Aerodays 2011

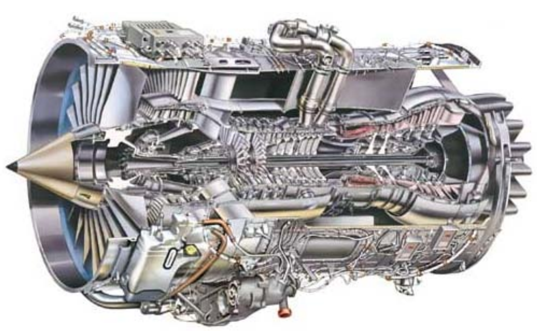
Presentation of EC Project FANTASIA

31th March 2011

Konrad Wissenbach

Fraunhofer Institute for Laser Technology ILT, Aachen, Germany

Session 4C: Advanced Manufacturing Technics for Engine Components



Flexible **a**nd near - **n**et shape genera**t**ive manuf**a**cturing chain**s** and repair techn**i**ques for complex shaped **a**ero engine parts, **FANTASIA**

Project duration: 01. June 2006 - 31. May 2010

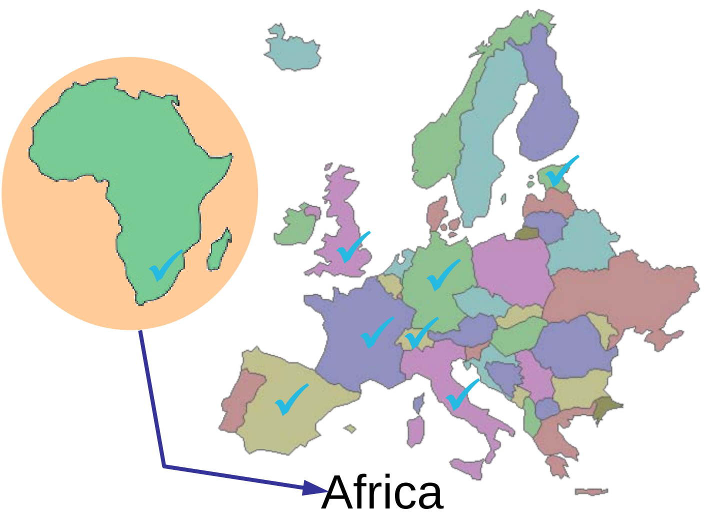
Fraunhofer ILT

Fantasia – Consortium

18 partners from 8 countries

5 Endusers

2. Rolls-Royce plc. (RR); England
3. Industria de Turbo Propulsores, S.A. (ITP); Spain
4. AVIO; Italy
5. Turbomeca (TM); France
15. SR Technics (SRT), Switzerland



6 Hardware, software and service providers

7. TWI Ltd; England
9. Trumpf; Germany
11. TLS; Germany
13. Sulzer Innotec (SI); Switzerland
14. Precitec (PT); Germany
17. BCT; Germany

7 R&D partners

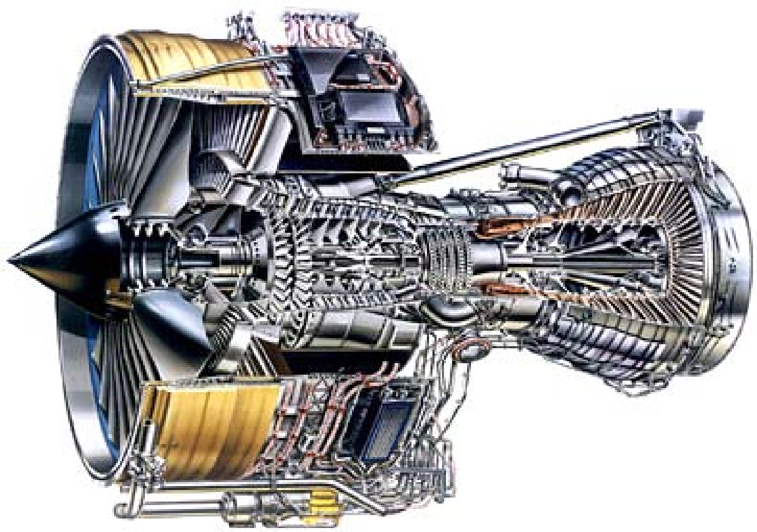
1. Fraunhofer Institut Lasertechnik (ILT); Germany
6. University of Manchester (UOM); England
8. AIDO; Spain
10. University of Riga (UoR); Latvia
12. Association ARTS, France
16. Lehrstuhl für Lasertechnik der Rheinisch-Westfälischen Technischen Hochschule Aachen (LLT); Germany
18. CSIR, South Africa

Aim of areo engine manufacturers:

- Delivery of economical and high quality products and services
- Reduction of time and costs to develop new products

repair

100 mm



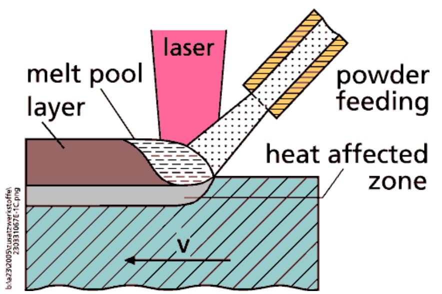
- **design & prototyping**
- **manufacturing**

100 mm

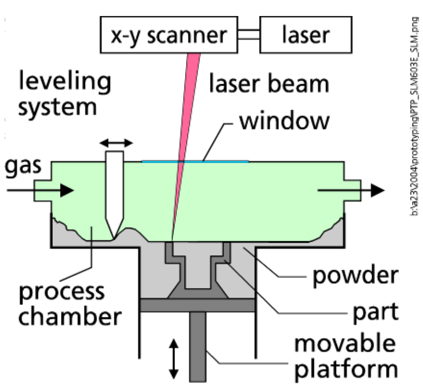
Solution approach: Near net-shape additive repair and manufacturing chains using LMD and SLM

Processes under investigation

Laser Metal Deposition

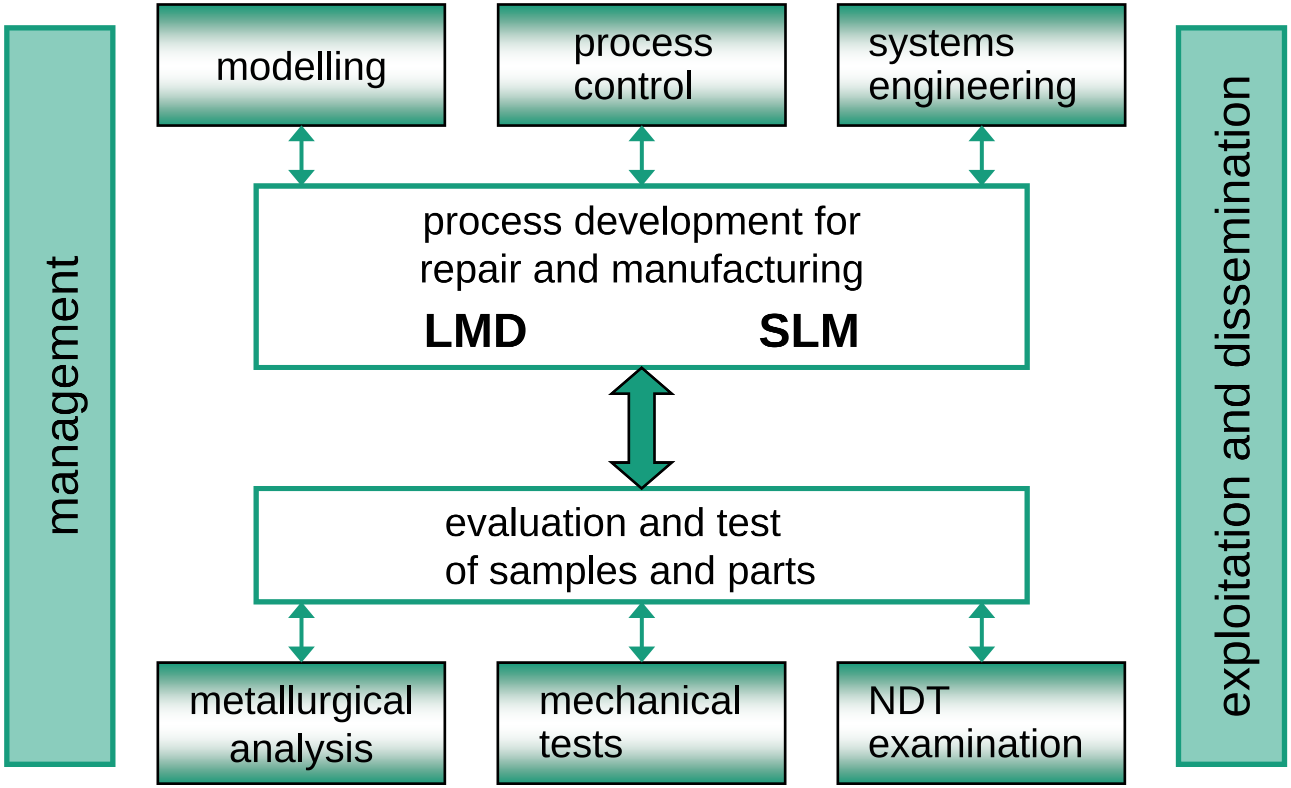


Selective Laser Melting (SLM)



characteristics	LMD	SLM
materials	large materials diversity	• limited and lower experience in comparison to LMD
part dimensions	limited by the handling system	limited by the process chamber (ø : 250 mm, height : 160 mm)
part complexity	limited	nearly unlimited
dimensional accuracy	≥ 0.3 mm	≥ 0.1 mm
build-up rate	10 - 40 cm^3/h	2 - 10 cm^3/h
build-up on	• 3D-surface • on existing parts	• flat surface • flat preforms
roughness R_z	60 - 100 µm	30 - 50 µm
layer thickness	≥ 0,1 - 1 mm	0,03 - 0,1 mm

