ADVANCED LASER MICRO AND MACRO DRILLING OF CFRP FOR AEROSPACE APPLICATIONS

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Motivation

[Duc]

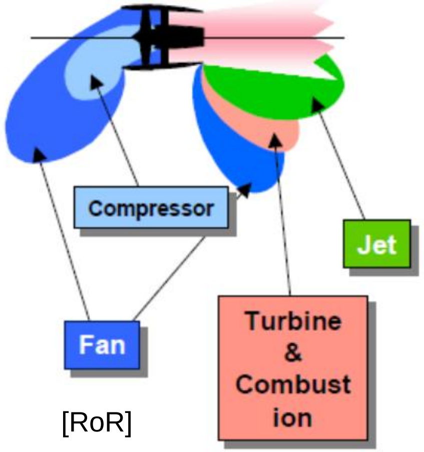
Motivation – Micro-drillings in aerospace

Air traffic is projected to recover and experience sustained growth

- Concurrent rise in noise pollution
- Aircraft engines constitute a significant noise source (fan noise, jet noise, …)

Modern jet engine [Sky]

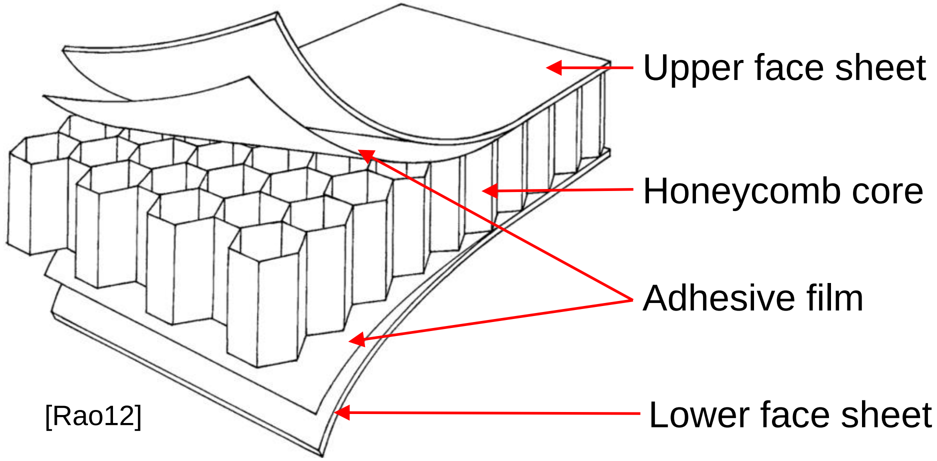
Noise sources of an engine [RoR]



Acoustic linings as a solution for noise reduction

- Mechanism based on Helmholtz resonance
    - » Energy dissipation through friction of vibrating air in microbores
- Design incorporates a perforated layer and a closed layer with an intermediate air volume
- Honeycomb sandwich materials with carbon fiber reinforced skin layers are utilized to optimize the performance of the acoustic linings

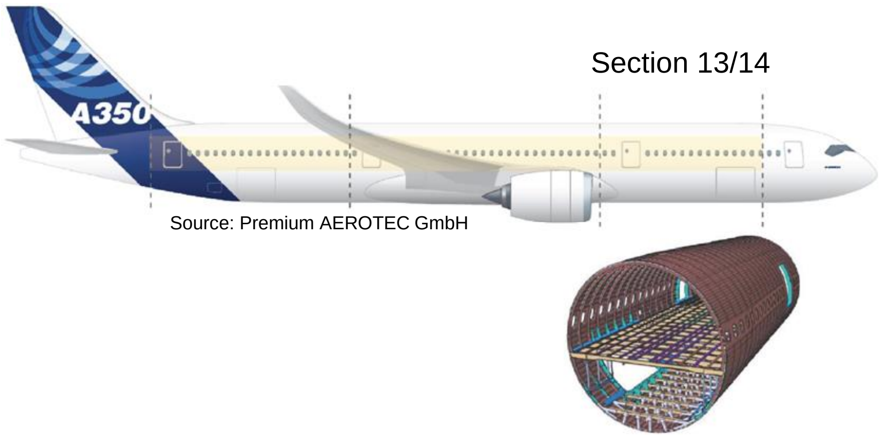
Honeycomb material [Rao 12]



Acoustic lining on engine nacelle [Duc]

Motivation – Macro boreholes in aviation industry

- Increased utilization of composites and hybrid materials
- Large number of boreholes
  - » ~34 000 boreholes per plane (Airbus A350, section 13/14 only)
  - » >150 000 000 drilling operations performed per year in the german aviation industry
- Subject to the highest requirements in terms of tolerances, quality, and process reliability

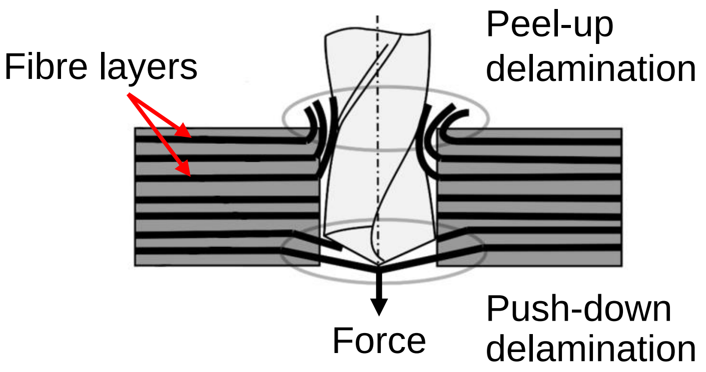


Source: Premium AEROTEC GmbH

Motivation – Why laser drilling & what are the challenges?

Conventional drilling

- Heavy tool wear can cause delamination, limited in bore diameter
- Complex device design for drilling multiple holes on large areas

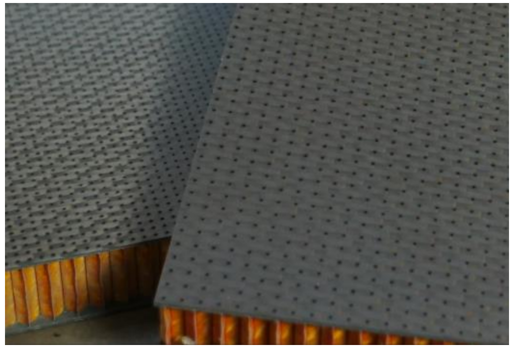


Laser drilling

- No tool wear, small bore diameters, flexibility in bore diameter and spacing

Challenges

- Understanding the intricate relationships between the various adjustable process parameters and indicators of quality and efficiency
- Minimization of thermal input
- Maximization of efficiency and quality



Machining setup

How it works: Laser remote processing

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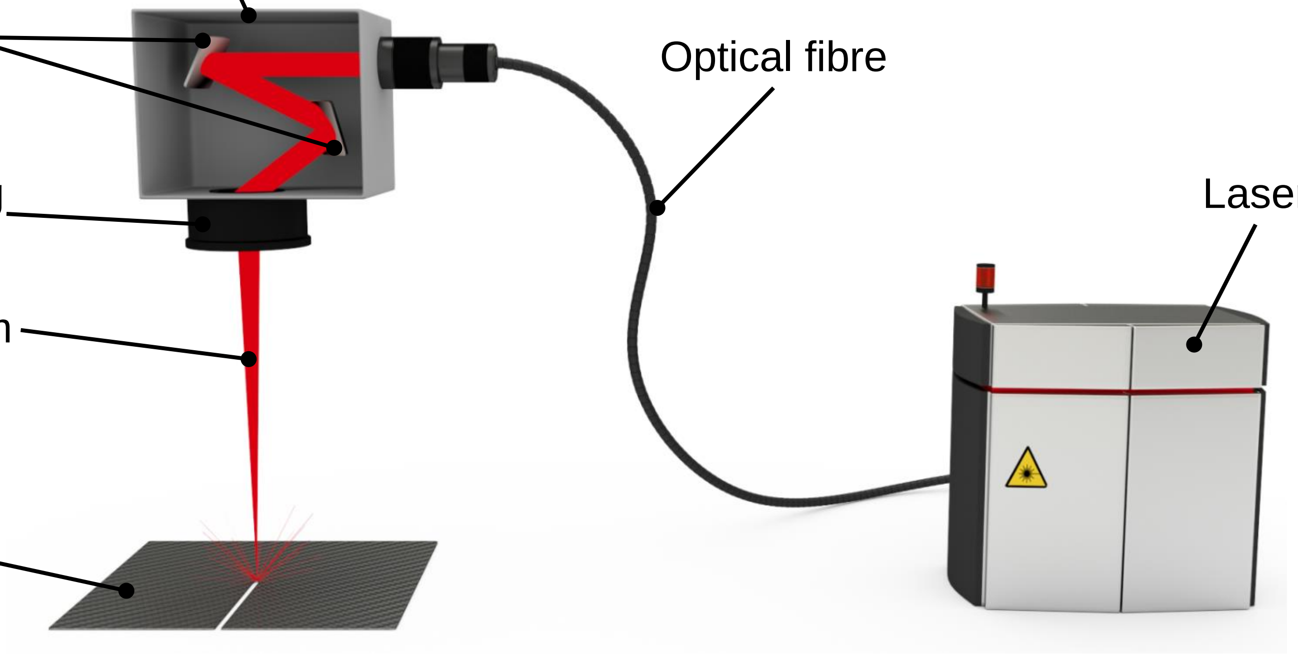
Multipass cutting / drilling

