Analyser av AM- och lasersvetsprocesser med höghastighetsfilmning på LTU

Alexander Kaplan, professor till äf produktion
Luleå tekniska universitet

Relevant **resources at LTU**

Laser welding project examples:

- Laser welding of T-joints
- Fatigue of hybrid and arc welding

Laser AM project examples:

- Metal powder sheets for AM
- Drop-on-Demand from wire
- Powder by DoD recycling
- Direct ore powder reduction
- Schlieren imaging of AM

Summary

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Summary

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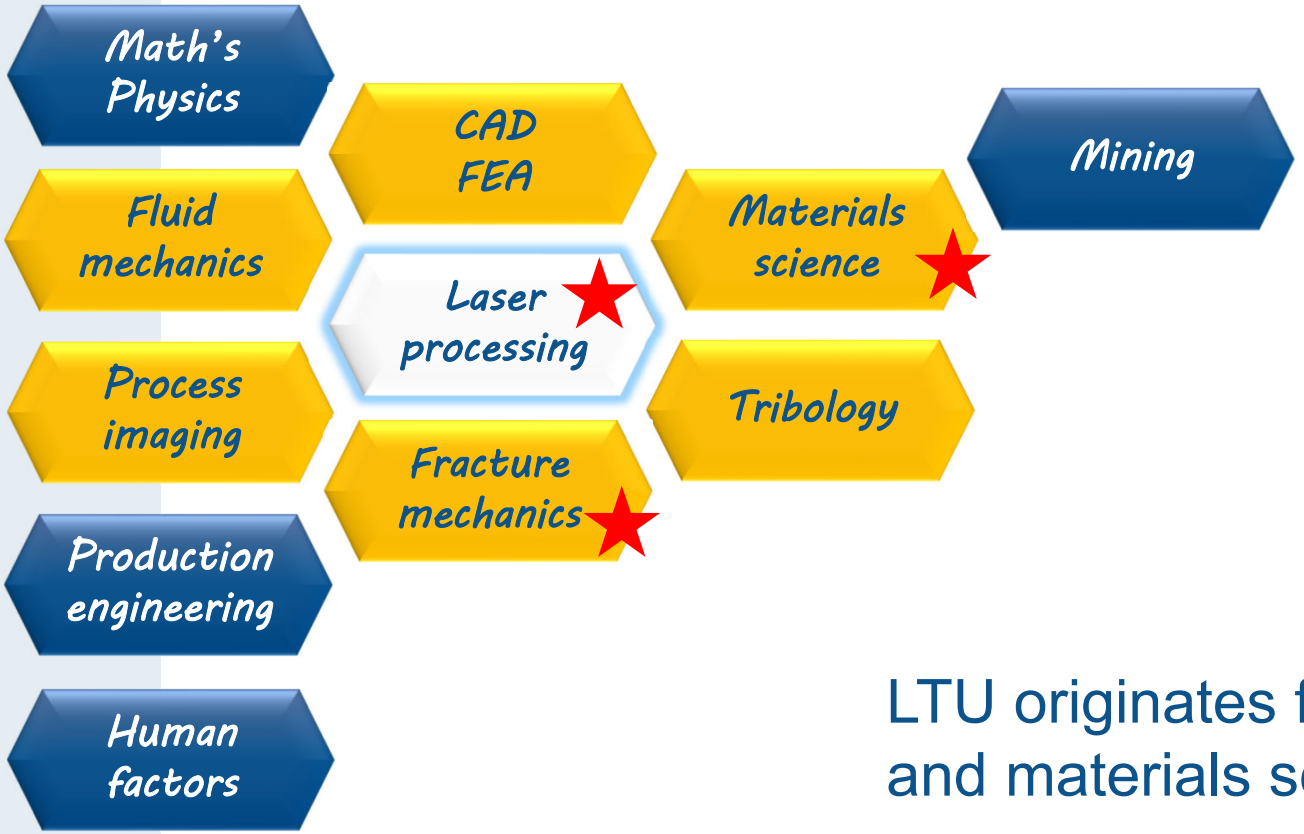
★ explicitely welding and AM