Project overview



End user group – study cases

- Turbomeca
- ITP
- Rolls-Royce
- SRT
- AVIO

Vanes and blades
- HPT vanes
- LPT blades
- Inlet Guide Vanes

Casings and structural parts
- compressor (LPC, HPC)
- combustor
- Turbine (HPT, LPT)

Centrifugal Compressors

Small Inconel parts

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Centro para el Desarrollo Tecnológico Industrial
SEVENTH FRAMEWORK PROGRAMME

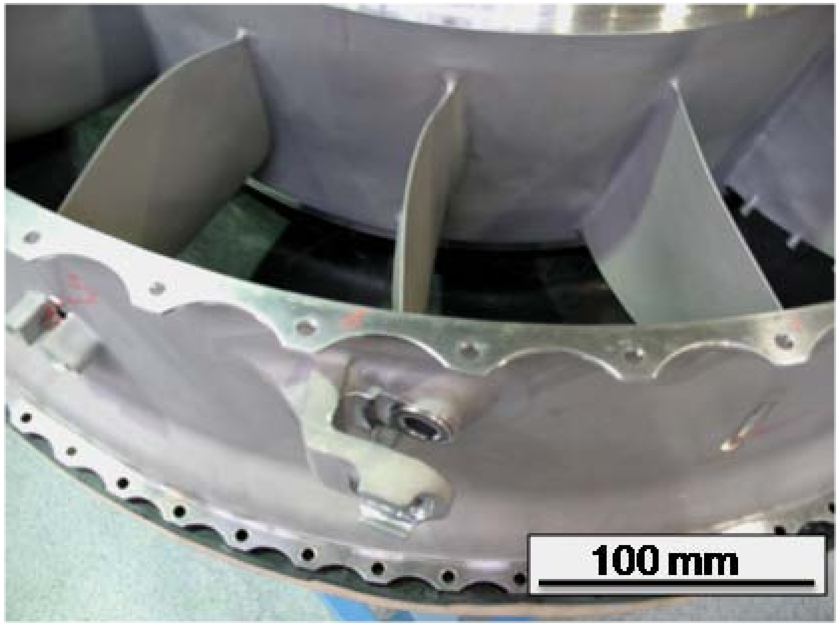
Results for LMD

process development for
repair and manufacturing
LMD

LMD repair for In718 OGV

Current status

- 2 damages occur for In718 OGV's flanges
  - Distortion: When the lack of relative flatness in the external flanges exceed 0.3 mm the OGV is out of tolerances.
  - Micro cracking in high stressed areas
- Current repair techniques for In718 OGV:
  - ***TIG welding*** for little defects (microcracks, etc.)
  - ***APS*** for large area repair
- Main drawbacks of present techniques are:
  - Excessive heat input and distortion (TIG)
  - Requirement of material removal before APS

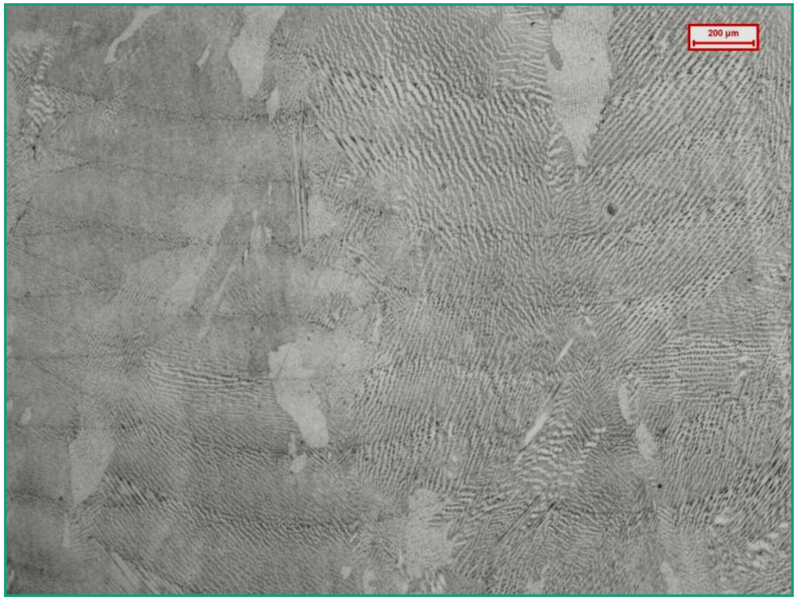


In718 Outlet Guide Vane (OGV)

LMD processing of In718 superalloy

Preliminary work

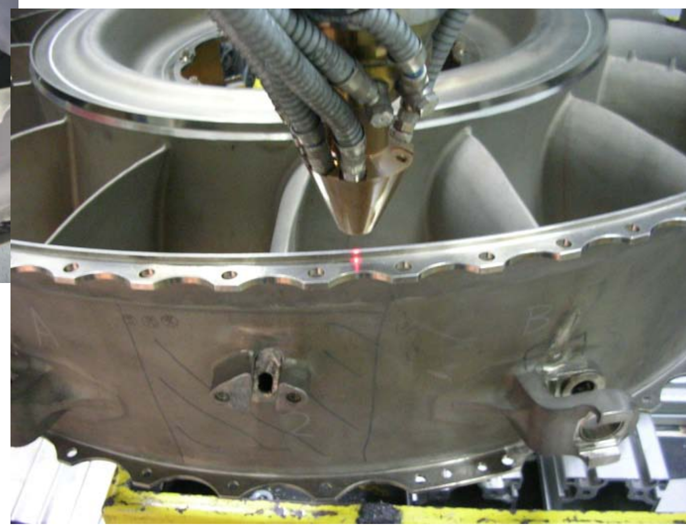
- Optimization of process layouts and parameters for LMD of In718 powder on In718 substrate (solution annealed).
- Following results have been achieved:
  - Dilution < 5%
  - Cracks and pore free layers
  - Good metallurgical bonding
  - Fine dendritic microstructure



Defect free In718 multiple layer coating by LMD (cross section)

LMD repair for In718 OGV

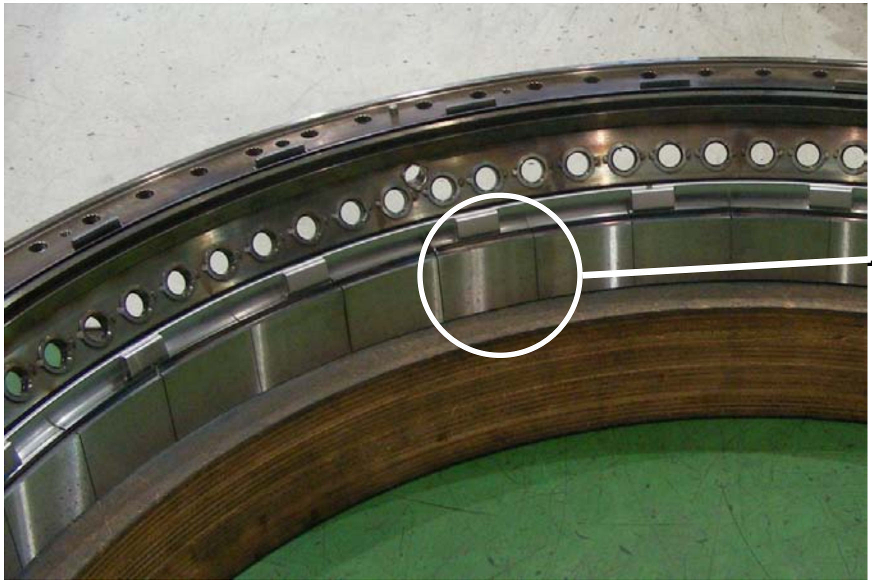
Outlet Guide Vane In718



LMD Repair - external flange

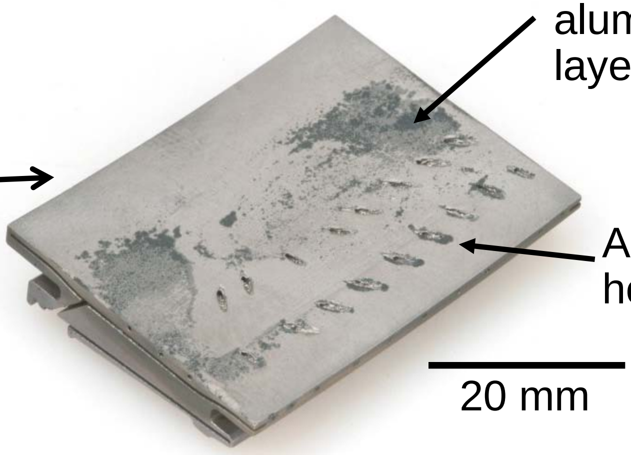
- Nd:YAG laser 1kW
- Cladding coaxial nozzle
- Cladding powder: In718
- Processing speed > 0,5m/min
- Track width: 2 mm
- Coating thickness: 0.5 mm
- Low dilution < 5%
- High reproducibility
- Complete automatization

Repair of worn SX shrouds by LMD



Shrouds fixed to a stator casing (Source: SRT)

Worn shroud



Material: Rene N5
(Ni-8Co-7Cr-2Mo-5W-7Ta-6.2Al-0.2Hf-3Re)

