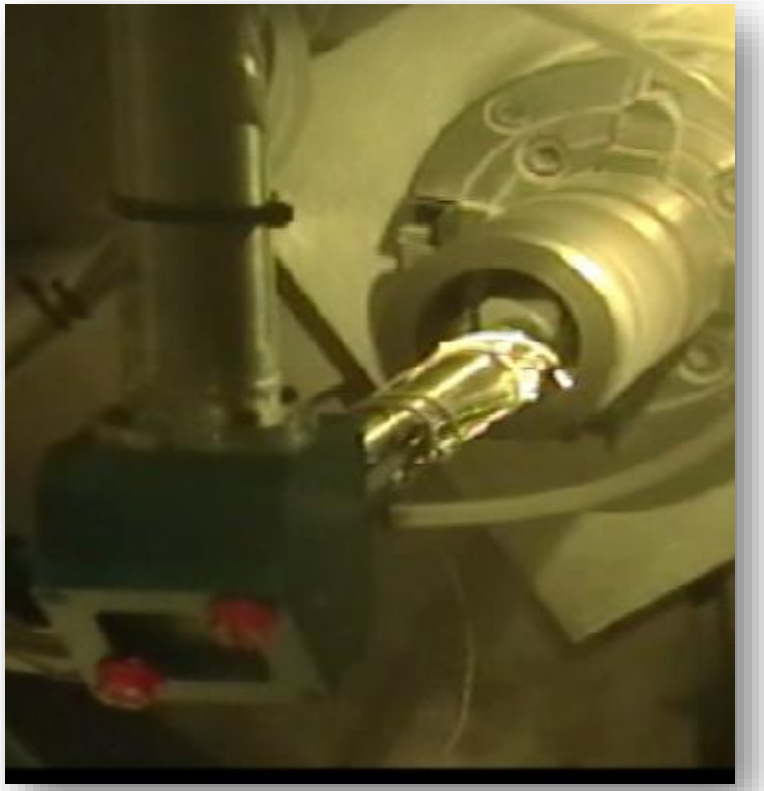
✓**60,000 rpm Spin Test**

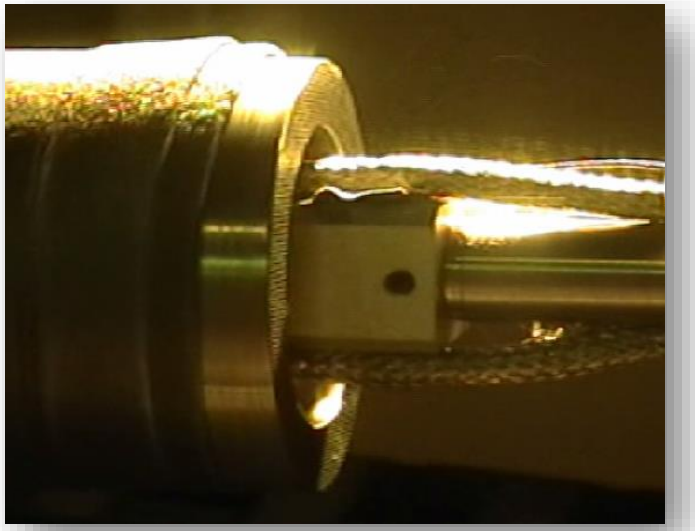
✓**50,000 Cycle LCF Spin Test**

After finishing and successful spin tests

LENS Deep Repair Head

- Laser power limited to 1kW
- Powder feed rate up to 24 g/min through two powder nozzles
- Minimum inner diameter of the workpiece: 4.5 cm
- Maximum insertion depth at minimum inner diameter: 30 cm





- **CCAT is a not-for-profit**
- **CCAT Advanced Manufacturing Center's mission is to:**
  - Introduce, demonstrate and validate new technology to manufacturers
  - Conduct applied research and applications development for industry, academia and Government entities

