Academia-Industry Matching Event on High Energy Lasers

Innovative Load-bearing Structures for Aerospace Applications by Laser Processing

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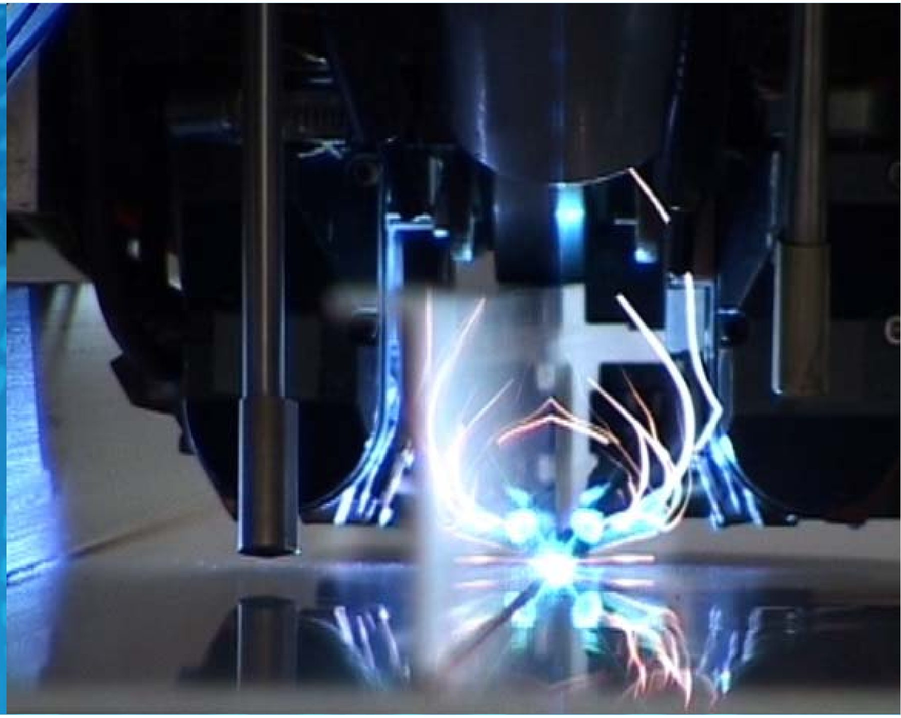
Institute of Materials Research
Materials Mechanics
Department Joining and Assessment (WMF)

November, the 13th 2014 / DESY in Hamburg



ACE | Light-weight Materials Assessment, Computing and Engineering Centre

Helmholtz-Zentrum Geesthacht
Zentrum für Material- und Küstenforschung

Outline

- Strategy for the development of load-bearing structures
- LBW of lightweight integral structures
  - LBW of fuselage structures
  - Hybrid Ti-CFRP-structures
  - Tailored Ti-Structures
- Laser modification processes
  - Laser Heating
  - Laser Shock Peening
- Outlook

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Strategy for the development of load-bearing structures

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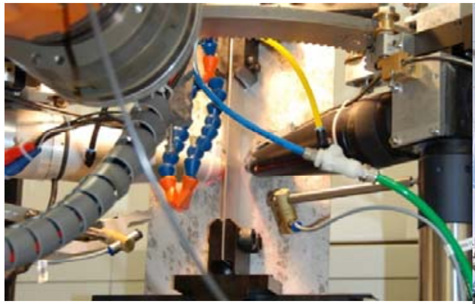

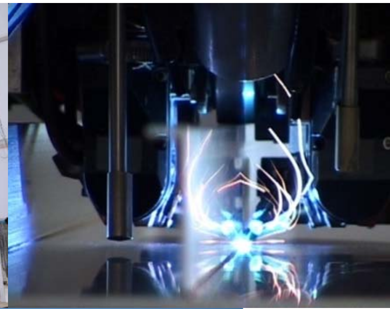
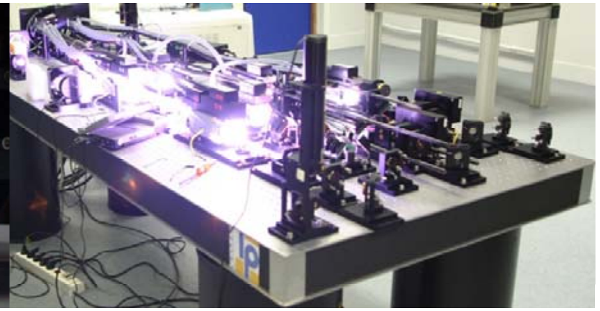

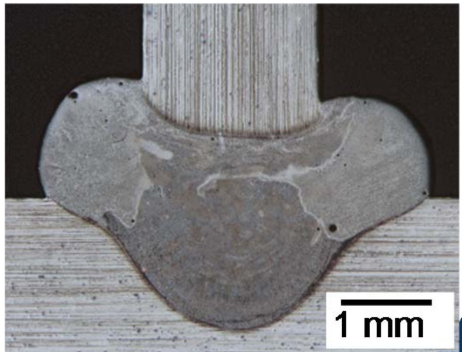

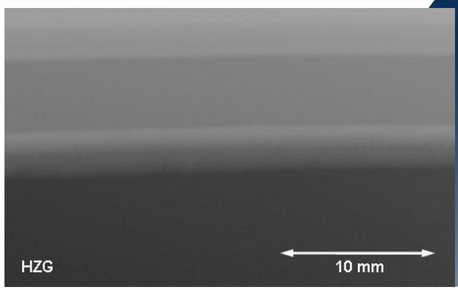

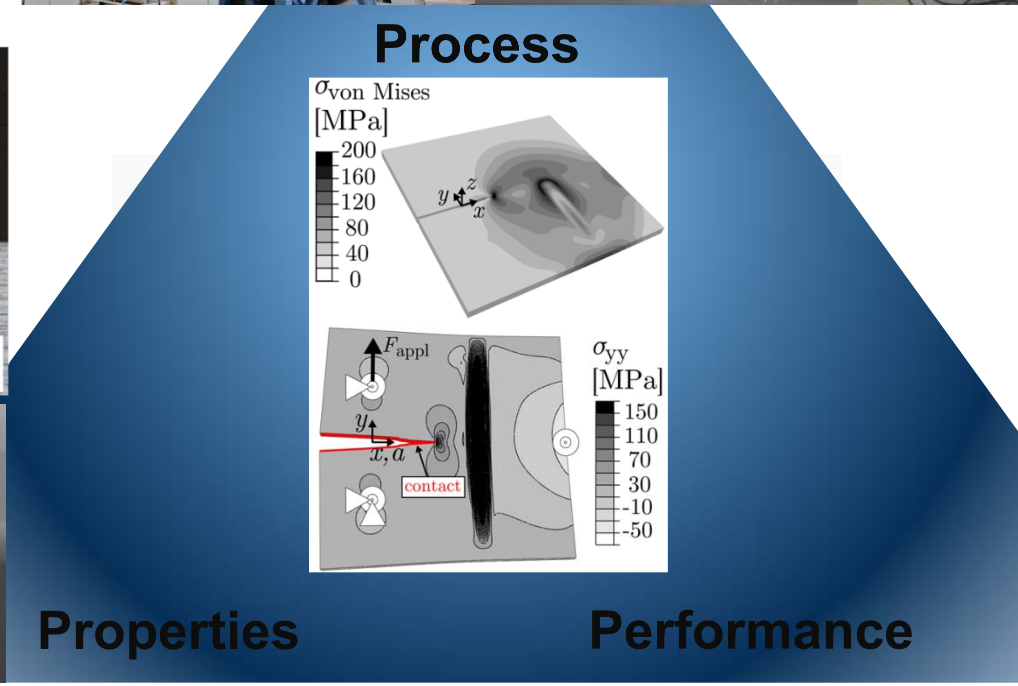

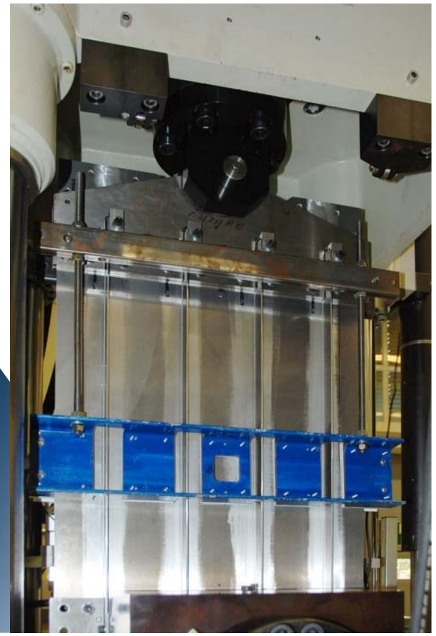

Joining and Assessment: → Development of laser joining and laser modification processes

→ Conception and realization of lightweight demonstrators

→ Test and assessment of damage tolerance behaviour

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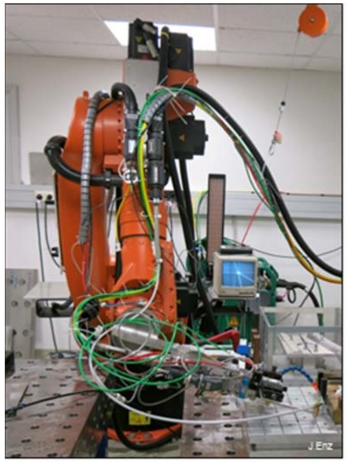
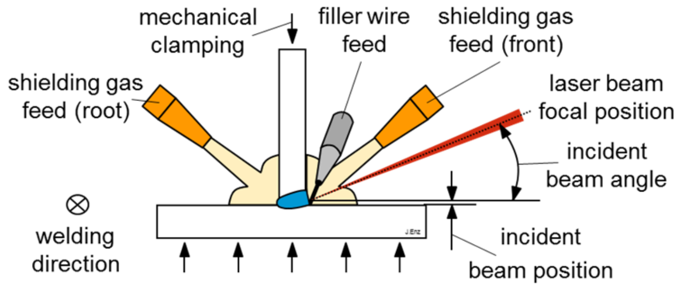
Laser beam welding of fuselage structures