- Multiple passes (repetitions) on same contour to achieve a full cut / borehole by gradual material ablation

Ways to minimize the heat input

- High feed rate of the laser beam on the material (scan speed)
- Additional delay times between passes
- (Ultra-) Short-pulsed lasers are increasingly being used for processing



Laser drilling principles

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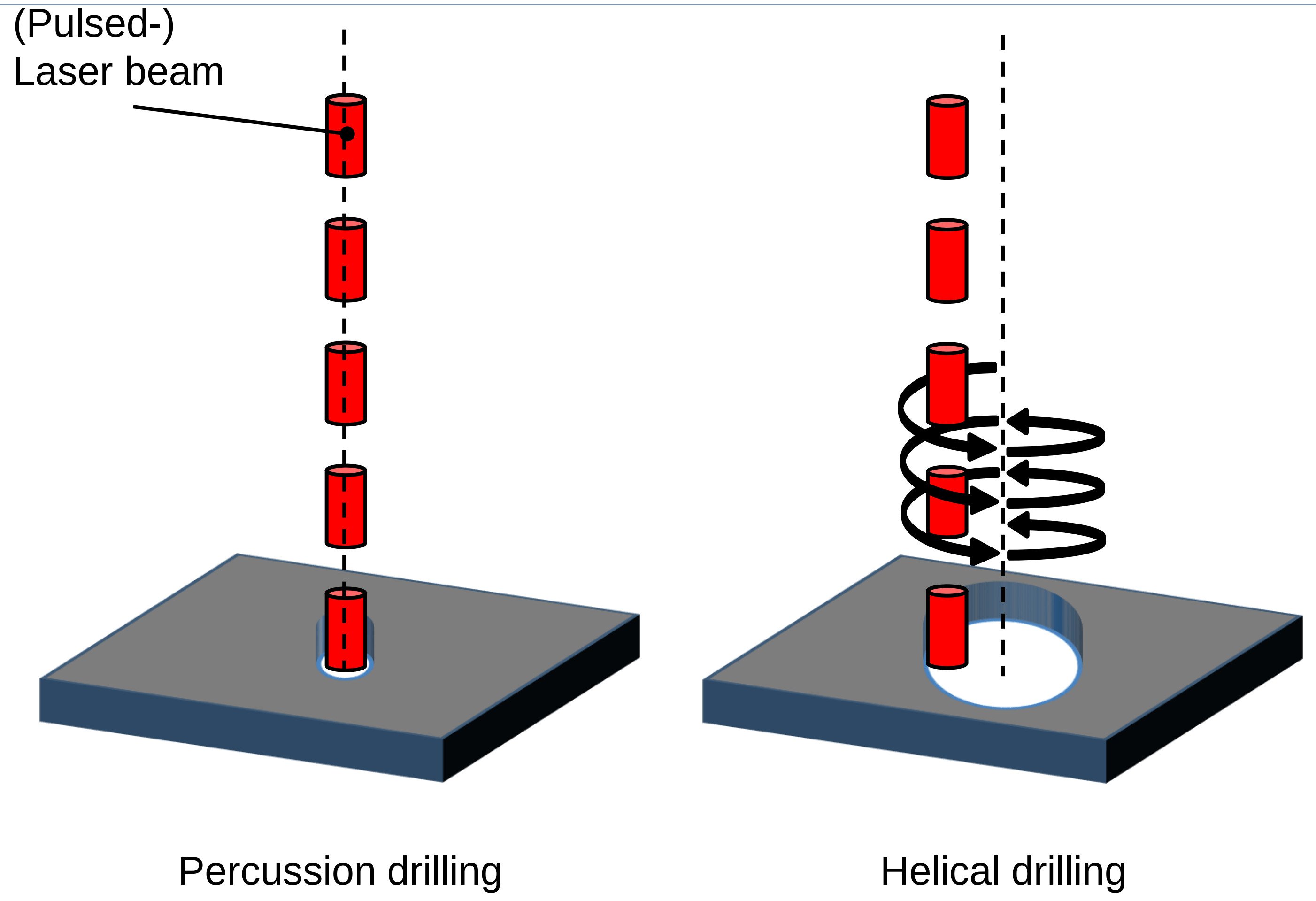
Percussion drilling

