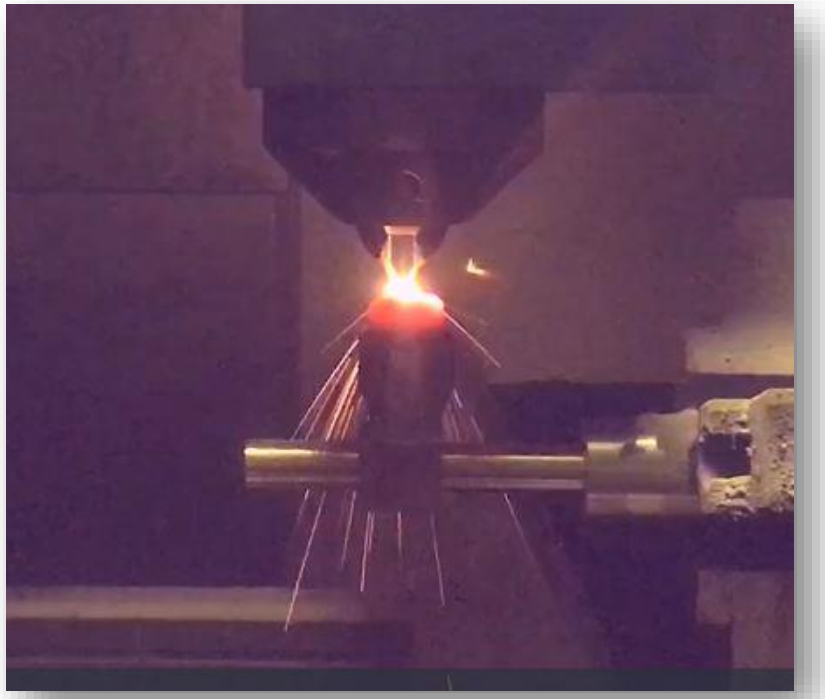
LENS Systems and Applications

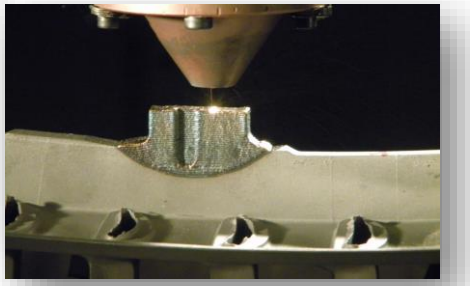


Agenda

- About Optomec
- The LENS Process
- Metal AM Processes- DED and PBF
- New LENS Platform Line-up
- LDH Technology
- Software – PartPrep and MC/LENS plug-in/Control Software
- LENS Applications

About Optomec

- Located in Albuquerque, New Mexico (Aerosol Jet in St. Paul, Minnesota).
- 20+ years experience in LENS metal Additive Manufacturing.
- World renowned for LENS technological advancements, systems, and software.
- About 100 Optomec LENS 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.



Leader in Additive Manufacturing (AM) Technology

- Experience – Production Proven for Metals, Electronics.
- Flexibility – Print Full Parts or Add Functionality to Existing Components.
- Full Solutions – Equipment, Software, Services.

Johnson & Johnson

GE Power Healthcare Aviation

United Technologies

ALCOA

LITEON

xerox

300+

Optomec Global Installations

50+ Issued
50+ Pending

Optomec IP

40+

Optomec' Material and Automation Partners

85+

Optomec Employees Albuquerque & St. Paul

BOEING

CORNING

Nordson

Rockwell Collins

BOSCH

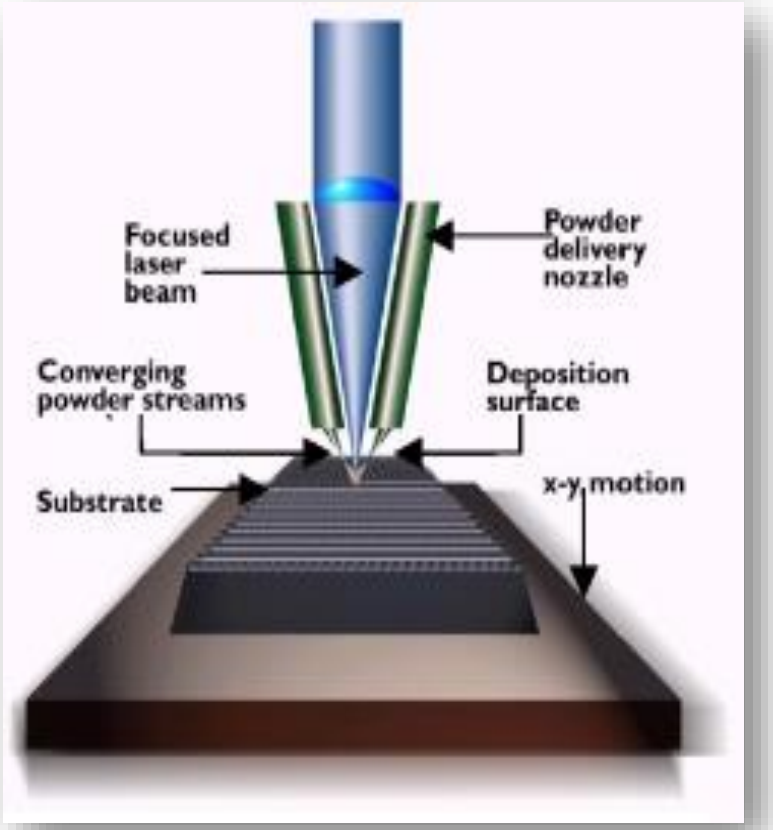
LOCKHEED MARTIN

Privately Held – Profitable – Investment from GE & Autodesk

The LENS Process

- "LENS"- Laser Engineered Net Shaping, also known as directed energy deposition (DED) or laser metal deposition (LMD).
- LENS systems print via the DED process, where gas blown metal powder is delivered to a melt pool generated by a focused laser beam and fusion bonded to form fully dense 3 dimensional builds.

LENS Process

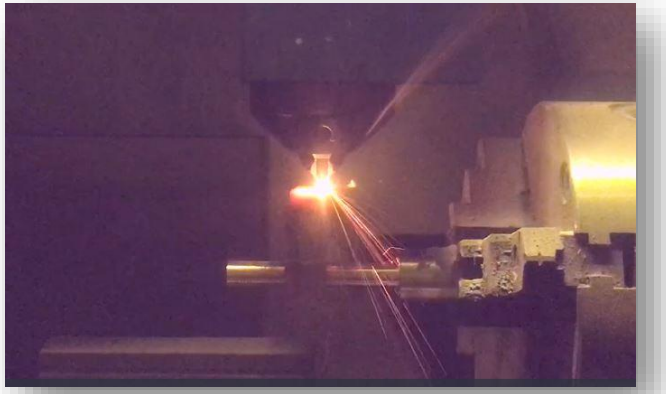


- Multi Nozzle Powder Delivery
- Metal Powder melted by Laser
- Layer by layer part repair

The LENS Process

- The LENS process was invented at Sandia National Labs back in the 1980's, and was commercialized by Optomec in the 1990's. Optomec has focused on the LENS process/LENS systems now for over 20 years.

- The LENS process is ideal for a number of applications:
  - Rapid Prototype
  - New builds
  - Repairs
  - Part modifications/add-ons
  - Rework
  - Remanufacturing
  - Coatings
  - Functional gradients



Metal AM Processes- DED and PBF

- There are two main metal AM processes for building parts additively from metal powder:

DED- Directed Energy Deposition

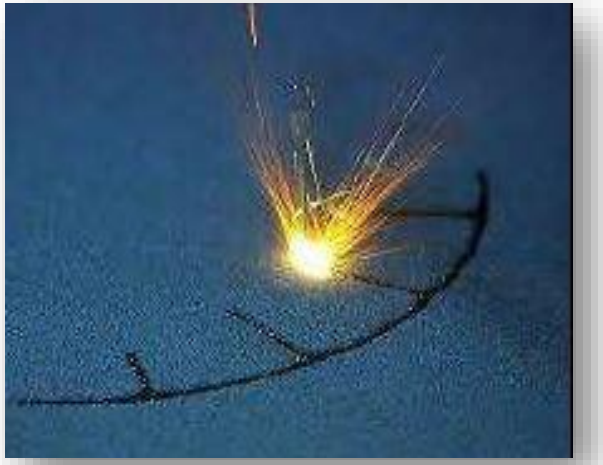
"Powder Fed"

Example- LENS (Laser Engineered Net Shaping)

PBF- Powder Bed Fusion

"Powder Bed"

Example- SLM (Selective Laser Melting)



Metal AM Processes- DED and PBF

DED

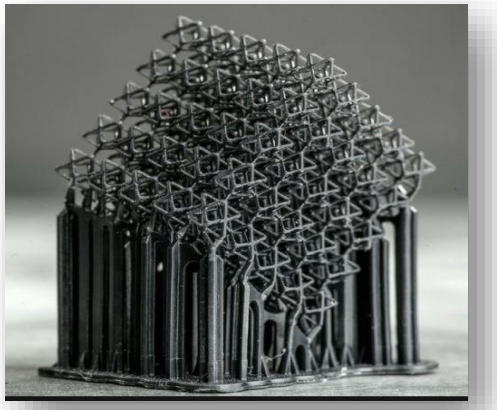
- Powder and focused laser energy are delivered simultaneously. Part is built up in free space.
- The part is visible during build- any powder not fused falls away from part/build area.
- For building larger features/ less complex shapes (when compared to PBF builds).