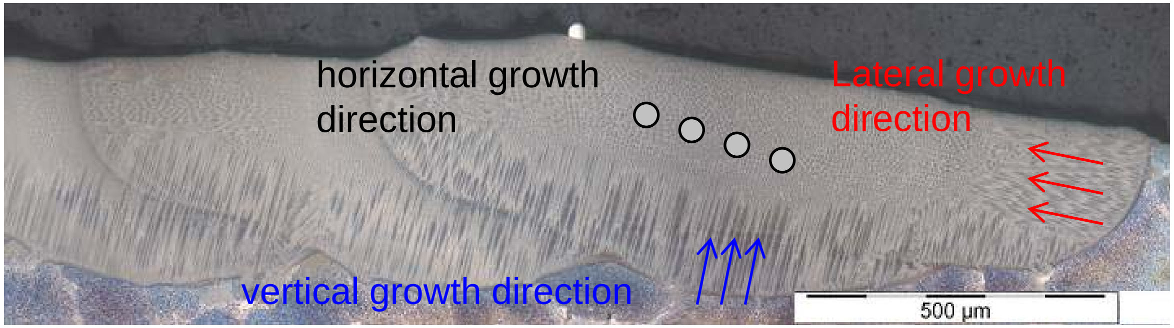
Task: Repair by Laser Metal Deposition using Rene N5 as filler material

Challenges:

- Regaining the SX structure (avoiding hot cracking)
- Minimizing distortion

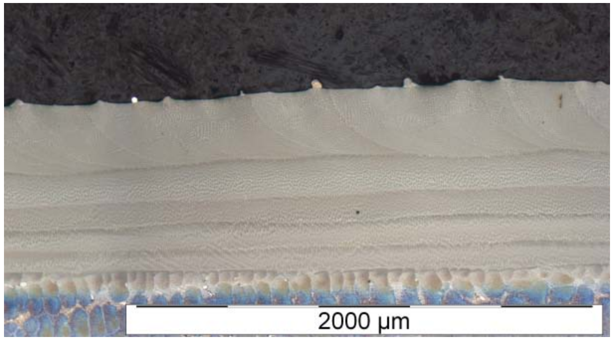
Single crystal growth

Single crystal growth is achieved for single and multi layer LMD



Cross section of single layer

Dendrites grow in <100> directions which are equivalent
⇒ Technical definiton of single crystal structure



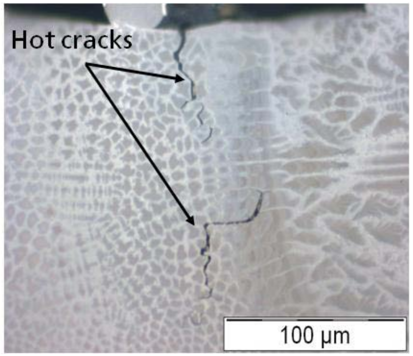
Longitudinal section of multi layers

Single crystal growth is determined by the process parameters:

- d(beam) = 2.4 mm
- P = 300 - 400 W
- v = 200 mm/min

small layer thickness ≈ 300 µm
Hot cracking can be avoided completely when the structure is 100 % SX

Hot cracking due to non-SX solidification

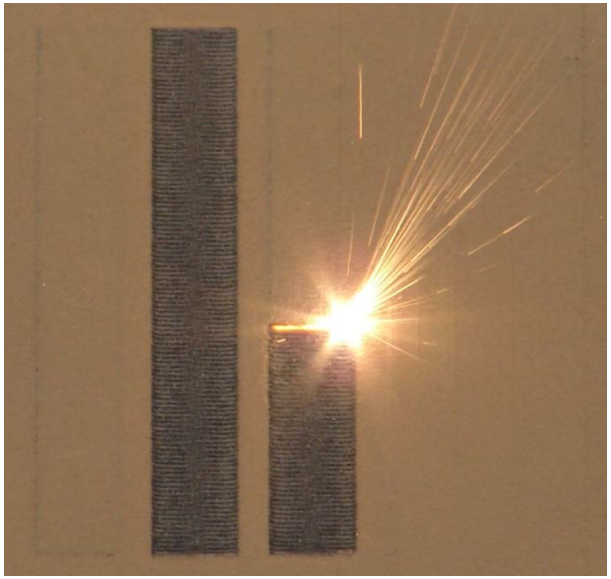


LMD of single crystal shrouds (Rene N5)

- Single crystal and crack free layers achieved
- Recovering of the whole surface without rounding the edges achieved
- Cooling holes can either be spared or closed during LMD (reopening required)
- Minimized distortion due to active water cooling during LMD

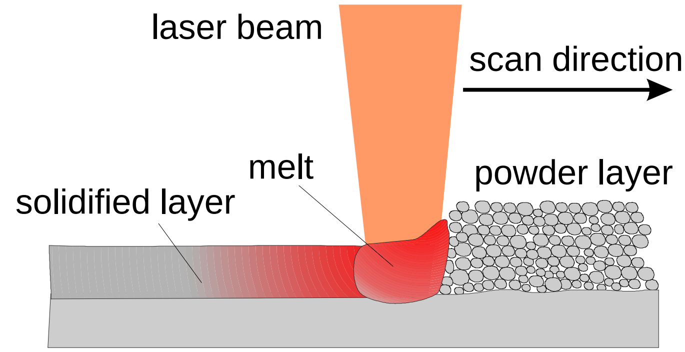
Results for SLM

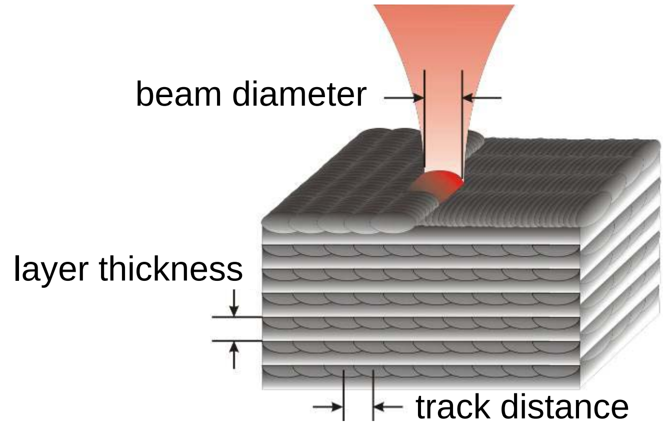
process development for
repair and manufacturing
SLM



SLM - Basic principle

- use of serial material
- complete melting of the powder particles
- part density of 100%
- preheating device enables processing of a wide range of materials
  - Titanium alloys
  - Aluminum alloys
  - Steel
  - CoCr alloys
  - Nickel alloys
  - …
- mechanical properties of SLM parts match materials specification