- Borehole diameter ≈ Laser beam diameter
- Material removal

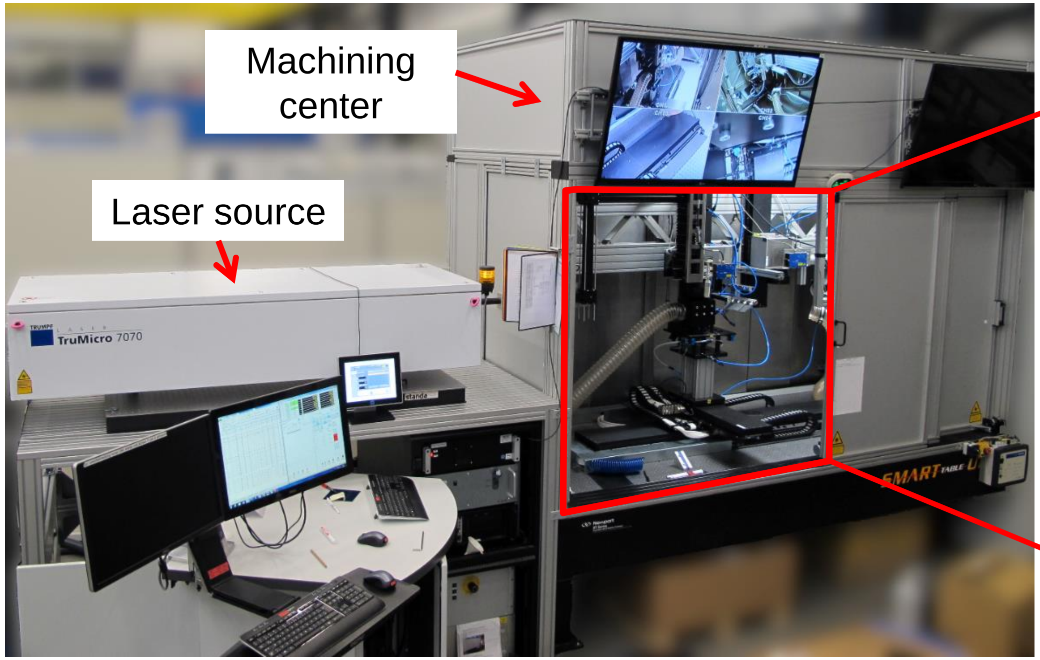
Helical drilling

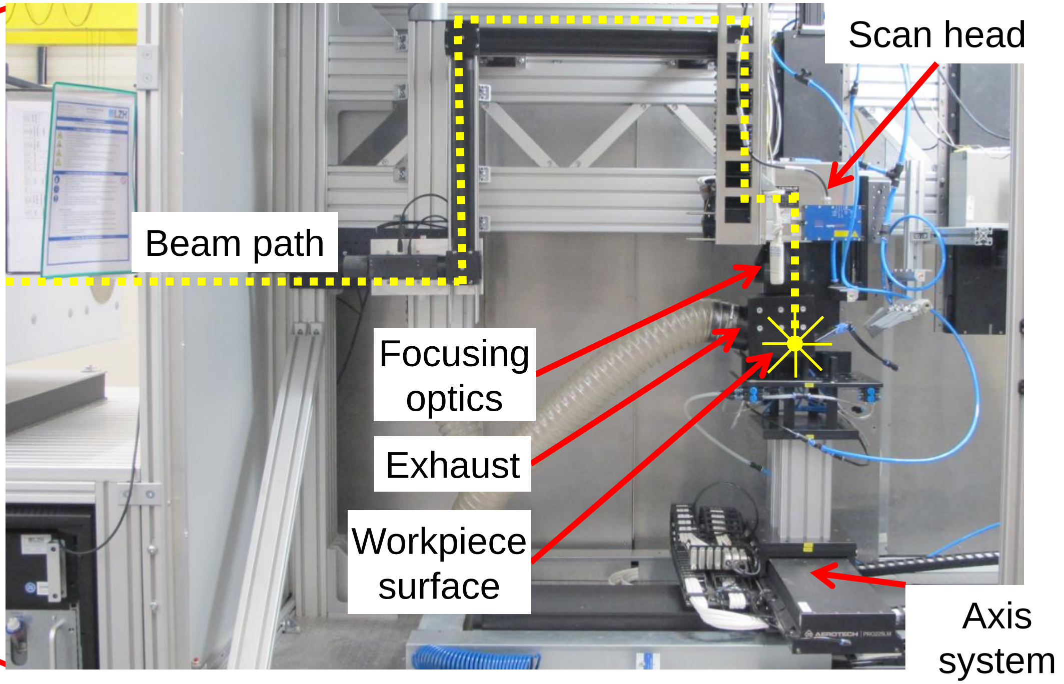
- Borehole diameter > Laser beam diameter
- Material removal / material cutout



Laser drilling principles [cf. MM13, p 254]

Drilling setup





TRUMPF nanosecond-pulsed prototype laser	
Wavelength λ [nm]	1030
Pulse duration t_p [ns]	20
Max. Pulse energy $E_{p,max}$ [mJ]	100
Max. average power $P_{L,avg}$ [kW]	1500

Machining quality evaluation

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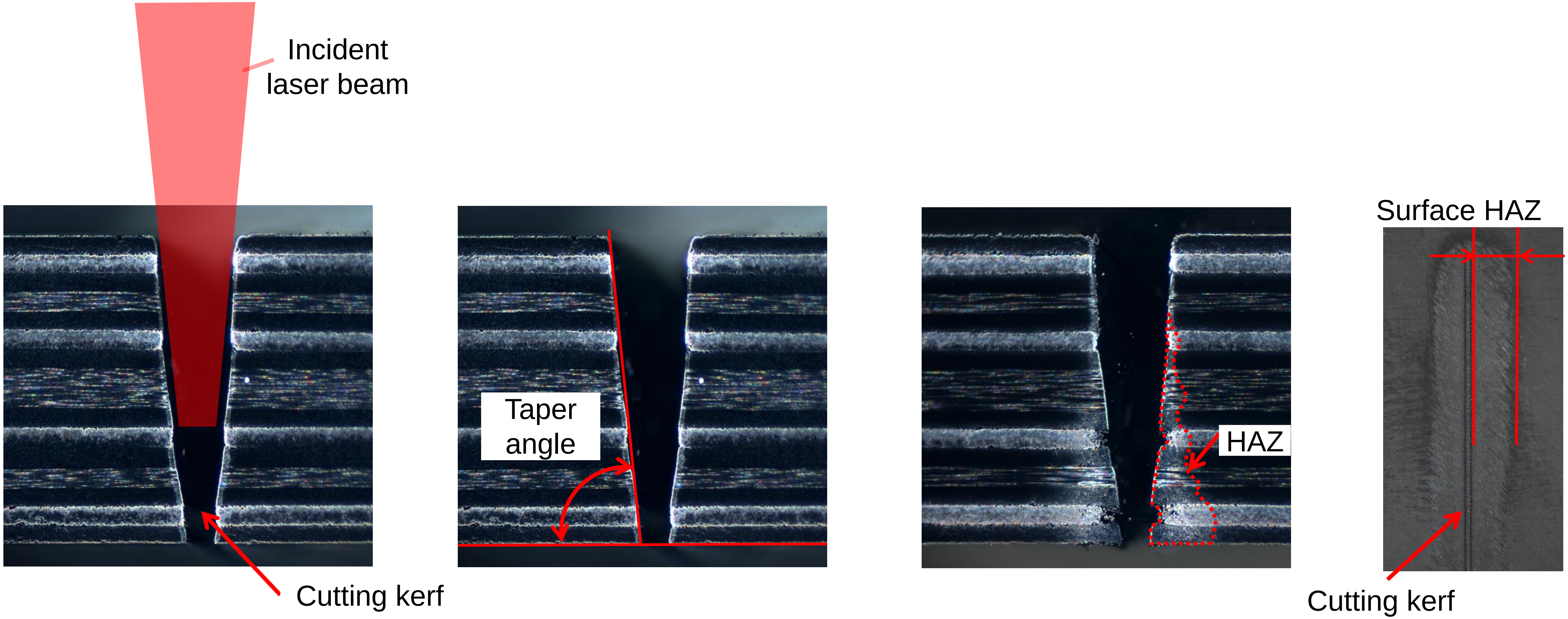
Typical evaluation criteria for laser machined CFRP that can be obtained from cross-section images



Optimizing laser drilling – Evolution of machining quality

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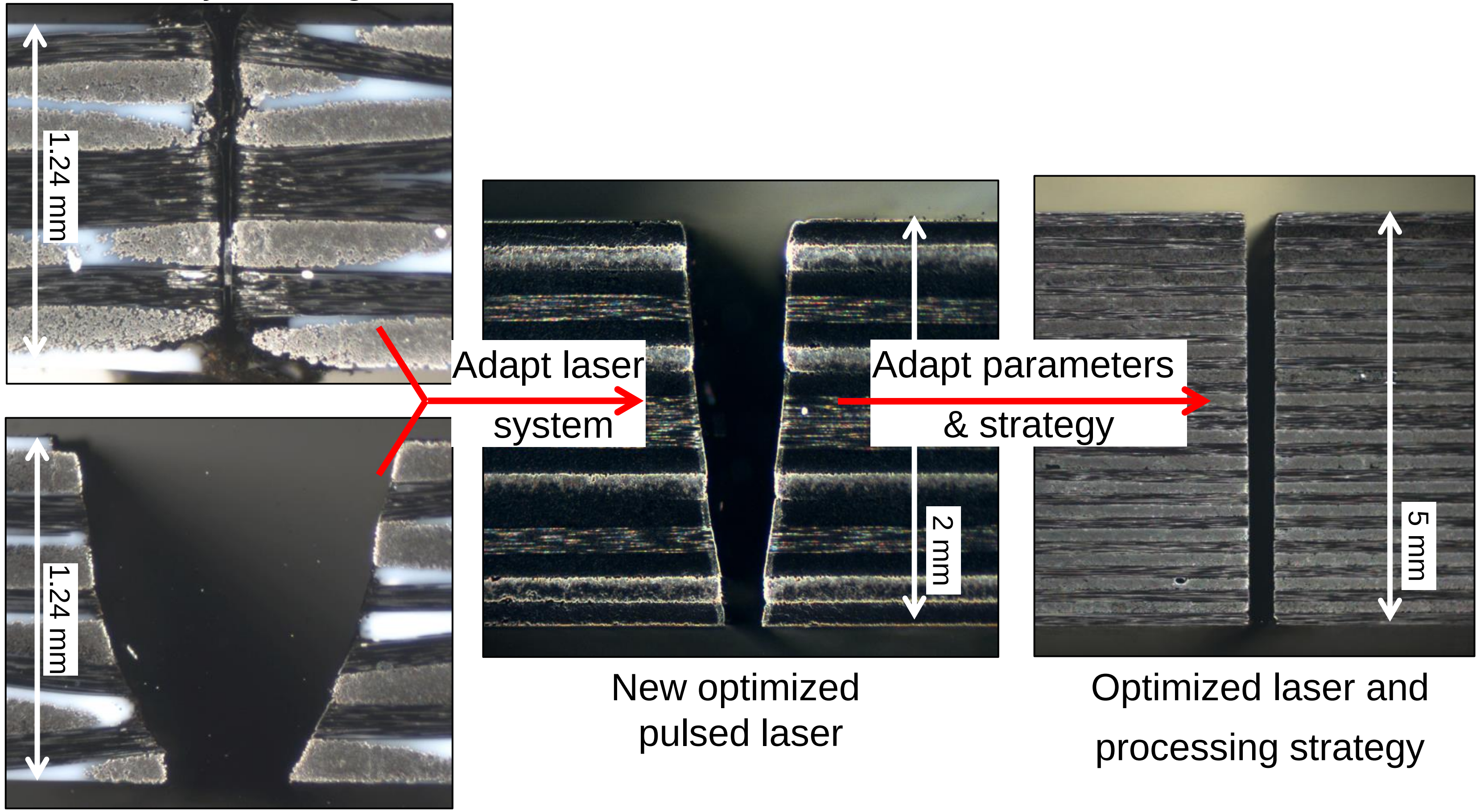
Cross-section images of CFRP materials, machined with different laser types and strategies