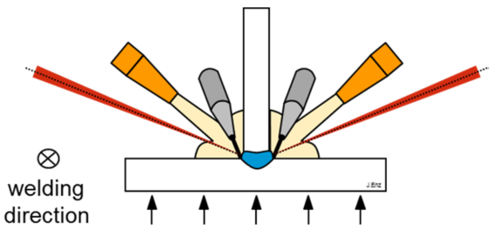
Small Scale Laser Facility

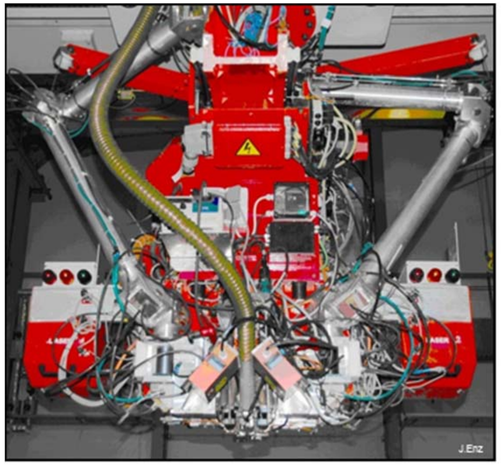
8.0 kW fibre laser, industrial robot



Large Scale Laser Facility

2 x 3.5 kW CO_2 laser,
movable portal and processing head

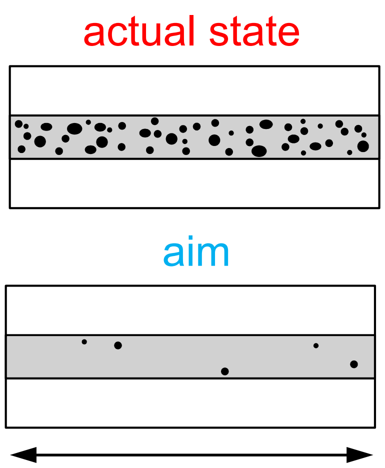




LBW of high strength Al-alloys

J. Enz: HZG-Presentation, 2013

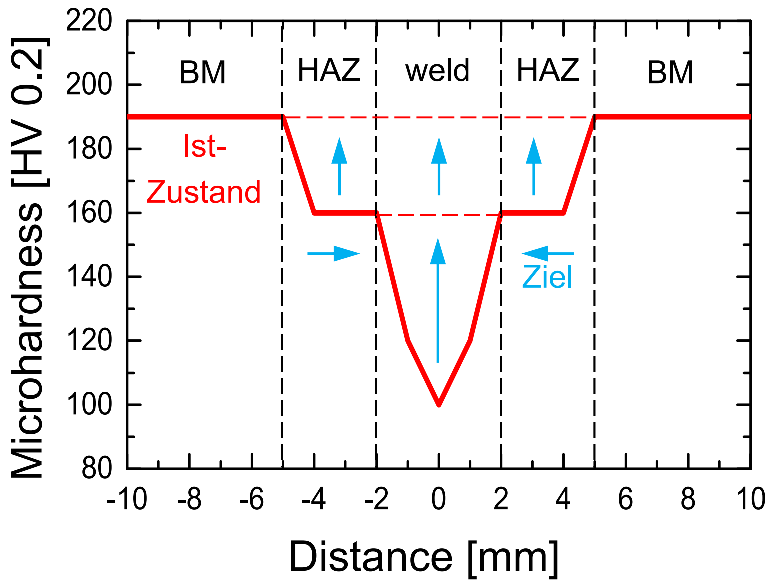
Reduction of porosity



$$\frac{N_{pores}}{L} \rightarrow 0$$

Weldability

Microhardness



Formability

Partial stress release

Stress Corrosion Cracking

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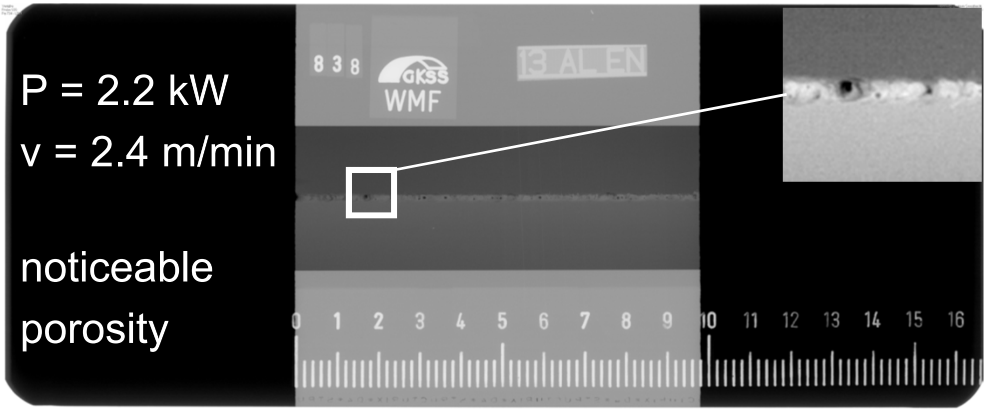
LBW of high strength Al-alloys

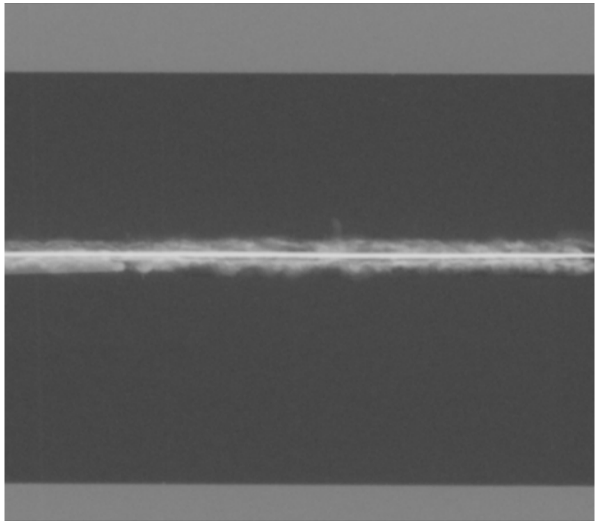
S. Riekehr et al.: European Patent N. EP12162865.5-2302

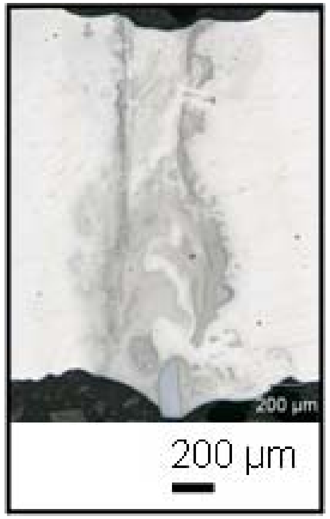
Solution:
Feeding the filler wire and optimisation of the process parameters



Optimized laser welding process: butt joint without defects

Nd:YAG-Laser
P = 2.0 kW
v = 3.5 m/min





- **Welded butt joint without significant defects**
- **Aim of the future research is the transfer of the obtained results to overlap joints and filled welds; Transfer of the obtained results to Al alloys from the AA7XXX family, e. g. AA7075**

Process transfer for high strength Al-alloys of 7XXX-family

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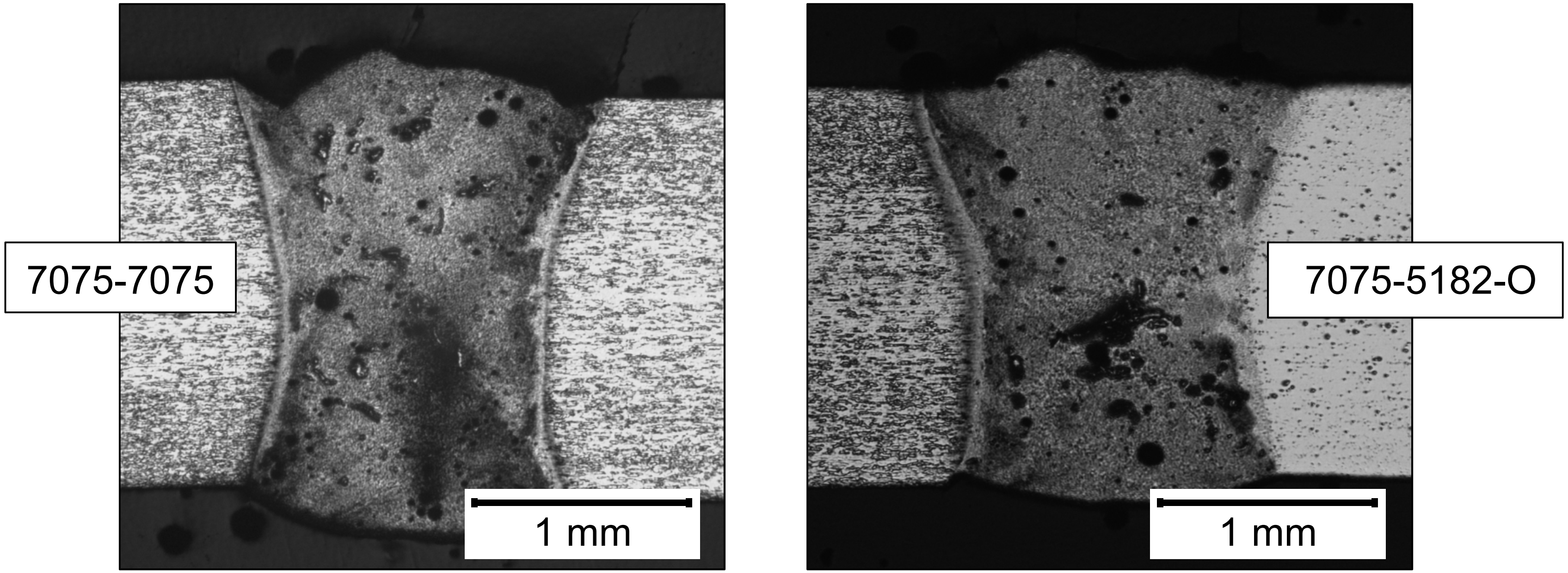
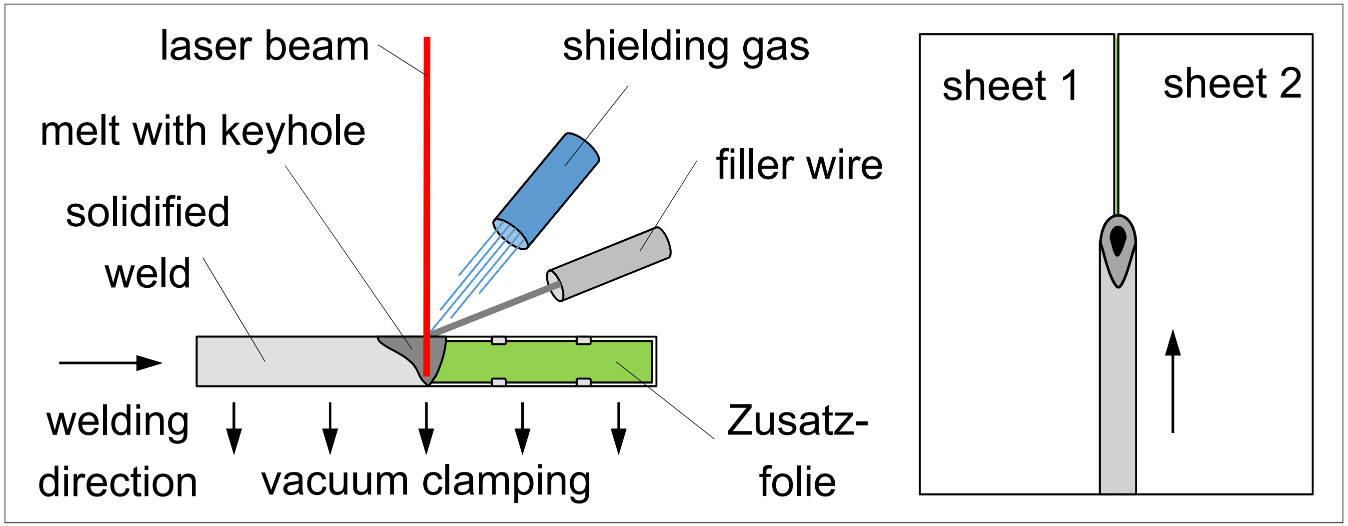
J. Enz et al.: Procedia CIRP 18(2014) 203-208, Procedia Mater. Science 3(2014) 1828-1833