DED Build

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 processing, the excess powder is removed and the part revealed.
- For building smaller feature parts with more complex shapes/geometries.

PBF Build



DED and PBF Comparisons-

Feature	Directed Energy Deposition	Powder Bed Fusion
Part Complexity/Resolution	Relatively simple geometry with less resolution (Ra 20-50 um)	Complex geometry with high resolution. (Ra 9/12um)
Part Size	Unlimited	Limited
Dimensional Tolerance	+/-1mm	+/- 0.2mm
Ave. Layer Thickness	500um	30um
Build Speed	0.5kg/hr. @ 2kW	0.06kg/hr. @ 400W
Powder Cost	Ti-64 ~ $160/kg IN 718 ~ $80/kg Stainless Steel ~ $30/kg	Ti-64 ~ $600/kg; IN 718 ~ $200/kg Stainless Steel ~ $100/kg
Repair/Coat & Add Features	Capable - add material onto 3D surfaces	Limited - requires horizontal build plane
Multi-material	Programmatically grade or blend	Limited

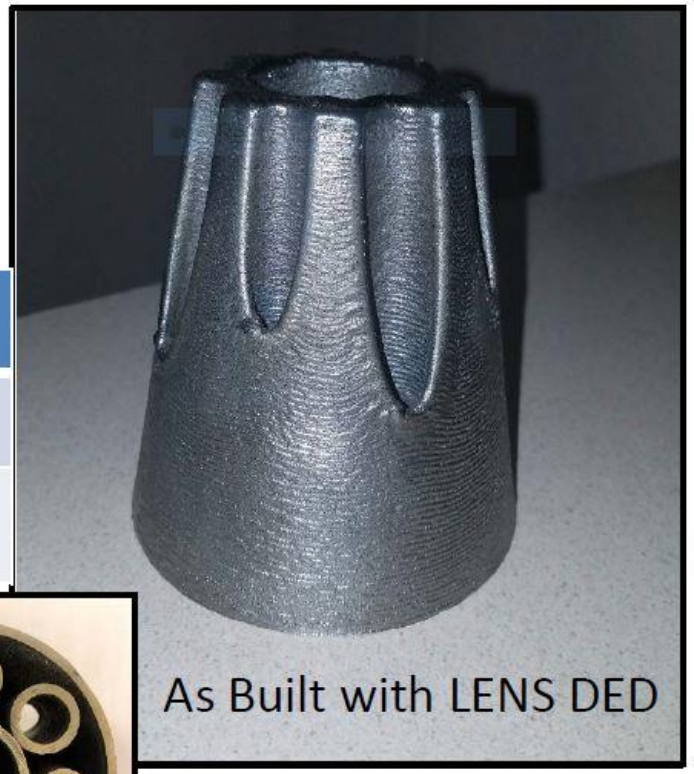
DED and PBF- Sample Build Comparison

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.



Distinct Advantages of the DED Process

- Part size- larger build envelopes possible.
- Build speed is ***much*** faster.
- Cheaper material cost, less material waste.
- Graded materials. New alloy development. Selective material properties in key build areas.
- Can start/stop process during building.
- Able to repair parts. Can repair builds in-situ during building.
- Process can be performed in open or controlled atmosphere. Process head can be mounted to a robot/gantry system.
- Process lends itself well to building new parts, building on parts, remanufacturing of parts, repair, and coating applications.
- Minimal effect on substrate microstructure.

New LENS Platform Line-Up

The Classic Series

LENS 150

LENS 600

LENS 800

LENS 1500

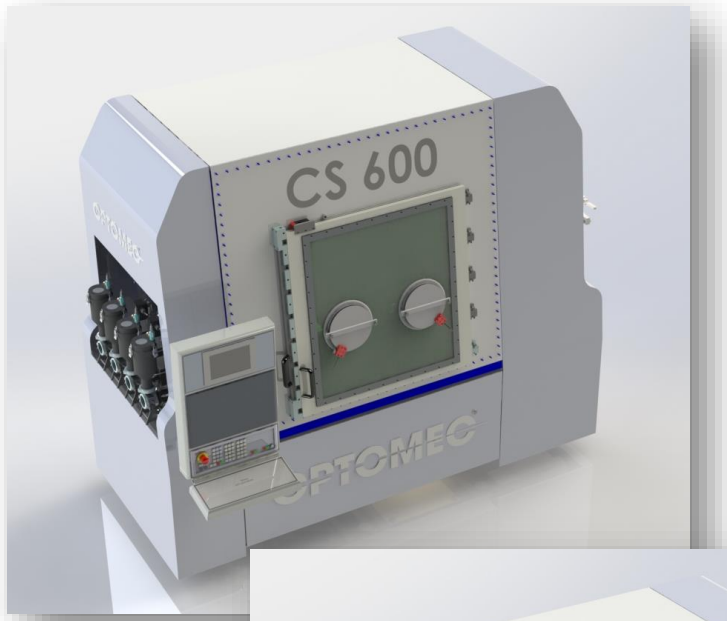
NOTE: ALL CS MODELS ARE ADDITIVE ONLY, CONTROLLED ATMOSPHERE SYSTEMS

LENS 150

- LENS 150 AM CA SYSTEMS
  - Machine type: 3 axis additive controlled atmosphere.
  - XYZ Travel: 150x150x150mm.
  - Oxygen moisture Level <10ppm.
- Proven LENS Print Engine Technology
  - Proprietary Optomec powder feeders: up to 4 feeders.
  - LENS deposition head 1.0: fiber laser 400W.
- Optomec Software
  - Easy to learn/use Windows HMI.
  - Supports standard CNC G&M codes.
  - PartPrep for CAD to tool path generation.

LENS 600/800

- LENS 600/800 AM CA SYSTEMS
  - Machine type: 3 axis additive controlled atmosphere.
  - LENS 600 XYZ Travel: 600x400x400mm.
  - LENS 800 XYZ Travel: 800x600x600mm.
  - Dri-train maintains O_2/moisture Level <10ppm.
  - Gas recirc system.
  - Antechamber Ø: 375mm.
  - Siemens 840D controller.
  - Optional Interchangeable rotary axis and TR trunnion.
- Proven LENS Print Engine Technology
  - Up to 4 feeders.
  - LENS deposition head 3.X: up to 3 kW, configurable optics/nozzle.
  - Optional closed loop process controls/thermal imaging pyrometer.
  - Up to simultaneous 5 axis tool path generation software, CNC G&M codes.



LENS 1500

- LENS 1500 AM CA SYSTEM
  - Machine type: 5 axis additive controlled atmosphere.
  - XYZ travel: 900x1500x900mm.
  - Tilt/rotate table:
    - Rotary axis : continuous 360 °
    - Tilt axis: +90° to -90°
    - Maximum workpiece load: 1427 kg
  - Modular part handling system.
  - Dri-train with 2 purification units maintain O_2<10ppm.
  - Siemens 840D controller.
- Proven LENS Print Engine technology
  - Up to 4 feeders.
  - LDH 3.X: up to 3 kW, configurable optics/nozzle.
  - Closed loop process controls/thermal imaging pyrometer.
  - 5 Axis Tool Path Generation Software, CNC G&M codes.

The Machine Tool Series

LENS 500 HYBRID CA
LENS 500 ADDITIVE CA
LENS 500 HYBRID OA*
LENS 500 ADDITIVE OA*

LENS 860 HYBRID CA
LENS 860 ADDITIVE CA*
LENS 860 HYBRID OA*
LENS 860 ADDITIVE OA*

LENS 1400 HYBRID OA*

* Longer lead times for these configurations.

LENS 500

- LENS 500 HY CA SYSTEM
  - Machine Type: 3 axis hybrid controlled atmosphere.
  - XYZ travel machining: 500x350x500mm.
  - XYZ travel additive: 350x300x500mm.
  - Tool changer: 8/10* tool carousel.
  - Table size/payload: 600x300 / 200 kg.
  - Gas purification/recirc system <40ppm.
  - Siemens 828 controller.
  - Optional rotary axis or T/R trunnion.
- Proven LENS Print Engine technology
  - Up to 4 feeders.
  - LDH 2.0: up to 2 kW, configurable optics/nozzles.
  - Closed loop process controls.
  - 5 Axis tool path generation software, CNC G&M codes.

LENS 860

- LENS 860 HY CA SYSTEM
  - Machine Type: 3 axis hybrid controlled atmosphere.
  - XYZ travel machining: 860x600x610mm.
  - XYZ travel additive: 598x600x610mm.
  - Tool Changer: 16 tool carousel.
  - Table size/payload: 1000x600mm / 600 kg.
  - Gas purification/recirc system <40ppm.
  - Siemens 840D controller.
  - Optional rotary axis or T/R trunnion.
- Proven LENS Print Engine technology
  - Up to 4 feeders.
  - LDH 3.X: up to 3 kW, configurable optics/nozzles.
  - Closed loop process controls.
  - 5 axis tool path generation software, CNC G&M codes, option for simultaneous 5x.