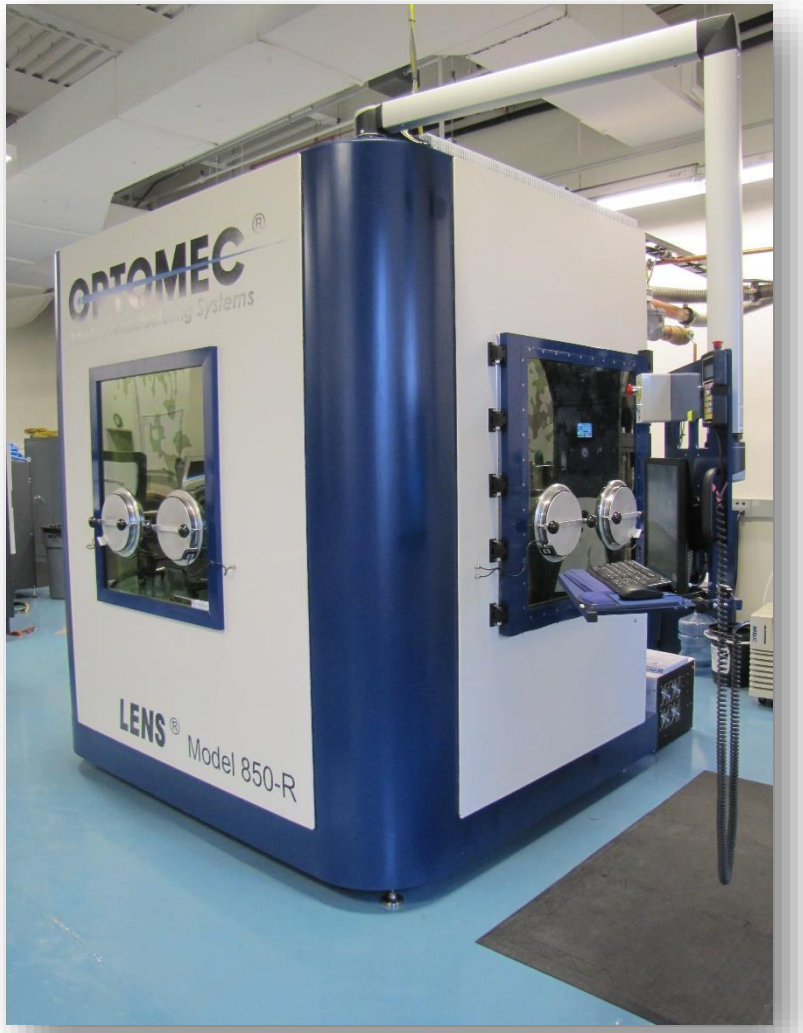
- **Customers and partners include:**
  - Industry (small companies to large OEMs)
  - Government (Federal & State)
  - Academia
- **Regional, national and international resource**
- **Focus on Additive Mfg, Precision Machining and Noncontact Metrology**

Key Technologies

- DED Metal AM
- Hybrid Metal AM
- High Deposition Rate Metal AM
- PBF Metal AM
- Polymer AM
- 5-axis precision machining
- Composite Machining
- Structured Light Scanning
- X-Ray/CT Scanning
- CMM

Optomec LENS CS 1500

– Installed 2011
– Large Build Chamber
– 3 Powder Hoppers
– 3 kW fiber laser
– <1 ppm O_2
– Build rates: 0.5 to 6 in^3/hour



Project: Component Modification – Aerospace

– Requirement:

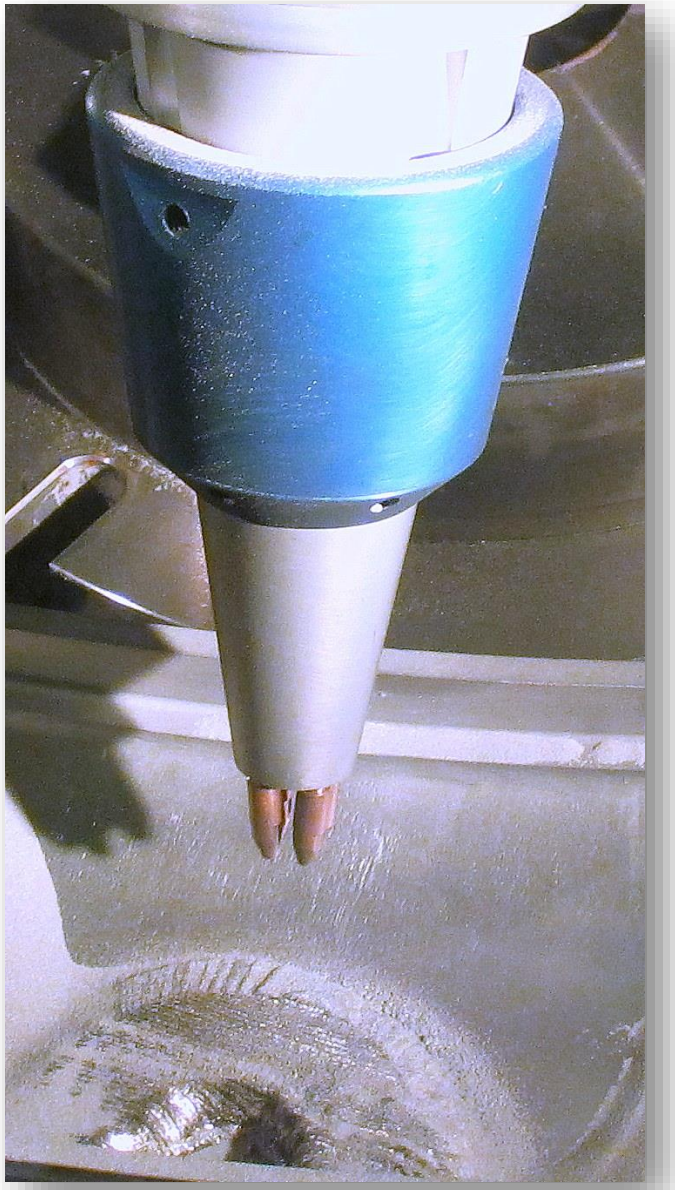
- Current Inconel casing being replaced by new design with landings on the ID
- 1.5k in the field, can they be modified and reused Vs time & $$$ to build new
- Company tried a number of traditional welding processes to add landings resulting in damage to material/casing

Project: Component Modification

–Solution:

– CCAT successfully developed a repair process using DED on the Optomec LENS CS 1500 with High Standoff Head

– Technology was transferred to the customer and they have implemented it in the factory



Project: Powder Bed Fusion Part Repair – PBF OEM

–Requirement:

– A quantity of parts were fabricated via PBF and a critical section was inadvertently underbuilt. Parts would conventionally be scrapped and new parts built with weeks of build time and thousands of dollars in costs.

– Can DED be used to add material with suitable metallurgy to salvage as-built parts?

Project: PBF Part Repair

–Solution:

– CCAT successfully developed a repair process using DED on the Optomec LENS CS 1500.

– Test parts have been clad and returned to the customer for analysis and certification.