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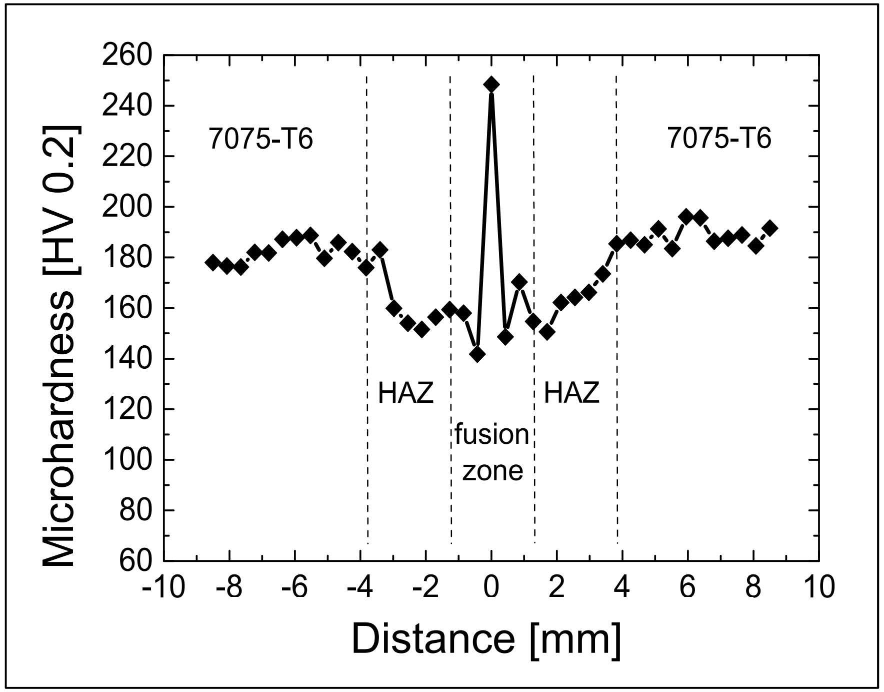
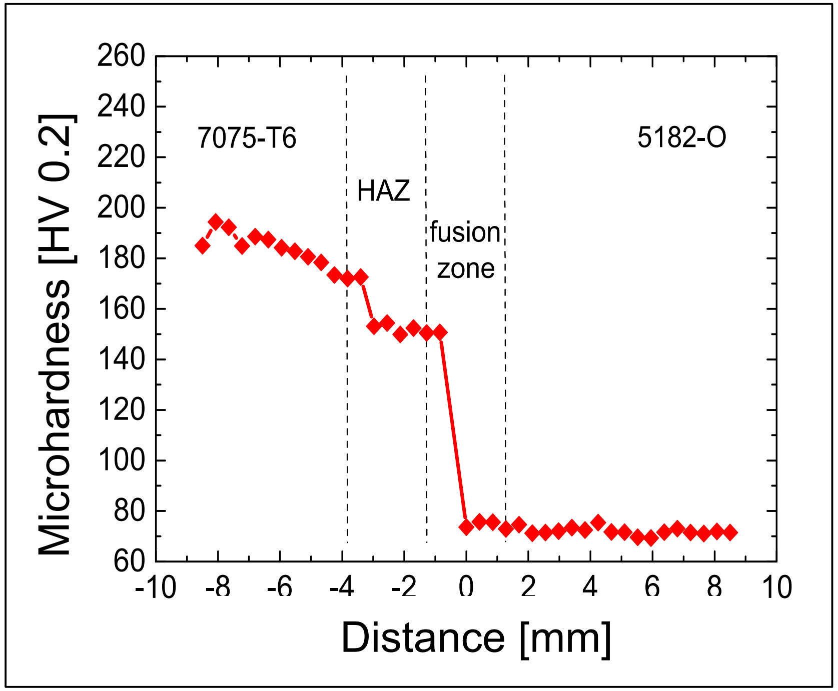
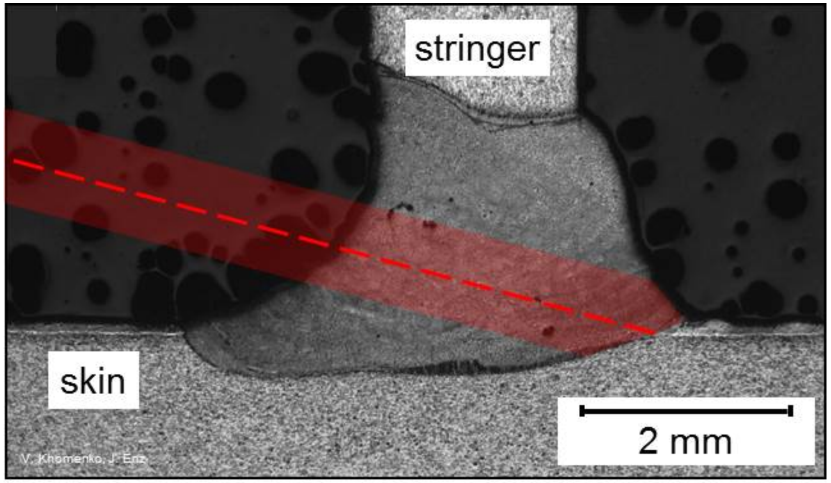
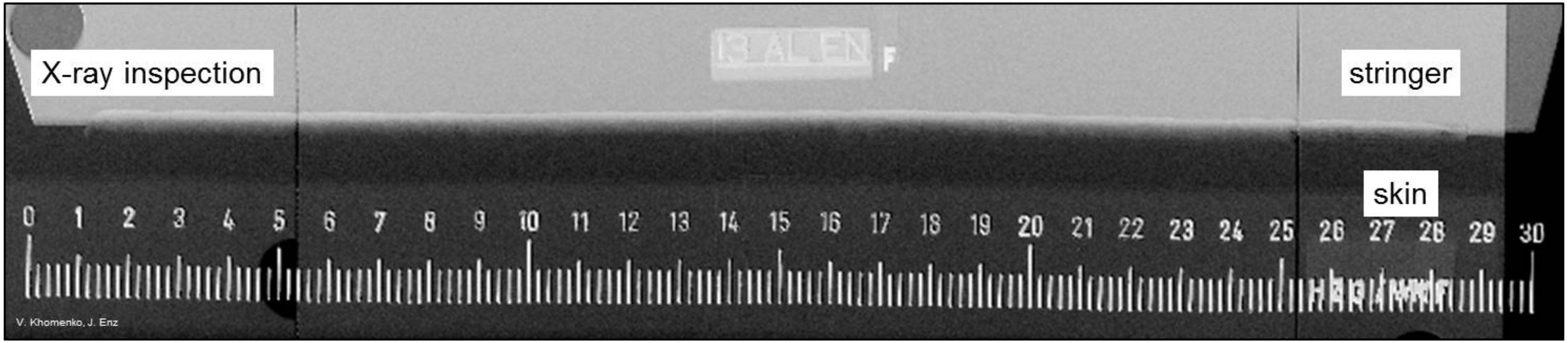




Single-sided laser beam welding



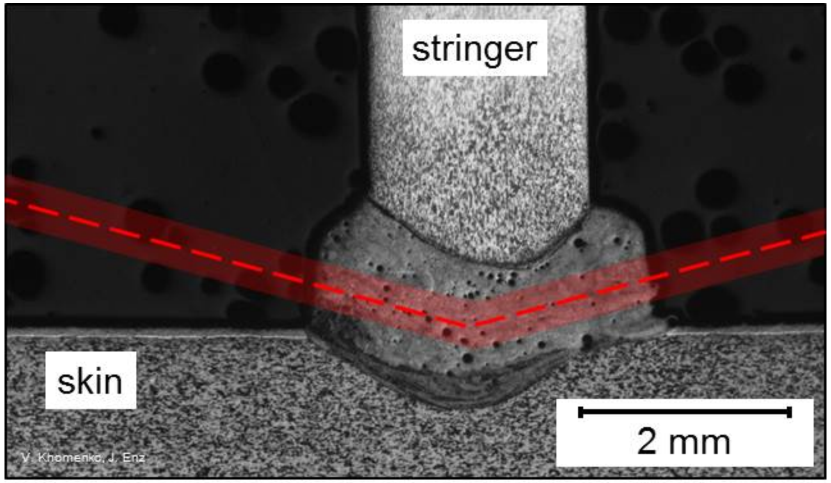
- laser beam welded T-joint with:
  - 2024-T3 stringer
  - 7050-T73 skin
  - 4047 filler wire
- welded only from one side
- with an 8.0 kW fibre laser, 6.0 m/min welding speed



- no porosity along the weld length
- low penetration into skin material → reduced weakening
- improved weld symmetry in comparison to conventional single-sided weldments
- low manufacturing effort

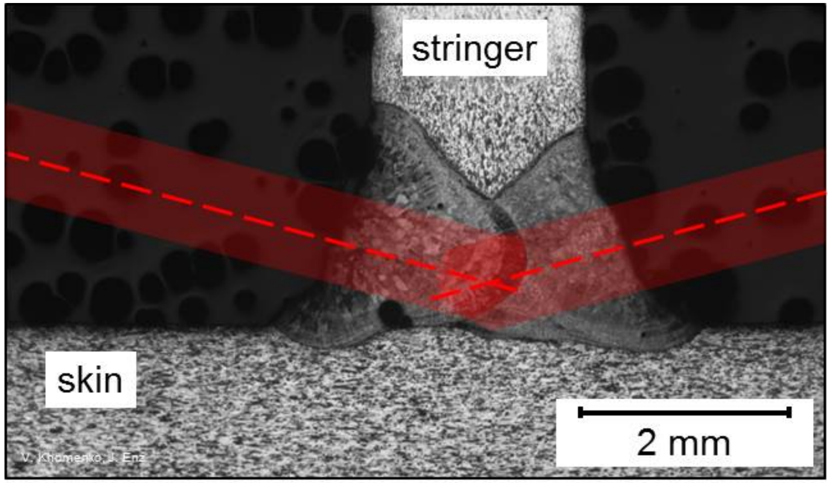
[Source: V. Khomenko, Laser Beam Welding of Dissimilar AA2024/AA7050 T-Joint, Master Thesis, 2014]

Double-sided laser beam welding



- welded simultaneously from both sides
- with two 3.5kW CO_2 laser

- high symmetry and small weld dimensions
- often residual porosity
- higher penetration into skin material → increased weakening



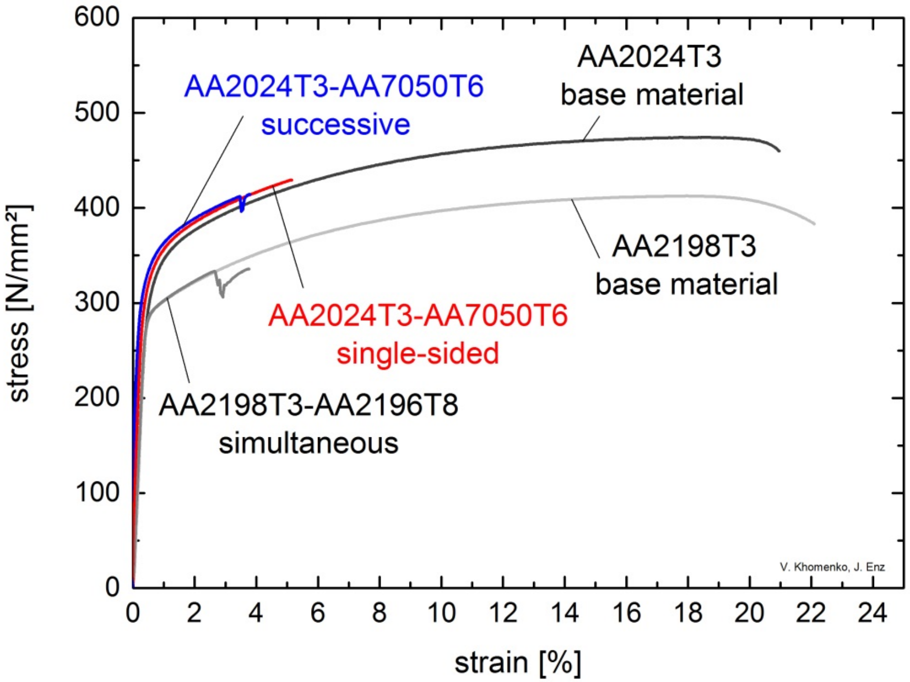
- welded successive from both sides
- with an 8.0 kW fibre laser

- high symmetry
- low penetration into skin material → reduced weakening
- higher heat input into material → increased weakening
- high manufacturing effort

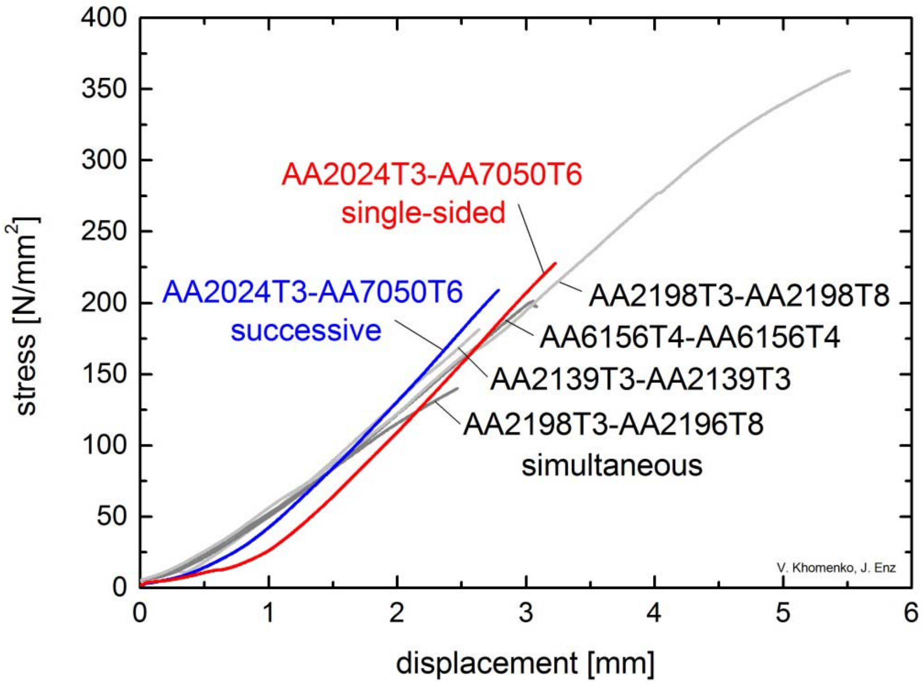
[Source: V. Khomenko, Laser Beam Welding of Dissimilar AA2024/AA7050 T-Joint, Master Thesis, 2014]