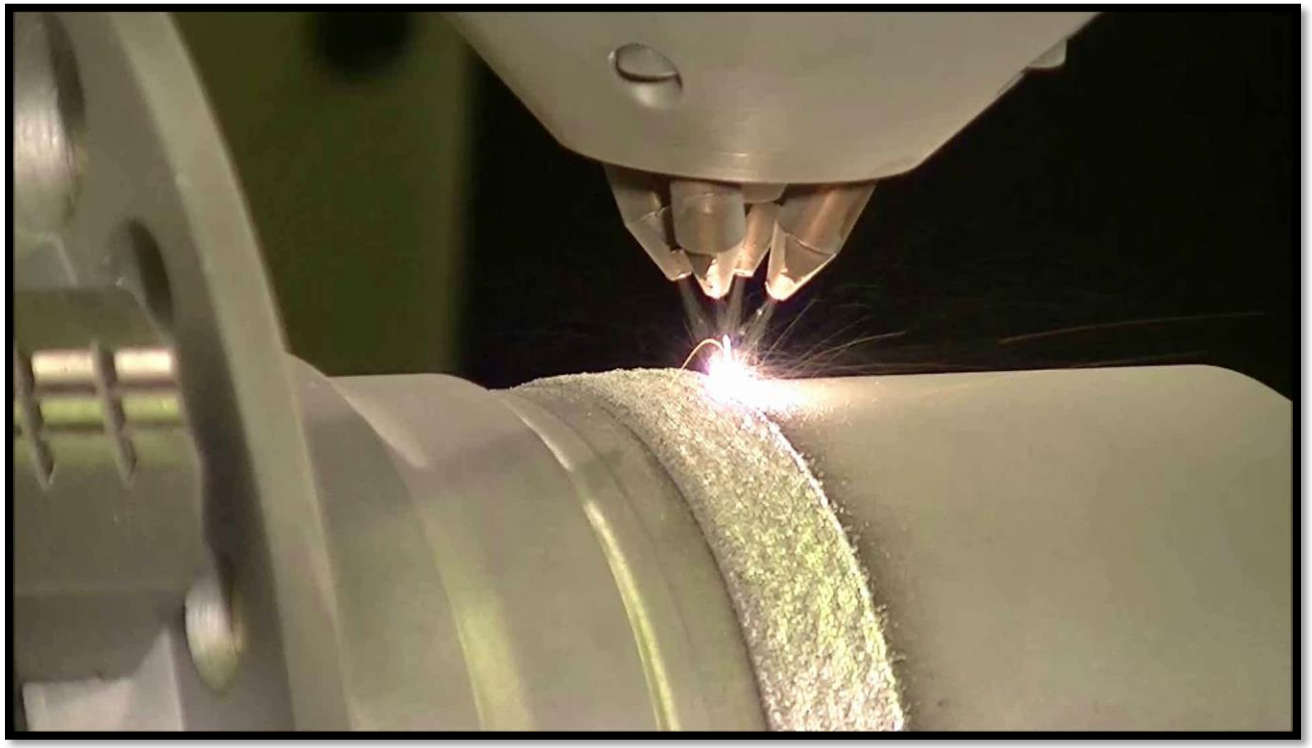
LENS 1400

- LENS 1400 HY OA SYSTEM
  - Machine type: 3 axis hybrid open atmosphere.
  - XYZ travel machining: 1400x700x600mm.
  - XYZ travel additive: TBD.
  - Tool changer: 24 tool arm type.
  - Table size/payload: 1450x600mm / 1400 kg.
  - Siemens 840D controller.
  - Optional rotary axis or T/R trunnion.
- Proven LENS Print Engine technology
  - Up to 4 feeders.
  - LDH 3.X: up to 3 kW, configuratble optics/nozzles.
  - Closed loop process controls.
  - 5 axis tool path generation software, CNC G&M codes, option for simultaneous 5x.

LENS Print Engine (LPE)

- Open Architecture / Modular Solution Approach
  - A la carte purchase of key components for integration of additive capabilities to existing CNC machines.
  - Integrate powder feeder, laser, deposition head, and controls.
- Enables A Wide Variety of Metalworking Applications
  - Repair, coatings, hybrid manufacturing, full part builds.
  - Process a full suite of open atmosphere metals.
- Dramatically Lowers Barriers to Entry
  - Cost reduction, minimal training requirements, floor space, etc.
- Can Be Integrated Into An Installed Base of Millions of Machine Tools

LENS Applications



LENS Applications

- The LENS process empowers users with a host of manufacturing capabilities:

- **Applications-**
  - Fast prototypes
  - New builds
  - Rework
  - Remanufacture
  - Repair
  - Part modifications/add-ons
  - Resurfacing
  - Coatings- corrosion/wear resistance
  - Material property enhancement
  - OD or ID cladding/coating

- **Distinct to Optomec LENS Capabilities-**
  - New designs through AM not possible previously
  - Near net shape builds
  - Range of laser powers/spot sizes
  - Material gradients
  - New alloy development
  - Open metal powder system
  - Process reactive materials (CA)
  - Build and machine in same system (HY)
  - Advanced simultaneous 5 axis motion
  - Closed loop process monitoring

Examples of LENS Fully Printed Samples

Nozzle
Inconel 718
7 hours

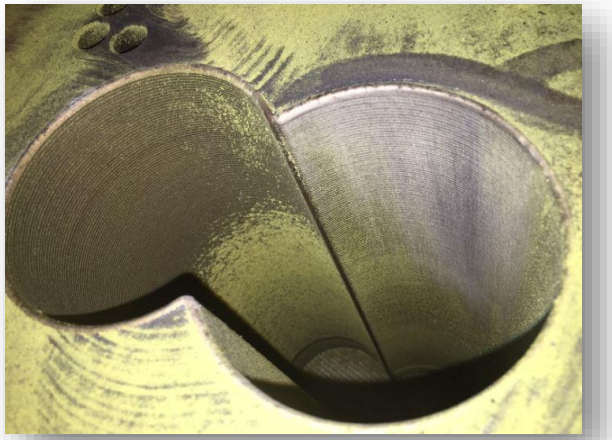
Cooling Channels
Stainless steel
4.5 hours

Venturi
Stainless steel
5.5 hours

LENS Production Application- Hard Facing

Proprietary Co / WC

- LDH mounted on gantry and used for hard facing/material property enhancement of injection mold tubing-
  - Tubes were cracking/failing after just a few cycles of use.
  - Company came to Optomec for solution in factory production line- to enhance material properties of “figure eight” tubing.
  - Simple tubes could be clad by other methods, but geometry of tubing required a 3D AM solution.
  - Tubes were clad with a proprietary hard facing powder that improved hardness and strength and eliminate cracking issues.



LENS Production Application- Worn Impeller

SS

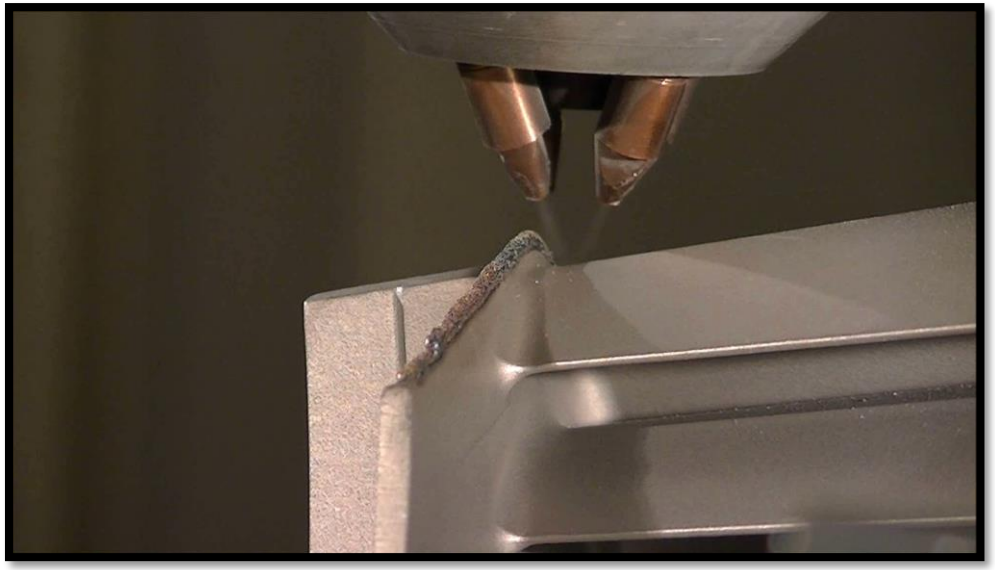
- Customer need- worn pump impeller degrades performance. Long lead and costly replacement item.
- Value proposition- shorten lead time/improve delivery, reduce costs.
- LENS used to print stainless steel on to hard iron to improve material properties and overall performance.