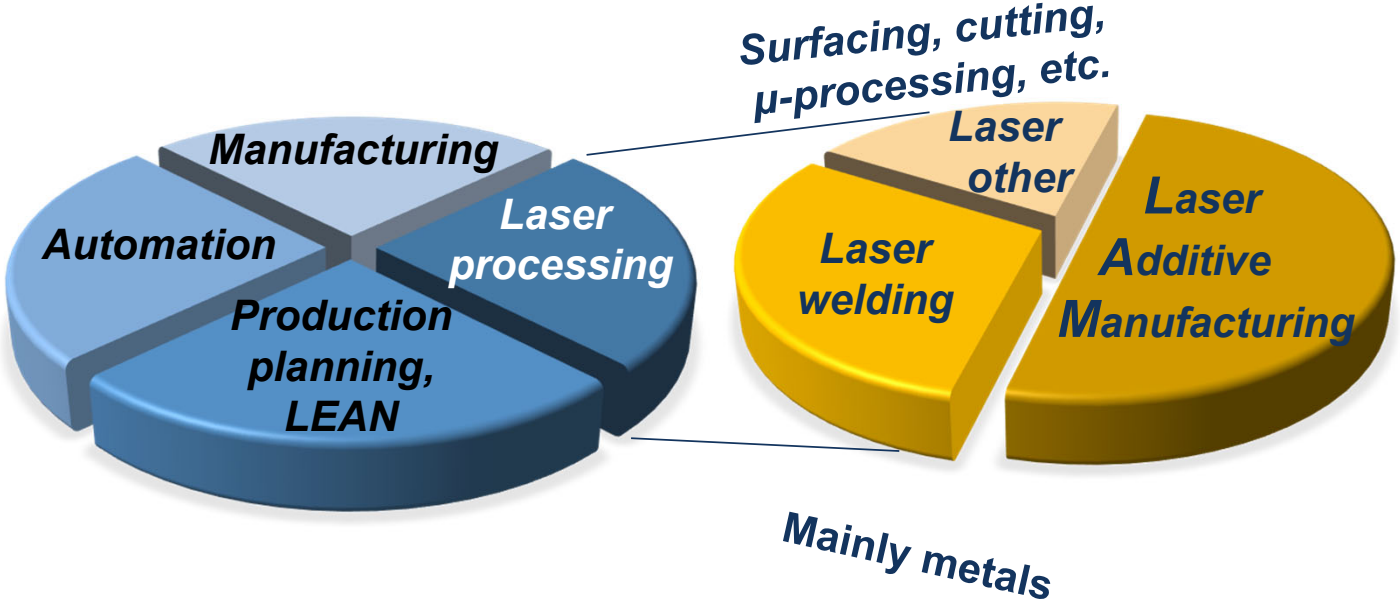


LTU originates from mining and materials science

Corporate mission and profile
Manufacturing Systems Engineering

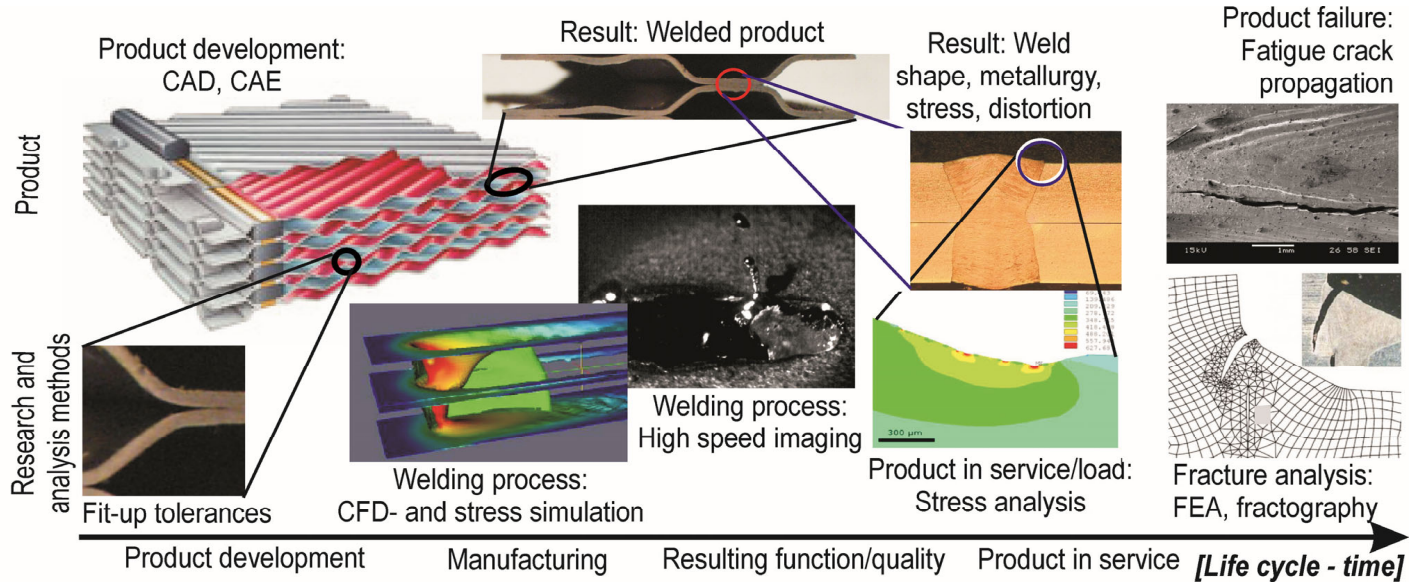
Teaching:
Production engineering

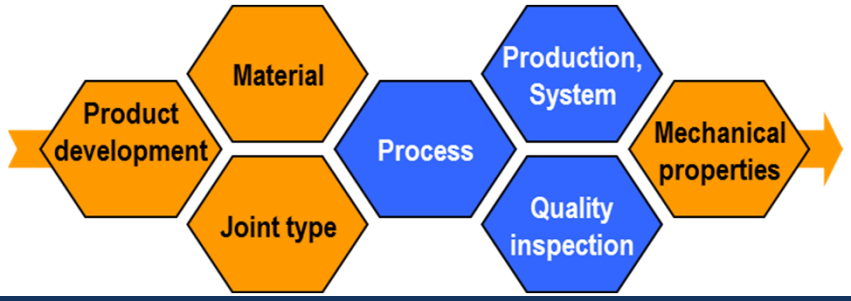
Research:
Laser materials processing



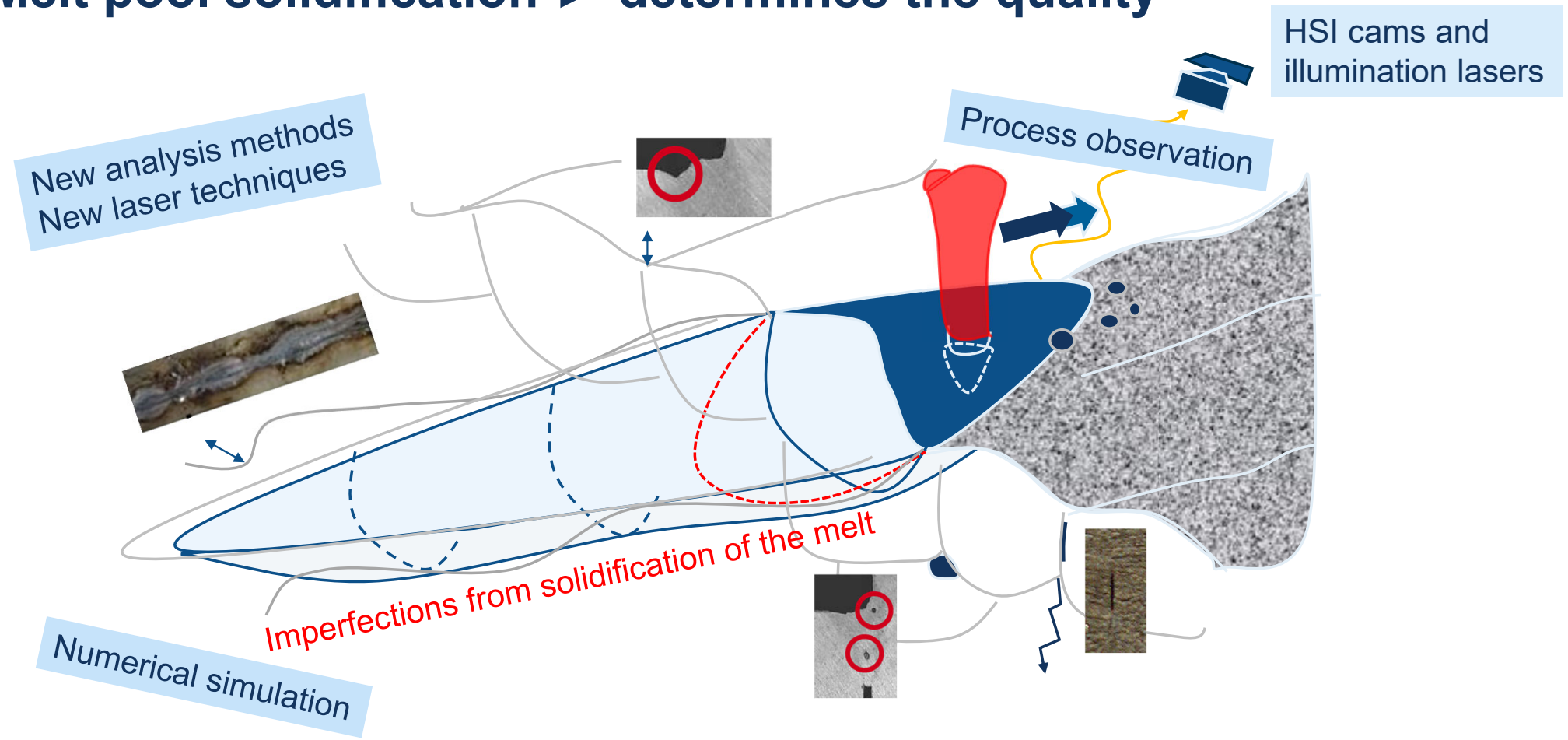
Life cycle of a weld

Product development ► Production ► Operation





Centre of research:
Melt pool solidification ► determines the quality



Laboratory equipment

Fibre lasers: 15 kW, 5 kW, 300 W, 400 W-PBF

Robots, axles <100 m/min, PBF-LB/M, DED-LB/M

Various optics, processing heads, nozzles

4 high speed cameras (up to 600 000 fps)