Mechanical Properties

Hoop-Stress Testing



Pull-Out Testing



- Comparable or even improved mechanical properties for the single-sided welding in comparison to successive and simultaneous welding

[Source: J. Enz, Laser Beam Welding of High-Strength Aluminium-Lithium Alloys, Diploma Thesis, 2012; V. Khomenko, Laser Beam Welding of Dissimilar AA2024/AA7050 T-Joint, Master Thesis, 2014]

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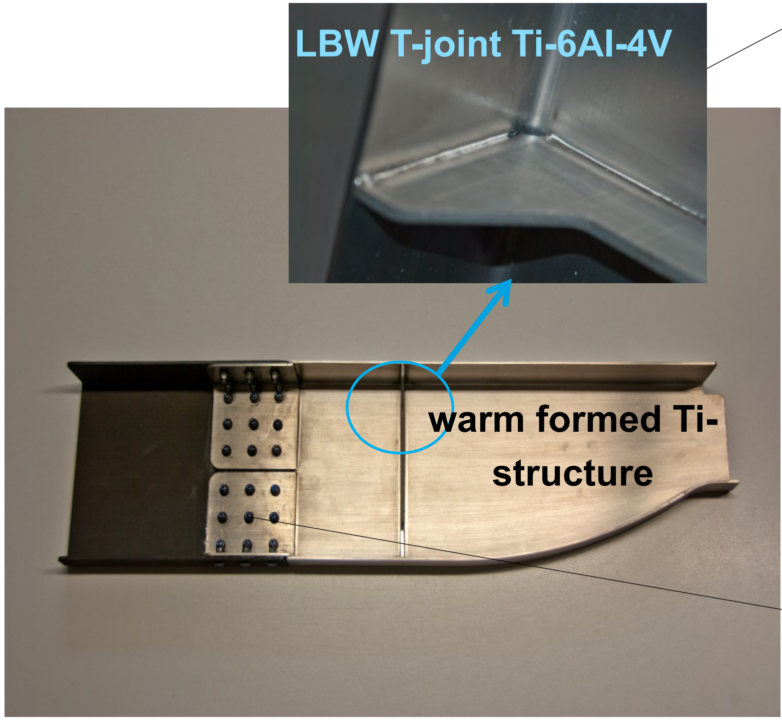
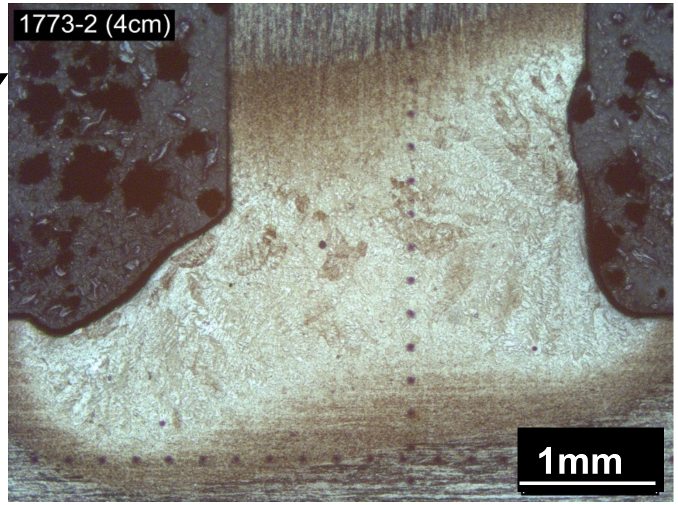
Innovative laser joining concept for fuselage CFRP and Ti structures

N. Kashaev et al.: Greener Aviation 2014, Brussels



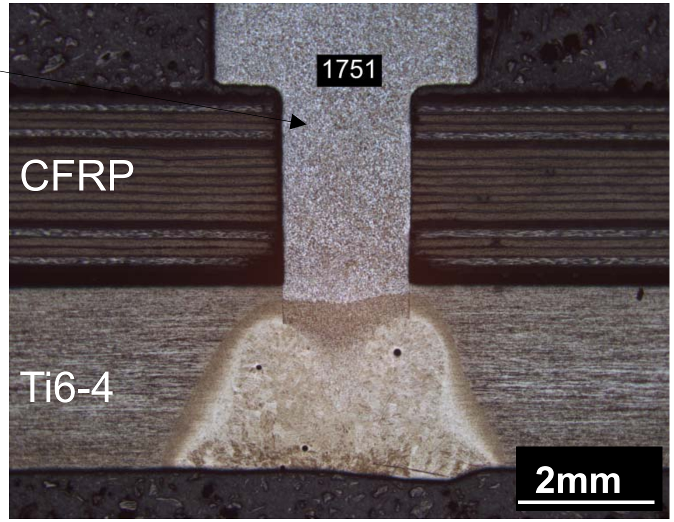
Project OPTiSTRUCT

Laser welding of Ti-6Al-4V, T-joint



P = 2500 W
v = 0.025 m/s
without filler wire
angle of beam incidence: 20 °

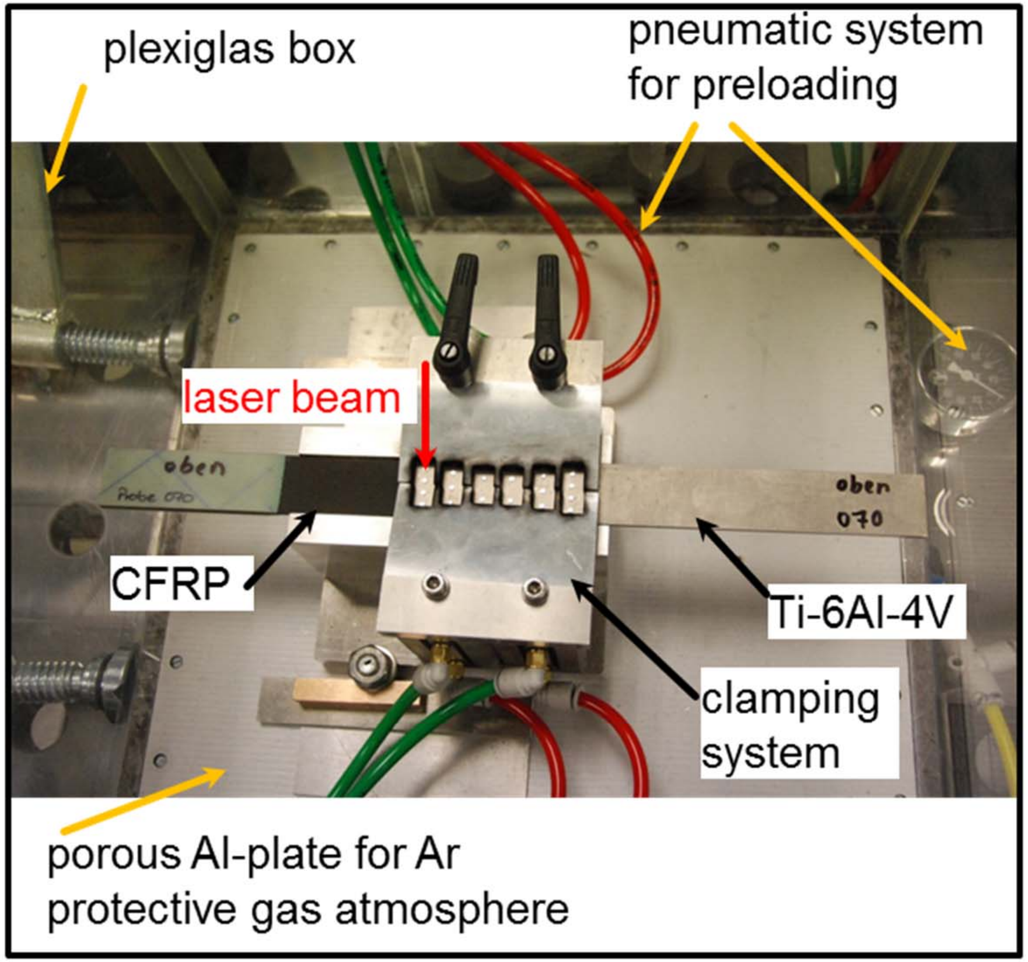
Laser riveting of Ti-6Al-4 mit CFRP

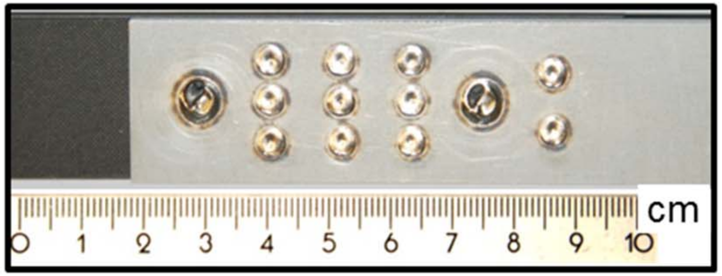


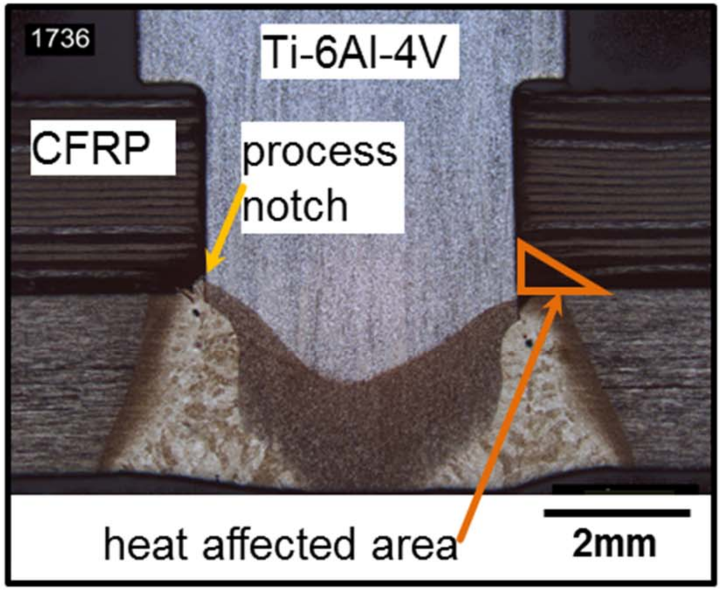
P = 1800 W
Programmed spot diameter = 2 mm
v = 0.025 m/s
Time for 1 spot = 0.25 s

Laser riveting of Ti-CFRP structures

Kolossa et. al.: European Patent N. EP12180617.8.