  • To date metallurgy results are excellent

– Used the same powder for the build and repair

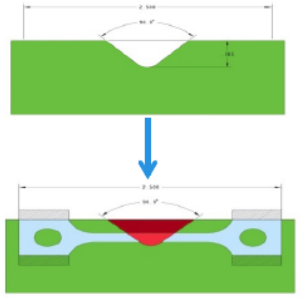
LENS/DED Part Repair

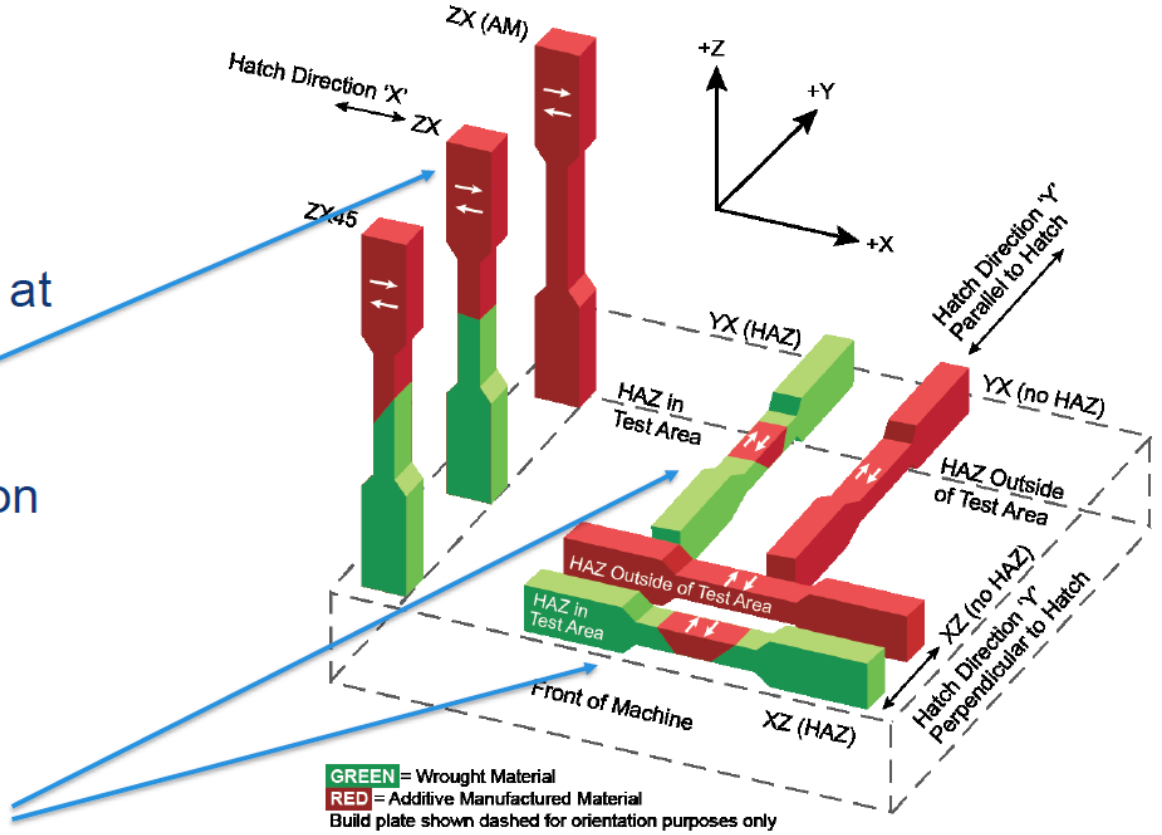
1. Effective for
    1. High dollar value and Legacy
    2. Long lead time
    3. Reuse / part modification
    4. Parts that may not be repairable conventionally

