Control of Residual Stress, Distortion and Mechanical Properties in WAAM Ti64 Parts

Cranfield UNIVERSITY

Jan Roman Hönnige

Welding Engineering and Laser Processing Centre

www.cranfield.ac.uk

Cranfield University

Welding Engineering and Laser Processing Centre
School of Aerospace, Transport & Manufacturing

- International Post-Graduate University
- Applied Research
- 50% of UK Aerospace Post Grad Degrees

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Welding Engineering and Laser Processing Centre
School of Aerospace, Transport & Manufacturing

- **The Department**

Arc- and Laser Welding
CNC & Robotic Manipulators

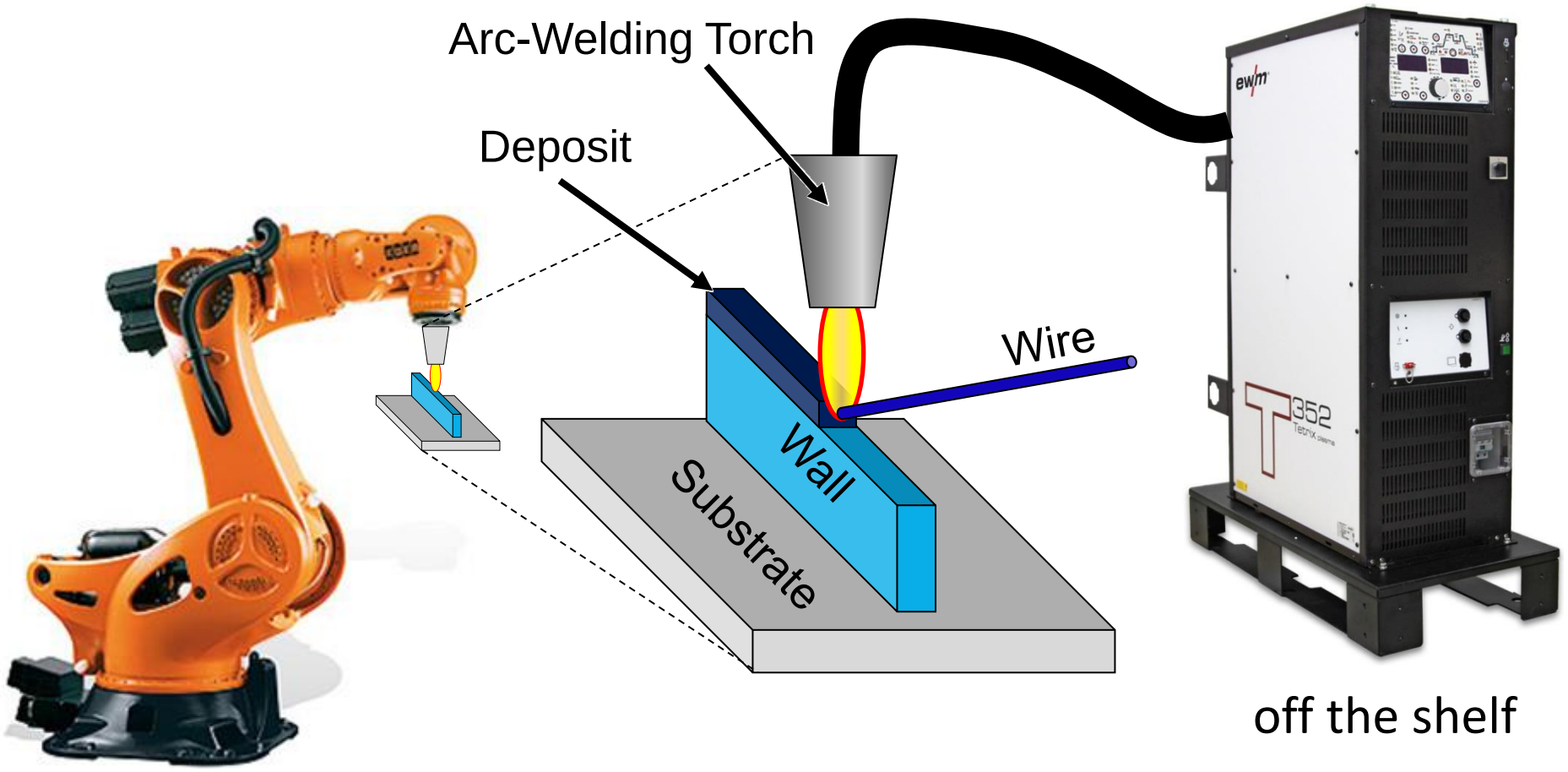
- **What we do**

Large Scale Metal AM
And more…

- **Material Range**

Aluminium, **Titanium**,
Mild/Stainless/Maraging Steel
Super Alloy, Invar,
Molybdenum, Tantalum, Tungsten

Wire + Arc Additive Manufacture (WAAM) Process



Expertise

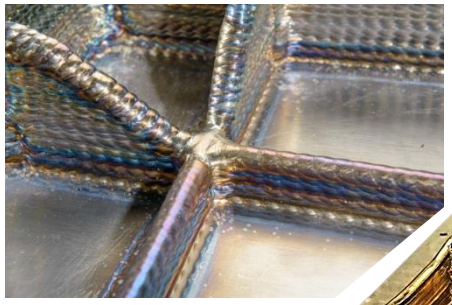
INPUT

- Welding Current
- Travel Speed
- Wire Feed Speed
- Wire Position
- Torch Position
- Gas Flow
- Initial Temperature
- Geometry
- more