Laser riveting of Ti and CFRP.
Tensile test results

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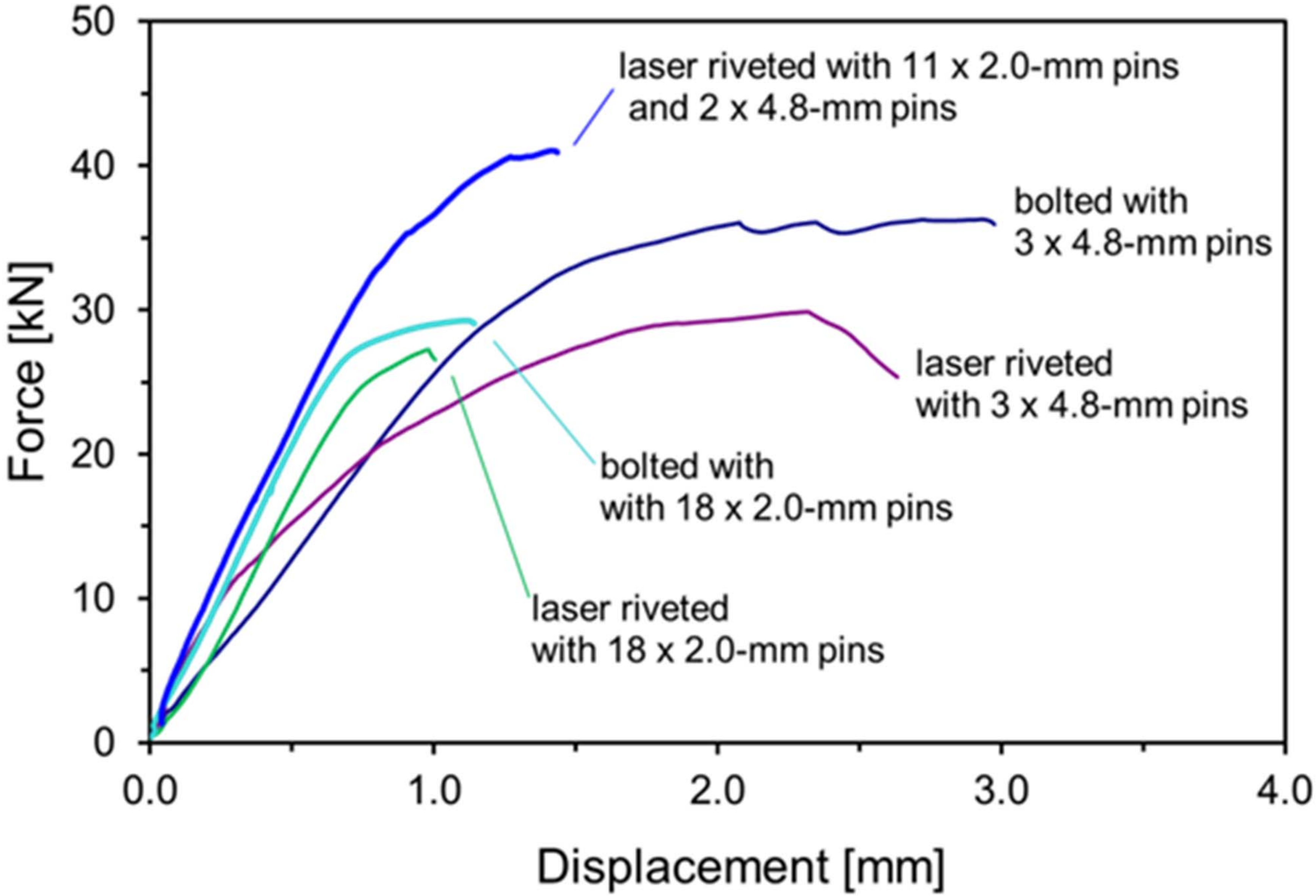

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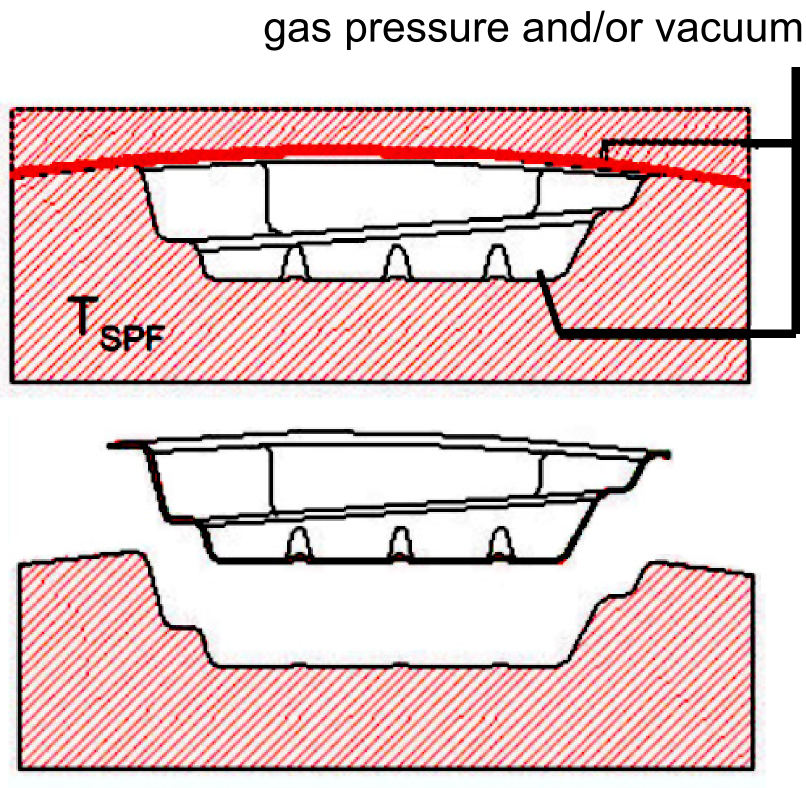
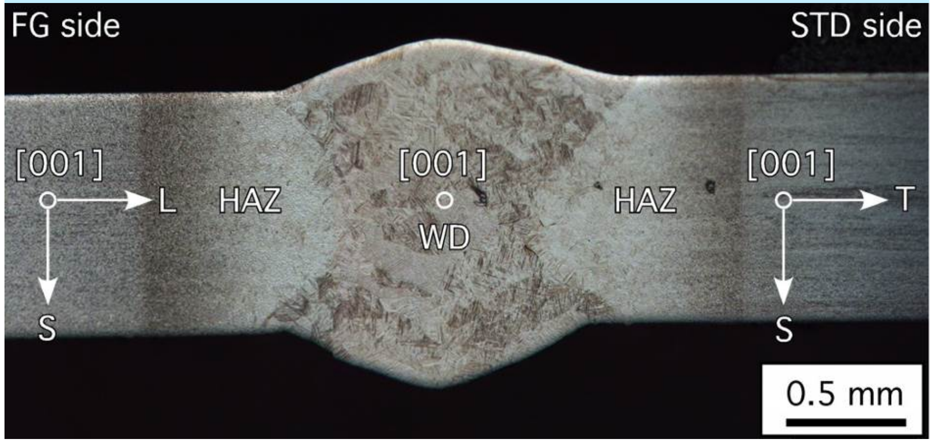
Tailored Ti-6Al-4V-structures through SPF

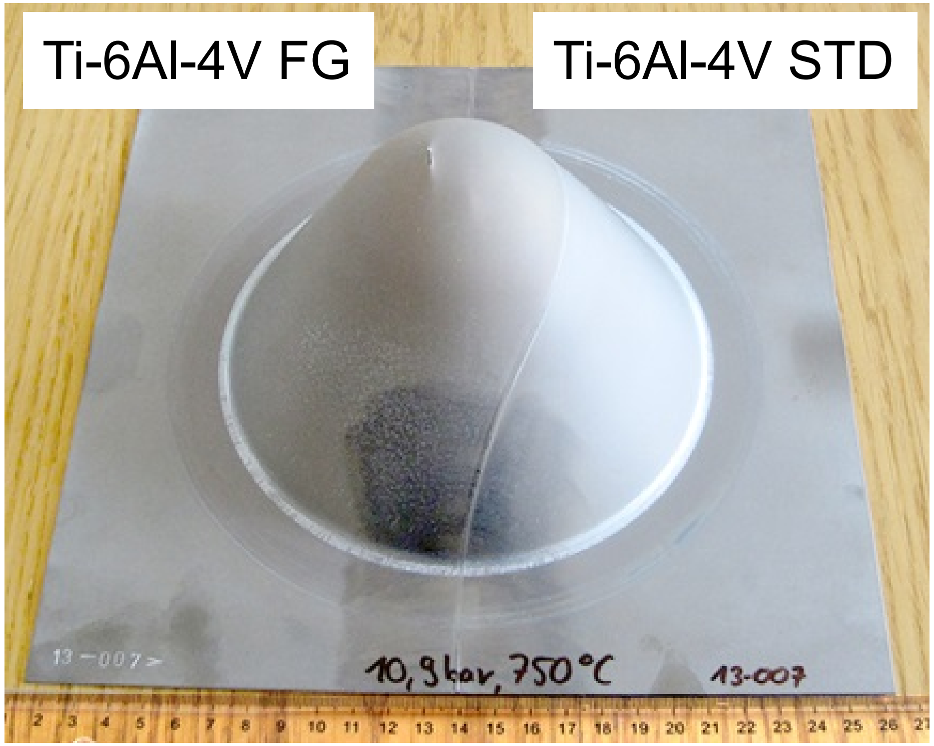
LuFo IV-3 Project „CoolTiTech“
Partner: FormTech GmbH (Coordinator), Helmholtz-Zentrum Geesthacht, Heggemann AG, Access e.V.



W. Beck: Materials Science Forum 447-448 (2004) 145-152

Kashaev et. al.: AEM 2014





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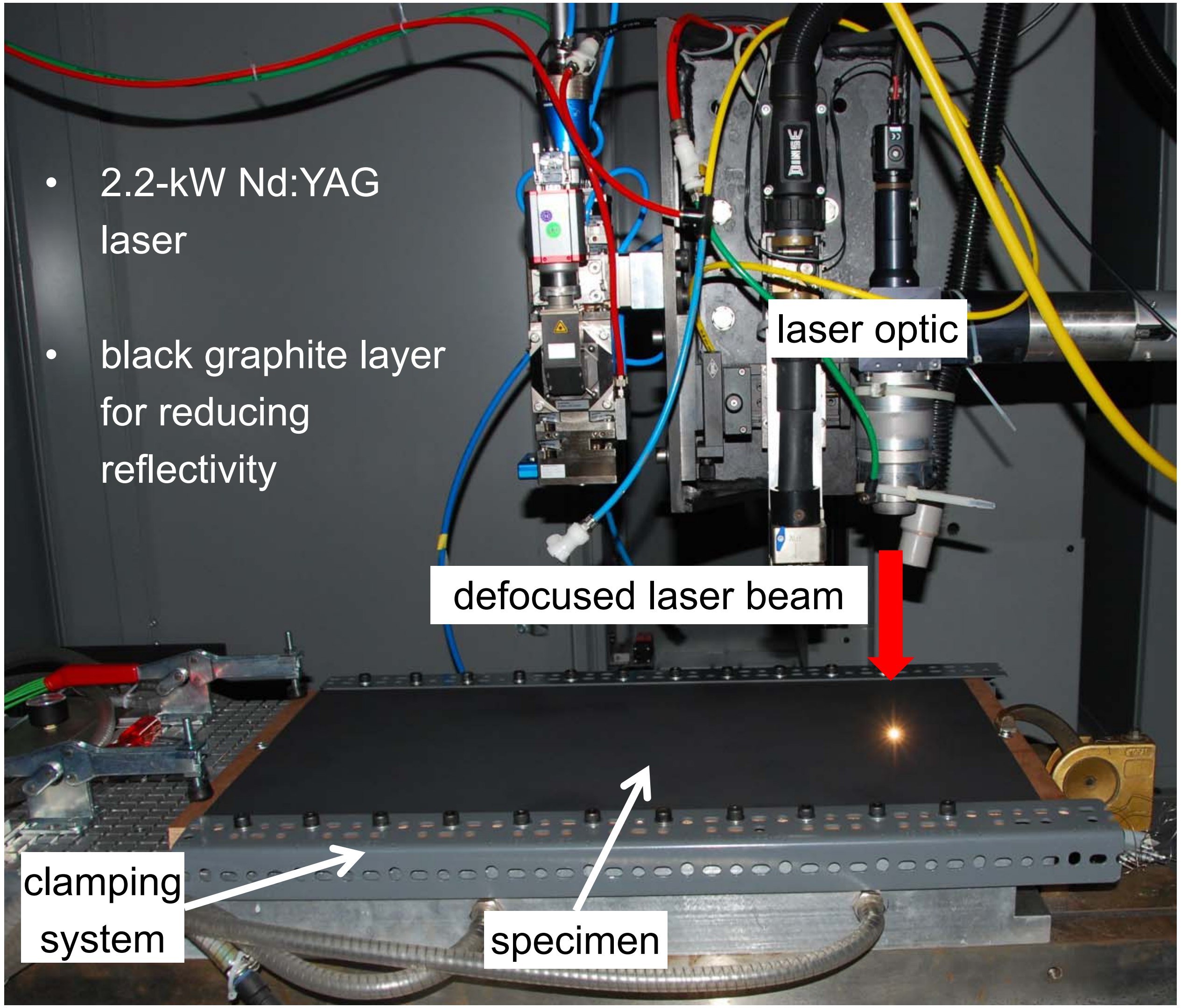
Laser heating
Working principle