Using LENS to restore worn areas

After machining

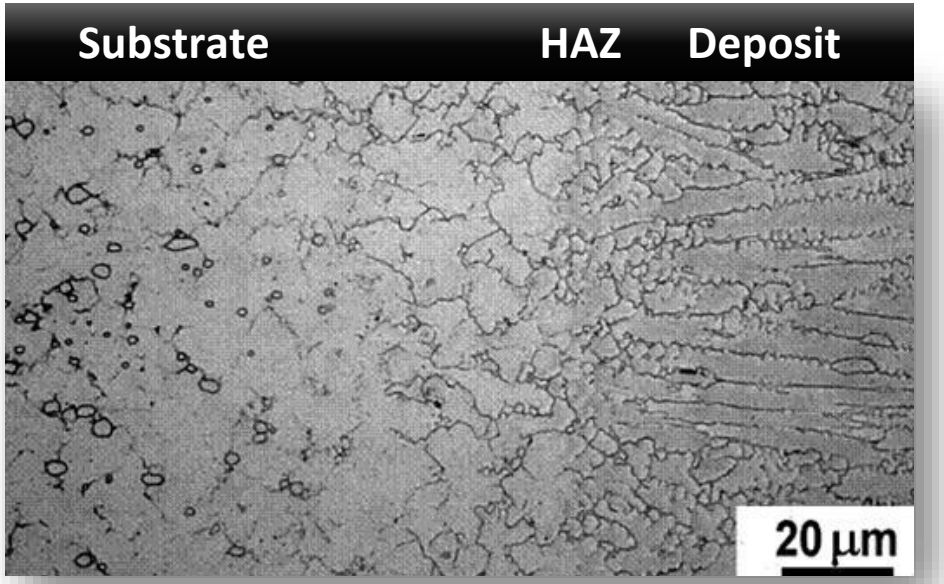
LENS Repair Overview

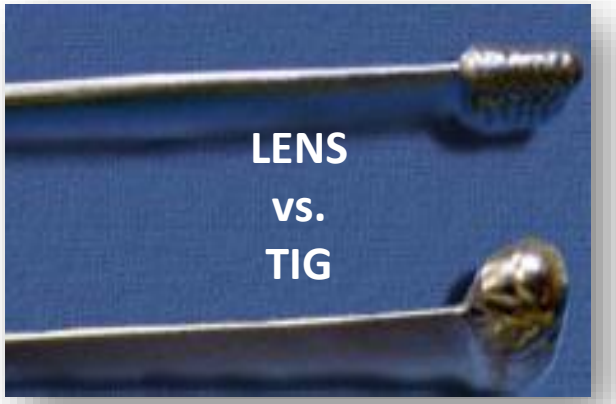
- LENS repair capabilities include:
  - Restoration of worn components.
  - Repair of damaged components and production defects.
  - Remanufacturing of spare parts.
  - Rework to new design iterations.
  - Functional grading/locally enhanced material properties-
    - corrosion or wear resistance, additional strength, etc.
- LENS can perform repairs on a wide variety of materials-
  - CMn steels- from basic (AS-30) to high strength steels (4140).
  - Stainless steels- 304L, 316, martensitics, PH stainless steels.
  - Nickel based alloys- Inconels, Monels.
  - Tool steels, Cobalt steels (Stellites).
  - Reactive metals- titanium, aluminum, magnesium.



LENS Repair: Benefits – Process Advantages

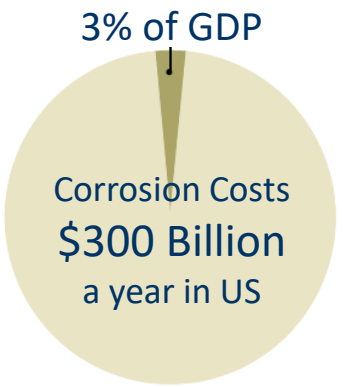
- Metallurgical bond vs. mechanical/adhesive
  - Much stronger bond.
- Small heat affected zone (HAZ); ie microns
  - Eliminates cracking and distortion.
  - Minimizes base metal dilution.
- Precision placement; near net shape deposition
  - Reduces finishing time and consumables.
- Rapid solidification
  - Fine grain size= superior properties.
  - Repair often has enhanced material properties.

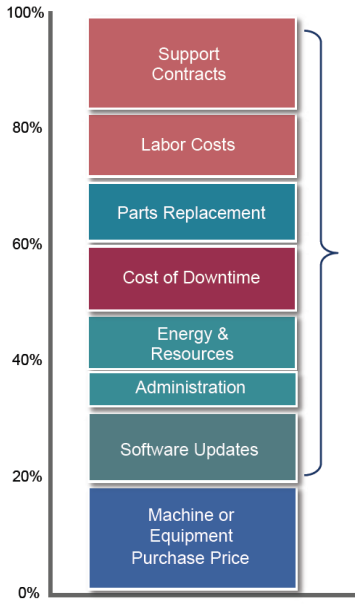




LENS Repair: The Need

- Corrosion or wear costs- $300B/yr in US-
- GE's "3 Million Things that Spin"
  - Spinning leads to wear, which requires repair.
  - 200,000+ gas turbines; ie aircraft, power, etc.
  - Lifecycle costs run 5-15X initial purchase price.
- $100B's/yr spent on spares and overhaul
  - Commercial aviation spends >$100B per year.
  - US DOD spends >$50B per year.
- More cost effective to restore vs. replace
  - DED repairs can be more wear resistant than original part.
- Significant ROI for LENS/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		
CT Scanners	52,000	104,000
	Total	**3M**

Ref: GE
Industrial Internet Vision Paper

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

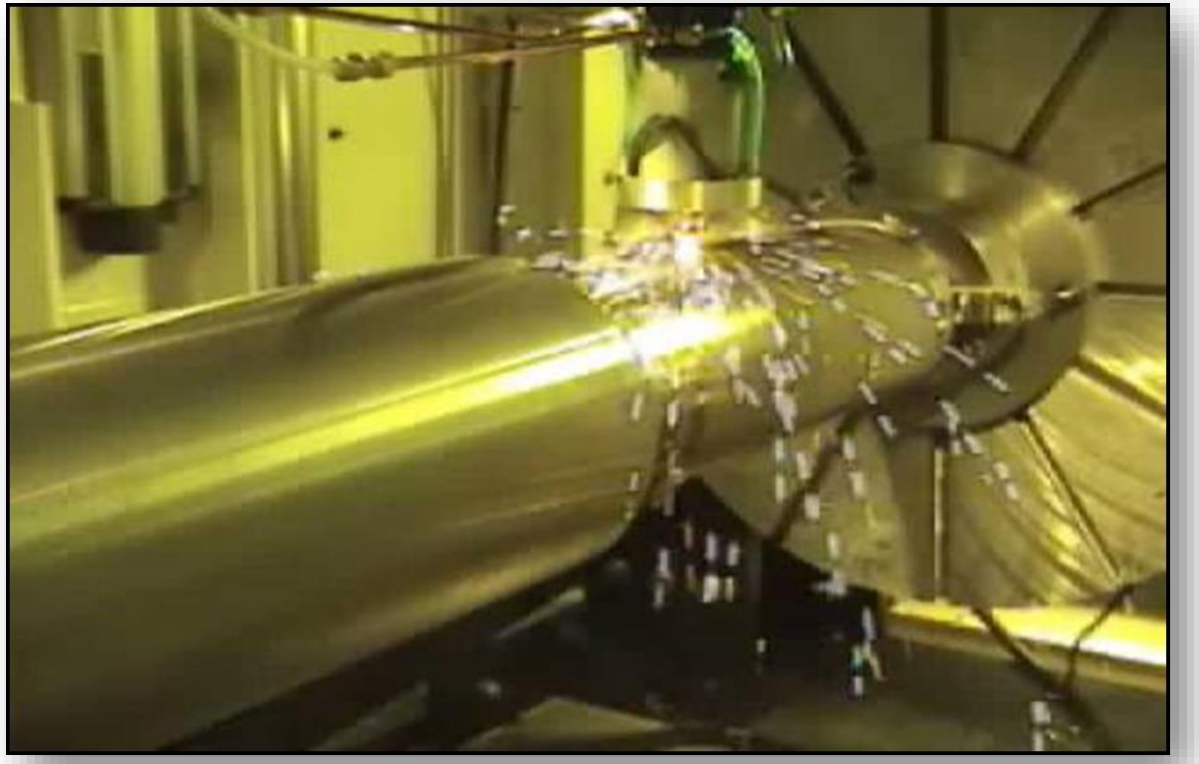
Material	Inconel 713	Inconel 713	Inconel 713	321 Stainless
New Cost	$ 8297	$ 5485	$ 6032	$ 910
Repair Cost	< $2,000	< $2,000	< 2,250	< $300
Savings/Part	**> 75%**	**> 60%**	**> 60%**	**> 60%**

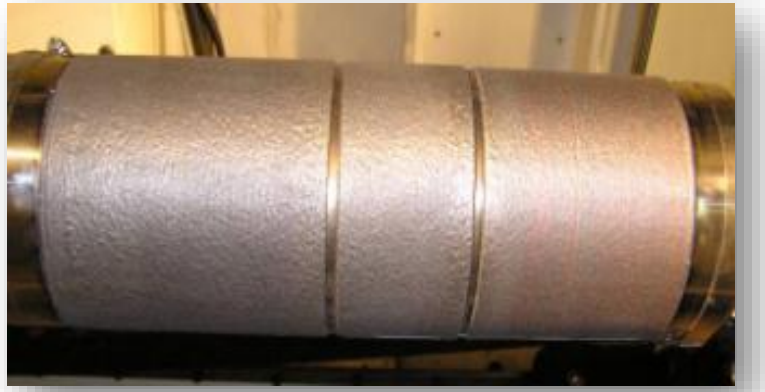
LENS Repair of Rotating Parts – Shafts

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

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

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)