Repair Simulation Coupon Build & Analysis

Specimen Build Geometries

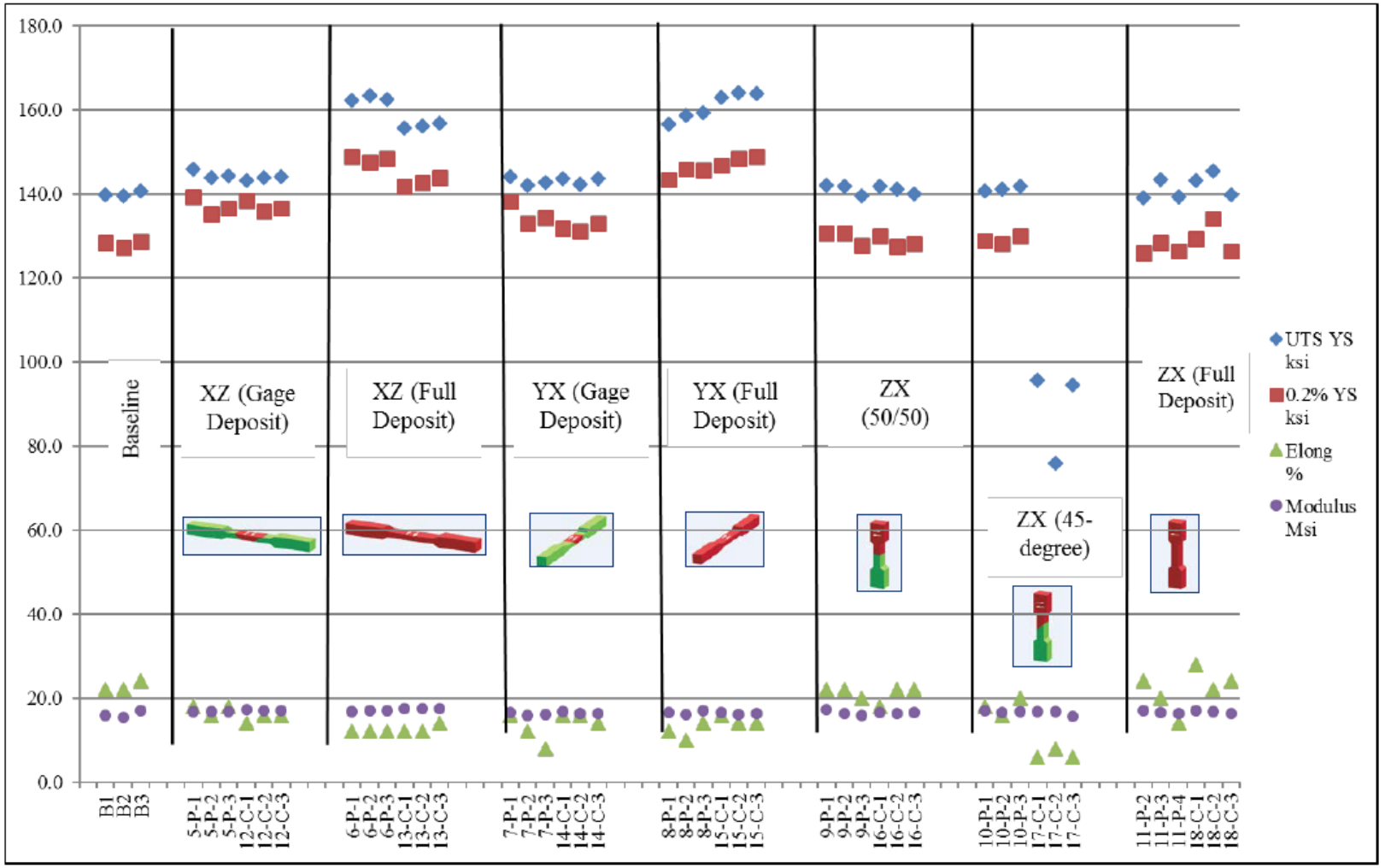
- Tensile
  - 3 of each configuration at both CCAT and PSU
- Fatigue
  - 15 of 50/50 configuration at both CCAT and PSU