Continuously emitting laser



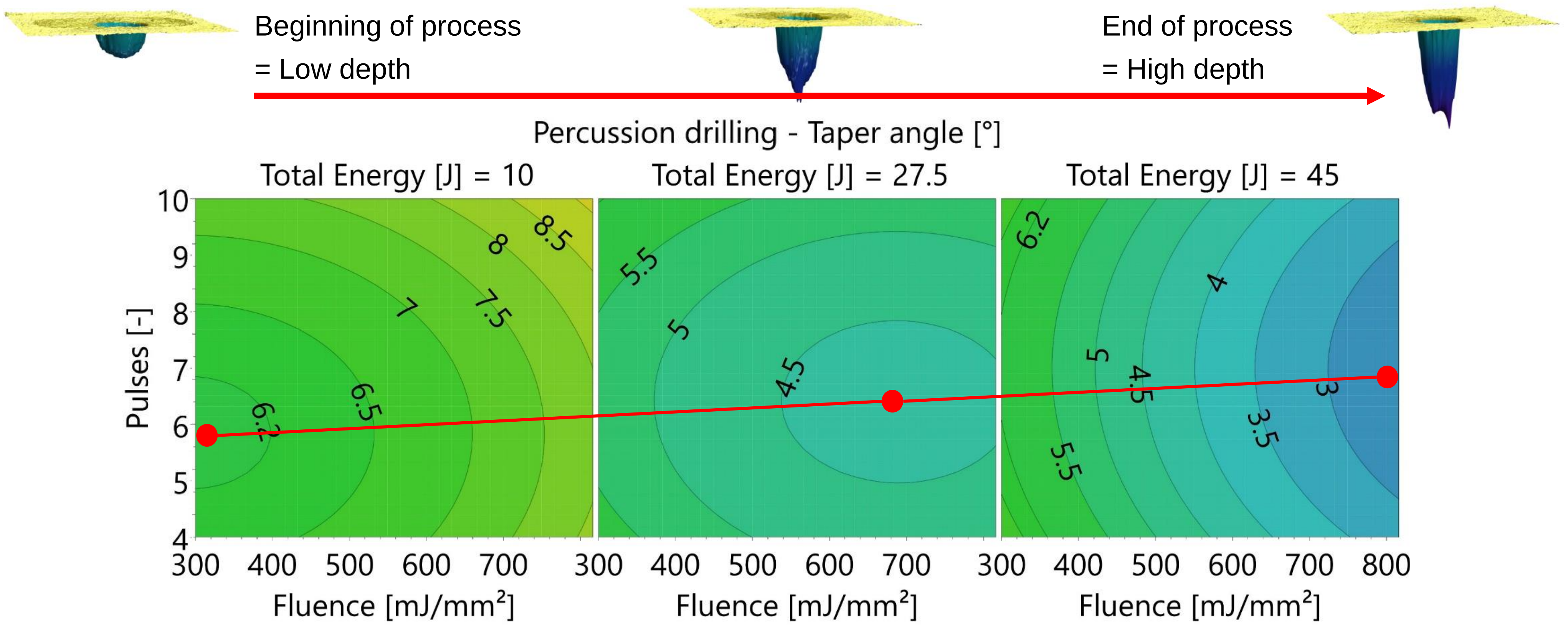
Pulsed laser

New optimized pulsed laser

Optimized laser and processing strategy

Optimizing laser drilling – Process control

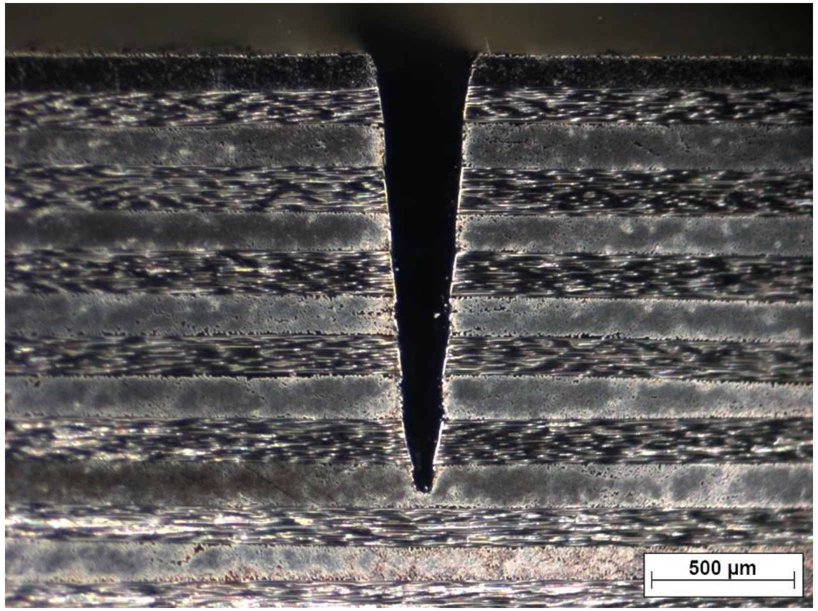
- Application of design of experiments to determine the optimal process window and the shift of the optimal range during the process progress
- Derivation of a process control based on the results



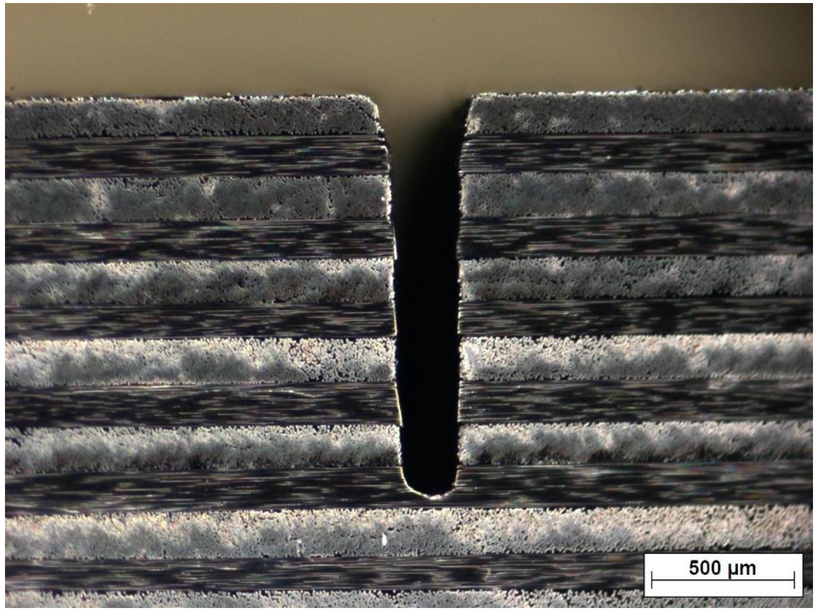
Optimizing laser drilling – Example focal tracing