4 illumination Lasers for imaging

IR thermocamera

Powder delivery, wire feeding

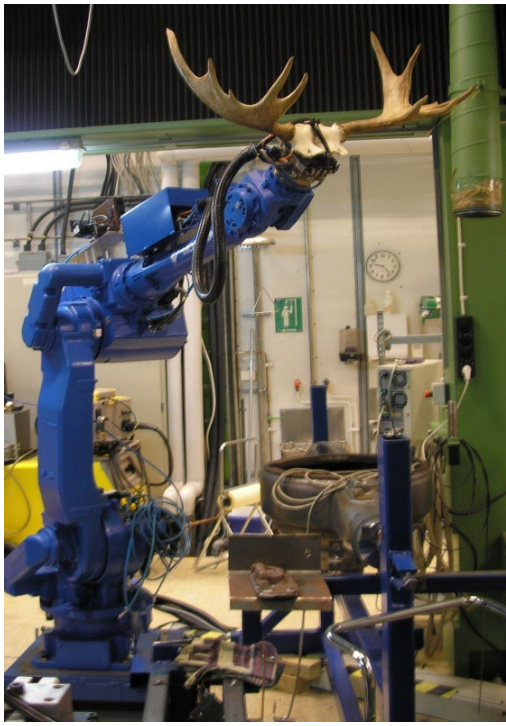
3 MAG-sources for hybrid welding or AM

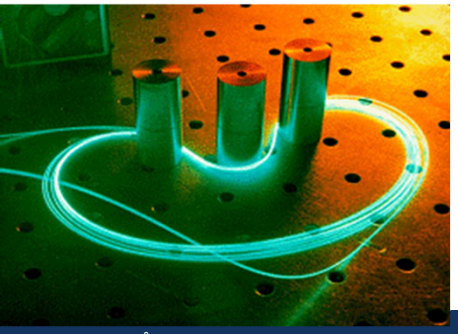
Seam tracking, beam profile, monitoring, etc.

CyberLab-conferencing

Microscopy & testing

+ Labs at IWS Dresden





Methods

Pre-process | In-situ | Post-process | In-service

Material characterization

Geometry

Scanner

High speed imaging

Thermal imaging

Spectroscopy

CFD

FEA

Modelling

Material characterization

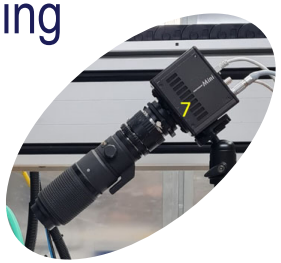
Microscopy

Scanner

X-ray µ-CT

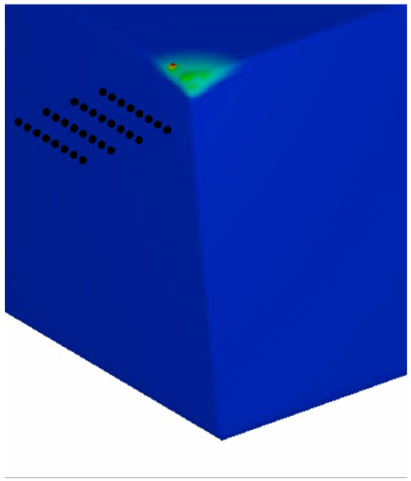
Stress analysis

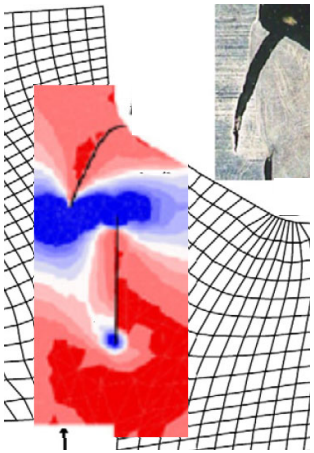
Testing

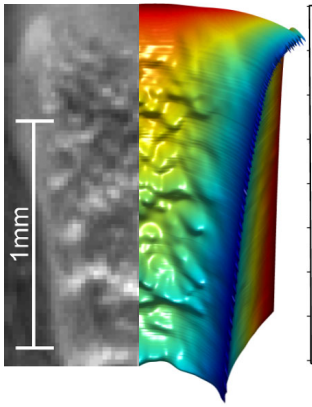


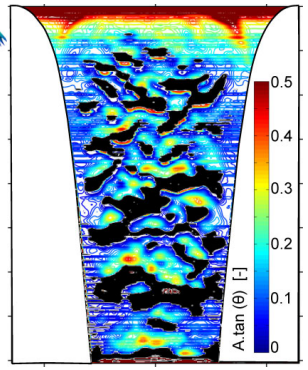
Numerical tools

- Numerical simulation of fluid mechanics by CFD
- High speed image-processing & -post-modelling





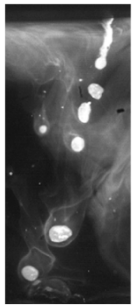


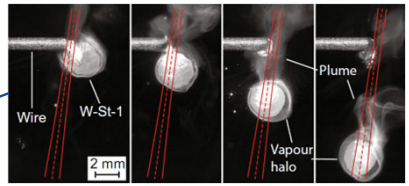


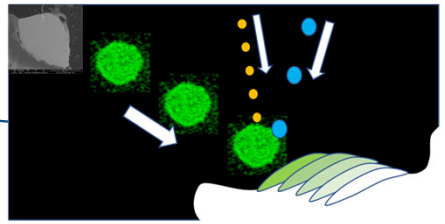
- Numerical FEA of stress and strain
- Semi-analytical mathematical models

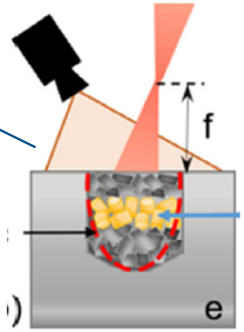
Approaches

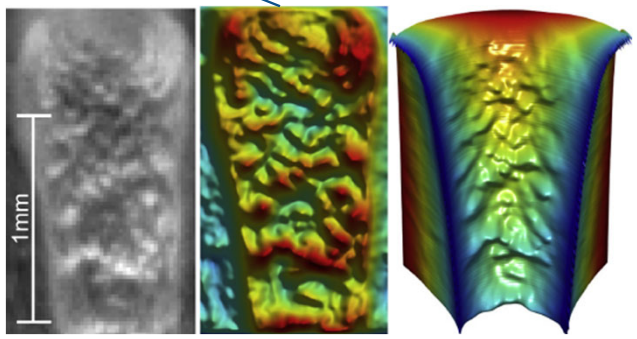
- Recycling (CYCLAM)
- Wire drop detachment (LAM-4D)
- Steelmaking (AM-ORE)
- Thermal cycle simulation (Snapshot)
- Post-modelling from HSI











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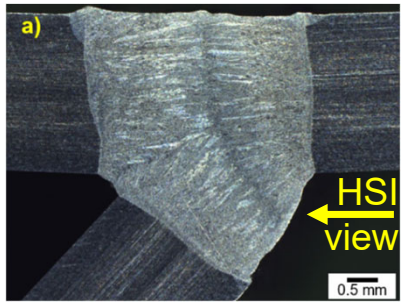
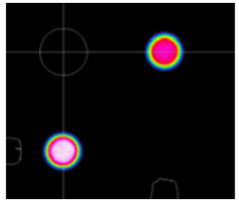
Summary