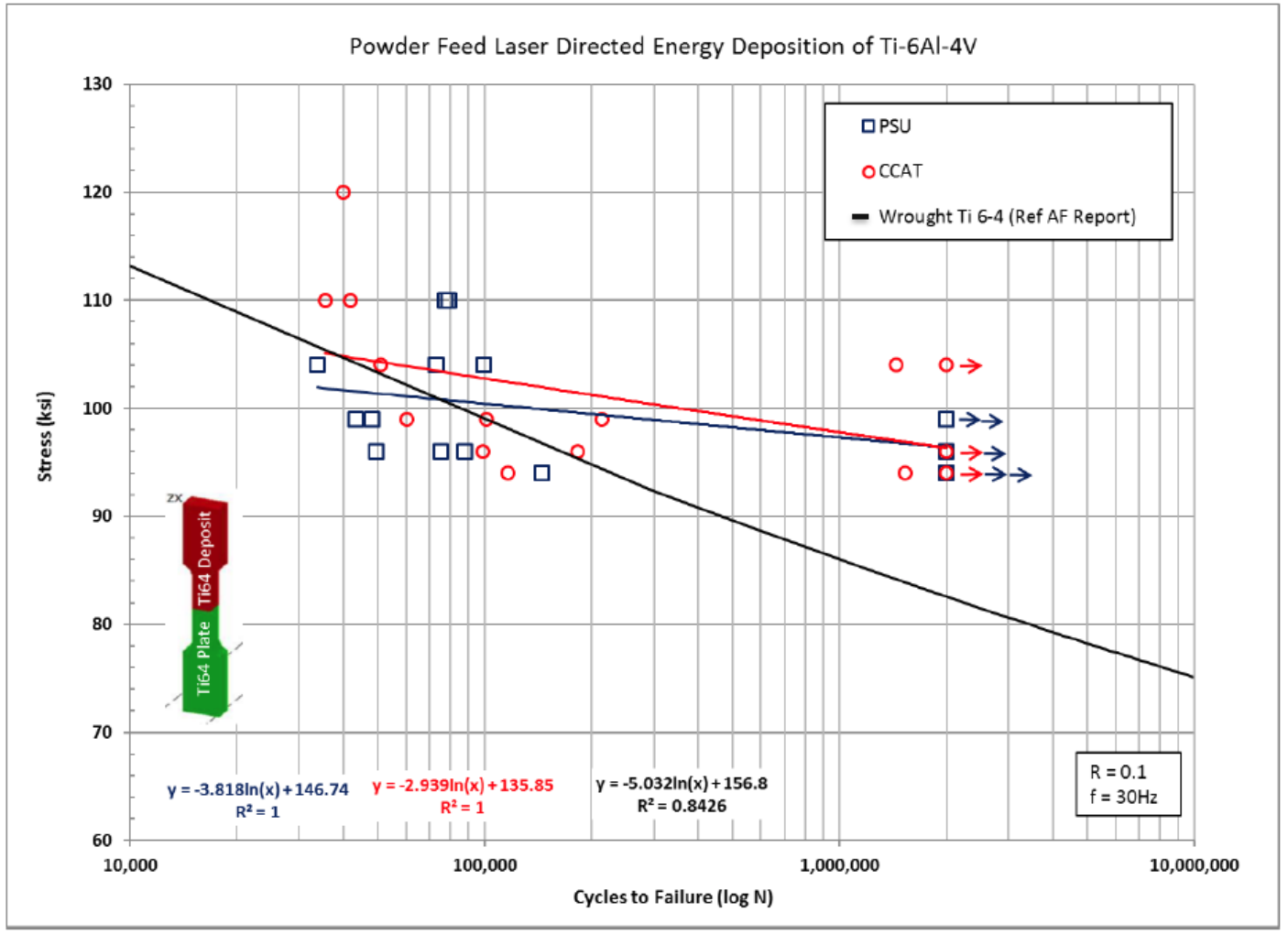
Task 3 Test Data - CTC

Tensile results sorted by coupon type



Task 3 Test Data - CTC

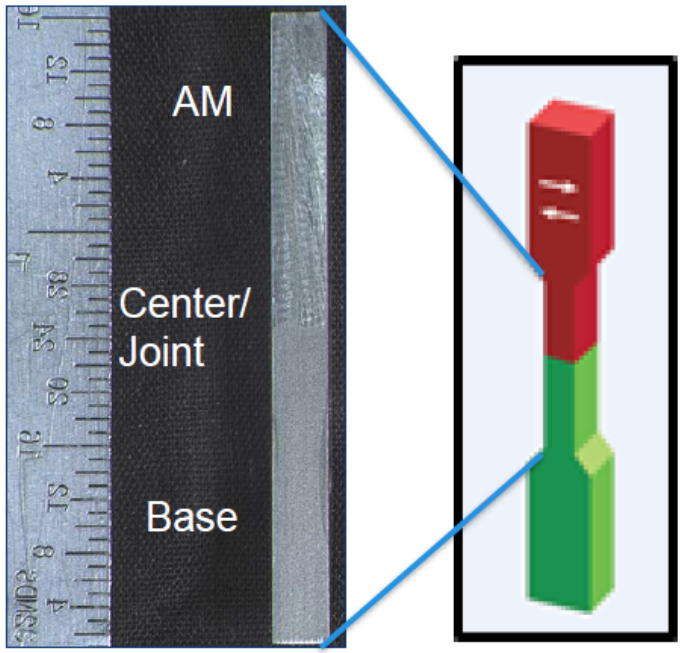
Fatigue data – slope trends



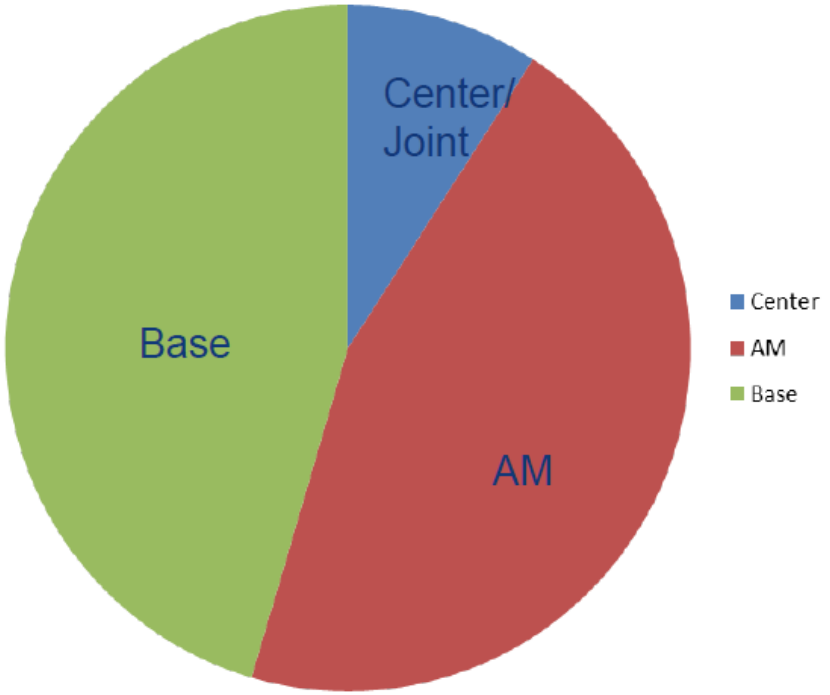