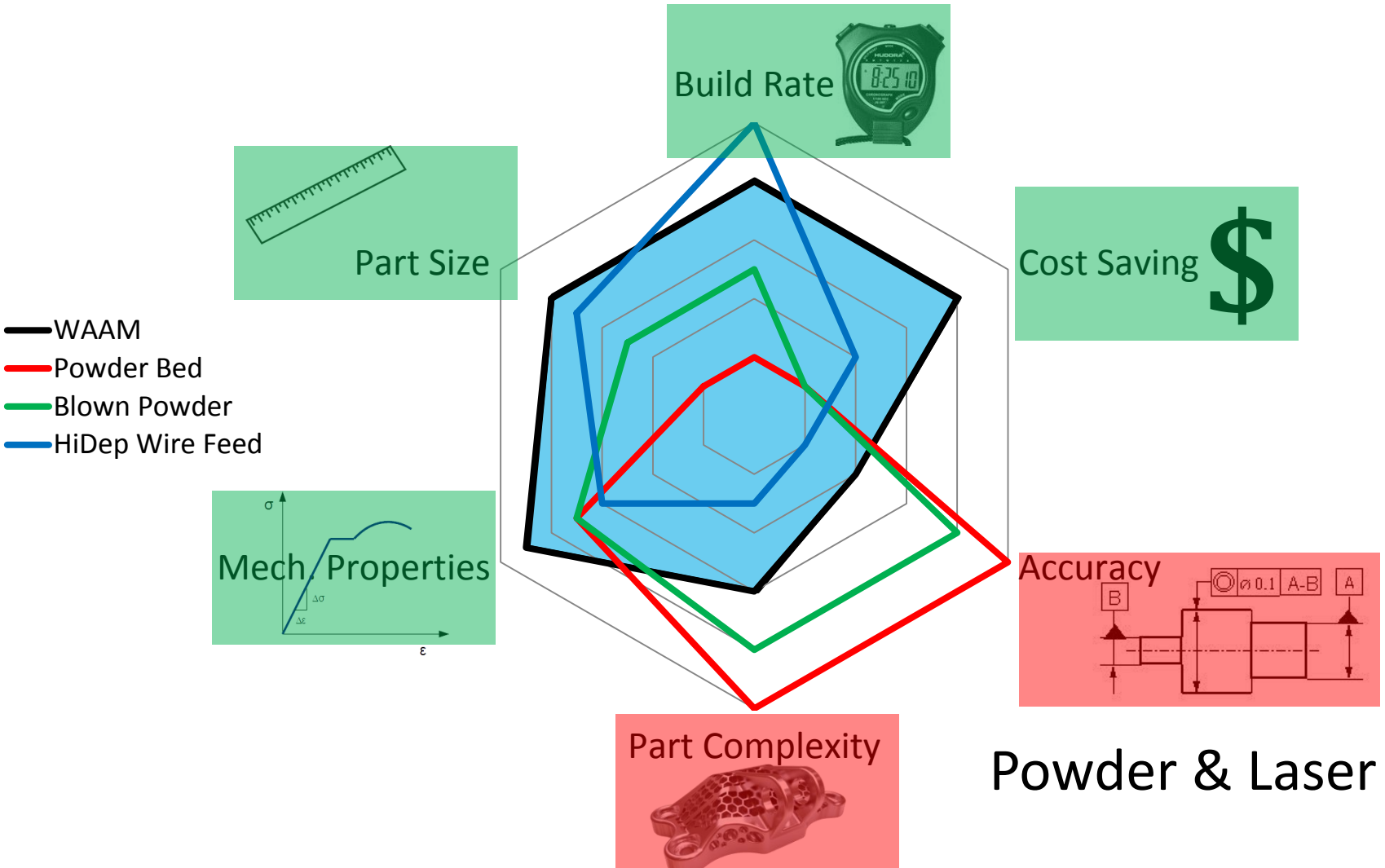
Experience

OUTPUT

- Wall Geometry
- Surface Quality
- Microstructure
- Mechanical Prop.
- Porosity (Aluminium)
- System Feedback
- more



Processes comparison



Powder & Laser

Wire + Arc Additive Manufacture (WAAM) Process

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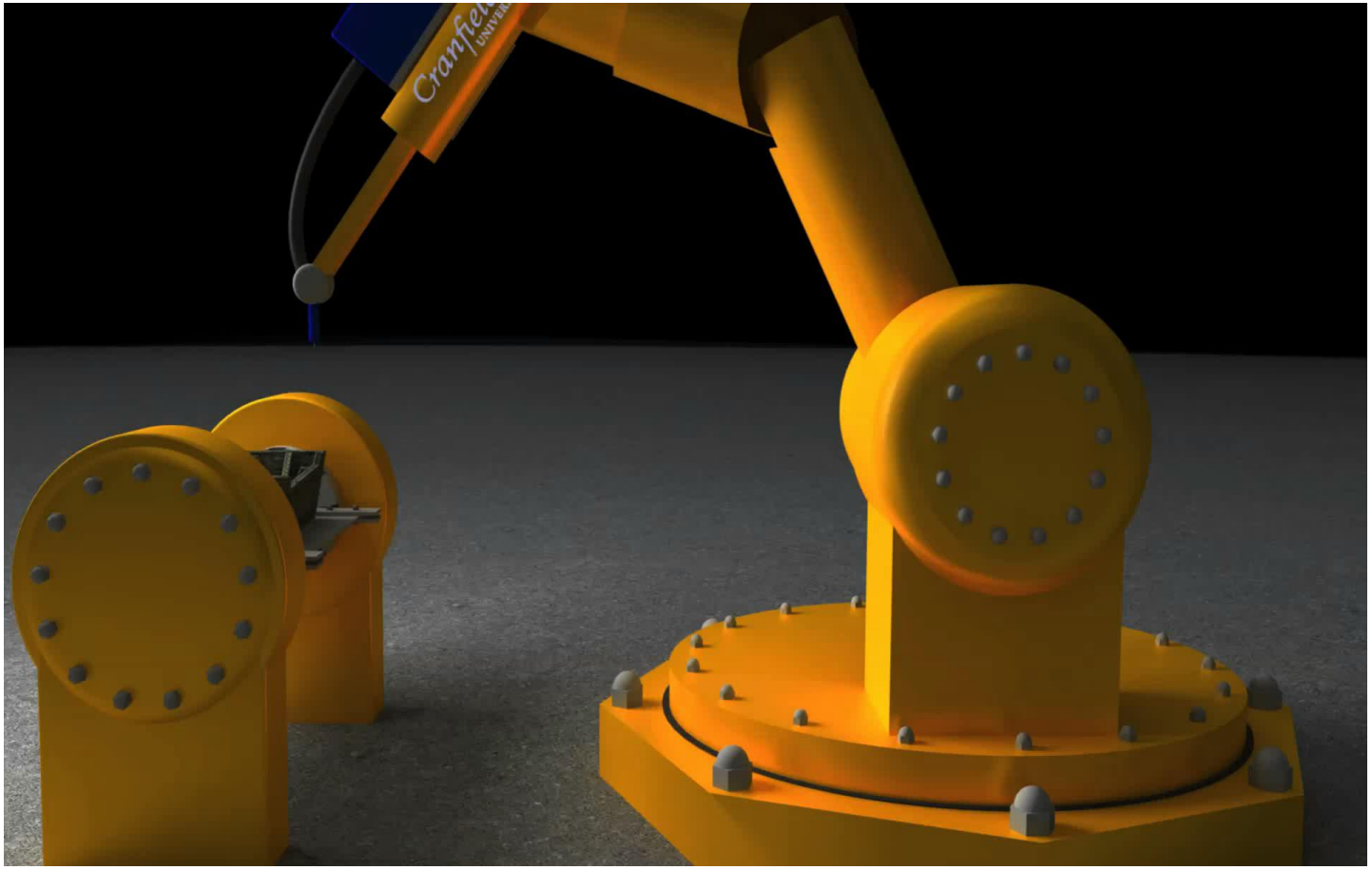
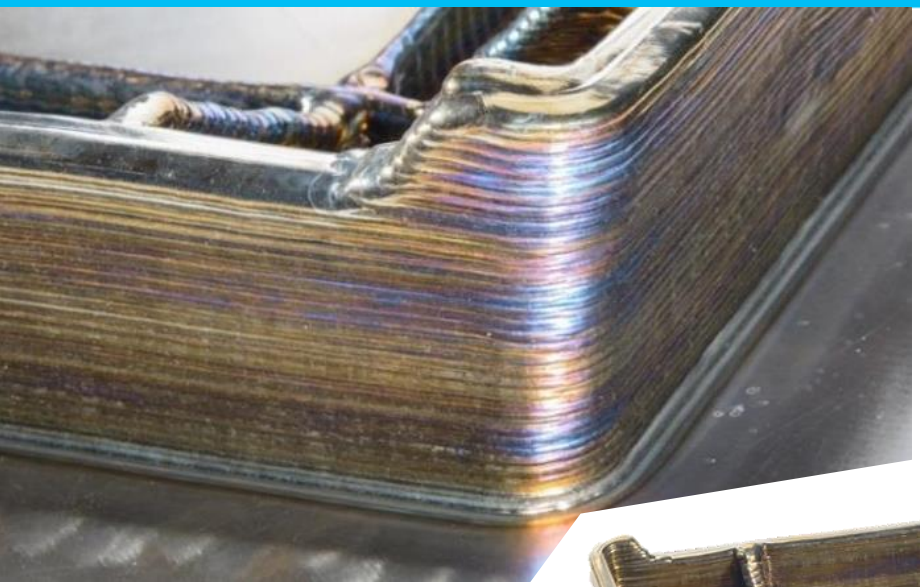
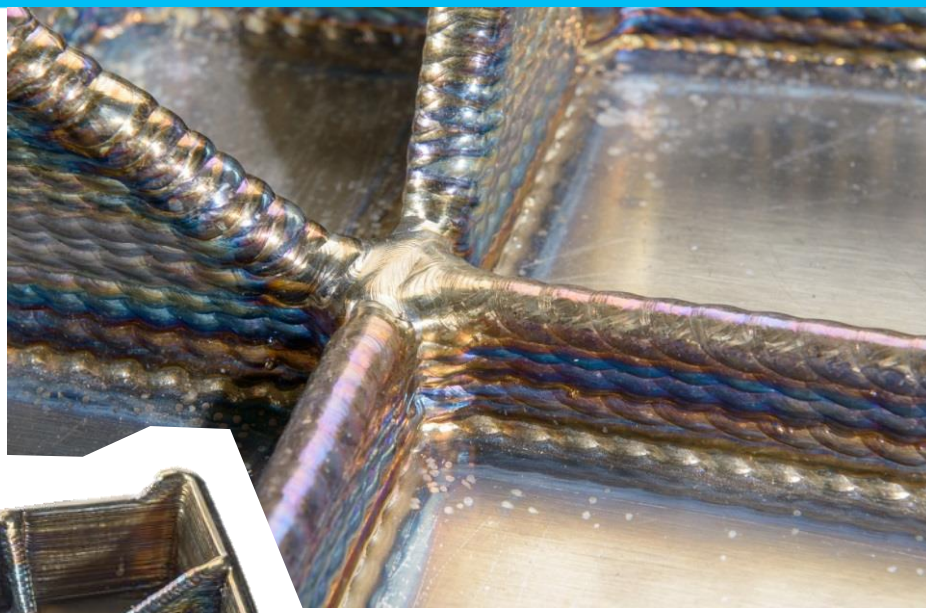
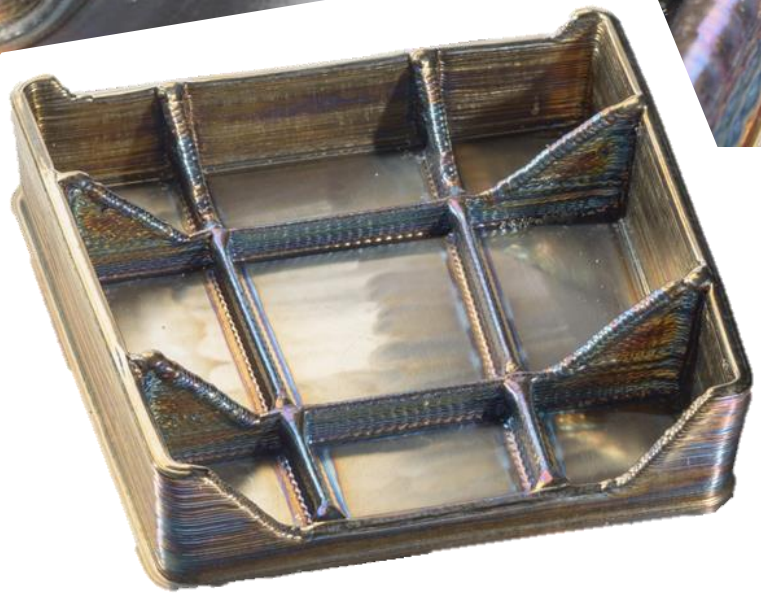
Metal 3D Printing