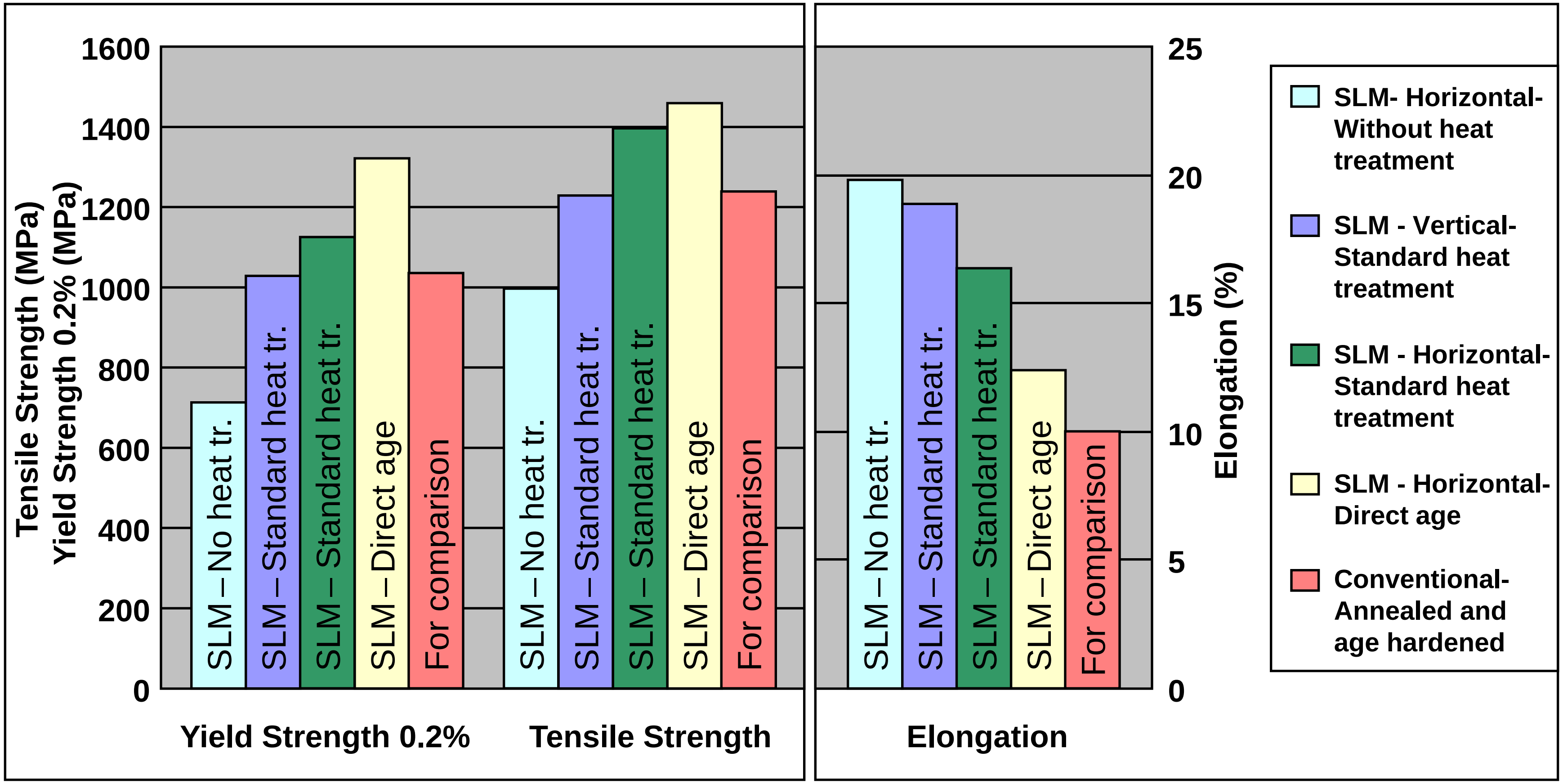




Processing of Inconel 718 by SLM

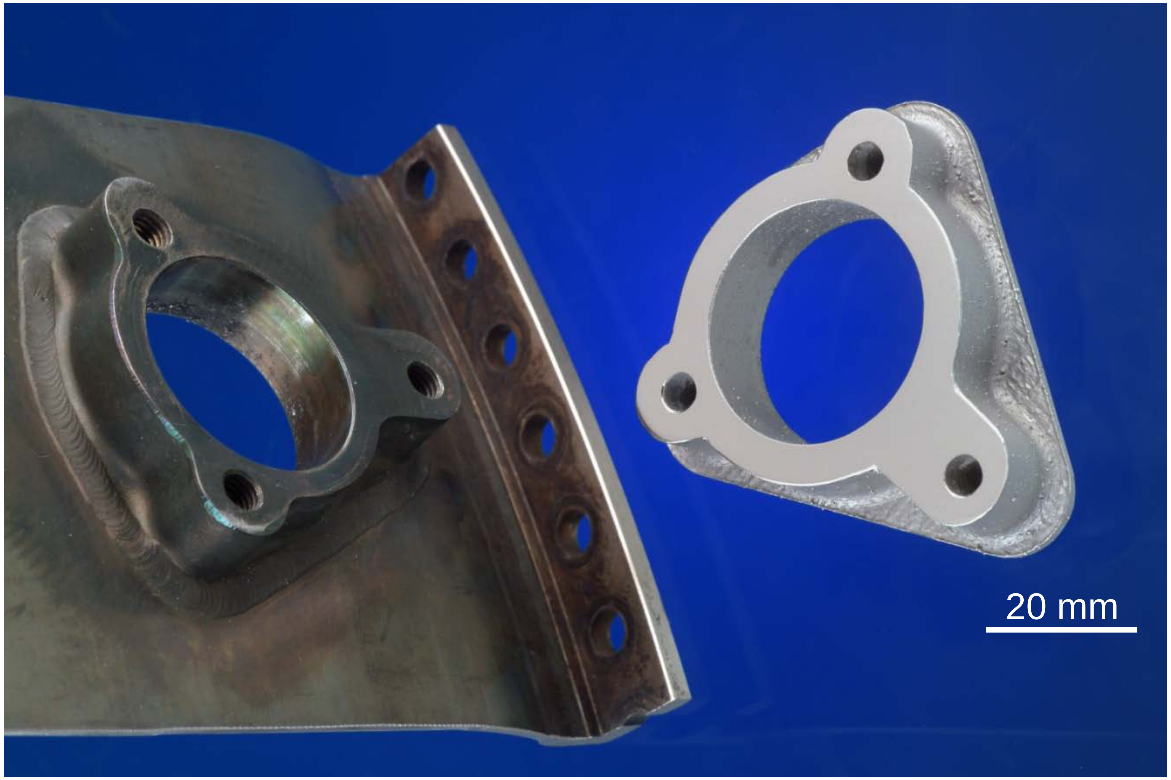
- Application: Manufacturing or repair of aero engine parts
- Photo: Cross section, slightly etched to reveal microstructure
- Almost no pores
- No bonding defects
- No cracks

Mechanical properties – Heat treated SLM Inconel 718



Repair of a casing – Boss made by SLM out of Inconel 718

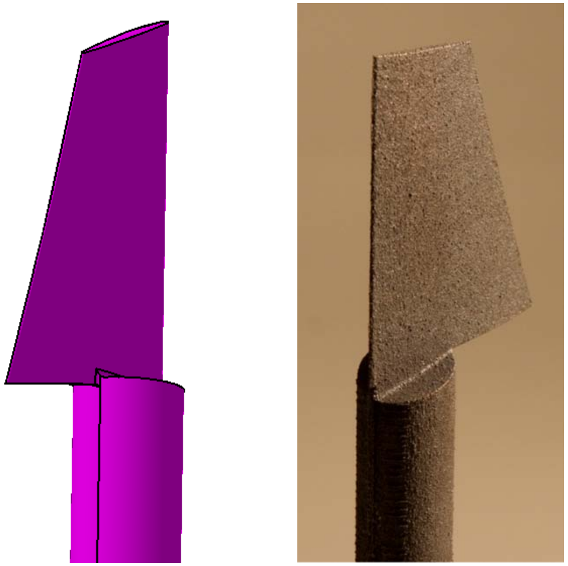
1. Worn boss is cut out
2. Replacement is manufactured by SLM
3. SLM-made boss is welded into the casing



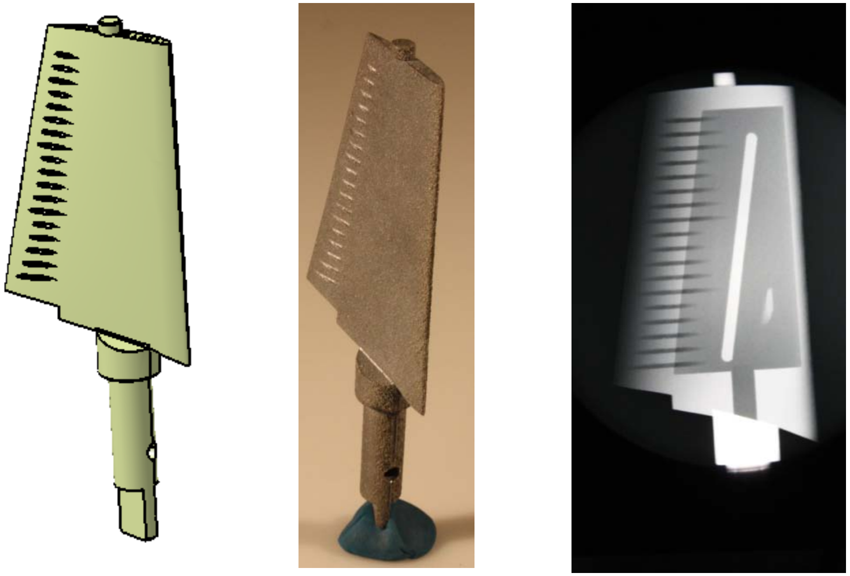
in cooperation with ITP

Inlet Guide Vanes

2 designs of Inlet Guide Vanes have been manufactured out of AlSi10Mg



Massive Inlet Guide Vane



Heated Inlet Guide Vane

Inlet Guide Vanes

SLM process applied to manufacturing of small parts gave very promising results:

- Good ability to produce complex shaped 3D geometries
- Geometrical accuracy on line with specifications
- Mechanical characteristics of AlSi10Mg obtained by SLM better than cast alloy

Summary

LMD repair chains have been developed and have demonstrated their efficiency to repair large aero engines components

- Outlet guide vanes made of In 718
- SX shrouds made of Rene N with regaining the SX structure and minimized distortion

SLM manufacturing has also been shown to be of huge interest for the manufacturing of small complex parts

- Process window and very good mechanical properties for In 718
- Manufacturing of Inlet Guide Vanes made of Al Si10Mg with high dimensional accuracy and good mechanical properties