Cross-section images of laser machined CFRP obtained with different focal tracing settings

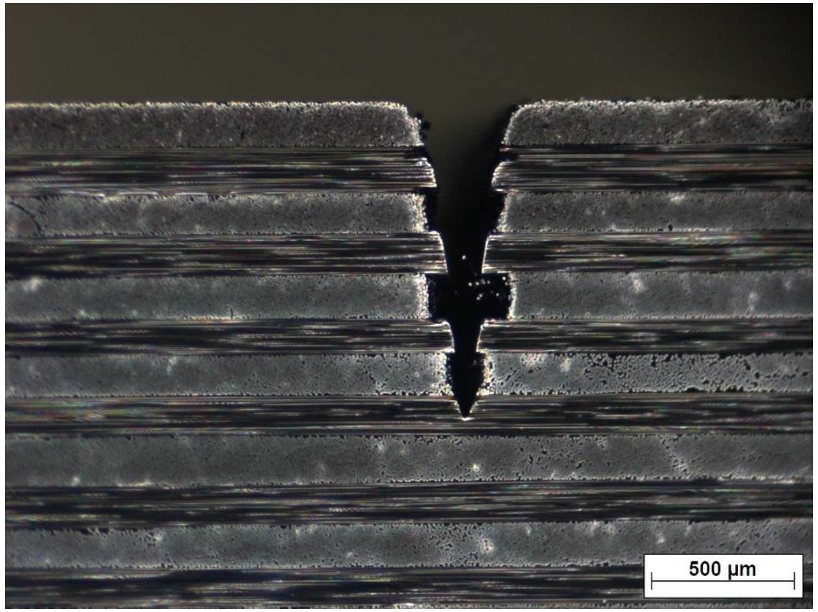
- No focal tracing
- Increased taper and HAZ



- Adjusted focal tracing
- Reduced taper and HAZ

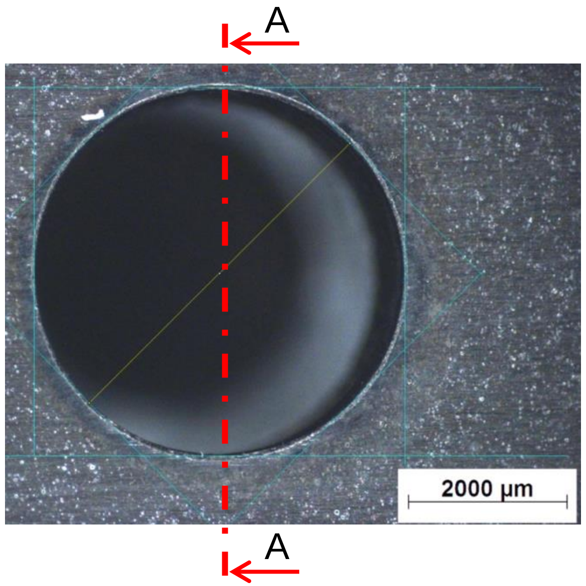


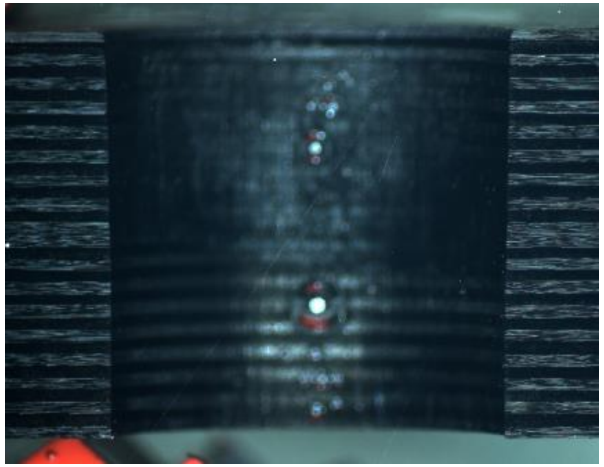
- Focal tracing set incorrectly
- Reduced material removal, increased taper, dents and HAZ



Optimizing laser drilling – Demonstration riveting borehole

- Material CF/Epoxy (aviation grade), thickness d = 4mm
- Drilling process of a Ø 4.82 mm borehole
- Roundness & diameter deviation of < 30 µm

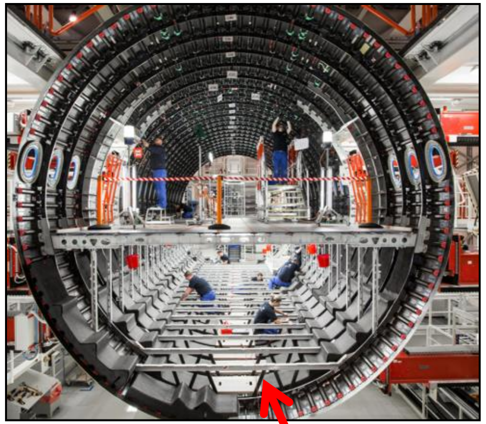




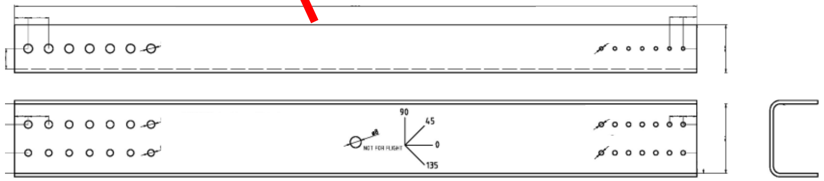
Multiple boreholes process demonstration – ‚Cargo strut'

- Cargo struts used as demonstration part
- 4 struts machined sequentially
- 160 holes with varying diameter drilled in one processing routine
- Total duration ~ 25 min → ~9 s per borehole