WAAM







Ti-6Al-4V
Landing Gear Rib
~ 20kg 0.7m
BOMBARDIER

WAAM vs. Machining = Additive vs. Subtractive

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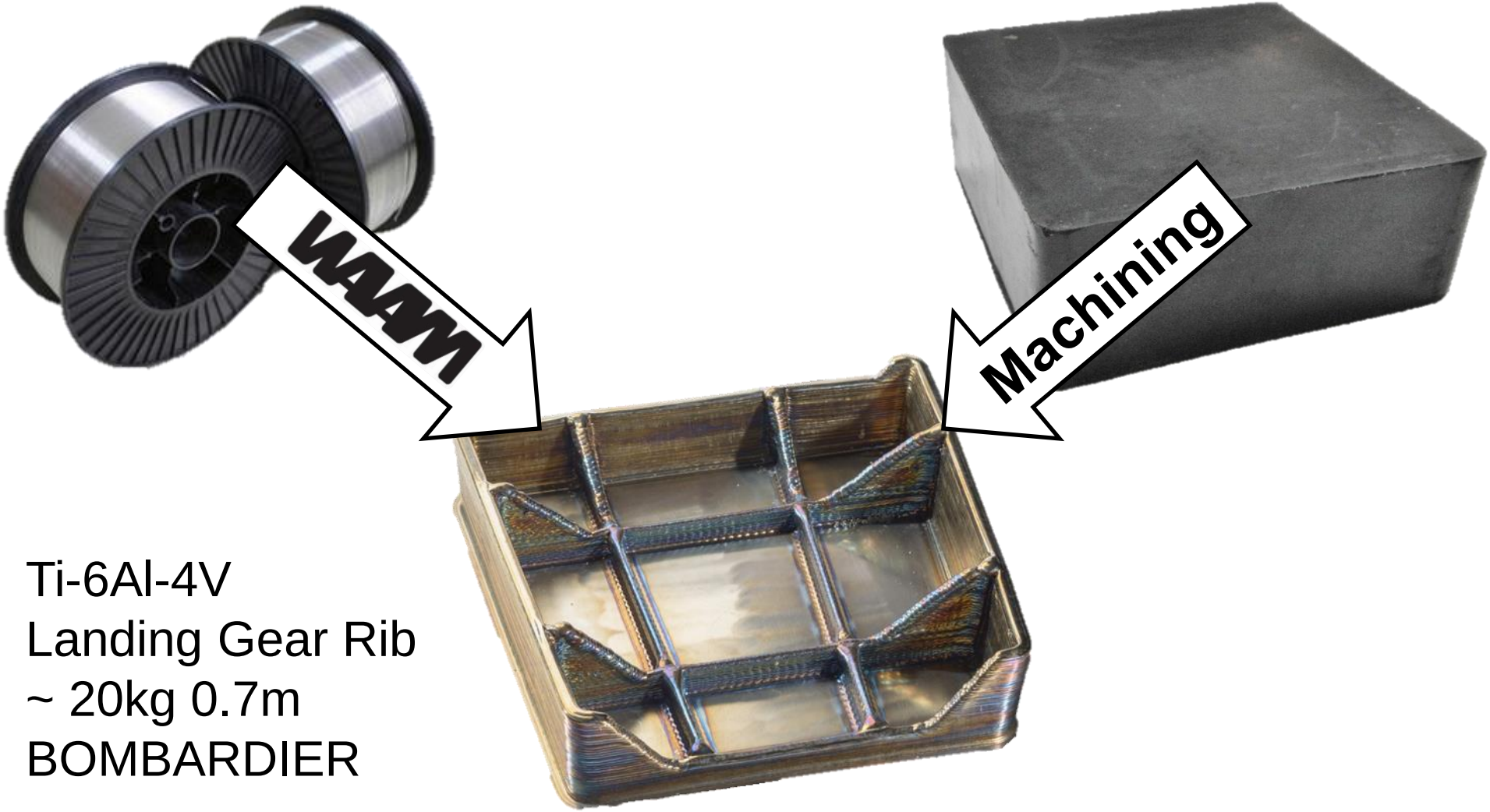

Ti-6Al-4V
Landing Gear Rib
~ 20kg 0.7m
BOMBARDIER

WAAM vs. Machining = Additive vs. Subtractive

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	Raw Material	BTF	Cost
Machined from Solid	Billet **240 kg**	**12**	**23,650 $**
WAAM + Machined	Substrate + Wire **46 kg**	**2.3**	**7,300 $**