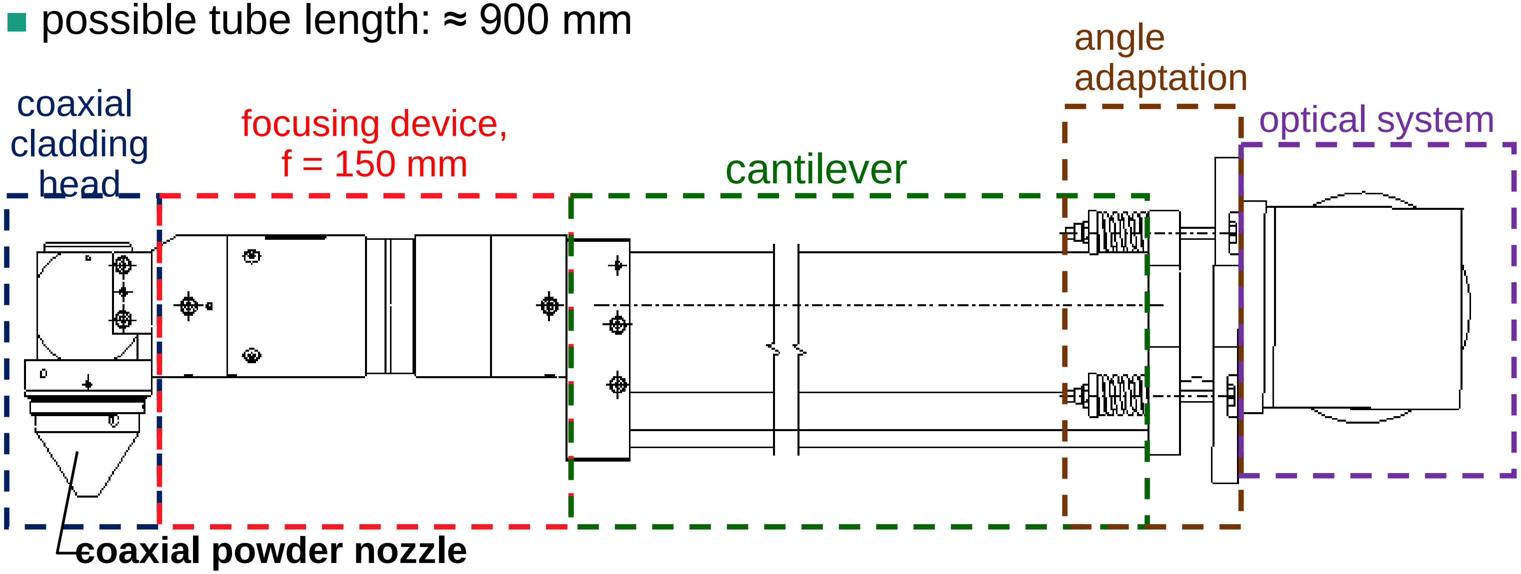
RESERVE

LMD processing head for inner contours

Scheme of the assembly

objectives:

- deposit geometry not dependent on cladding direction therefore
- coaxial powder nozzle
- minimum inner diameter to be cladded: 105 mm
- possibility to use a CCD camera for positioning and monitoring
- possible tube length: ≈ 900 mm



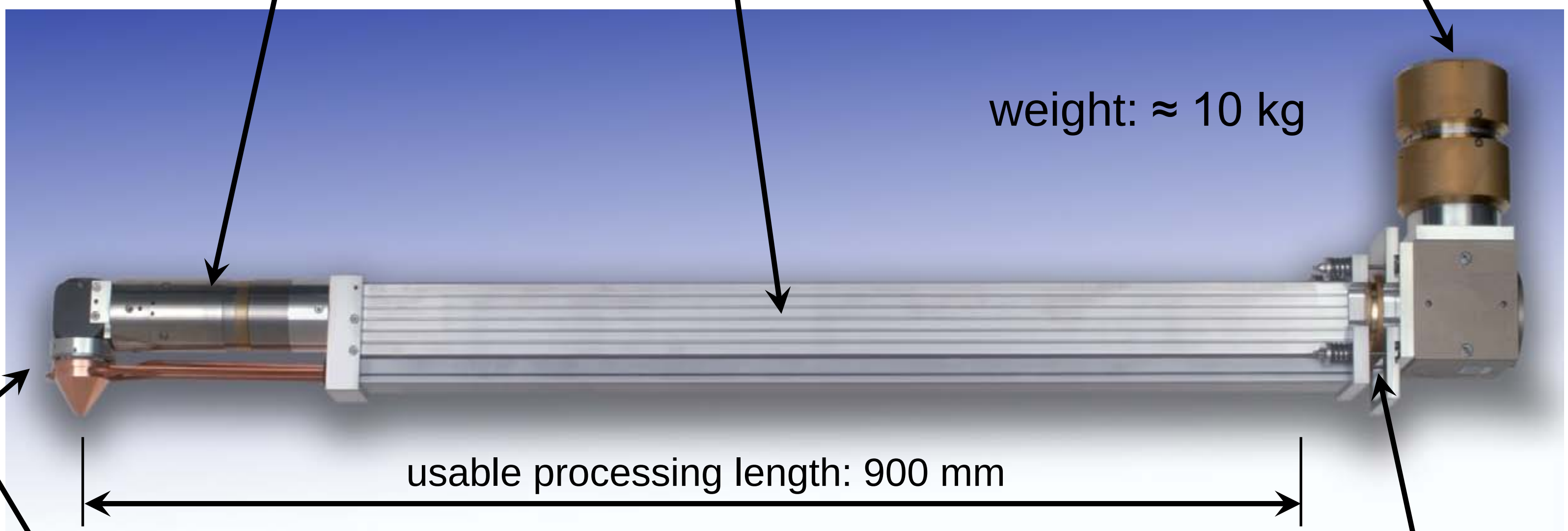
LMD processing head for inner contours

Assembled Groups

focusing device: f = 150 mm
laser beam size adjustable:
0,7 mm – 2 mm at work piece

cantilever

optical system (OS)
laser radiation: Nd:YAG ≤ 1,5 kW



coaxial cladding head
distance nozzle tip - work piece: 6 mm

angle adaptation

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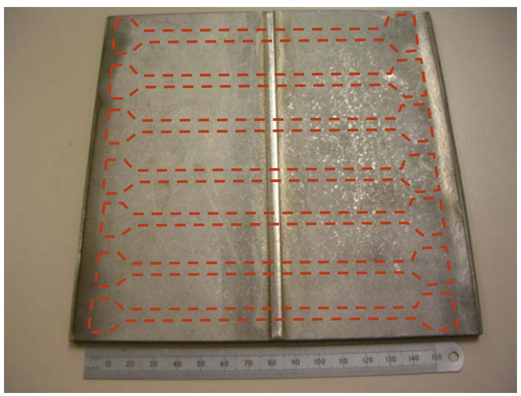
SEVENTH FRAMEWORK PROGRAMME

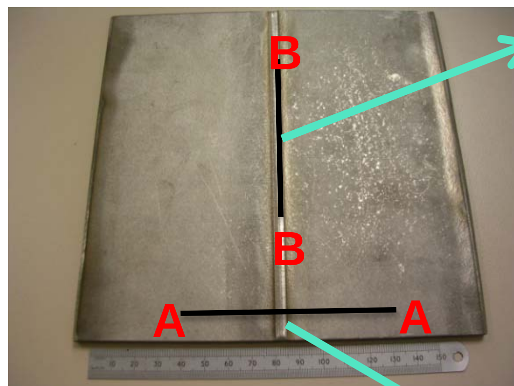
LMD processing of In718 superalloy

Preliminary Work

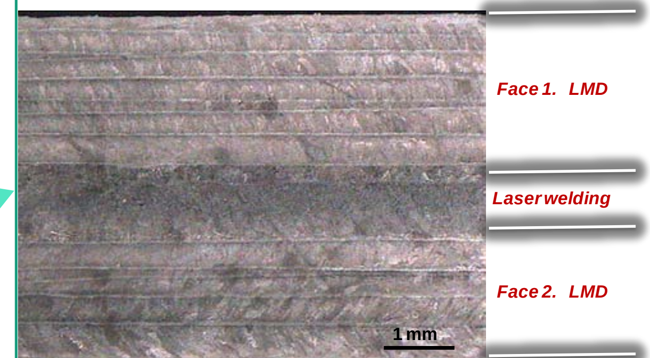
- Fabrication of samples for tensile and low cycle fatigue testing



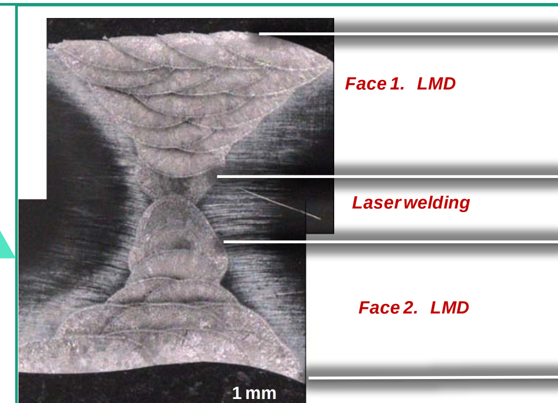
In718 test sample
Blue broken lines depicts individual LCF and/or tensile test samples



LMD cross sections



Section B – B along the LMD axis



Cross section A - A

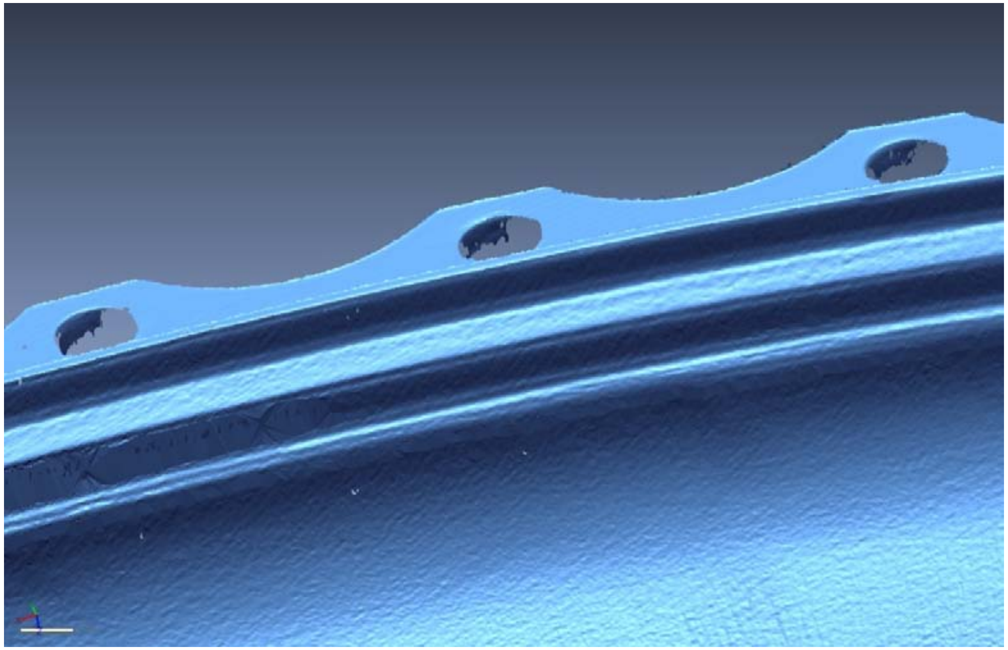
- Testing of LCF and tensile samples is ongoing

LMD repair for In718 OGV

LMD as an alternative technique

3D Digitizing:
The OGV is digitized before and after the LMD repair in order to:

- Design the NC-program for the LMD processing.
- Check the initial geometry of the OGV.
- Establish the distortion generated by the LMD process.