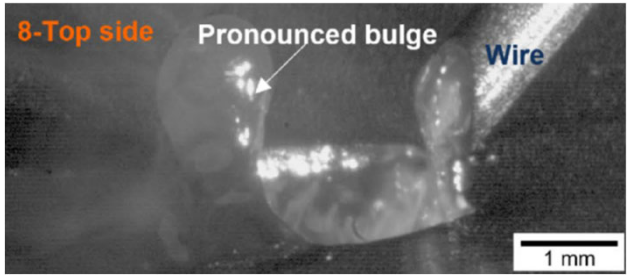
Project LUV 2 – laser welding of hydrogen storage

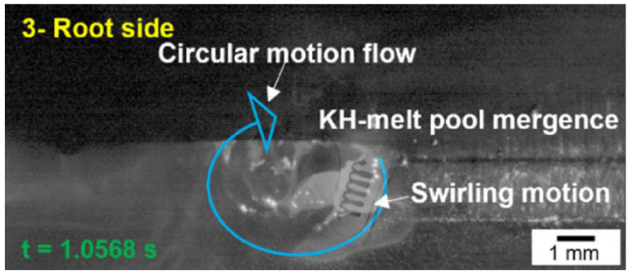
Asymmetric T-joint welding: complex geometry

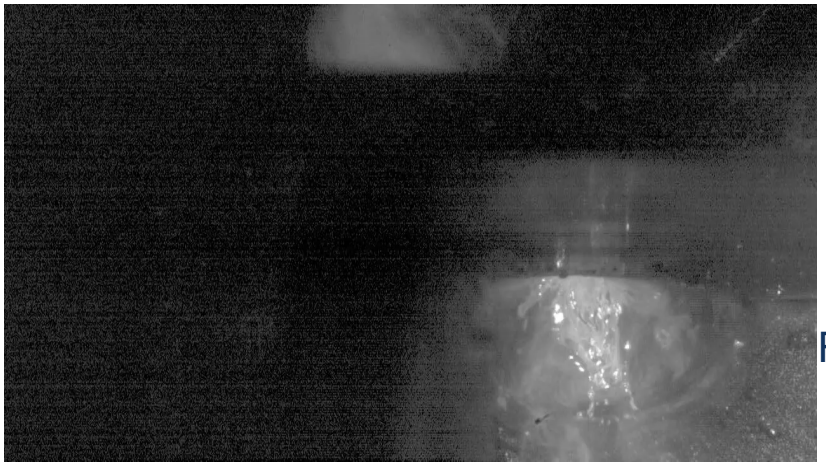




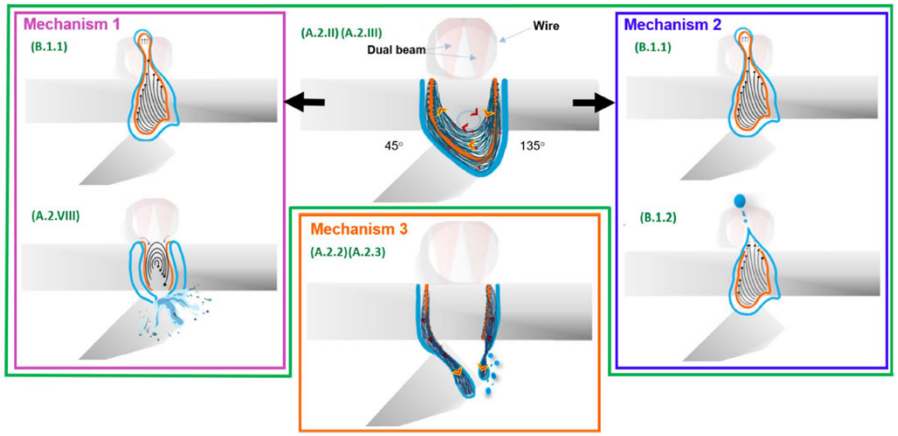
- Wire feeding
- Melt pool manipulation
  by beam shaping:
  multi-spot vs. scanner







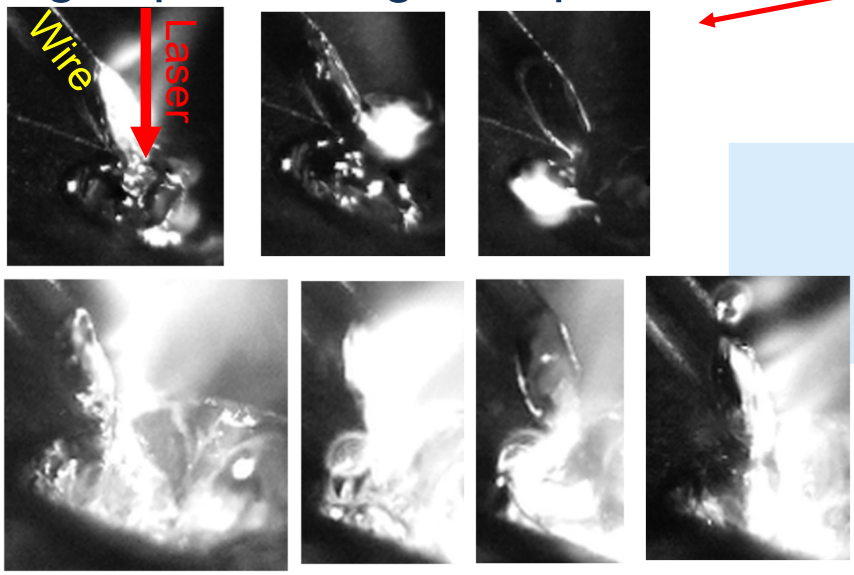
Complex melt flow
► theory

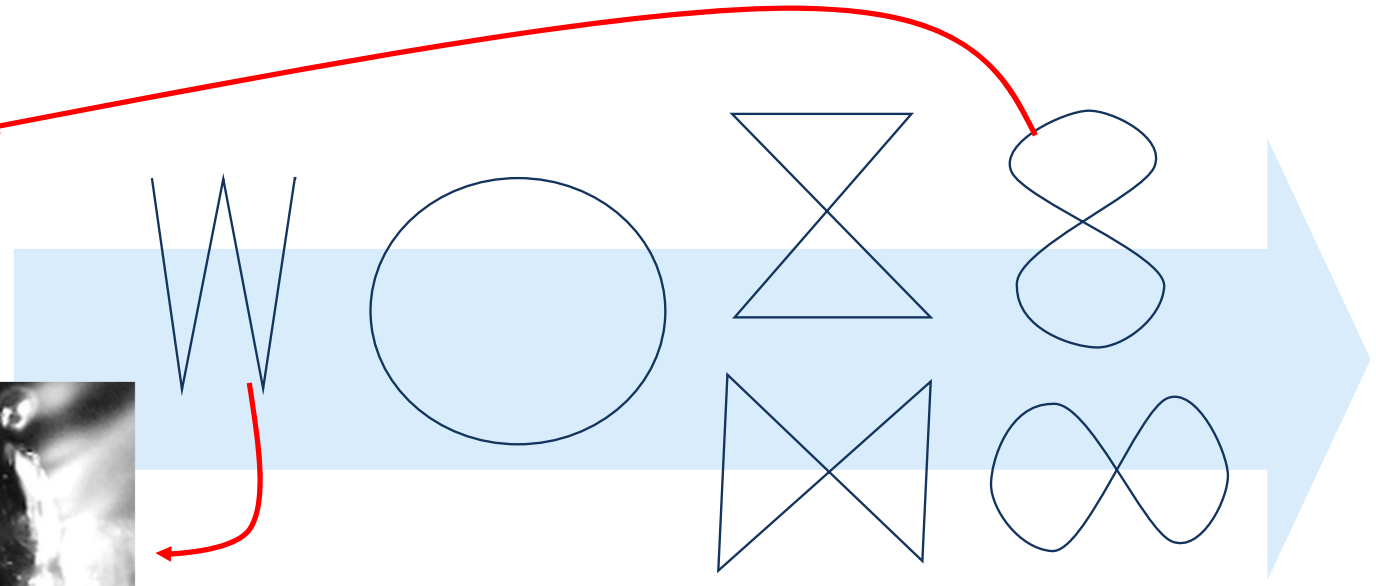


LUV 2: Scanner very flexible for beam shaping and melt flow

Beam shapes studied:

High speed images, top view



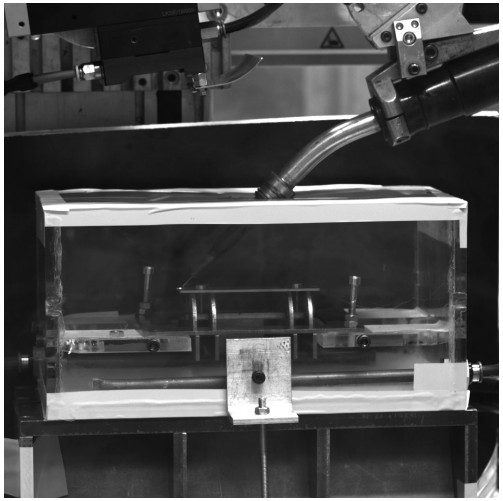


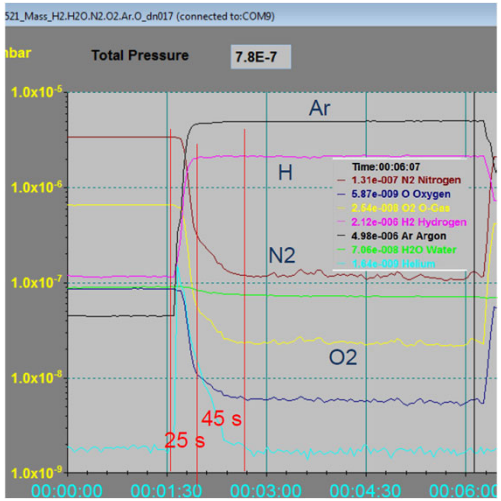
Zig-zag works very well for the present application

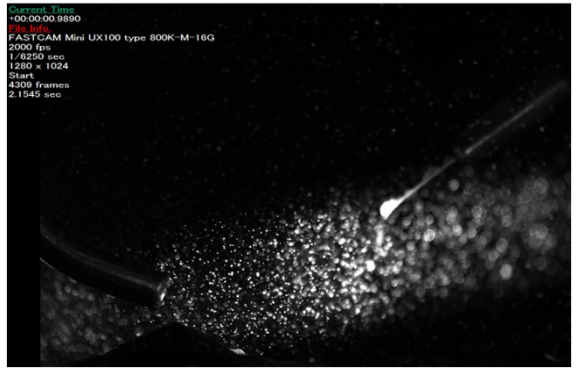
Rounded shapes would avoid sharp direction changes, for example spatter

LUV 2: Various methods to study shielding gas mixture and flow

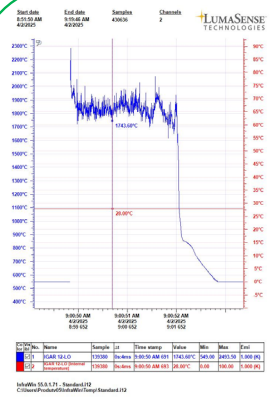
Gas box filling, and cross jet:
Visualized by smoke generator;
gas chemistry by mass spectrometer

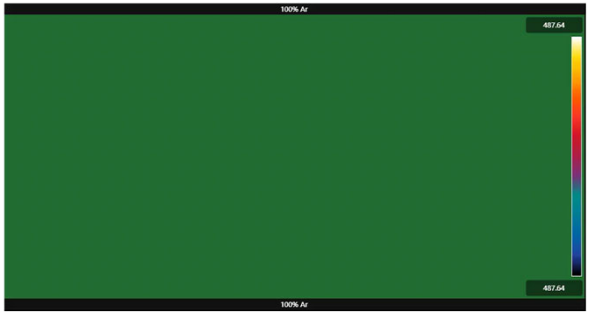






Nozzle gas flow:
Visualize by bubble generator





Pyrometer and IR-thermocam

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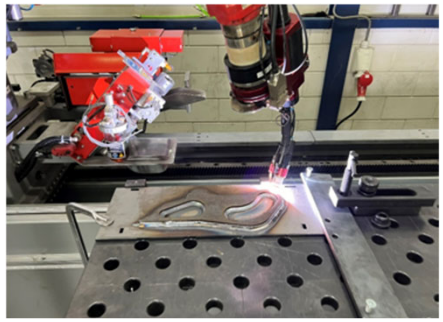
Summary

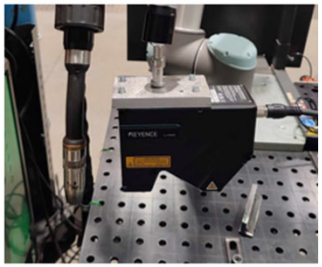
Project SIMS – extending fatigue life for laser arc hybrid welding, GMAW and WAAM

Welding (or AM) ►Topology ►Fatigue testing ►Crack initiation ►Fatigue life

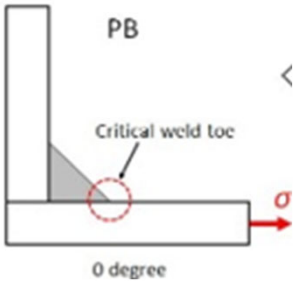
Process imaging *Scanner+SW* *AI-correlations* *Camera* *Better standards*

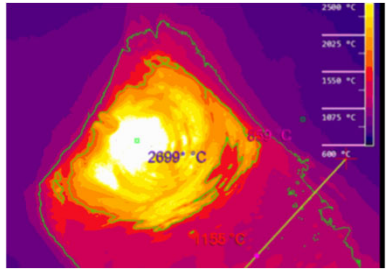


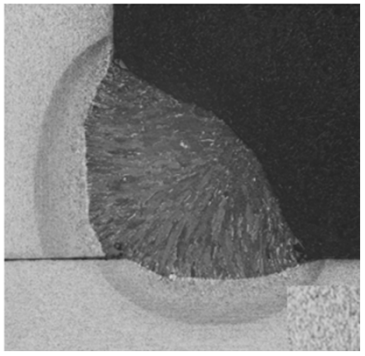
Laser Scanning by Smulders/HIAB

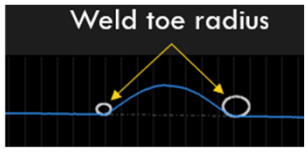


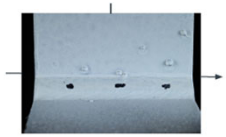
Laser Scanning by BWI

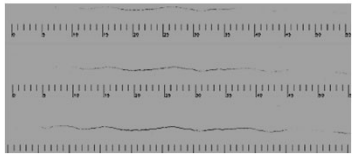










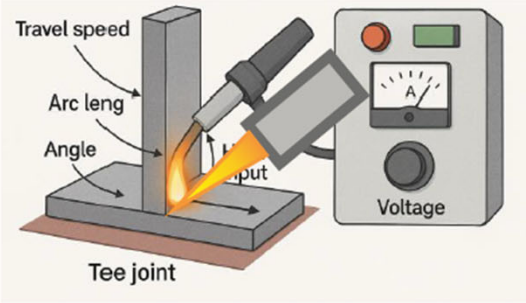


HIAB
Volvo CE
Winteria
also KTH
& Belgium

Laser Arc Hybrid Welding SIMS

Weld goals: Quality level C, A2/A3 throat thickness, no undercut, Toe radius > 1mm