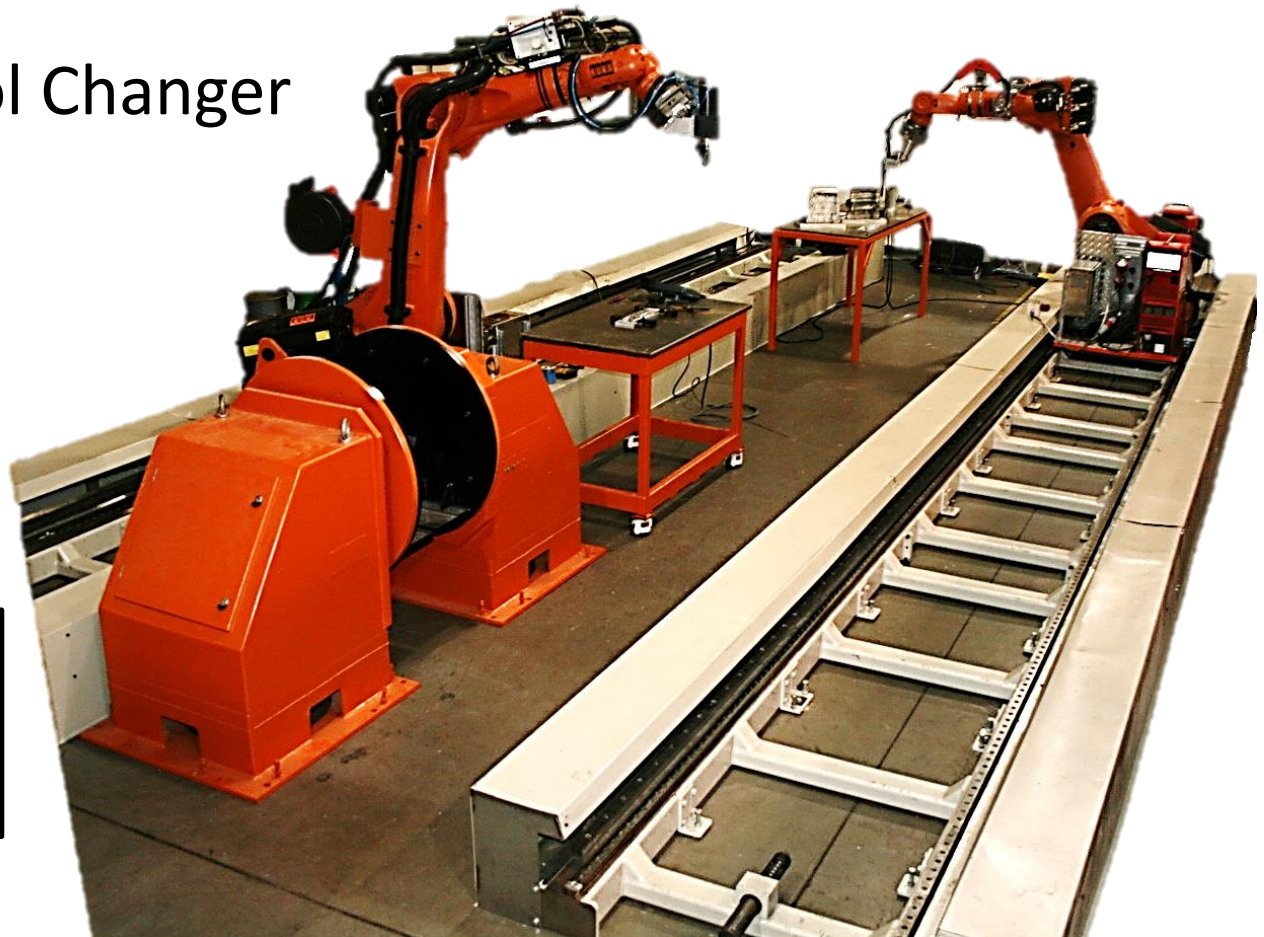
Ti-6Al-4V
Landing Gear Rib
~ 20kg 0.7m
BOMBARDIER

System:
Open Robot Cell

- Twin 7 Axis Robot System on Rails
- Customizable Tool Changer
  - Welding Torch
  - Machining
  - MH Peening
  - more

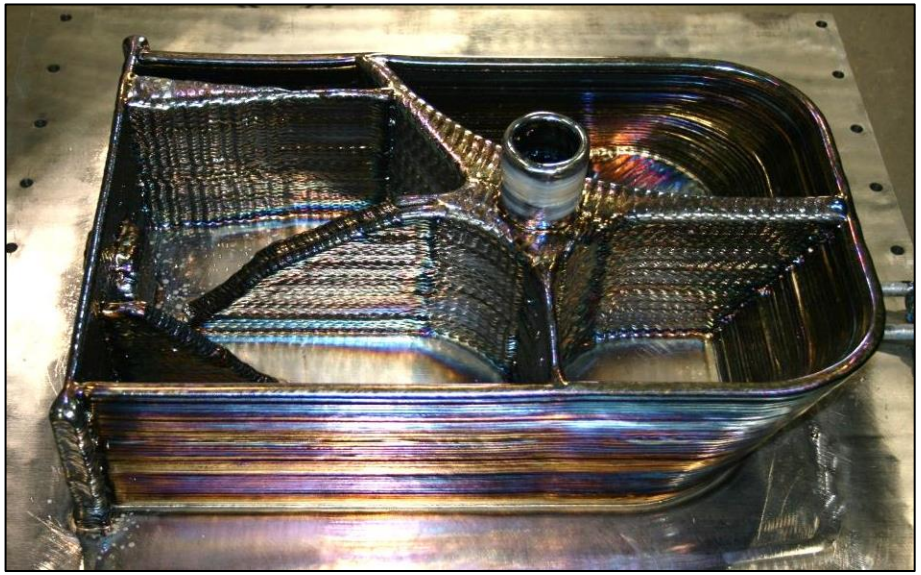
Possible:

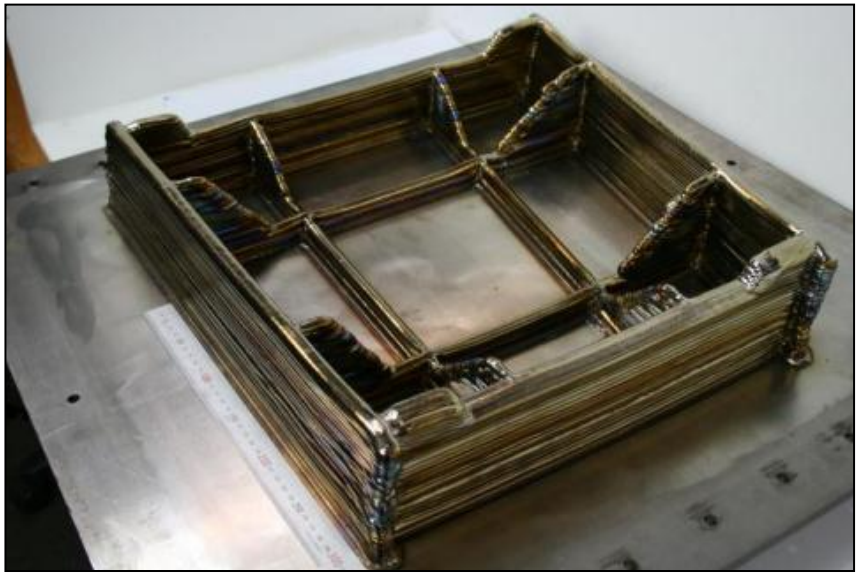
Parts > 10 m



WAAM: Advantages

- Material / Time / Cost Saving
- Mechanical Properties
- Part Size > 10 m

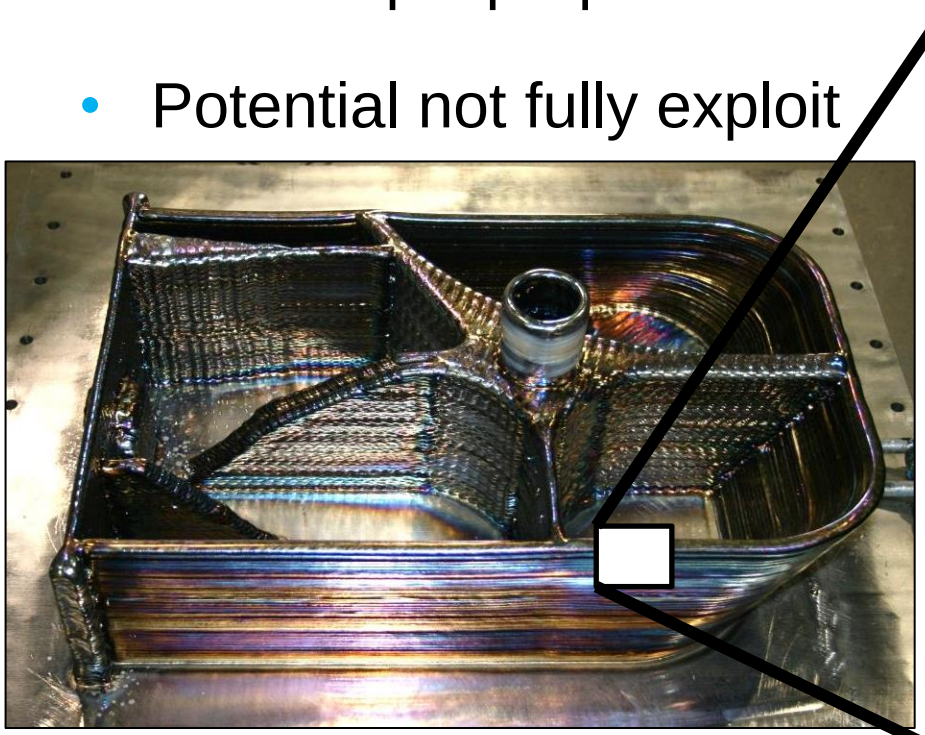




Ti-6Al-4V demonstrator components

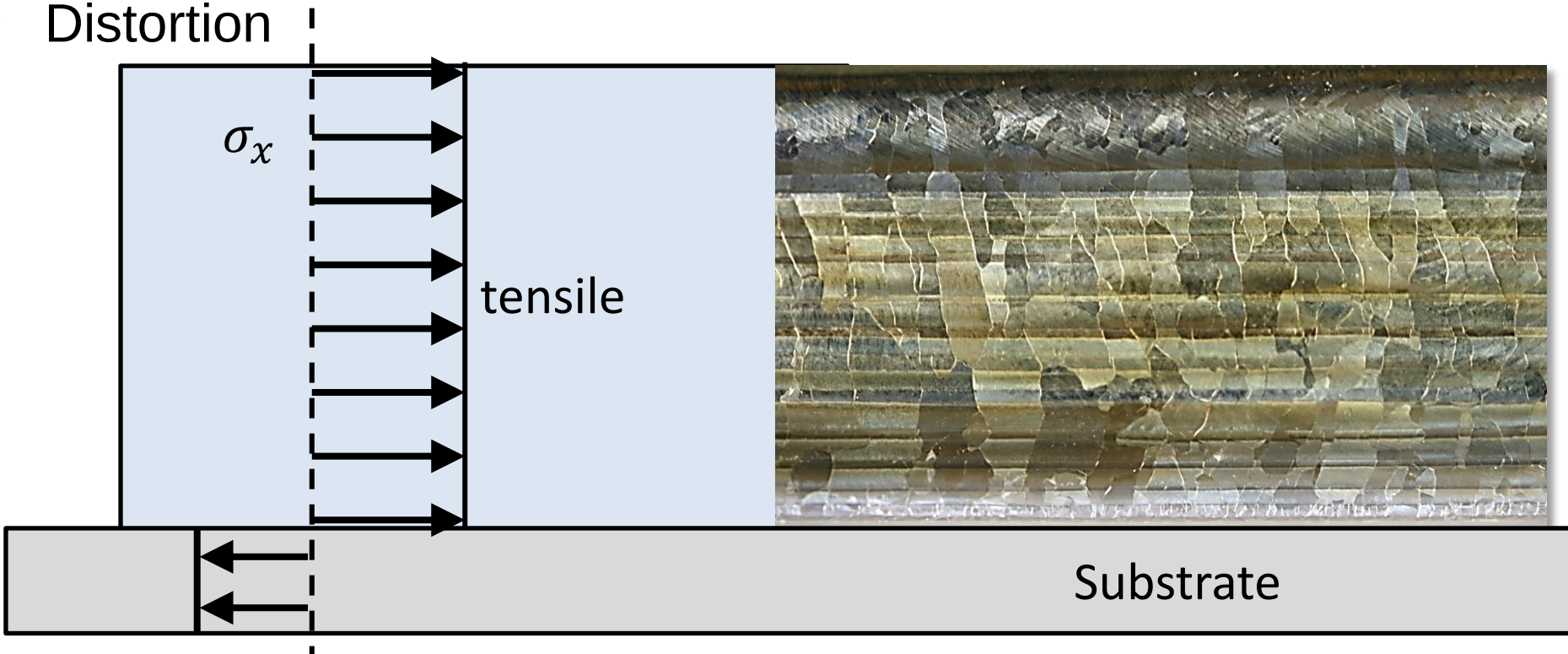
Issue A:
Grain Growth

- Large columnar grains
- Anisotropic properties
- Potential not fully exploit