A. Groth et al.: ICAS 2014

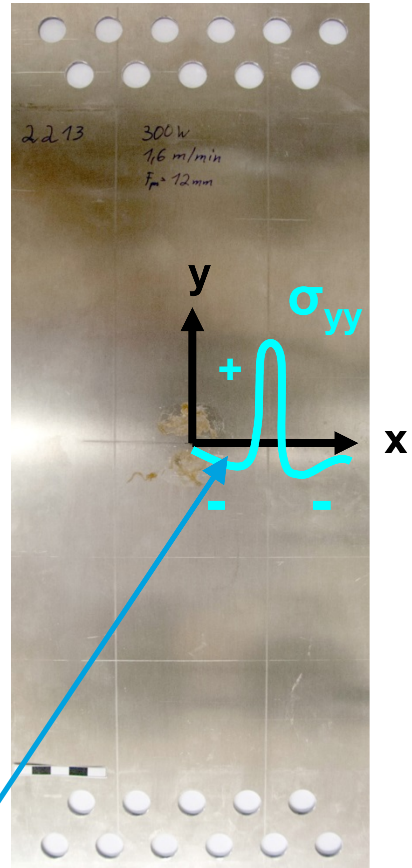


AA2024 T3, M(T)200 200 mm x 500 mm x 2.0 mm

Heating with defocused laser:

→ Local plastic yielding

→ Residual stresses



Retardation of fatigue crack growth

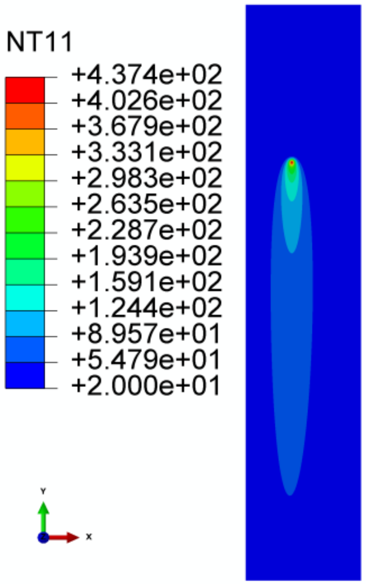
Simulation overview

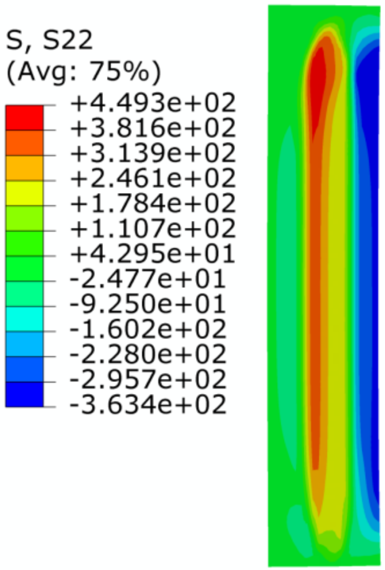
Thermal FE analysis	Mechanical FE analysis	Fracture mechanics analysis

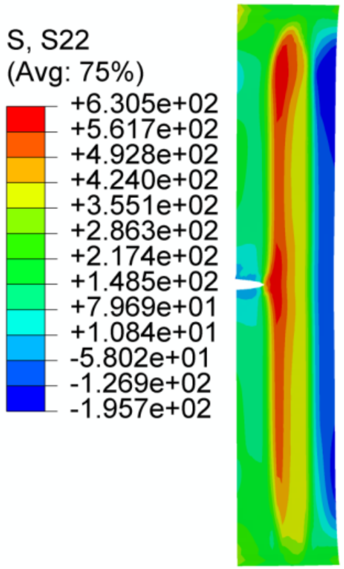
Empirical crack growth law
e.g. Walker equation

$$\frac{da}{dN} = C\left[\Delta K_{tot}\left[1 - R_{tot}\right]^{m-1}\right]^{n}$$

Comparison of the simulation and experimental results







Laser heating
Experimental validation

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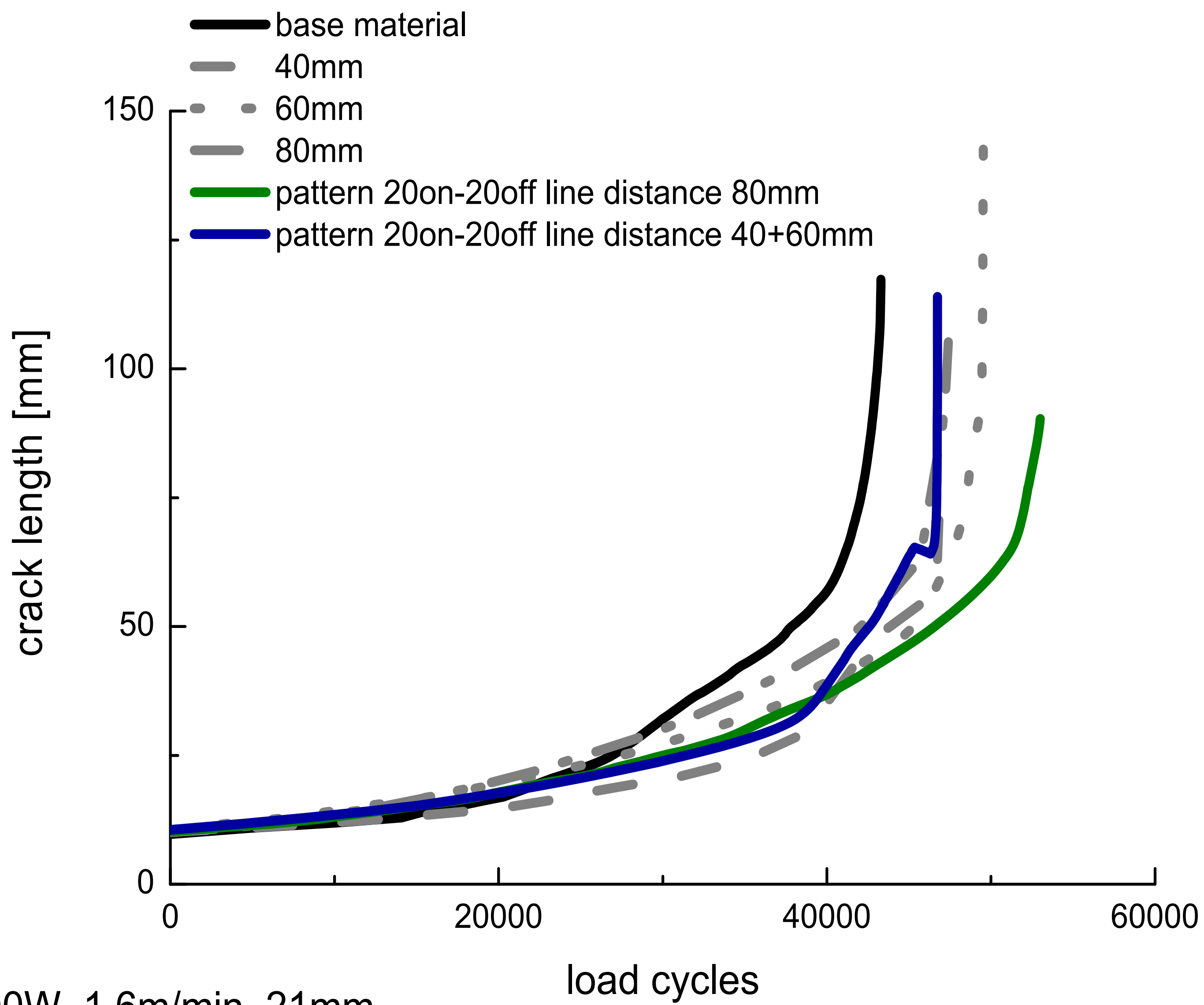

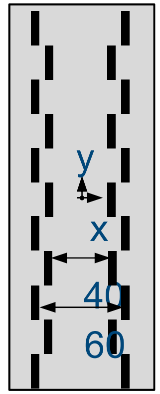

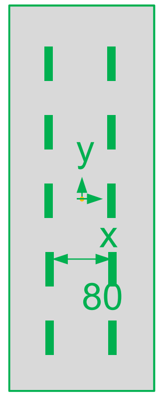

600W, 1.6m/min, 21mm

Laser heating
Experimental validation

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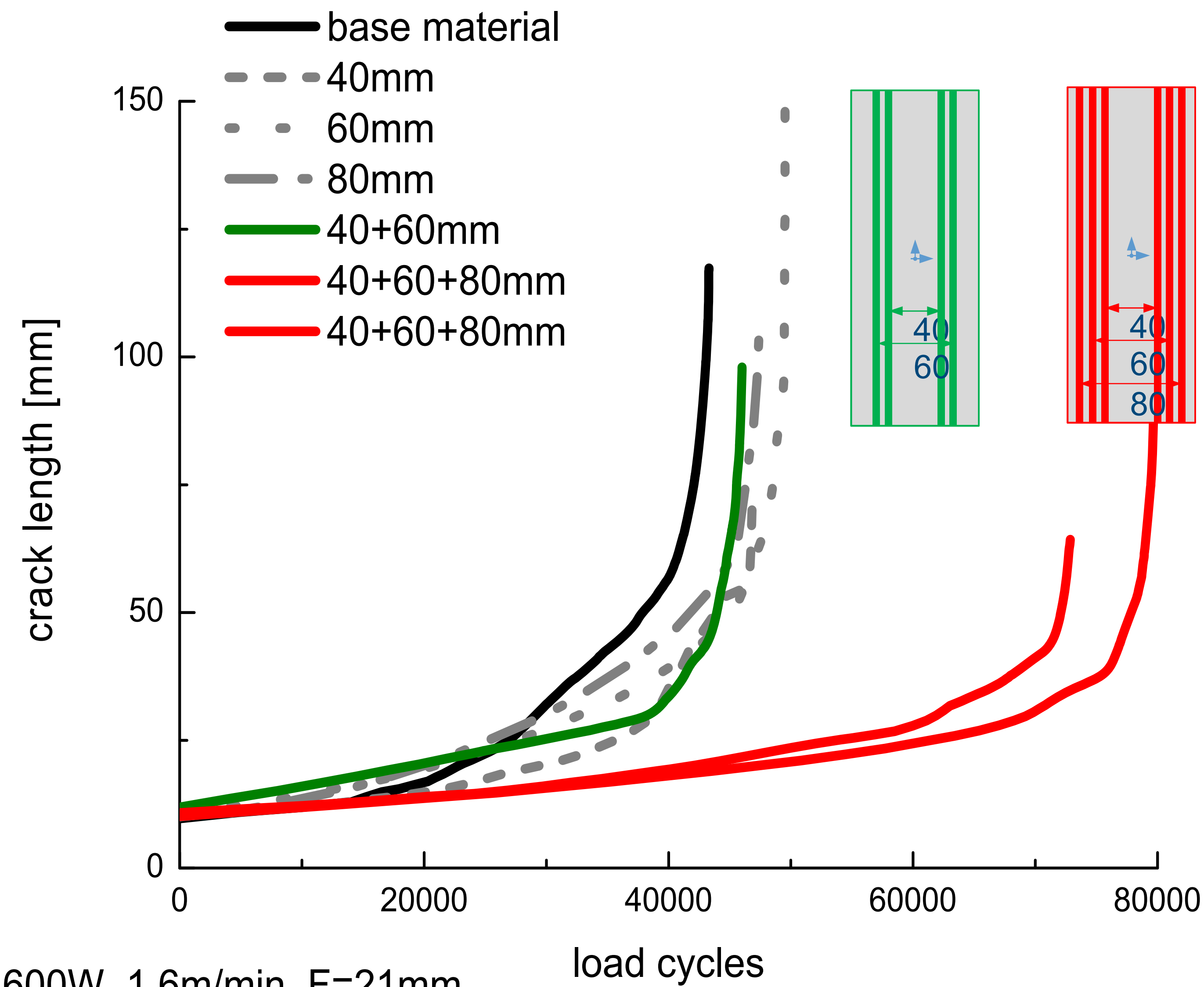