3D Digitizing

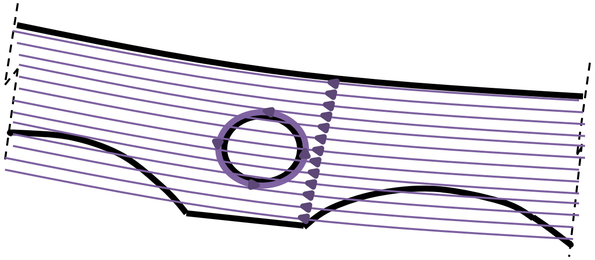
LMD repair for In718 OGV

LMD as an alternative technique

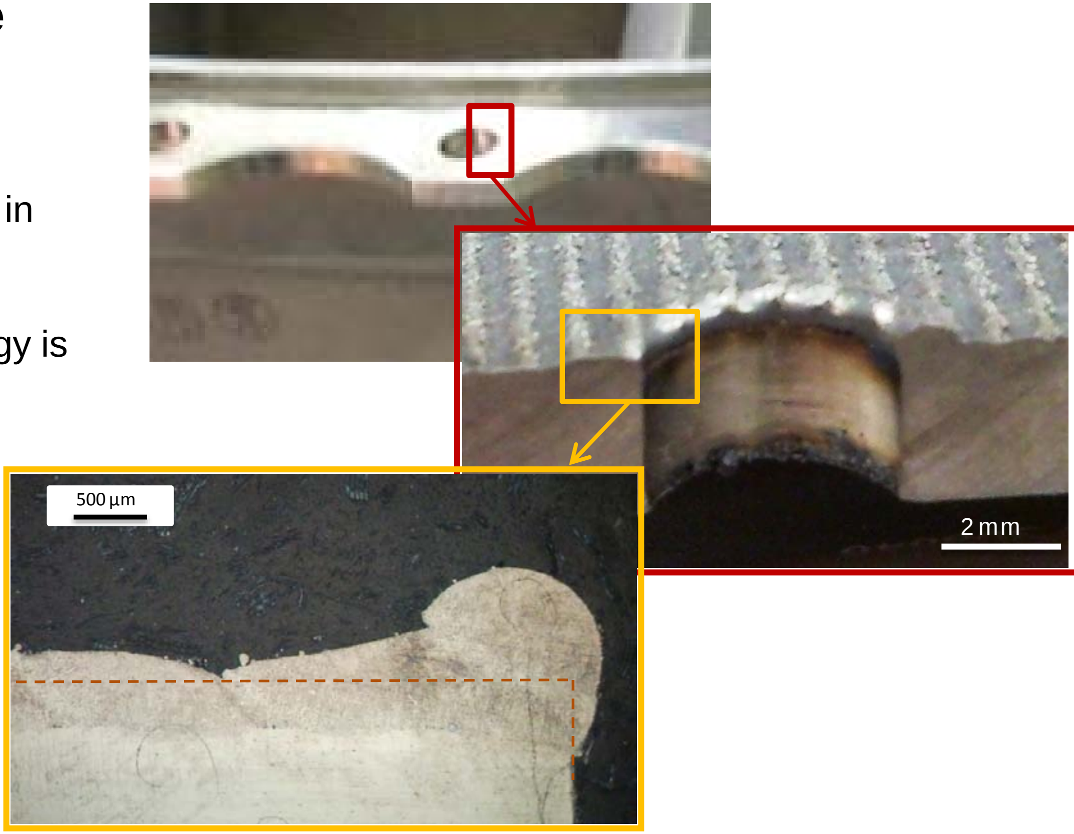
Processing difficulties:

<u>Holes:</u>

In order to ensure hole's diameter continuity in the coating and to avoid diameter increase caused by opening angle in the peripheral coating of the holes, specific NC-path strategy is designed in which a double clad around the holes is deposited before LMD on the whole surface of the flange.



NC-path strategy for LMD

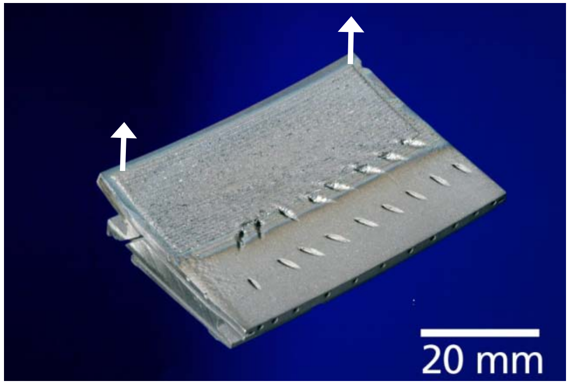


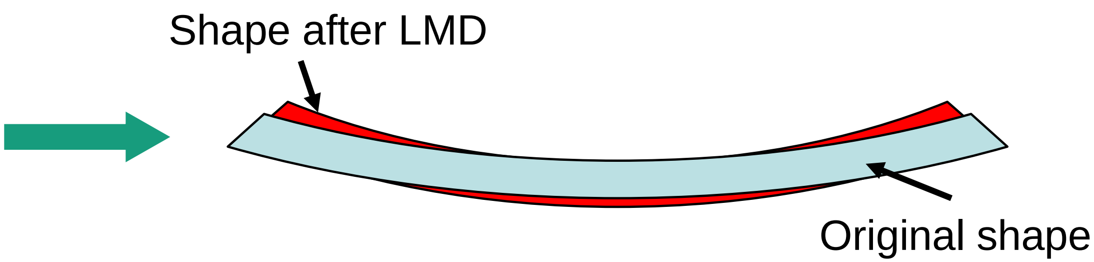
LMD around holes. Blue broken line depicts section required after machining

Distortion

Heavy distortion during cladding without cooling due to:

- small thickness (2 - 3 mm) of the shroud
- complete cladding of the shroud

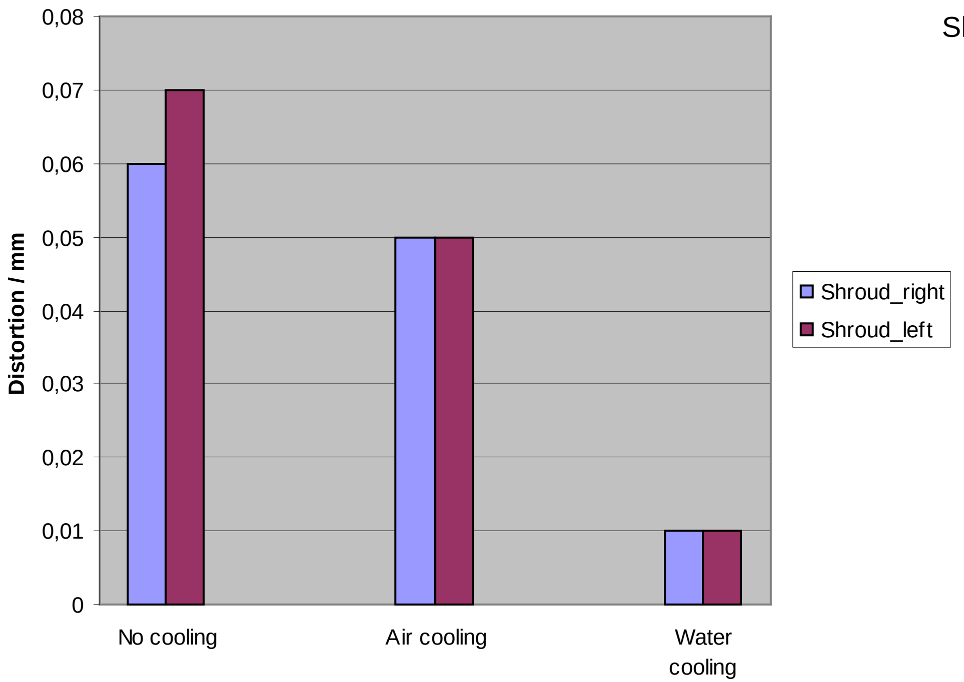


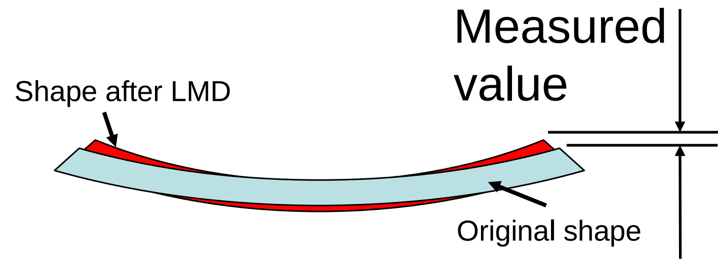


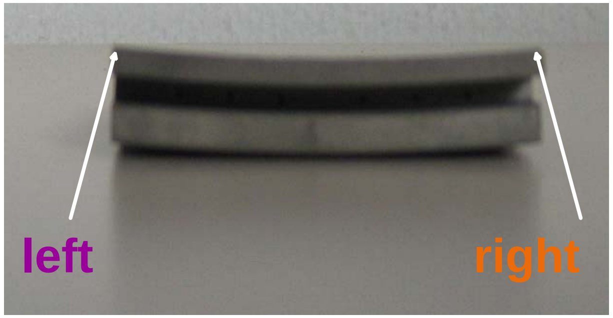
Solution: Active cooling in a water quench during LMD