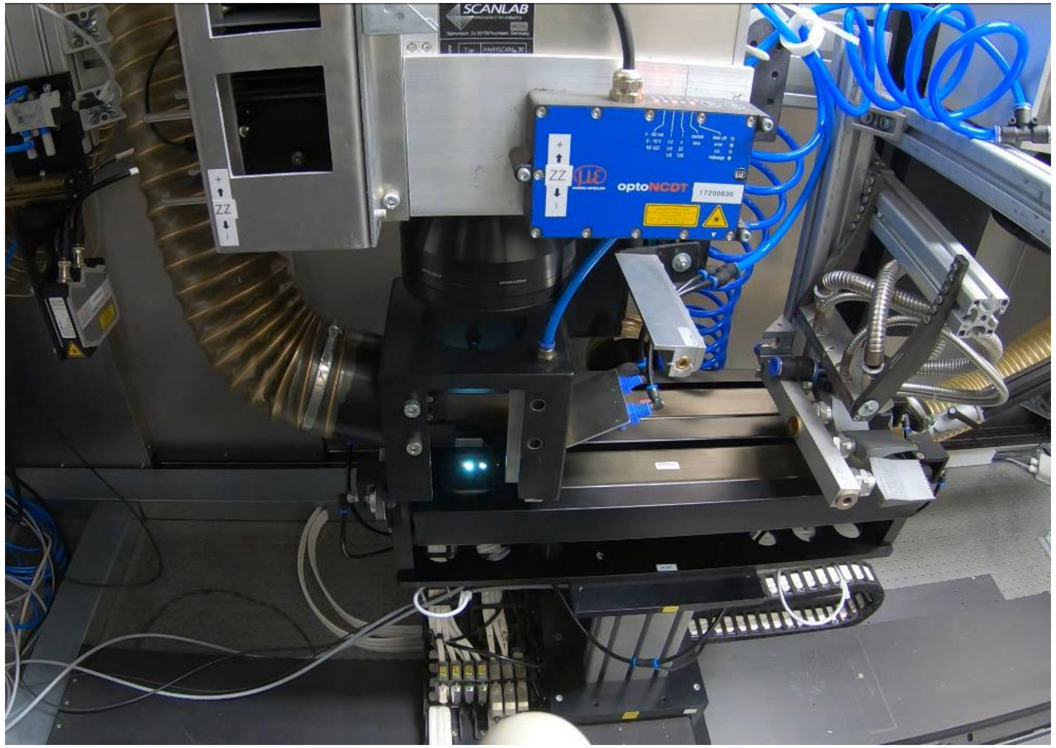
Mounting location



Struts in clamping fixture

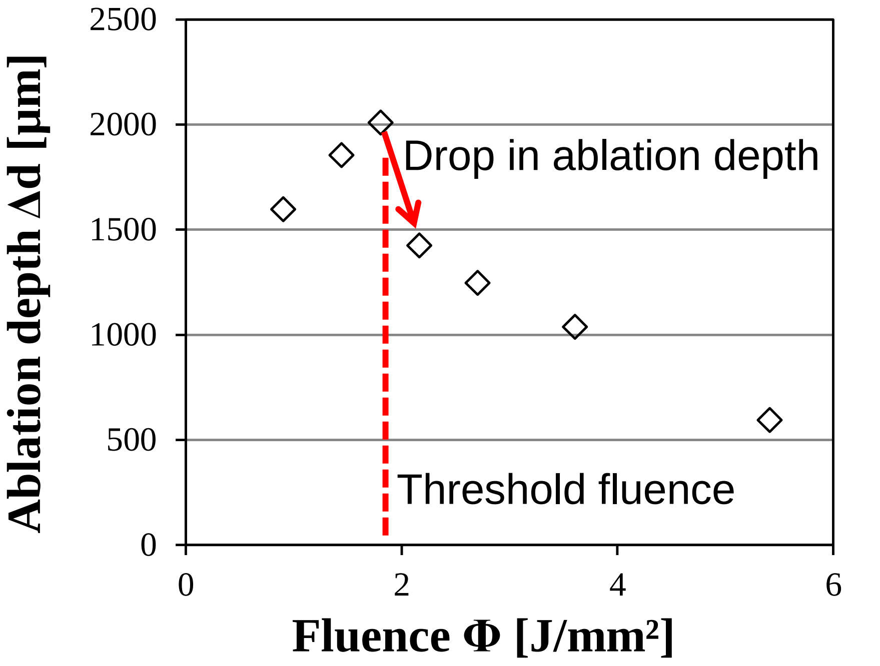


Video of drilling process

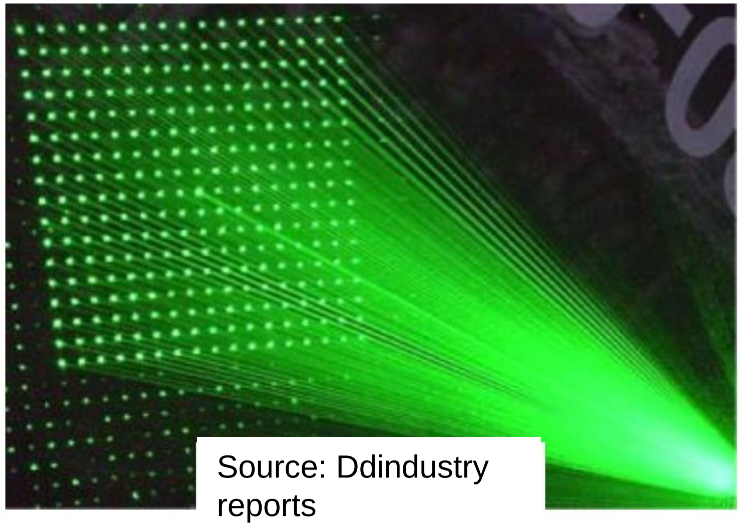


Optimizing laser micro drilling – Beam splitting

- Too much fluence (energy per irradiated area) is inefficient due to plasma shielding effects
- The laser beam can be split into several beams by diffractive optical elements (DOE)
- Beam splitting enables parallel processing of several holes and utilization of full laser power → increased efficiency



Visualization of beam splitting by DOE



Source: Ddindustry reports

Optimizing laser micro drilling – Process control

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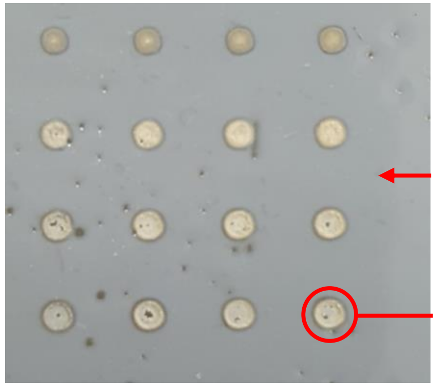
Why is a process control for monitoring of the completion of the borehole required?

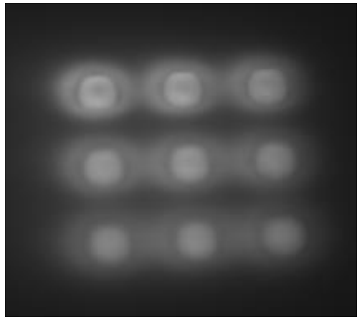
- Varying energy input for full drilling, no ‚feed stop' once drilled through
- Regarding micro drilling for acoustic linings:
  - » Excessive irradiation of lower face sheet on honeycomb materials may cause damage and needs to be avoided



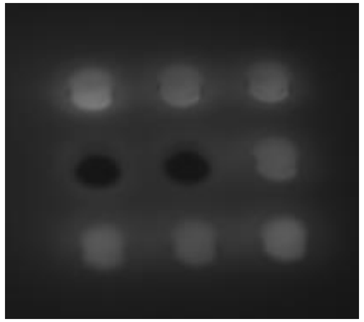
Thermography is included in current setup, low cost & robust monitoring solution

Thermographic images of a drilling assembly as the drilling process progresses

Beginning of the process,
matrix of 3x3 boreholes



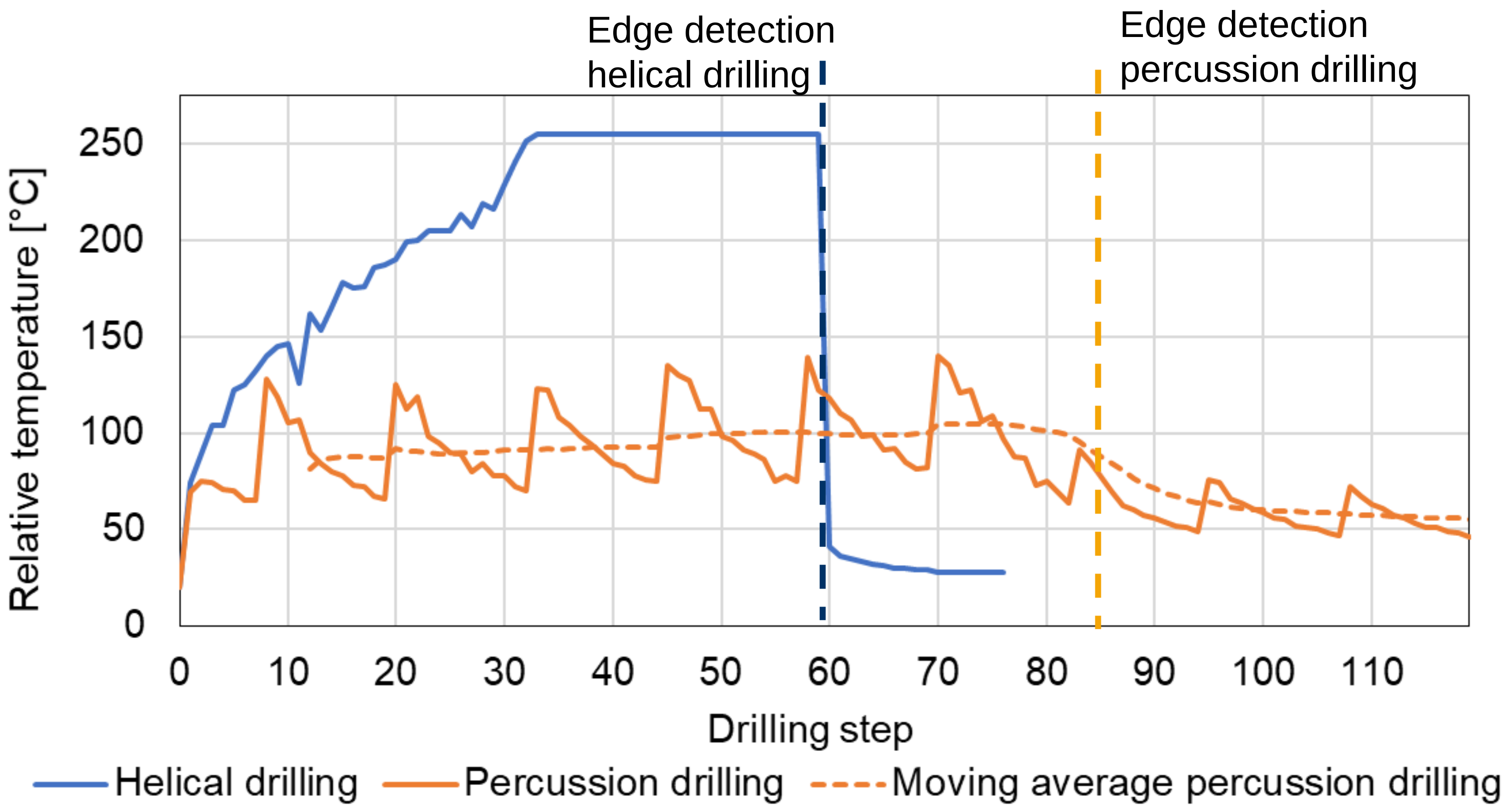
Material heats
up during process (bright area)