Input parameters



9 parameters varied

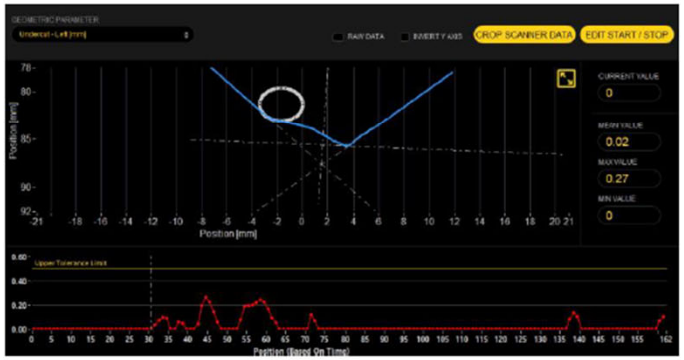
Welding

44 samples welded

HSI monitoring

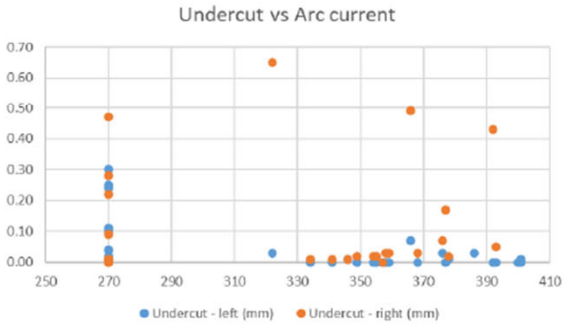
32 samples monitored

Weld quality inspection



37 samples inspected in Winteria

Analyzing the data



5 topological features studied

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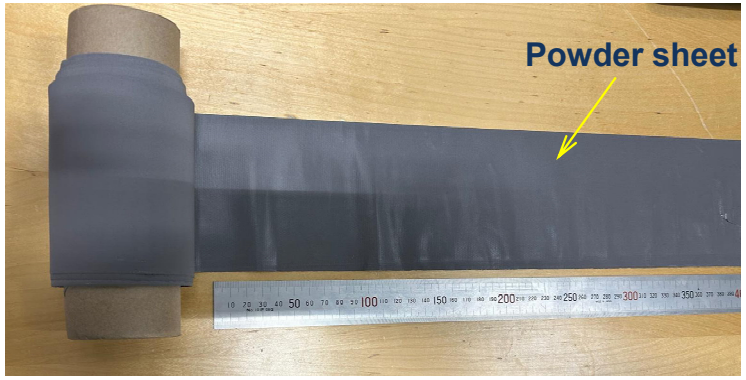
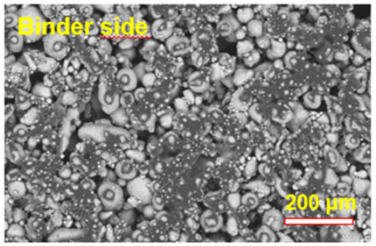
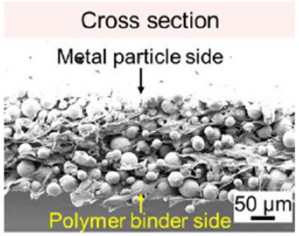
Project PosAddive – AM with Metal powder / binder sheets

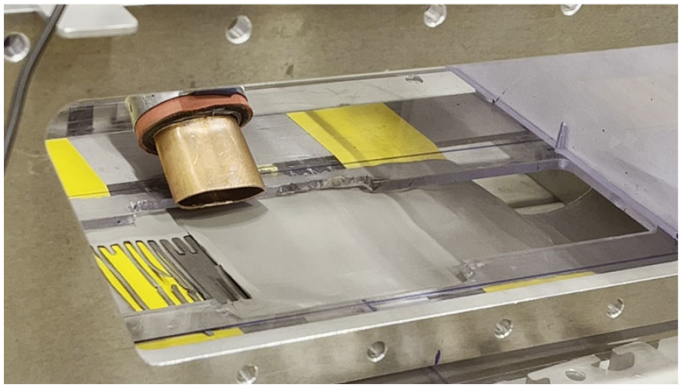
Powder sheets cast with binder

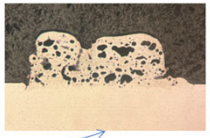






Laser melting of tracks, binder evaporates

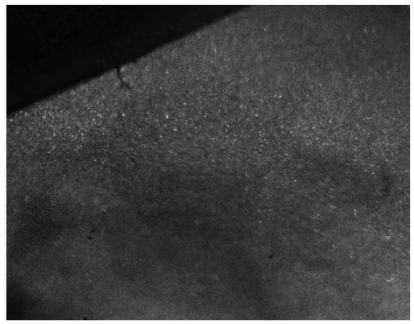




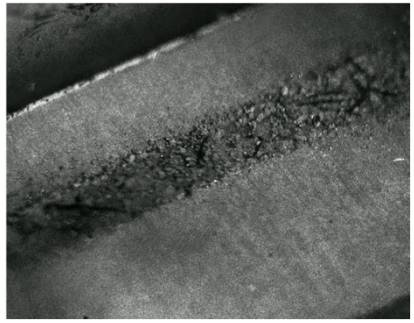
First demonstrators;
Binder causes porosity

No issues with lose powder before, during and after the process

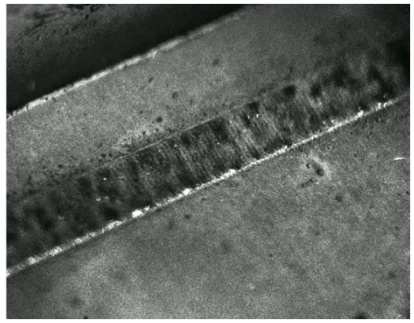
Scanned laser beam enables laser remelting and cleaning steps



Melting of substrate and 1st sheet

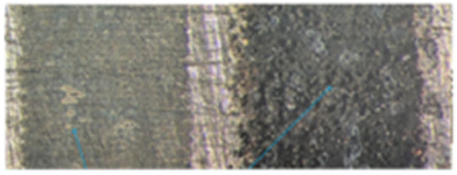


Remelting #1

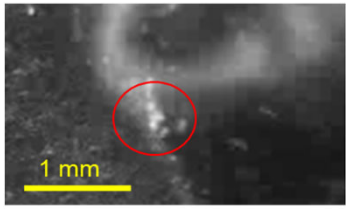


Cleaning

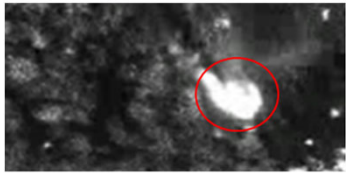
Flexibility of sheet melting by a scanner beam