600W, 1.6m/min, F=21mm

Laser heating
Experimental validation

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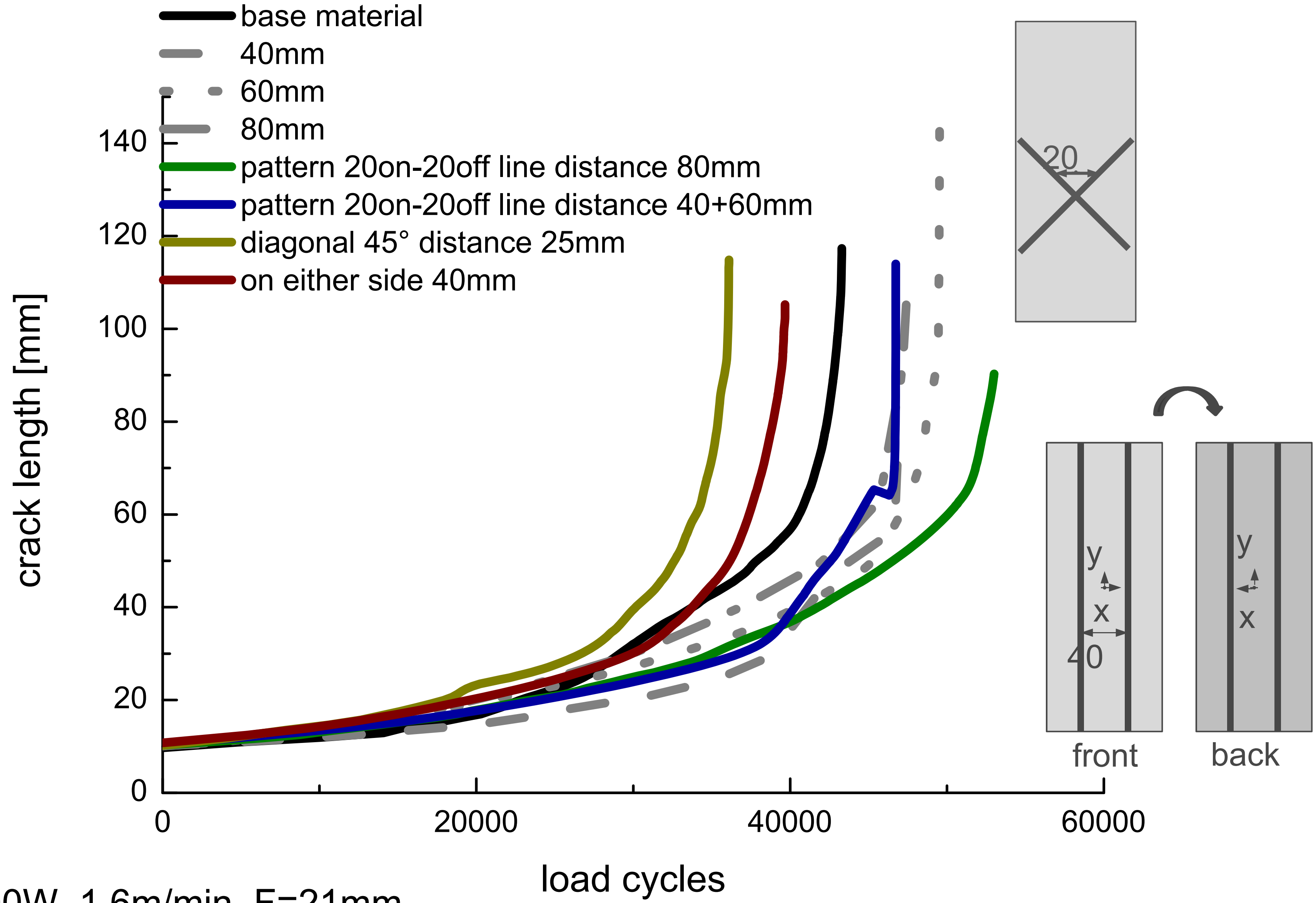


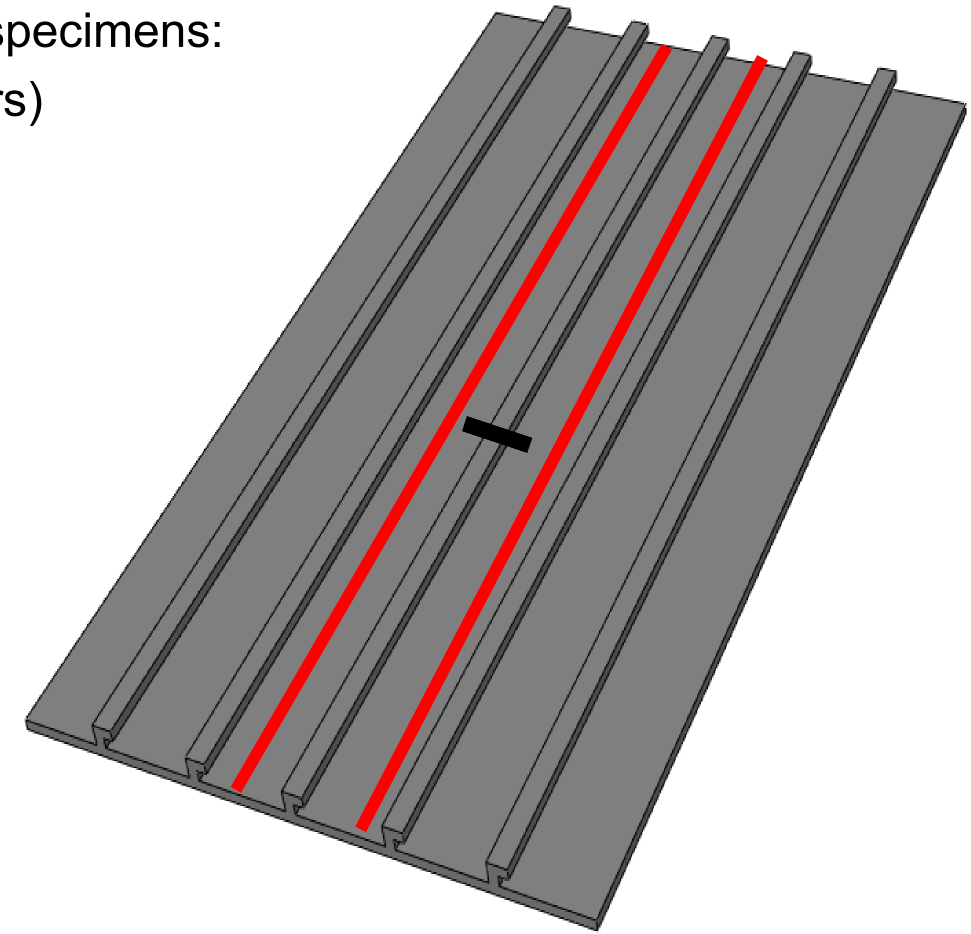
600W, 1.6m/min, F=21mm

Laser heating
Scale-up to multi stringer panels (LISA-Project)

- Transfer of this approach to large scale specimens: from **M(T)200** to **M(T)760** (with 5 stringers)

- Planned Experiments:
  - Residual Strength
  - Fatigue Crack Growth
  - Residual Stress Measurements

- Requirements for simulations
  - Accurate prediction for Fatigue Crack Growth
  - Short computational time



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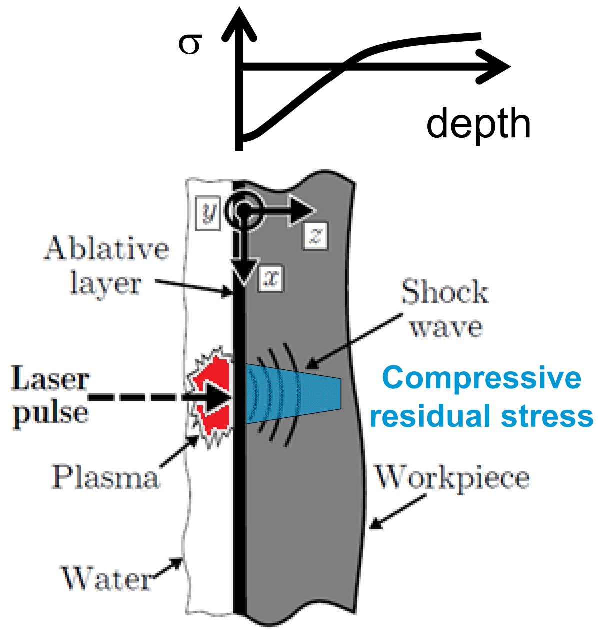
Laser shock-peening for life extension and repair

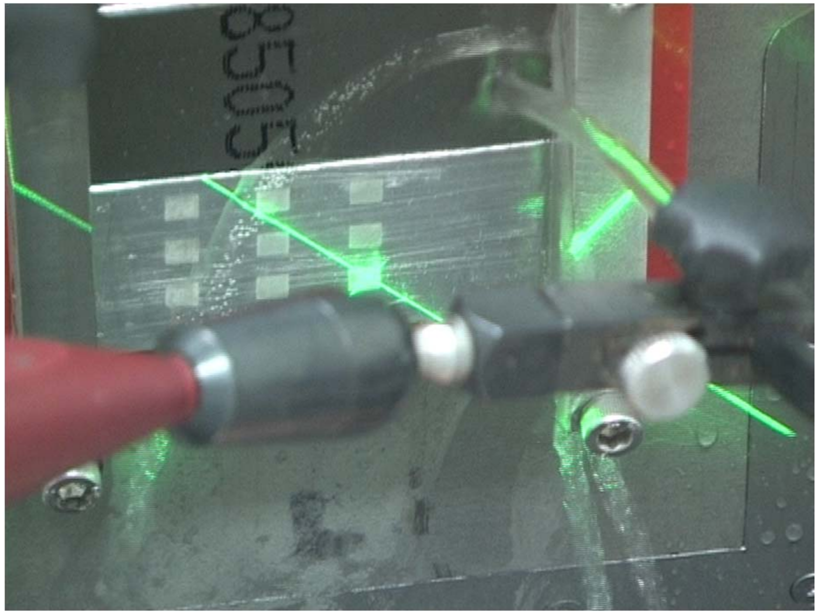
- Tailored residual stress fields
- Low surface roughness
- Retardation or suppression of crack initiation
- Deceleration of crack growth