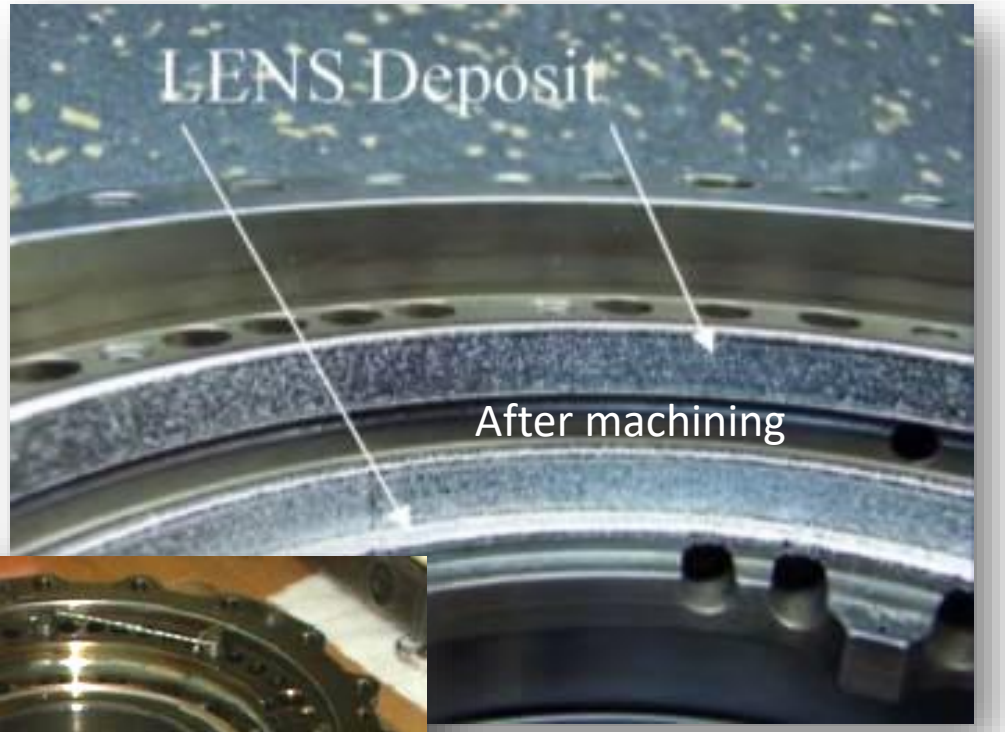
After LENS printed repair

Machined to spec

LENS Repair of Rotating Parts – ID Seals

Ti-6-4

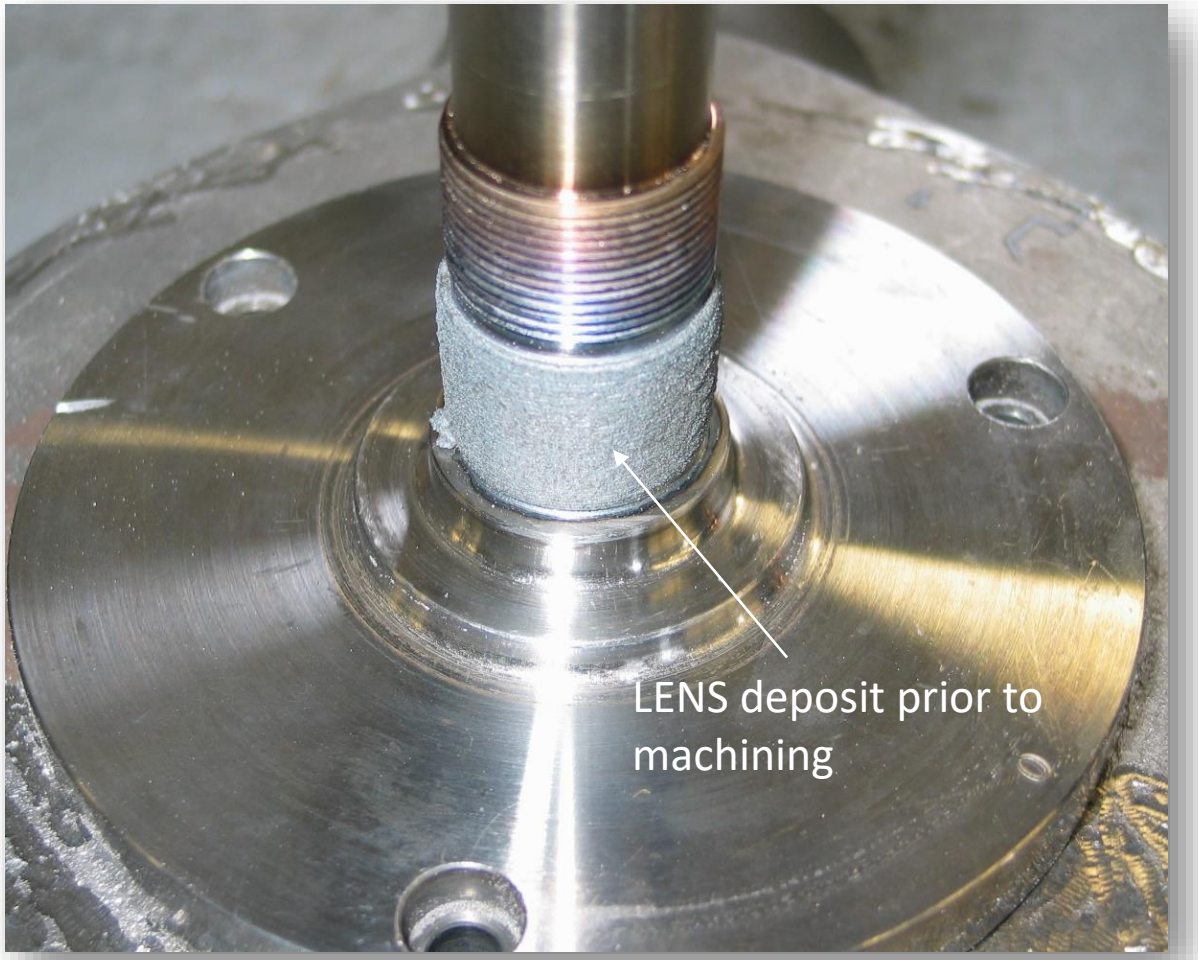
- Material: Ti-6-4
- Engine: T55 – Chinook Helicopter
- LENS Advantage:
  - Quality
  - Access to recessed features
- Two repairs qualified by U.S. Army
- Saving >$10K vs. part replacement



LENS Repair of Bearing Surface- Material Property Enhancement

410 SS

- LENS used to resurface a worn bearing surface.
- 4340 high carbon steel resurfaced with 410 stainless steel.
- 410 stainless steel used to build up worn surface and to provide better corrosion and wear resistance over original material.
- Quick turnaround repair of part to place back into service with minimum down time.



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.

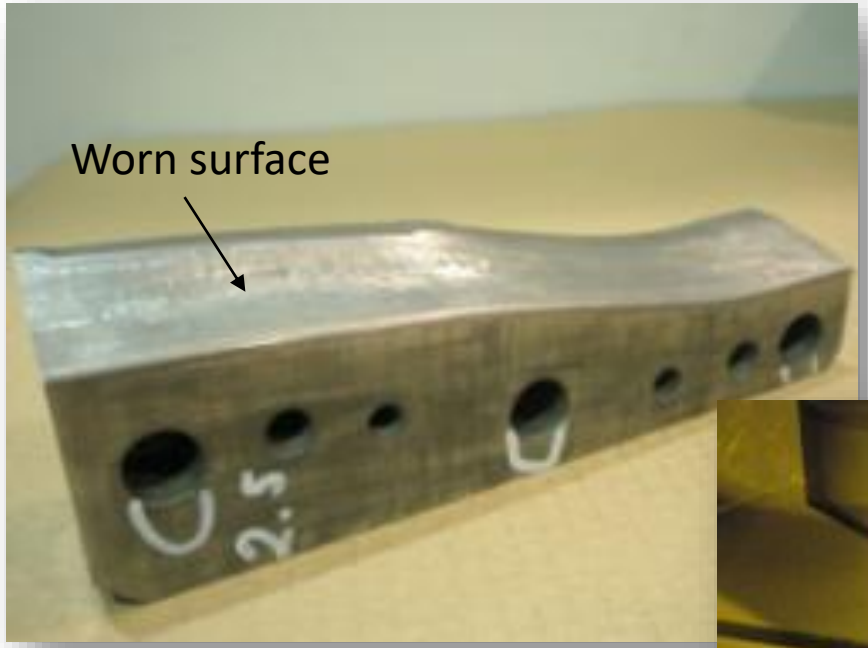
1” long scratch

After printing; before finishing

machined & polished

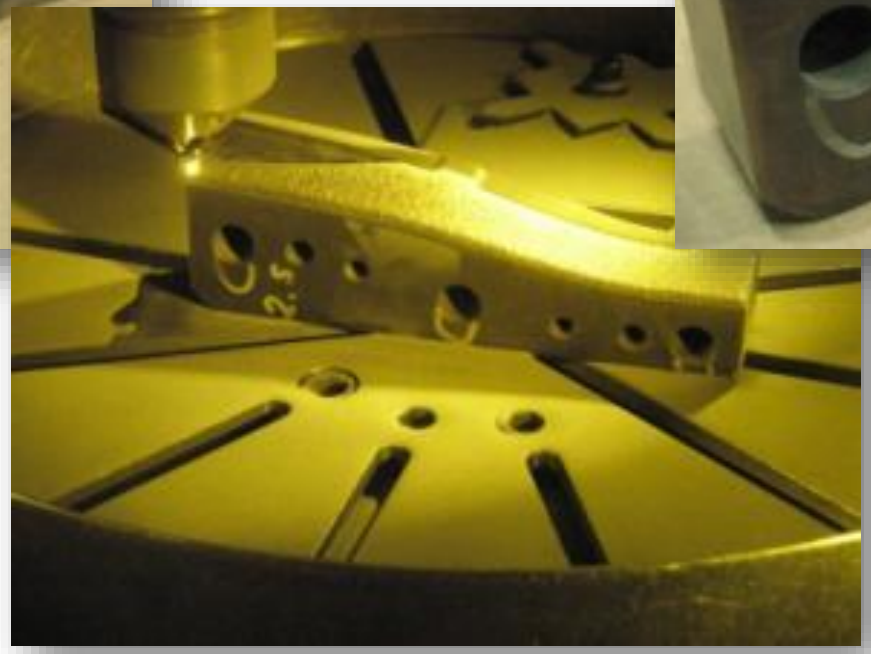
LENS Repair of Tooling – Deep Draw Tools