Distortion

Distortion measurement







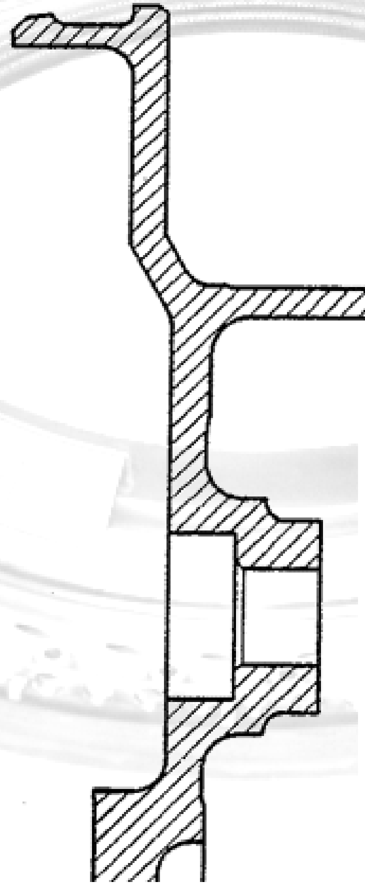
Distortion can be minimized below 0.01 mm

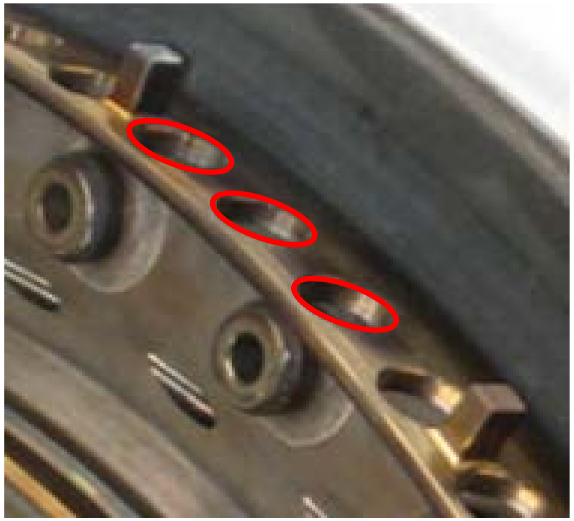
LMD: Nozzle Inner Air Seal (Sulzer Innotec, SR Technics)

- **Task:**

  Weld repair on inner diameter of up to 96 holes
- **Material**: IN718 / IN718
- **Challenge:**
  - Distortion
  - Accessibility
  - Weld geometry
  - Weld quality
- **STATUS:**

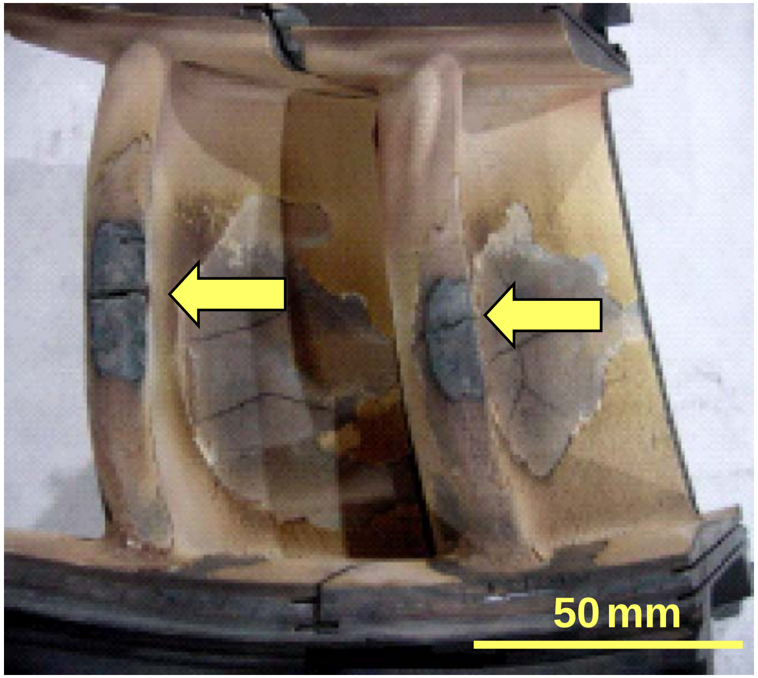
  Process qualified, transfer into commercial solution in progress





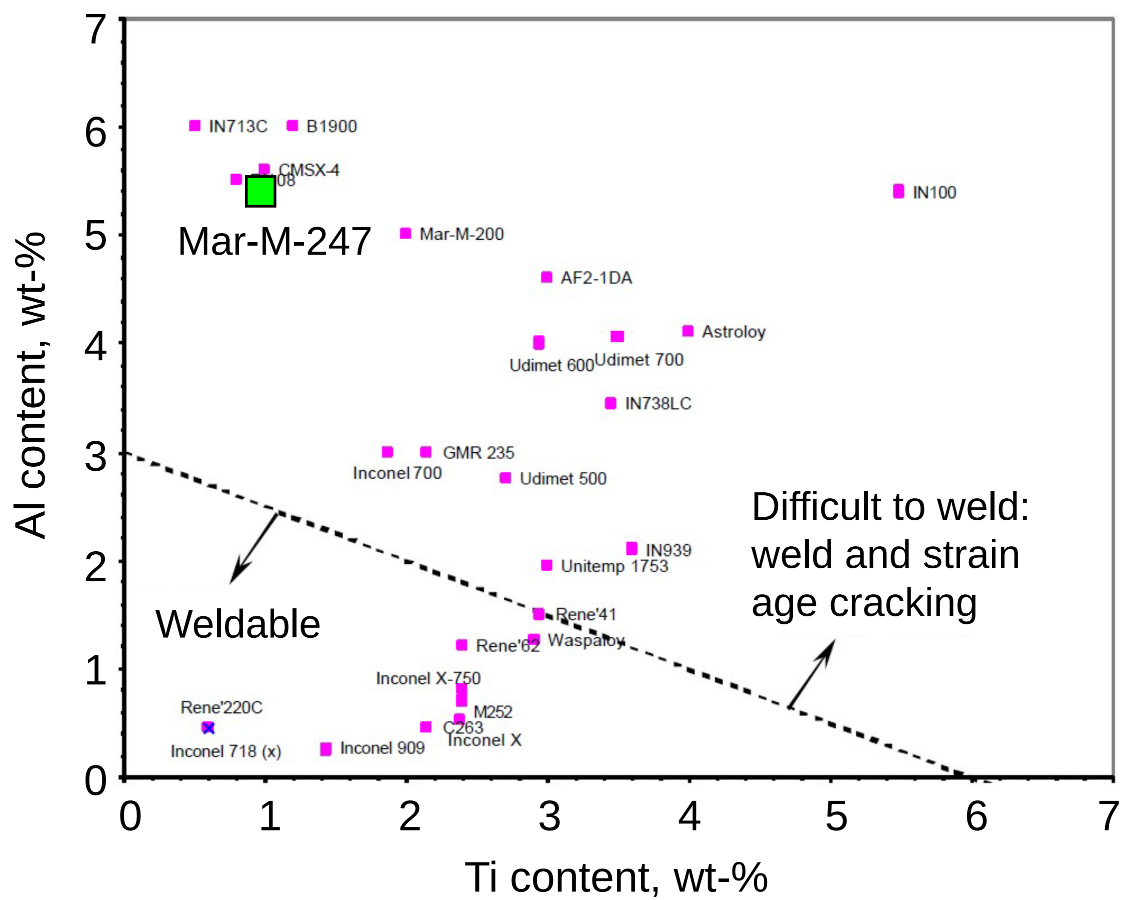
Process development SLM for Mar-M-247 alloy

- Application: Repair of high pressure turbine vanes
- Mar-M-247:
  - Nickel-base alloy
  - Used for very high temperature applications (up to 1040°C)



Challenge: Mar-M-247 is susceptible to crack formation

- Mar-M-247 is very difficult to weld
- High Al and Ti content ⇒material is prone to hot cracking
- Extensive cracking occurs during SLM