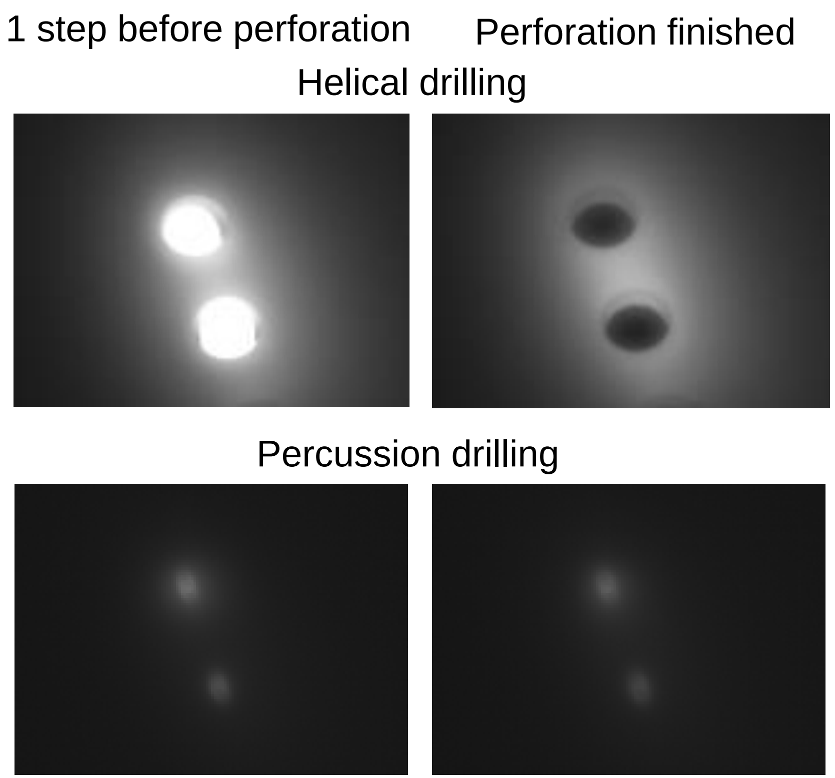


End of process,
first material cut-outs appear cooler (dark area)

Optimizing laser micro drilling –Temperature course during drilling processes

- Distinct temperature drop of drilled through for helical drilling, strong contrast in grey values → ideal for edge detection
- Moving average needs to be calculated for percussion drilling due to fluctuations
- Inner part intact for helical drilling, full material ablation for percussion drilling





Validation of acoustic and mechanical properties of laser processed samples

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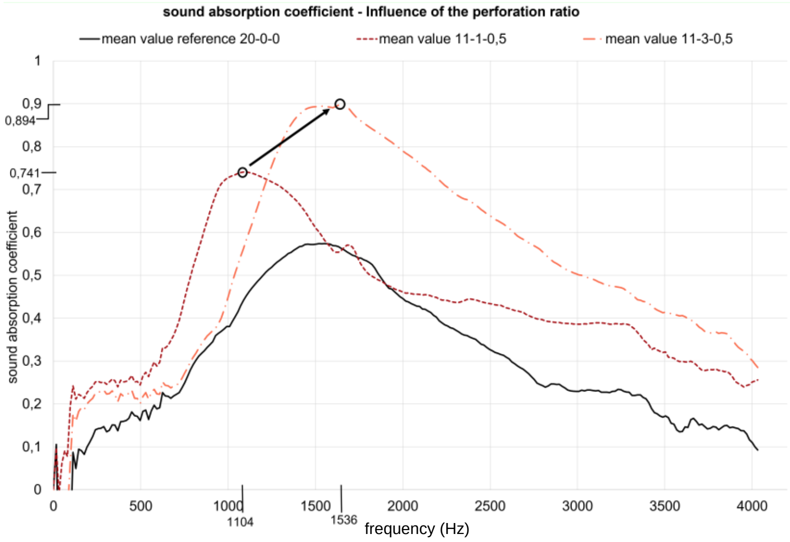
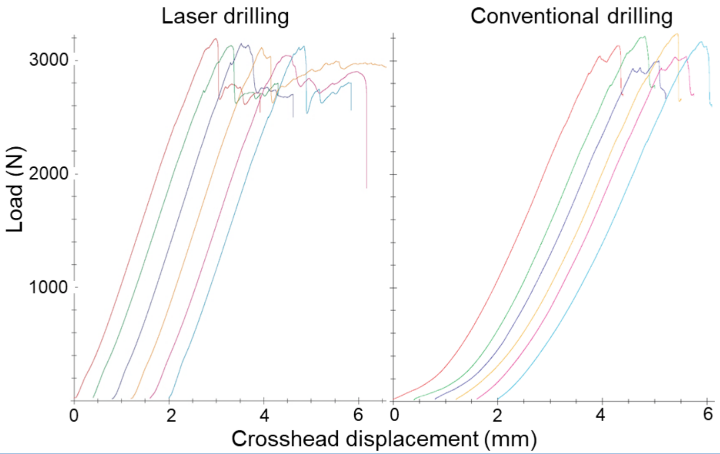
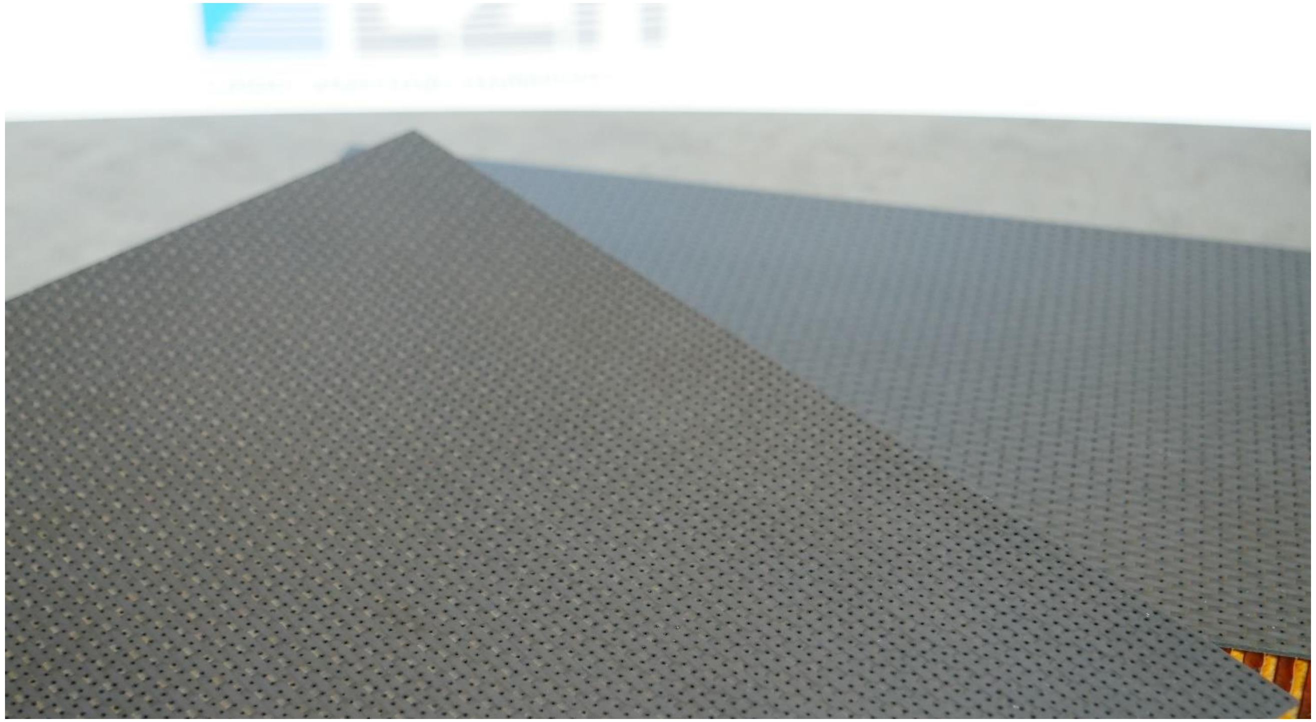
- The sound absorption properties were successfully demonstrated by the project partner INVENT GmbH
- It has also been successfully shown by the project partner INVENT GmbH that the mechanical properties of laser-drilled samples are not compromised