Wrought data per AFRL-ML-WP-TR-2001-4159

Task 3 Test Data - CTC

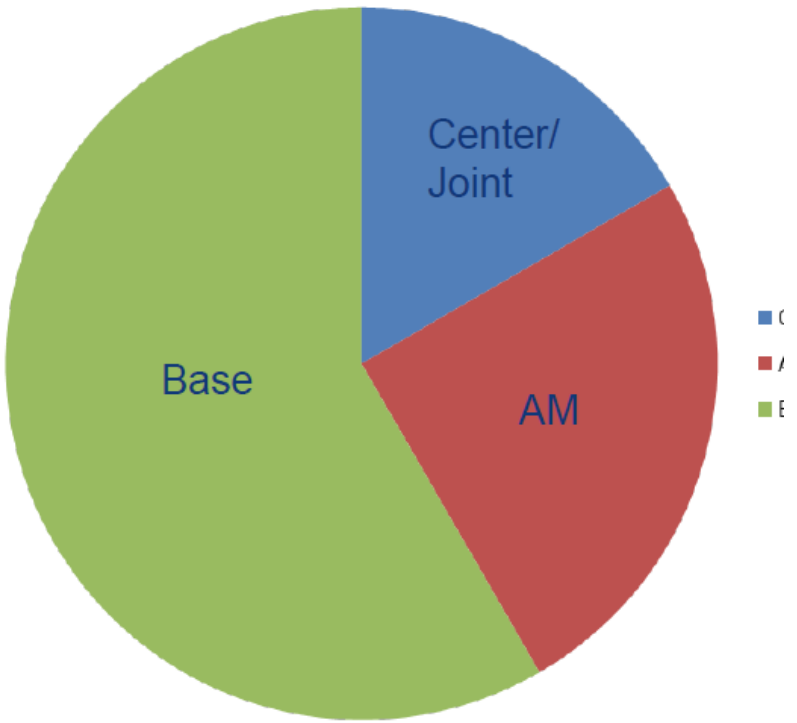
Fatigue test failure locations



PSU



CCAT



Thank You.

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