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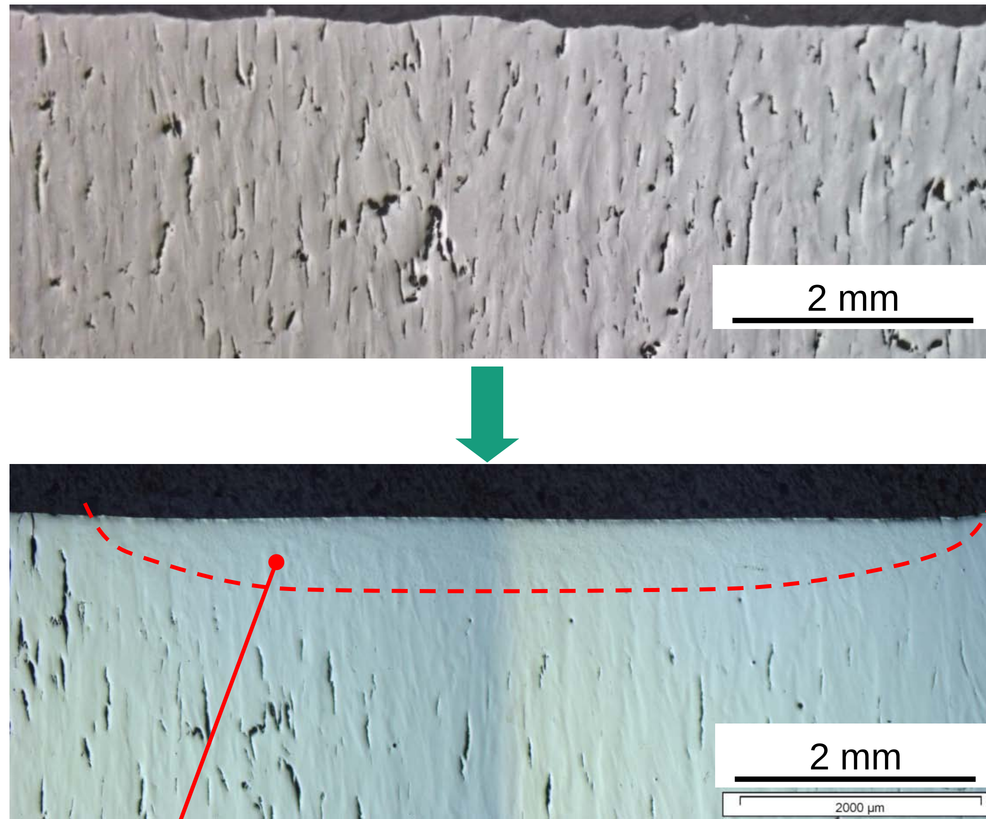
SEVENTH FRAMEWORK PROGRAMME

High temperature preheating to avoid crack formation

- Large number of cracks when using standard SLM-parameters (scanning speed 200 mm/s, cross section upper figure)
- Formation of cracks can be avoided by preheating the material to 1150°C before laser melting
- Demonstrated by laser-remelting of the surface of an SLM-specimen (cross section lower figure)

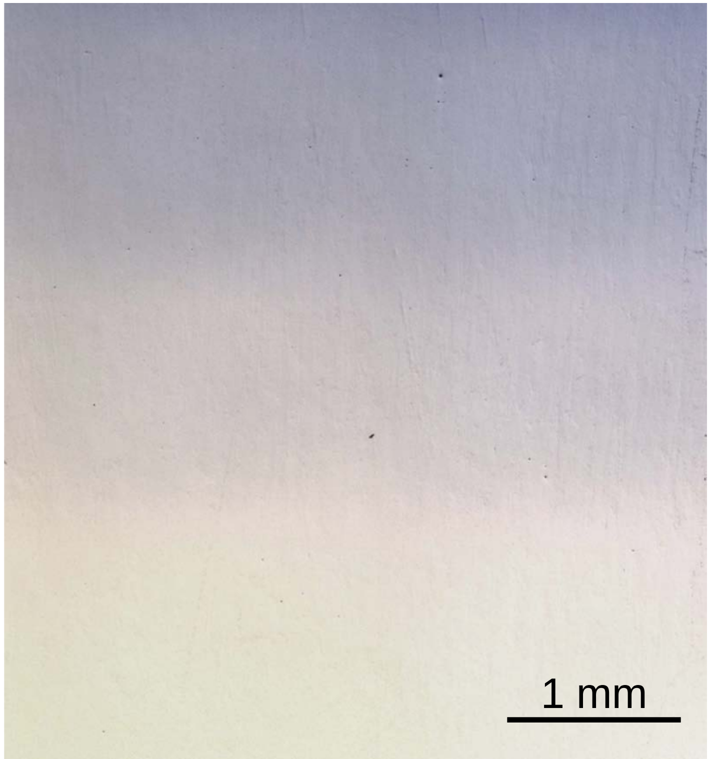


Material laser-remelted at 1150°C (Mar-M-247)

EU-FP6 FANTASIA
Fraunhofer ILT

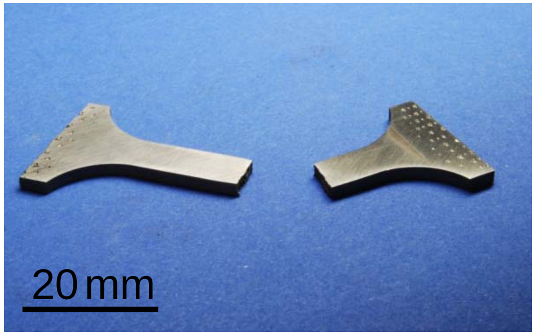
Hot isostatic pressing to eliminate cracks – Mar-M-247

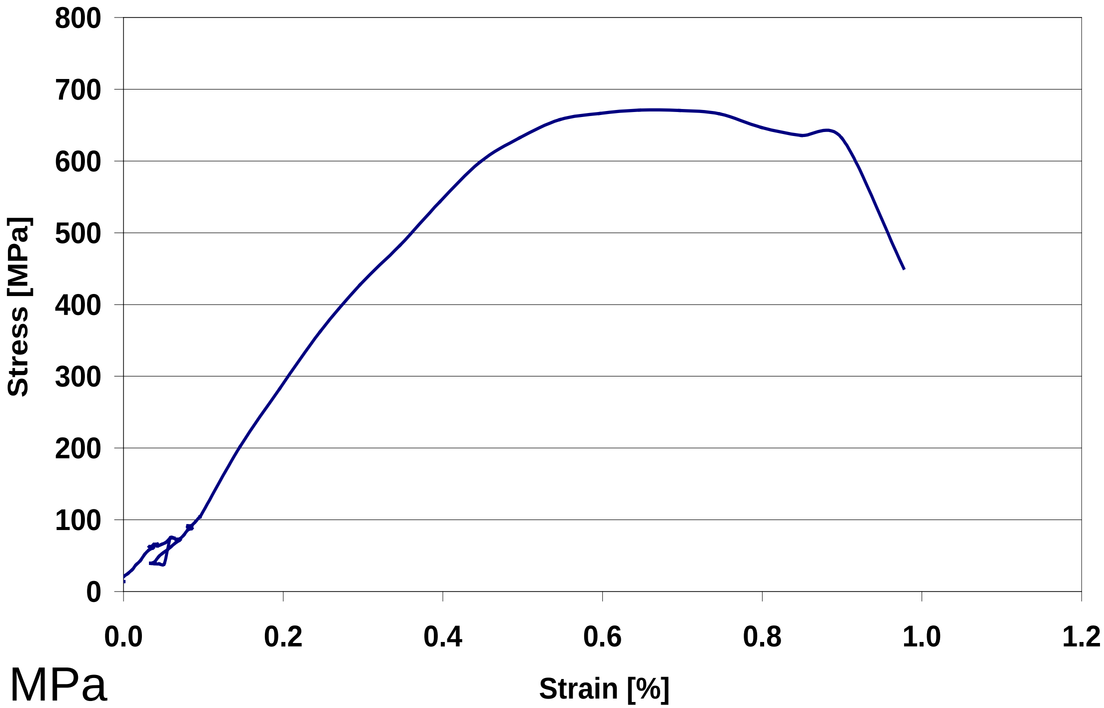
- When surface is sealed, cracks can be eliminated by HIP
- Processing steps currently used:
  1. Laser-remelting of the whole surface at 1150°C preheating temp
  2. HIP
- This way virtually crack-free parts have been made by SLM out of Mar-M-247



Hot isostatically pressed SLM-specimen (cross section)

Tensile strength of SLM-specimen after HIP – Mar-M-247





- Yield strength (0.2 %): 671 MPa
- No post heat-treatment
- Cast Mar-M-247 for comparison: 827 MPa including post heat-treatment

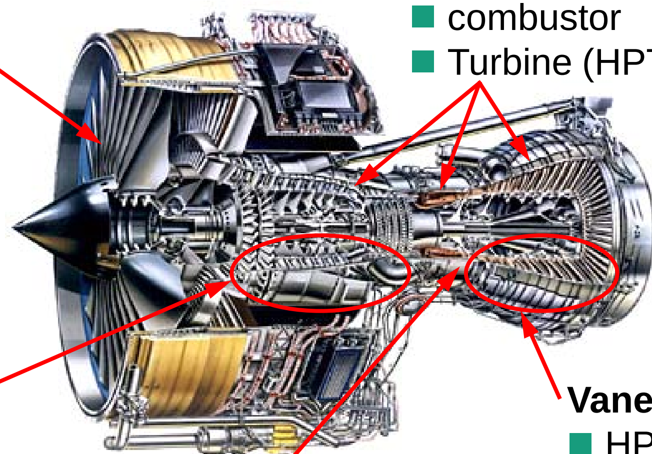
Parts under investigation

Fan blades

100 mm

BLISKs
- LPC BLISKs
- HPC BLISKs

150 mm

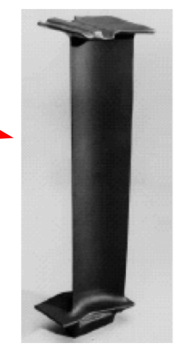


Casings and structural parts
- compressor (LPC, HPC)
- combustor
- Turbine (HPT, LPT)

200 mm

80 mm

Vanes and blades
- HPT vanes
- LPT blades



20 mm

Small Inconel parts

75 mm

Centrifugal compressors

50 mm