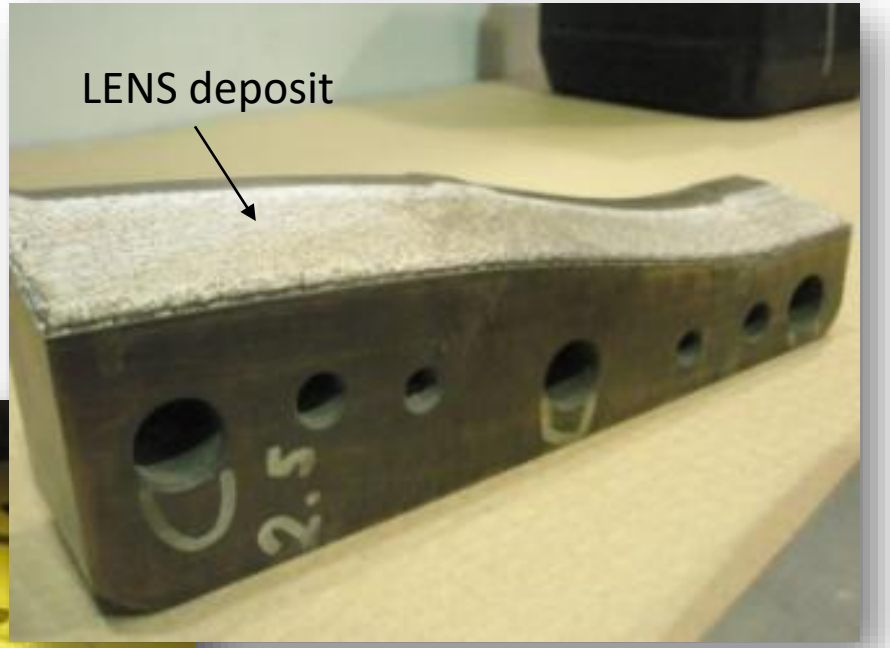
H 13 tool steel



Worn Tool

LENS Printing





As Printed

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

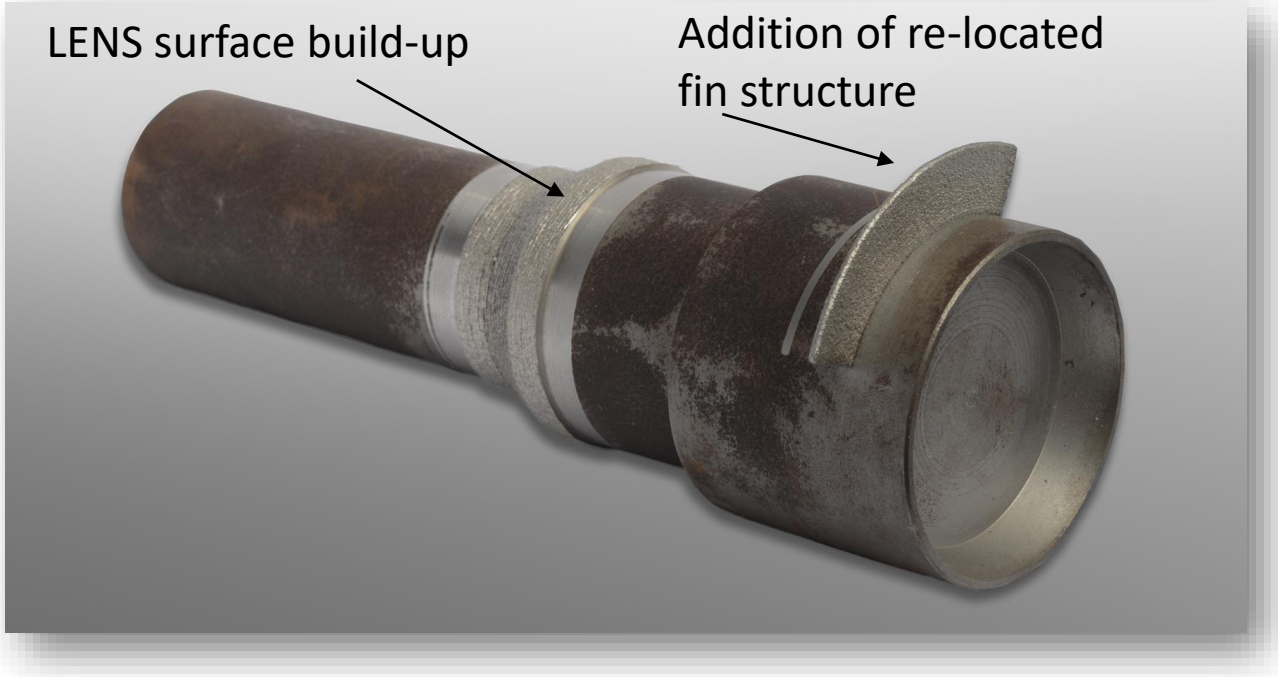
Machined to spec

LENS Repair of Tooling – Core Pin

Tool Steel

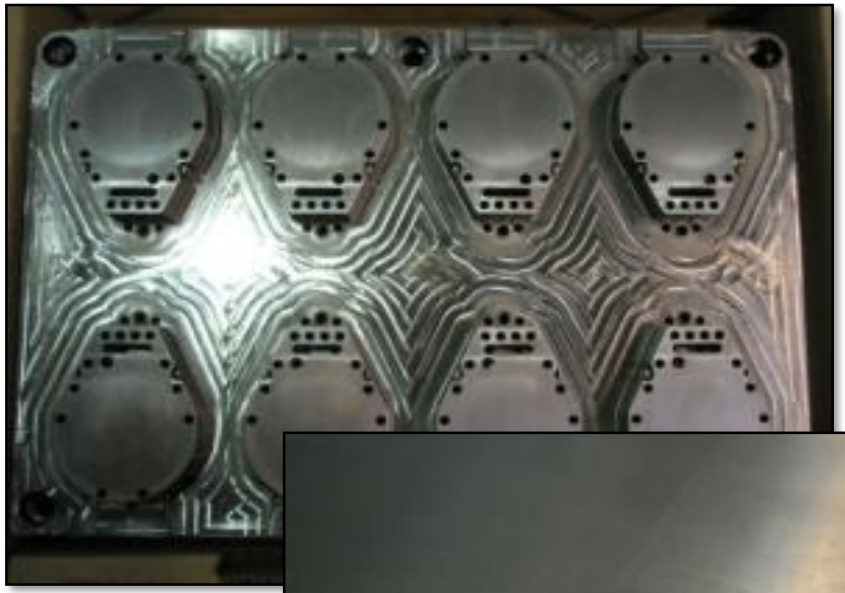
Repair/Rework

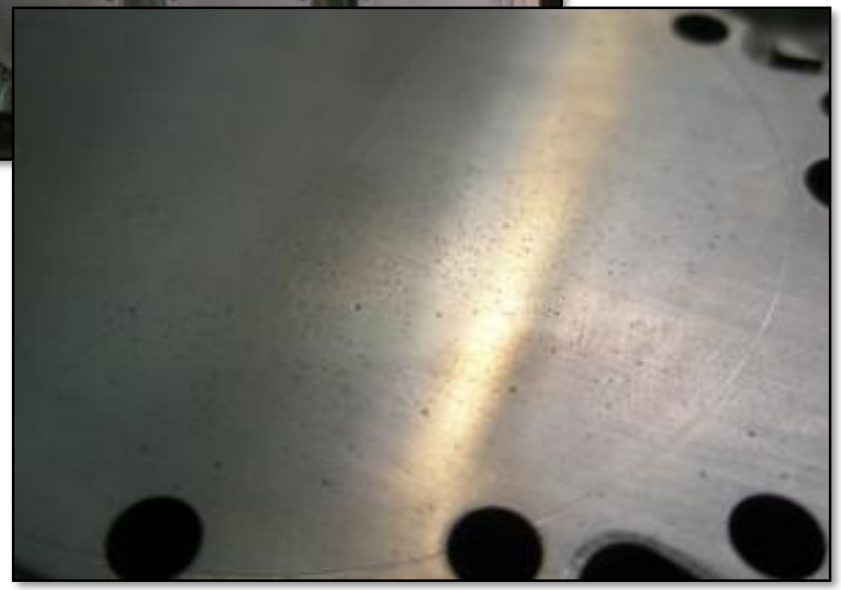
- Build up of worn shaft surface.
- Re-design- the fin structure location was moved.
- Cost savings/lead time reduction vs. new part.