Issue B:
Residual Stress and Distortion

- Constant tensile stress in wall
- Unbalanced stress condition
- Distortion

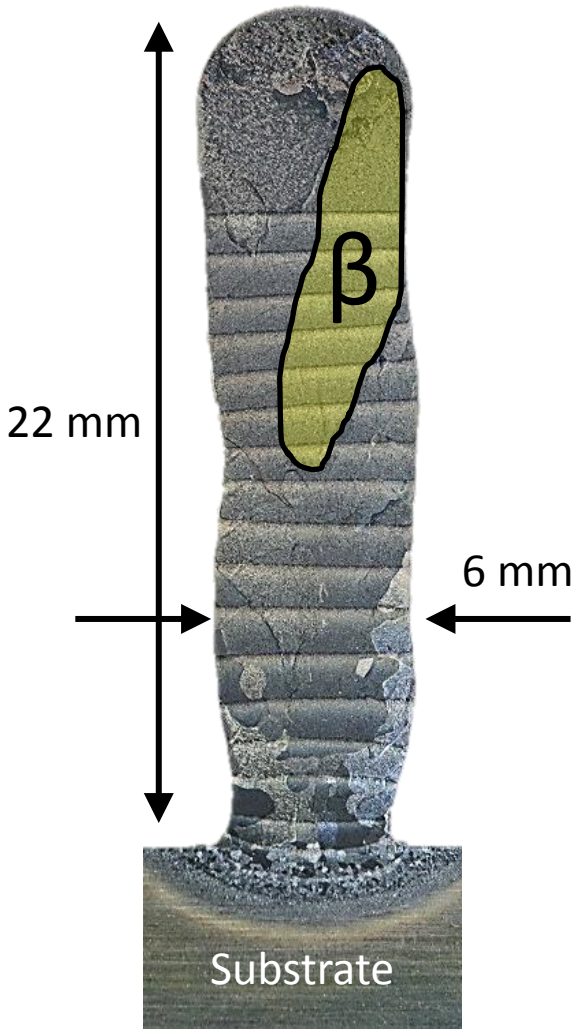


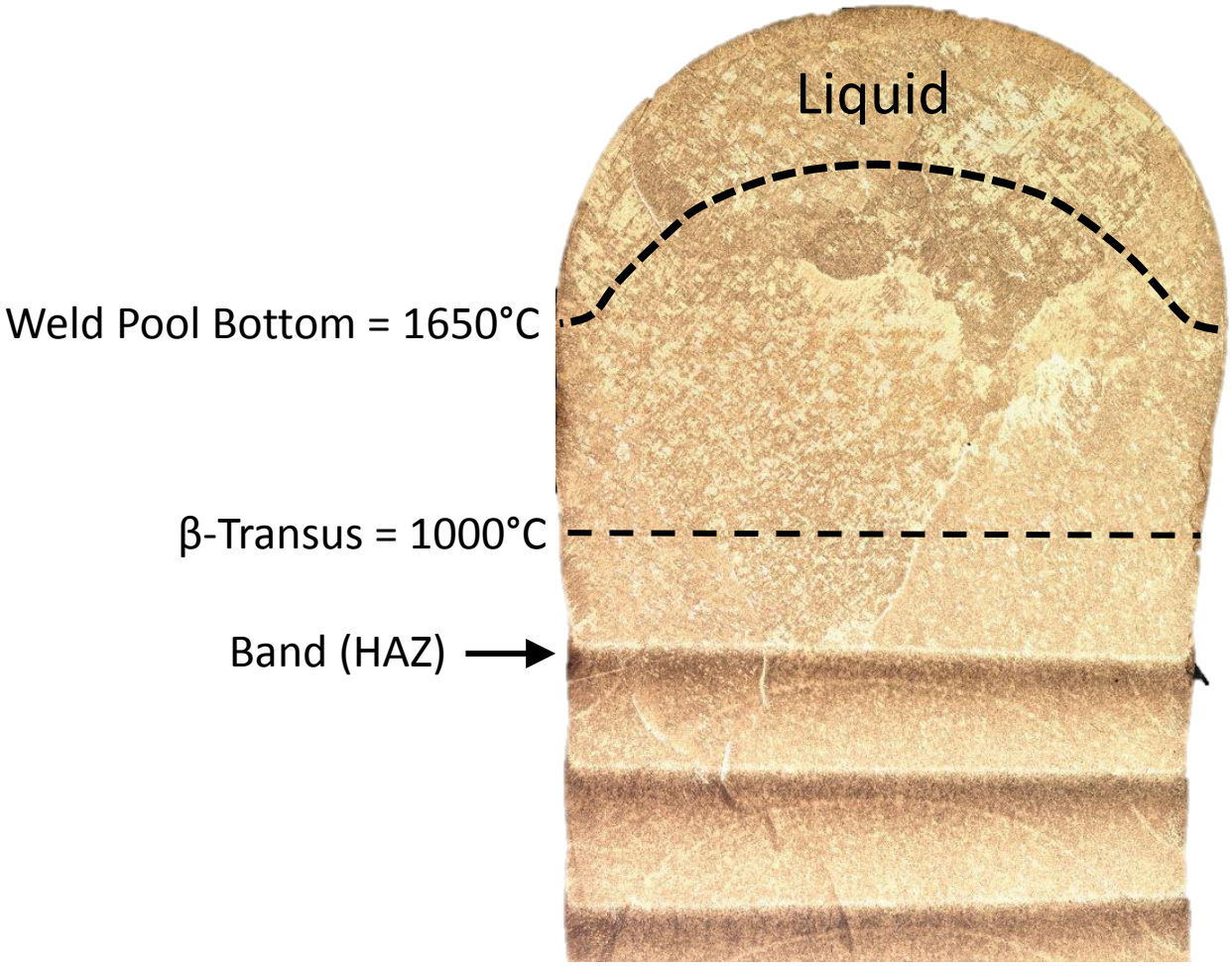
Issues

How big are the Issues?

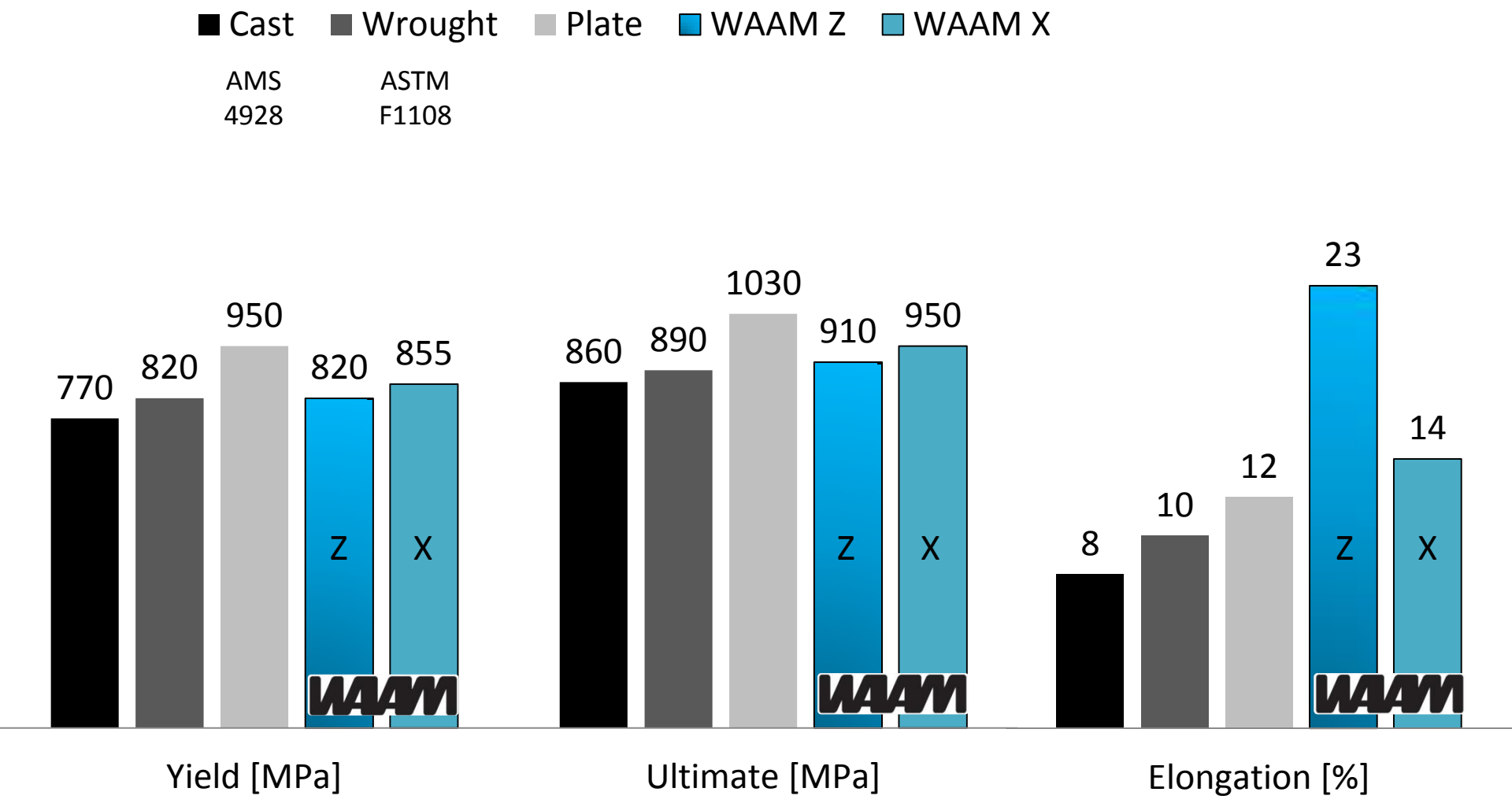
- A: Microstructure – Mechanical Properties
- B: Residual Stress – Distortion