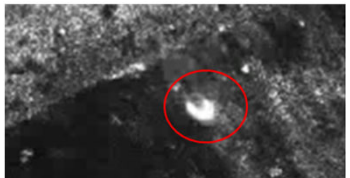
Melting of substrate and sheet



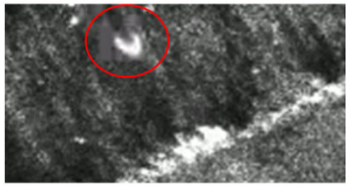
Remelting #1



Remelting #2



Remelting #3



Cleaning

Relevant **resources at LTU**

Laser welding project examples:

- Laser welding of T-joints
- Fatigue of hybrid and arc welding

Laser AM project examples:

- Metal powder sheets for AM
- Drop-on-Demand from wire
- Powder by DoD recycling
- Direct ore powder reduction
- Schlieren imaging of AM

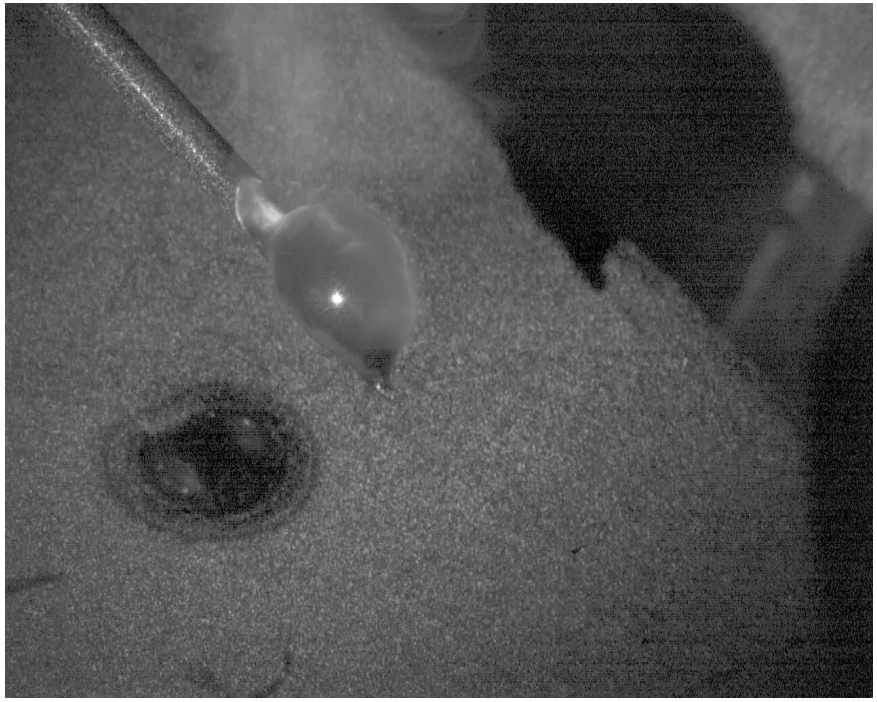
Summary

Project IDiD – AM by laser drop deposition from wire

Drop-on-Demand approach
Every drop can be placed, as voxel

Here: DoD from wire, laser melted
Ablation pressure from boiling

Different pros and cons
Multi-material combinations, e.g. Cu-SS



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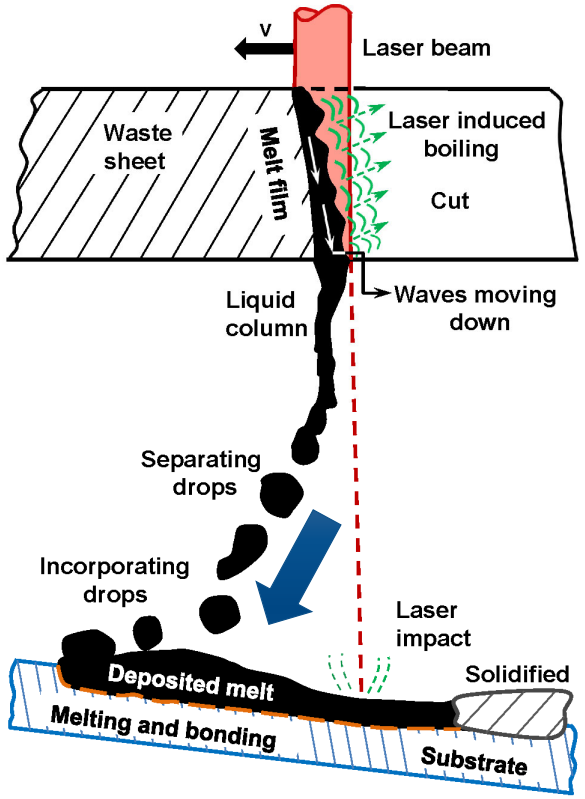
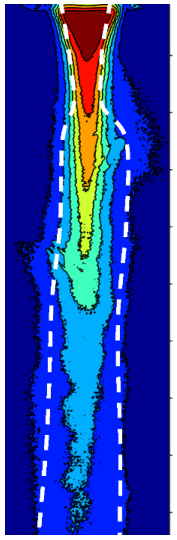
Summary

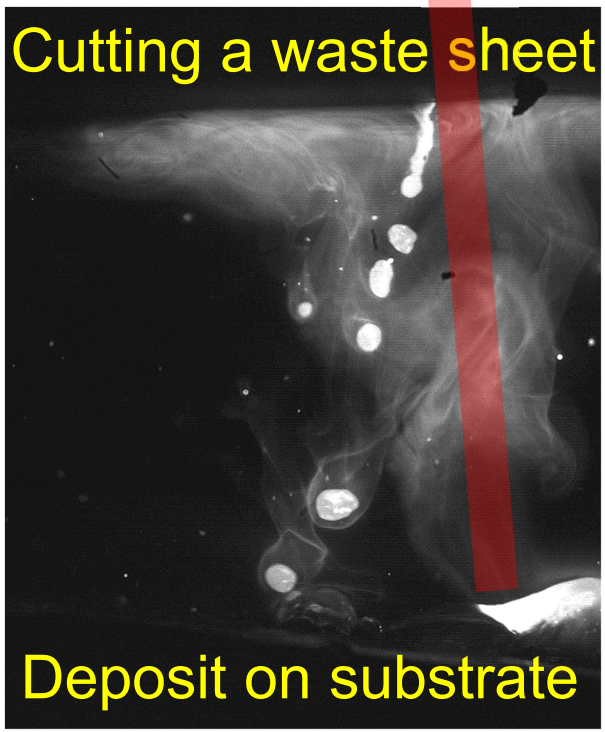
Project REPAM: Recycling of metal powder for AM

Applying the CYCLAM technique of LTU:
Waste ► Laser-induced Drop-on-Demand ► powder ► AM