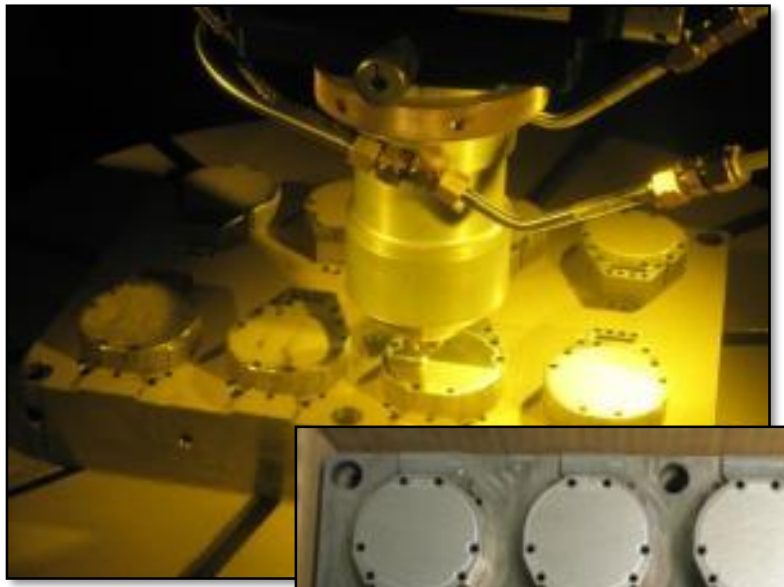
LENS Repair of Tooling – Injection Mold Resurfacing

H 13 Tool Steel

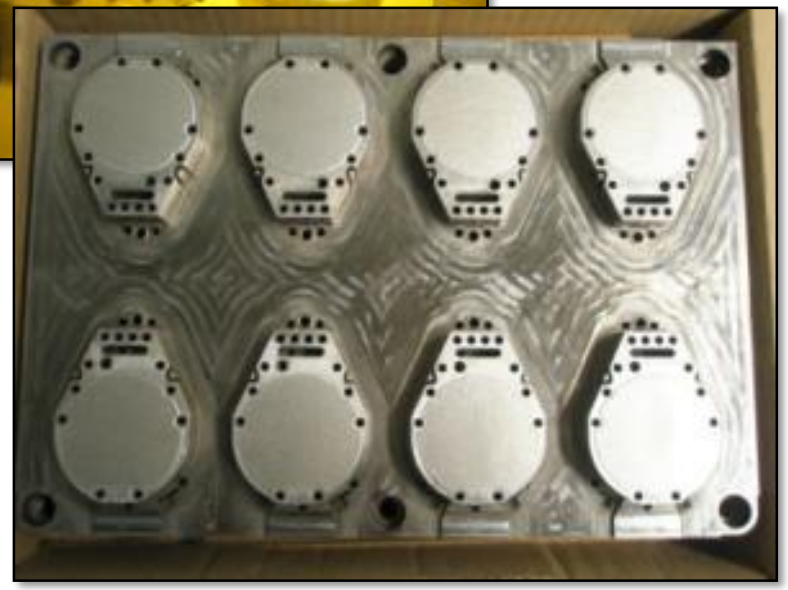




Mold prior to repair shows pitting on surface



Resurfacing worn areas with LENS printing



LENS Injection Mold Wear Coating- Deep Repair Head

Stellite 694

- Barrels used to eject hot resin in injection molding.
- High wear surface, especially with glass-filled resins.
- LENS printing of a carbide wear resistant material on ID surface.
- LENS proprietary “Deep Repair Head” used.

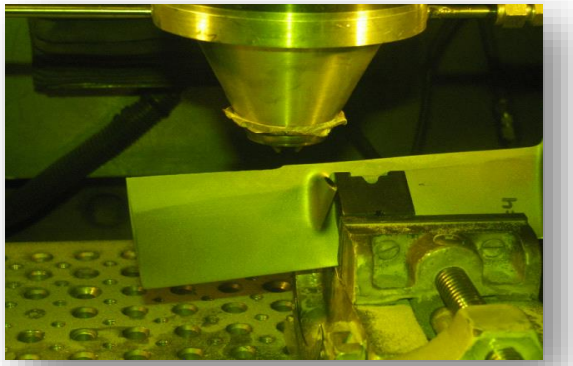
LENS Repair of Gas Turbines – Blade Tips, Edges, and FOD

Titanium

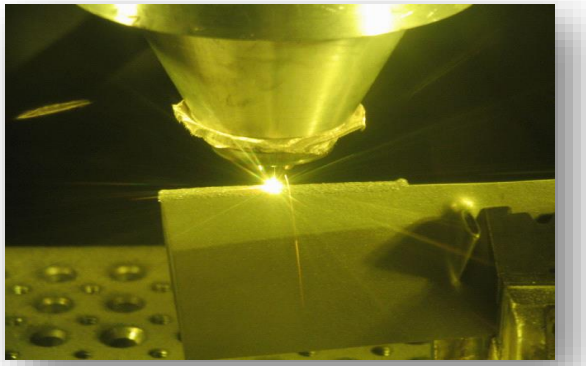
- Turbine blades wear over time and suffer damage from ‘foreign objects damage’ (“FOD”).
- New blades can be very expensive, and very long lead times for older units.
- LENS can be used to cost-effectively restore/resurface blades at a fraction of the cost.

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

Auto alignment



LENS restoration



As deposited

After finishing

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)

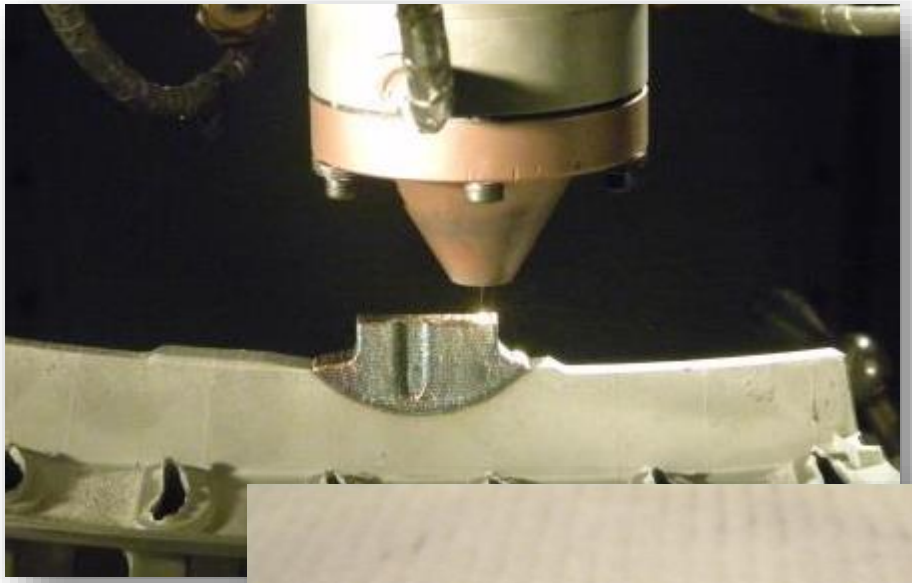
✓**60,000 rpm Spin Test**

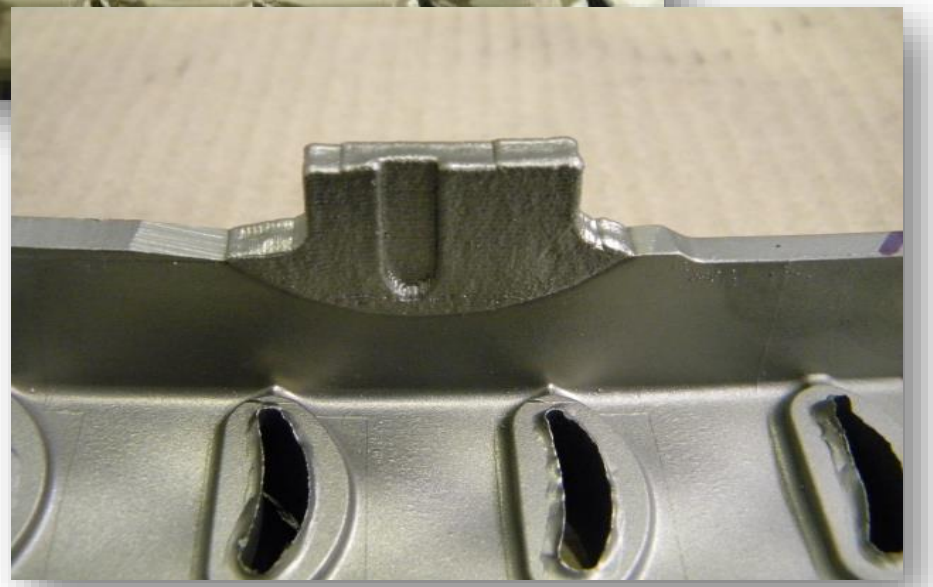
✓**50,000 Cycle LCF Spin Test**

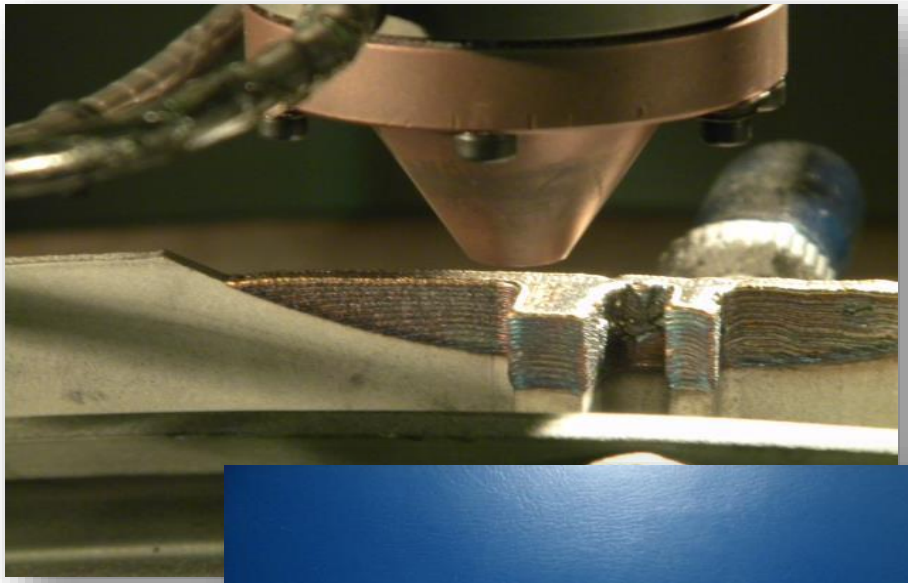
After finishing and successful spin tests