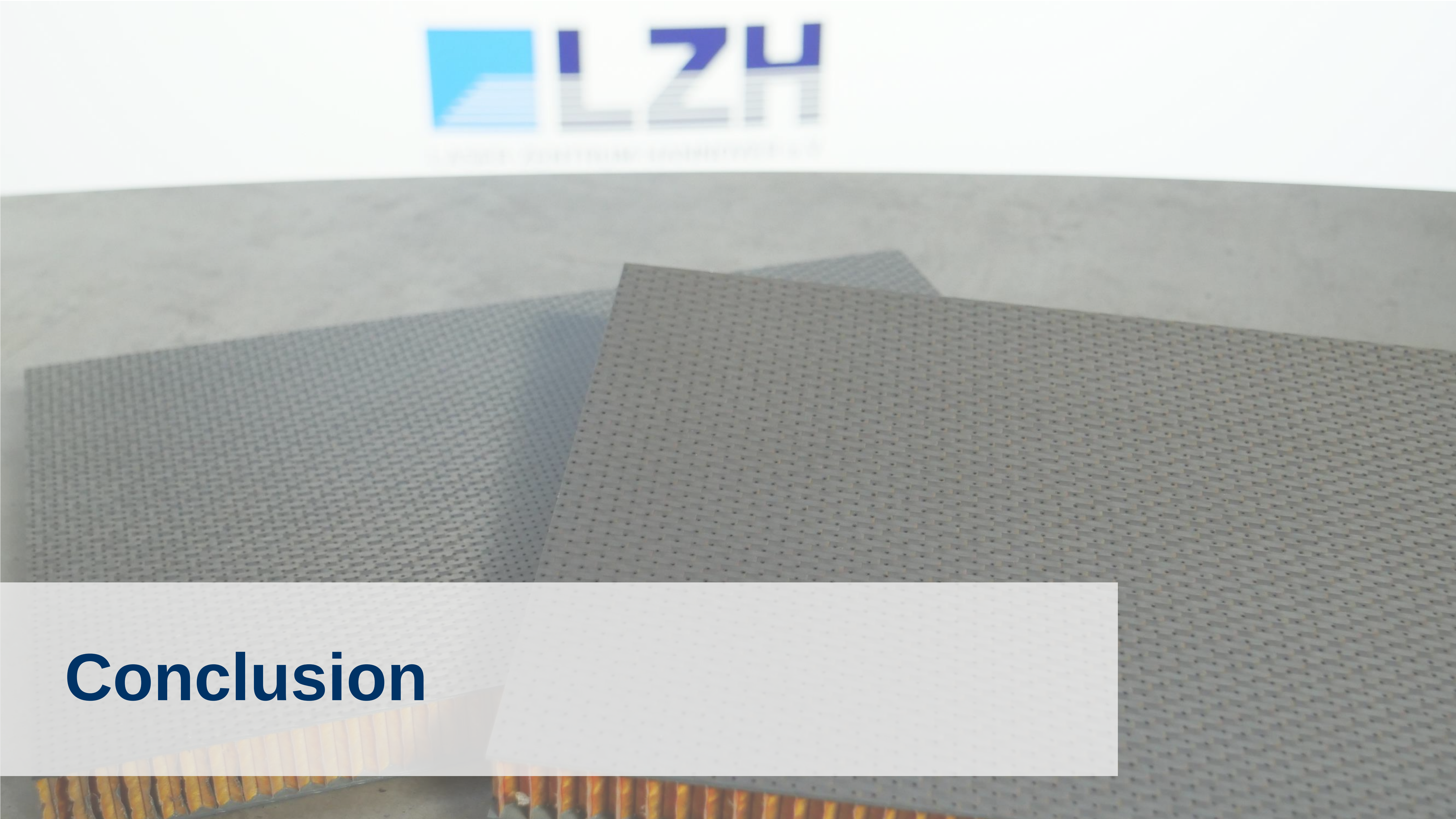
Source: INVENT GmbH







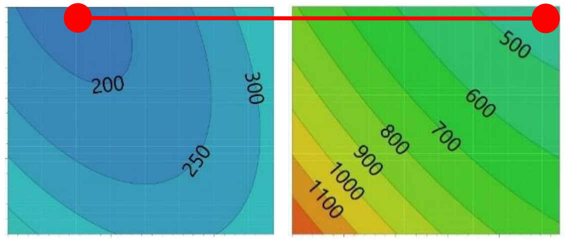
Laser-machined carbon fiber-reinforced honeycomb panel with microbores

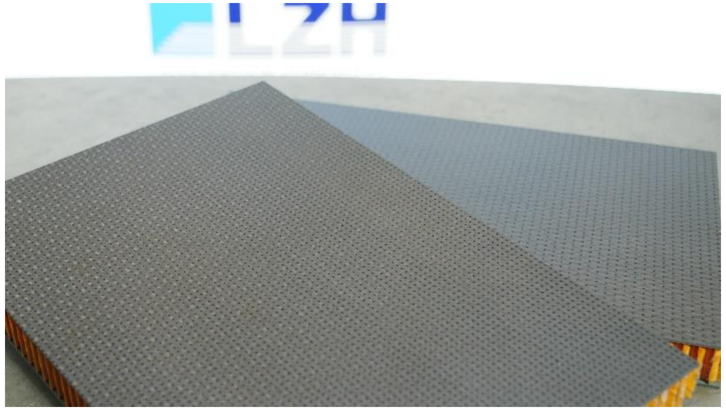


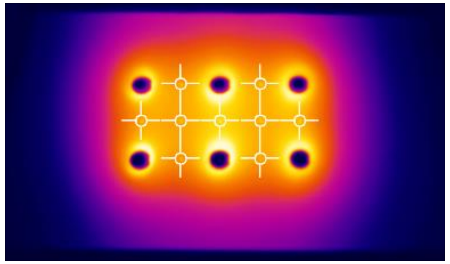
Conclusion

Conclusion

- Growing interest in alternative macro & micro drilling processes for composites, especially in the aviation sector
- Micro-drilling of CFRP is a frequently requested topic especially for acoustic applications
- At the Laser Zentrum Hannover various drilling processes were developed and improved to maximize quality and efficiency
- Adapted monitoring solutions help to improve process reliability







Acknowledgements

This work is based on the miBoS project (“Micro-drilling of sandwich materials”), which is funded by the German Federal Ministry for Economic Affairs and Climate Action (funding code 20T1926C).

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

Furthermore, the authors would like to thank TRUMPF Laser GmbH for providing the laser source.

Thank you for your attention.

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