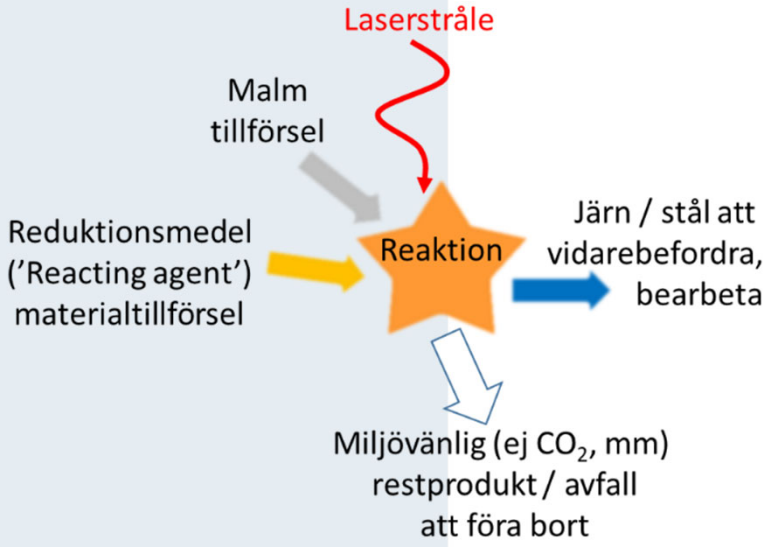




Drop jet



Coordinator: KTH



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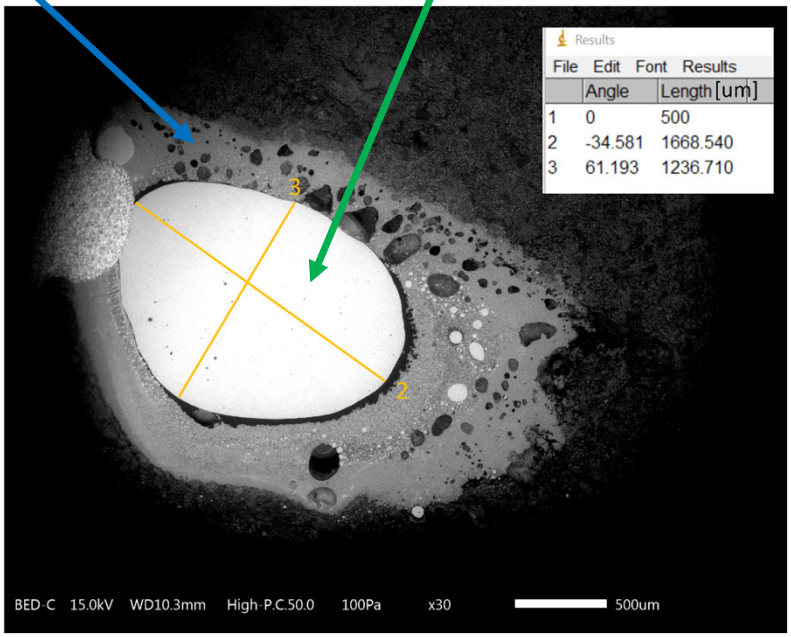
Summary

Project AMORF: Laser-driven direct reduction of iron ore powder

The laser beam melts a combination of iron ore powder and a reacting agent

The oxygen moves to the reacting agent, here Ca, and highly pure Fe remains



Ideally, the Fe-drop is used for AM, and alloyed

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Summary

Industrial PhD-student at Jenoptik, Germany

Benedikt Brandau: PhD in June 2025: “Optical monitoring of laser AM”

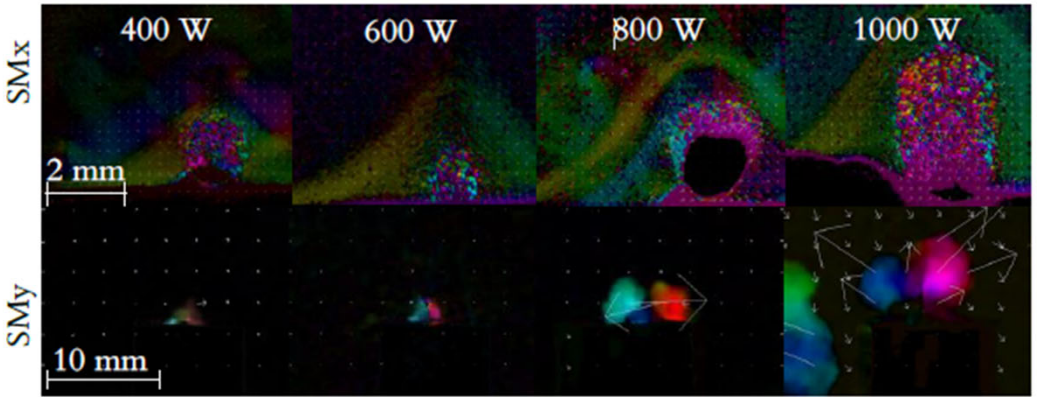
Imaging of the gas flow

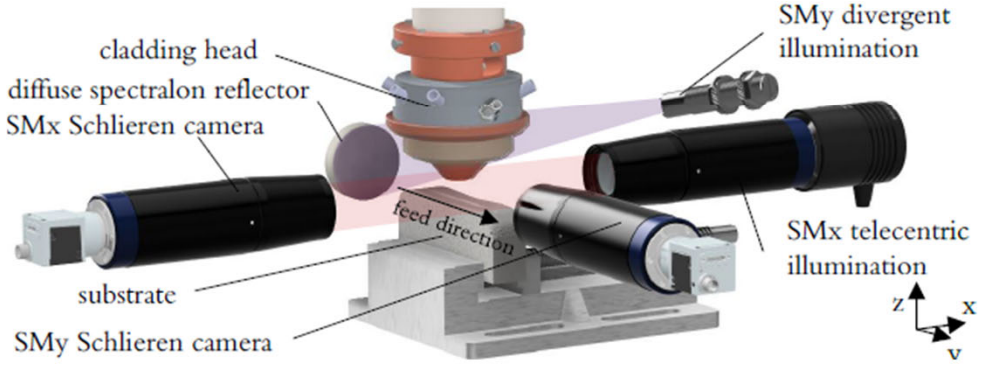
Manifold methods

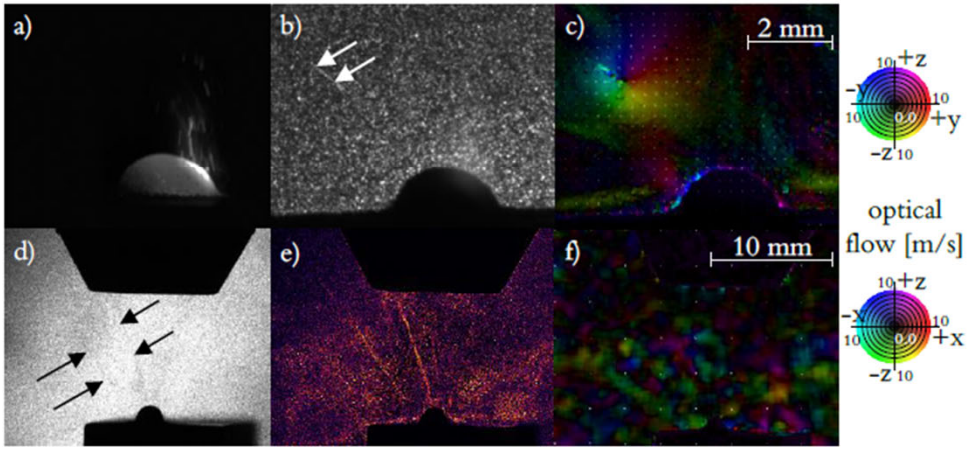
Schlieren imaging

Data-post-analysis

Phenomena then visible







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Summary

Summary

- Expertise on laser welding and AM processes at LTU
- High speed imaging and other in-situ methods provide additional information
- More accompanying calculations, like CFD, are desirable
- New AM approaches are proposed and studied, like powder sheets, drop-on-demand from waste, or direct reduction of iron ore
- Laser beam shaping provides flexible process manipulation, in welding and AM
- Much potential for innovative techniques, supported by research methods