LENS Repair of Gas Turbines – Stator Guide Walls

Nimonic 75





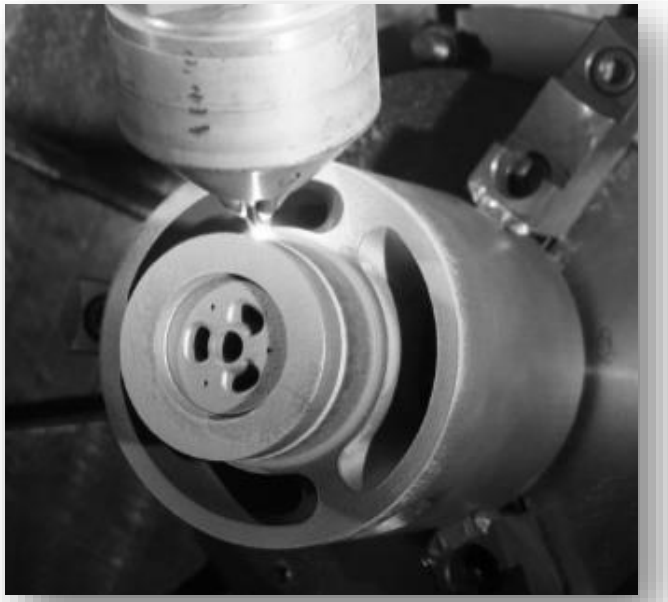


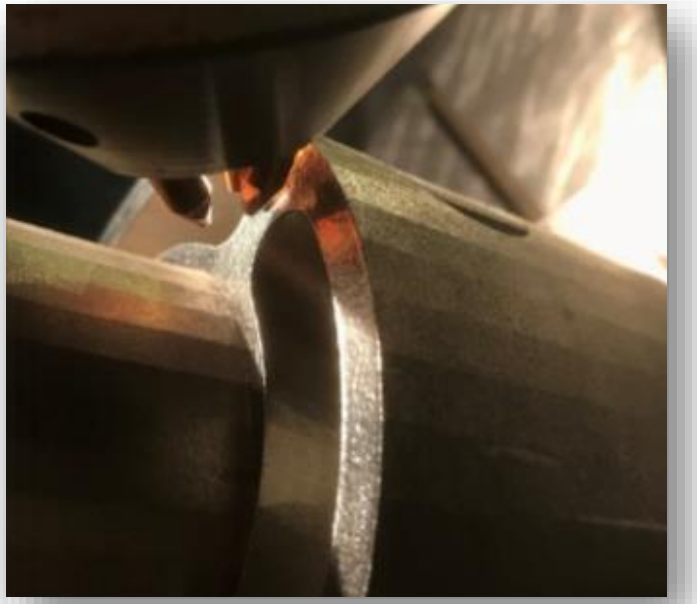
LENS Repair: Powder Bed Fusion Parts

Inconel

- Powder bed fusion parts are very expensive to fabricate, but must be scrapped if underbuilt, if defects are found, or if the process is interrupted prior to completion.
- The LENS process can effectively repair/add metal to powder bed parts to repair/complete the build.

LENS repair of an Inconel PBF part



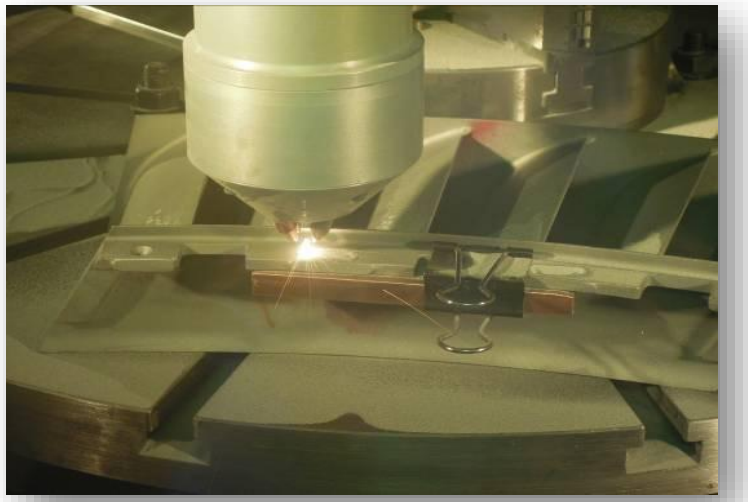


LENS used to extend shaft length on PBF fabricated fork joint

LENS Repair of Defects – Machining Error

Waspaloy

- Tier 1 aircraft engine manufacturer.
- Machining error on high cost part.
- Developed rework procedures for IN718, Waspaloy, Rene 77 and Mar-M-247 parts.
- Machine and qualified processes delivered to Field Repair Center in Taiwan



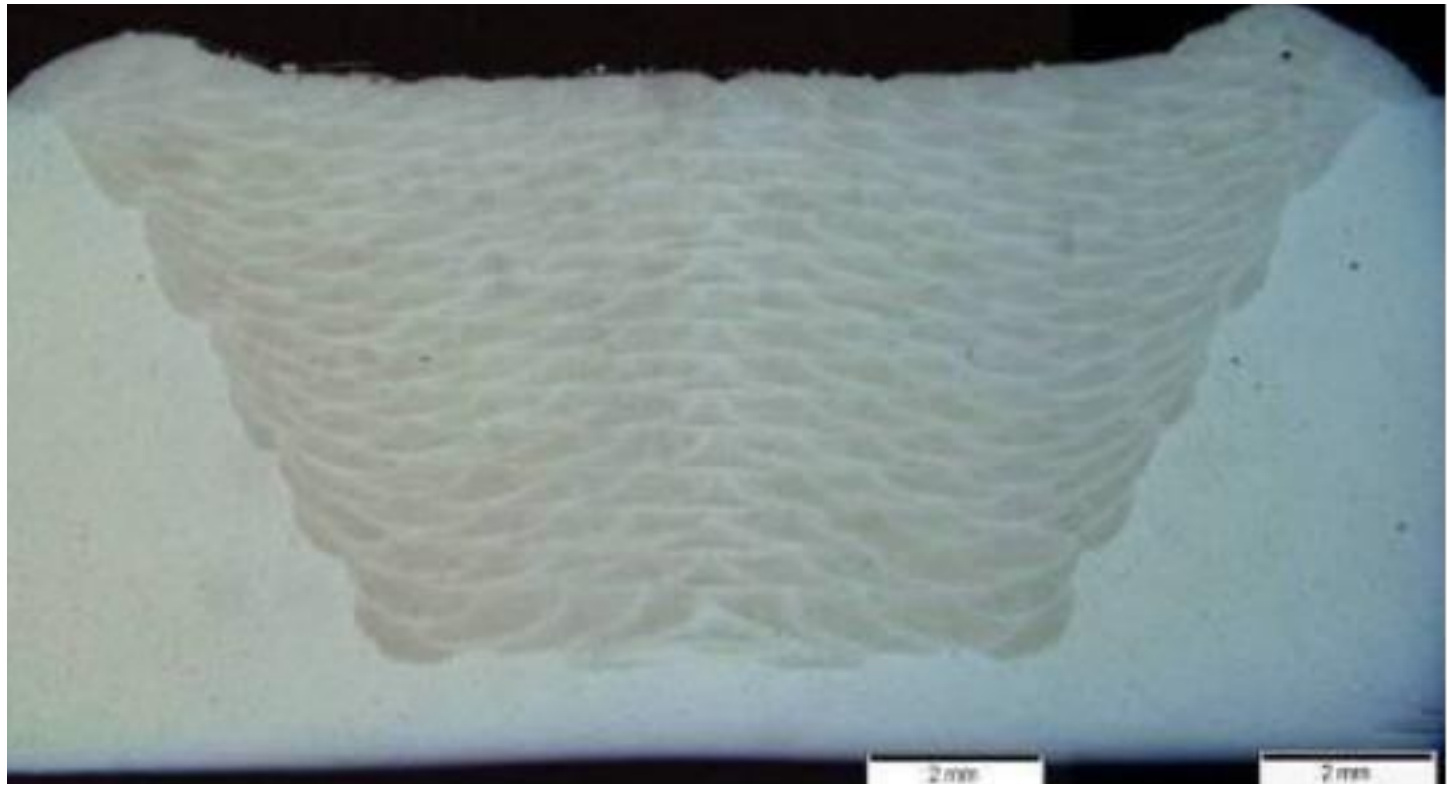
LENS Repair of Defects – Filling Blind Holes

Waspaloy

Machined sample

Surface remelt

After LENS deposition



Cross-Section

Thank You.