Q-Switched-Nd:YAG-Laser 3J/5J, 10Hz

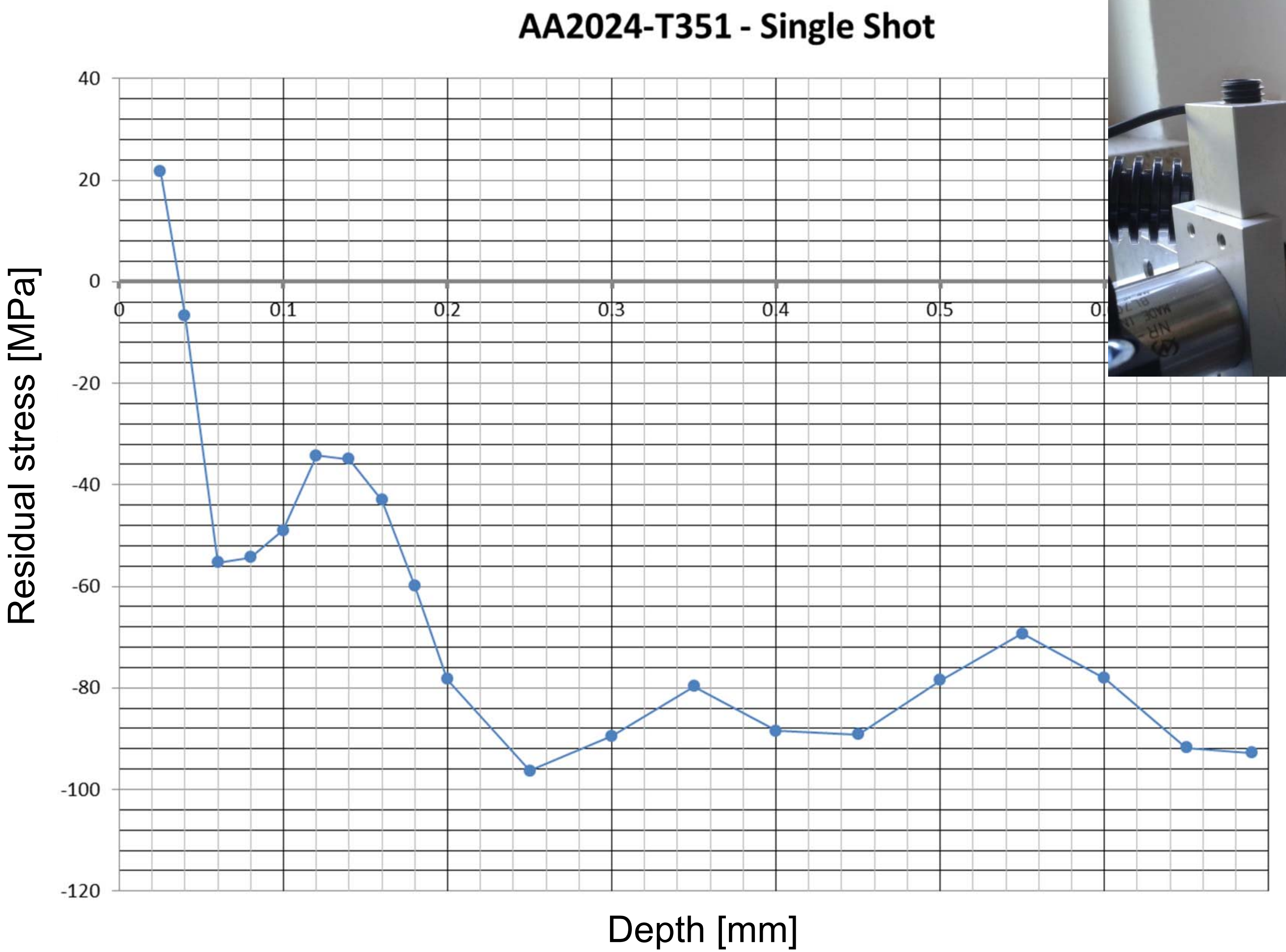
2 x 10 Hz Oscillator (1x 10ns, 1x 20ns)

Optics for 1mm, 3mm and 5mm square spot



LSP at HZG. Preliminary results

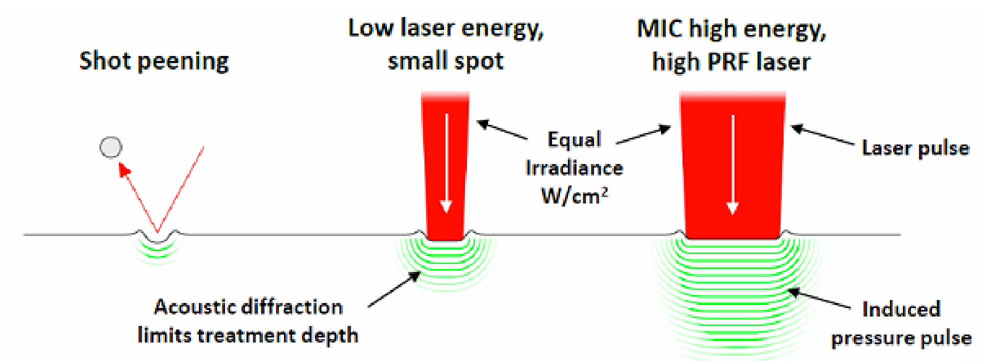
Single shot – Case 2 – Spot 3 mm x 3 mm:



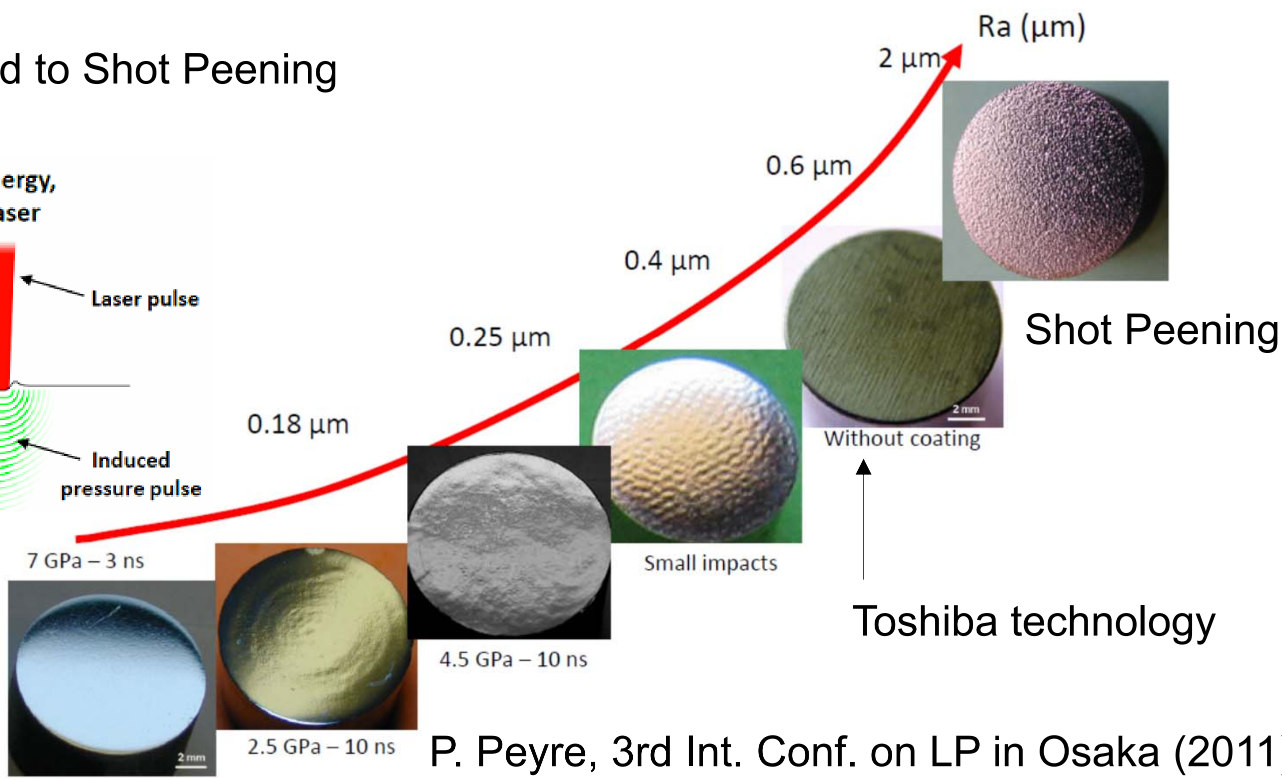
Laser Shock Peening (LSP) is Superiour to Shot Peening w.r.t. Roughness and Fatigue Strength

As compared to Shot Peening LSP exhibits the following advantages:

→ Very well defined process control, no static peening process
→ Applicable to most geometries
→ Clean process, no shot media to be removed
→ Low risk of cracking in the surface due to low work hardening than after Shot Peening
→ Deep affected zones of compressive residual stress state can be generated
→ Low surface roughness
→ Superior fatigue strength as compared to Shot Peening



C.B. Dane, 3rd Int. Conf. on LP in Osaka (2011)



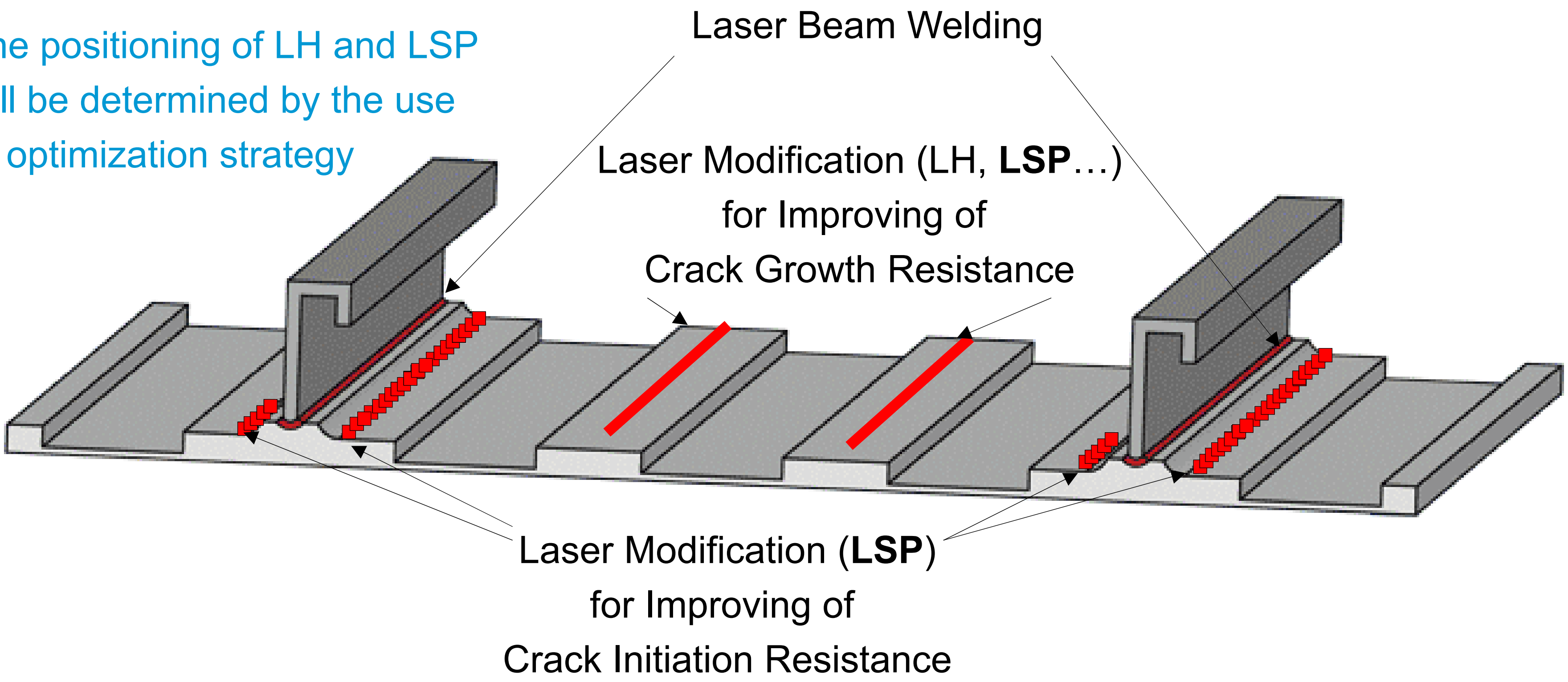
P. Peyre, 3rd Int. Conf. on LP in Osaka (2011)

Outline

- Strategy for the development of load-bearing structures
- LBW of lightweight integral structures
    - LBW of fuselage structures
    - Hybrid Ti-CFRP-structures
    - Tailored Ti-Structures
- Laser modification processes
    - Laser Heating
    - Laser Shock Peening
- Outlook

Lightweight concept for aerospace structures

The positioning of LH and LSP will be determined by the use of optimization strategy



Outlook:

Establishment of a spectrum of suitable processes (LH, LSP) for improving the damage tolerance behaviour of metallic structures

Expectations for LSP:

LSP for residual stress design improvement and repair of metallic lightweight structures under field conditions

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Thank you very much for your attention!