A: Microstructure:
Cross Section of Ti-6Al-4V Wall

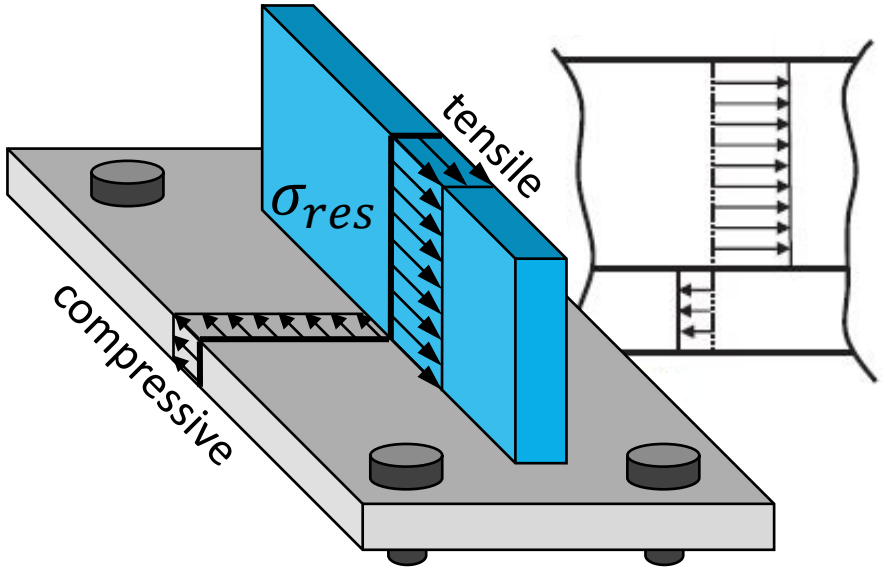


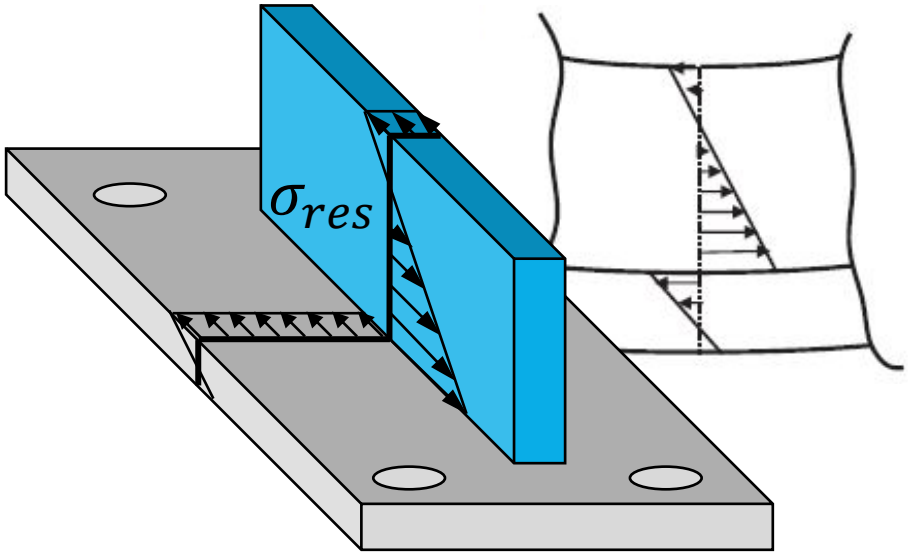


A: Microstructure:
Minimum Mechanical Properties
Ti-6Al-4V



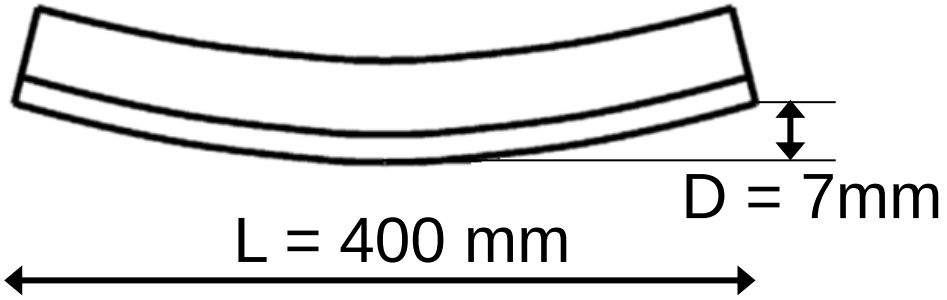
B: Out-of-Plane Distortion





"clamped"

"unclamped"



Solution

Idea:

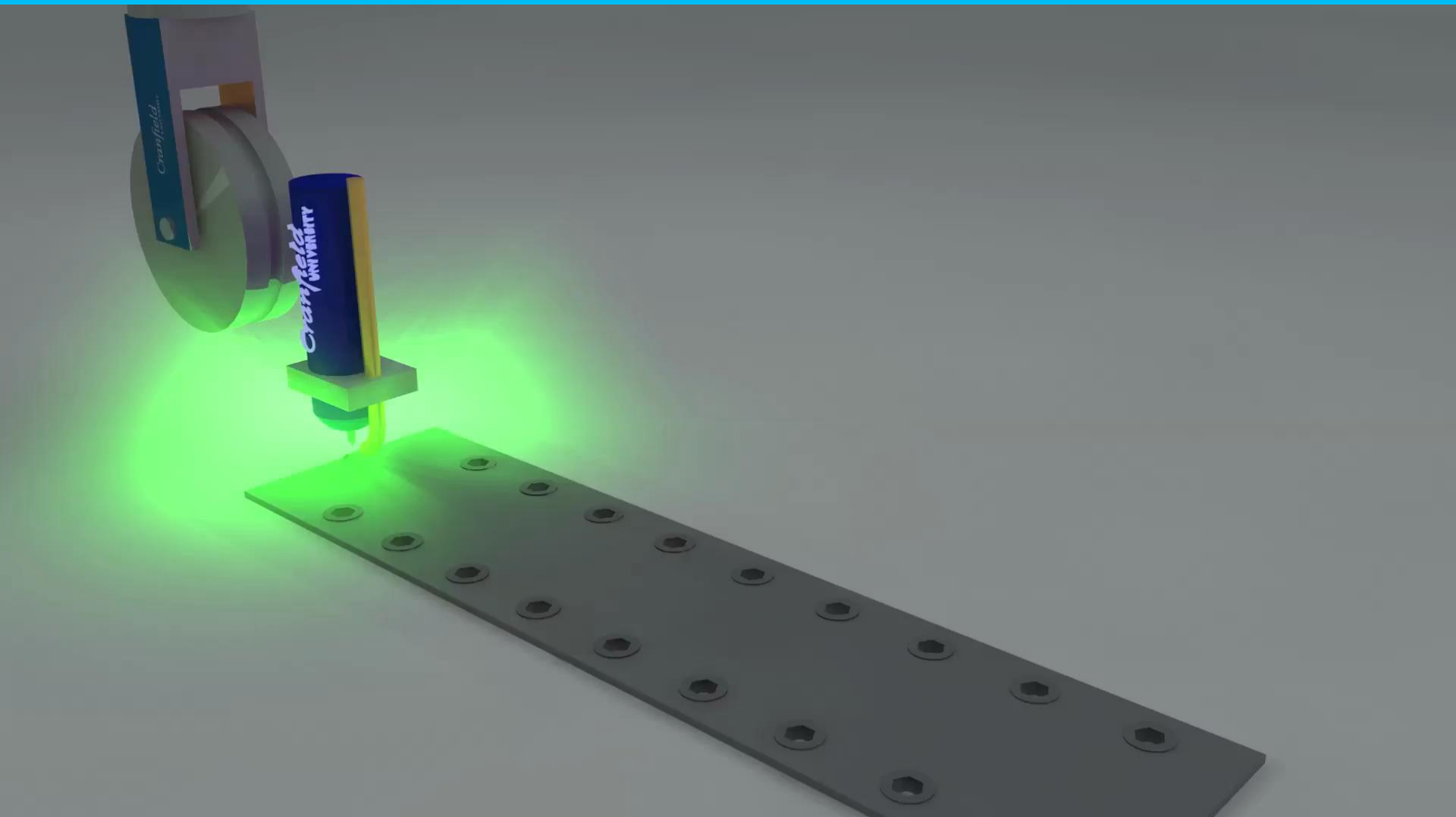
Induce compressive strain

+ Heat Treatment

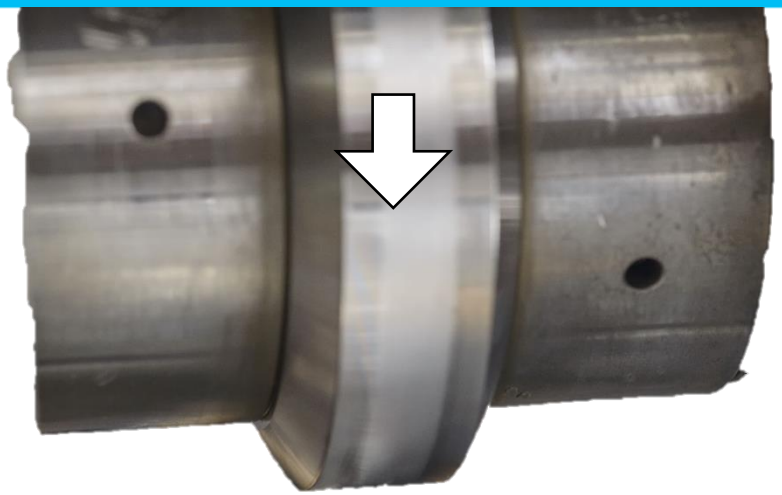
How:

Cold Inter-Pass Rolling

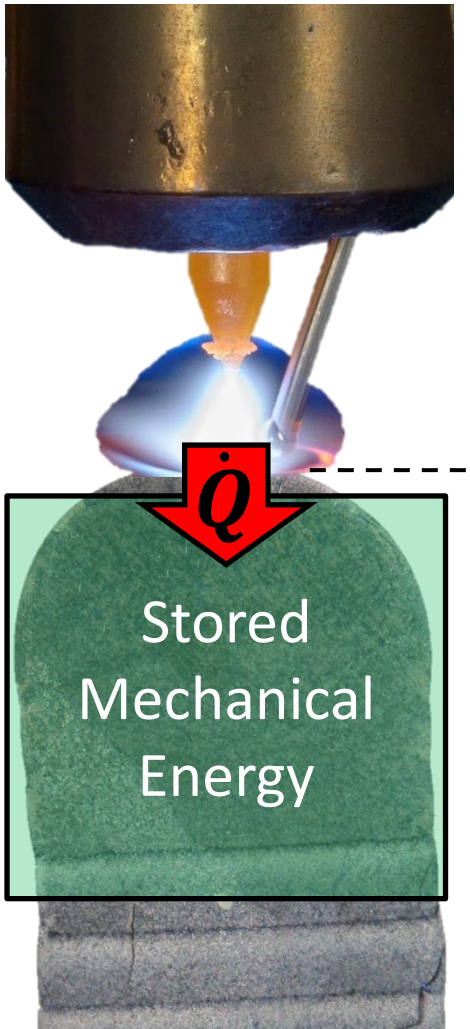
Vertical Inter-Pass Rolling

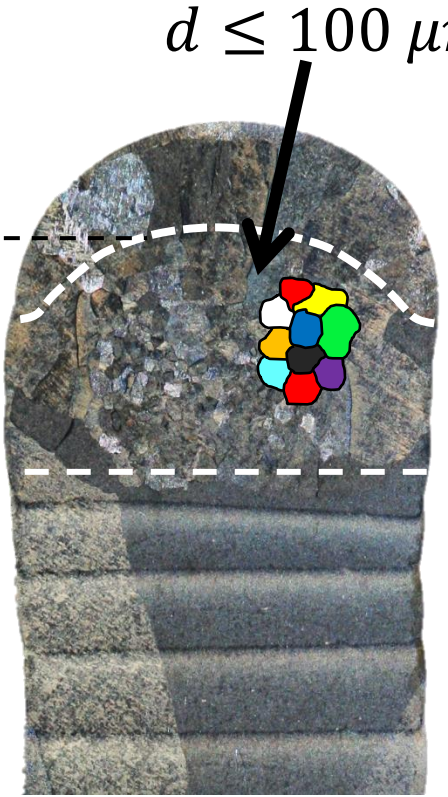


Rolling on Microstructure



Rolling on Microstructure





Rolling on Microstructure: Improve Mechanical Properties

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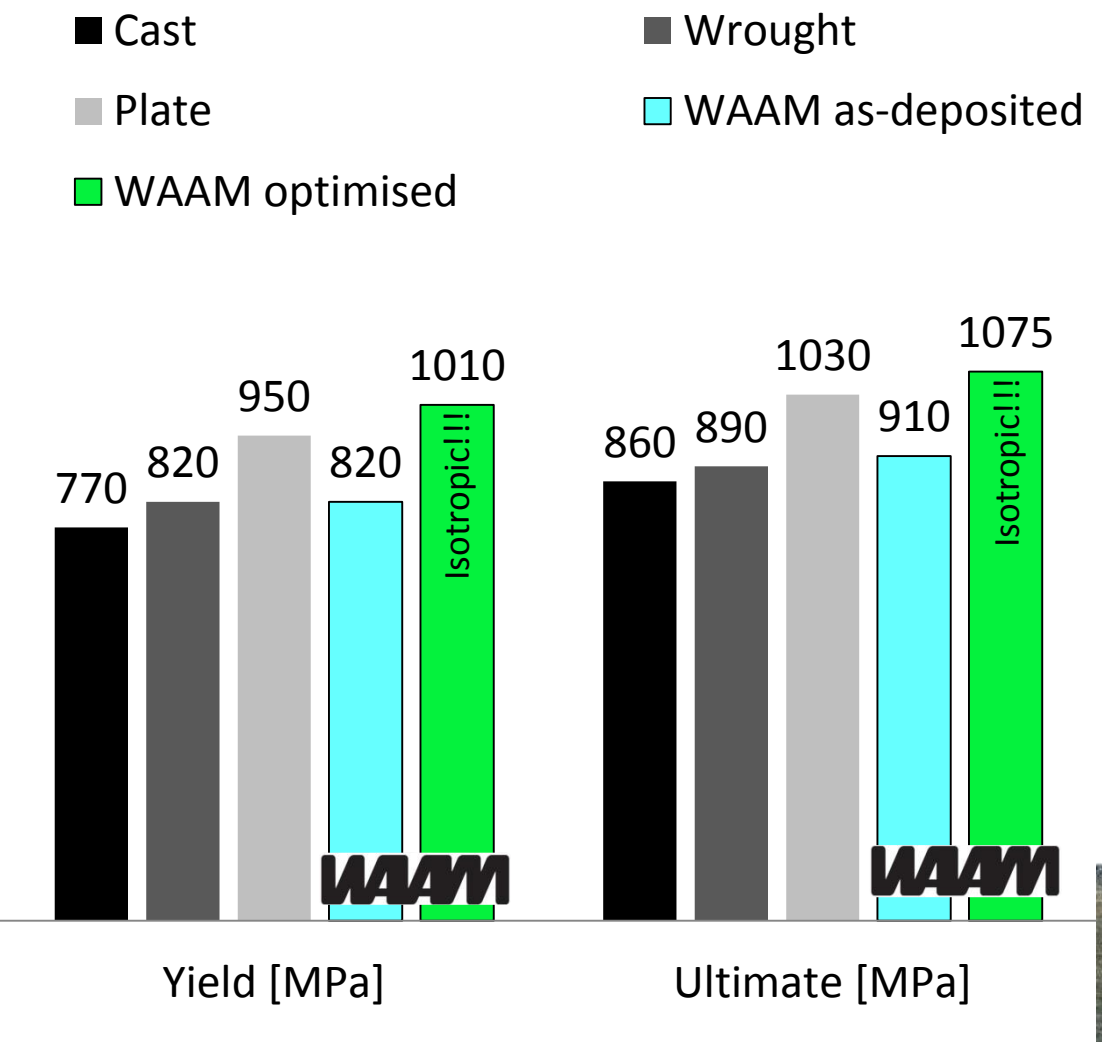
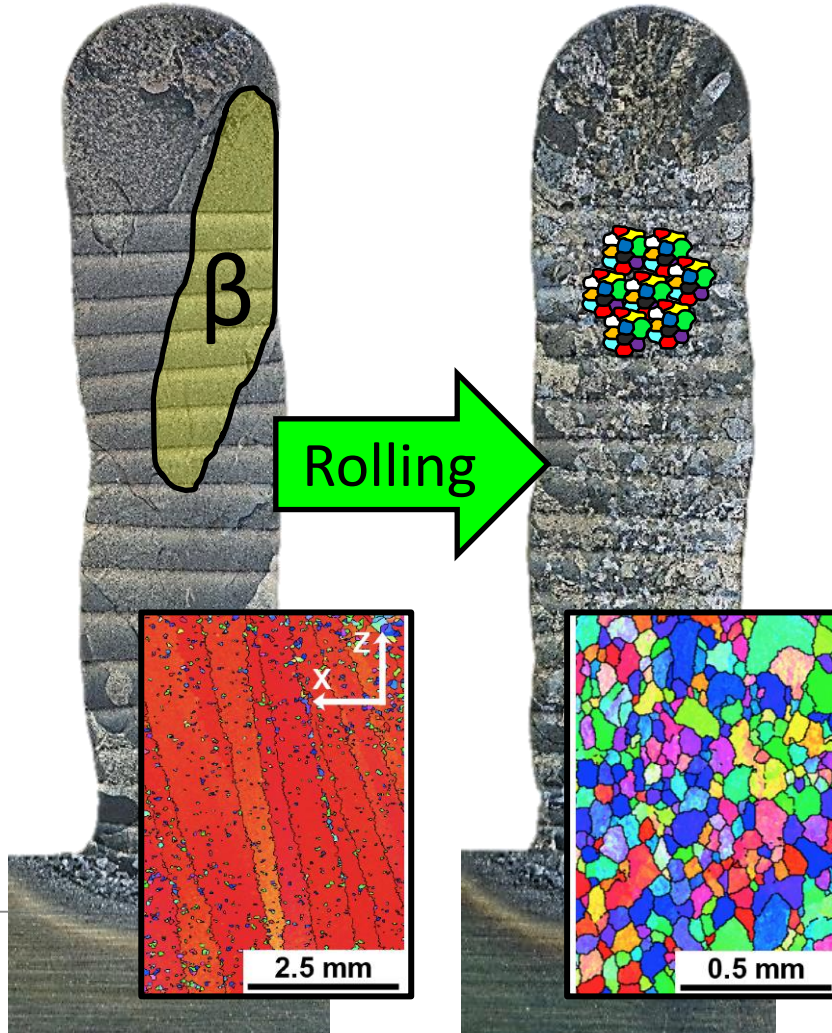
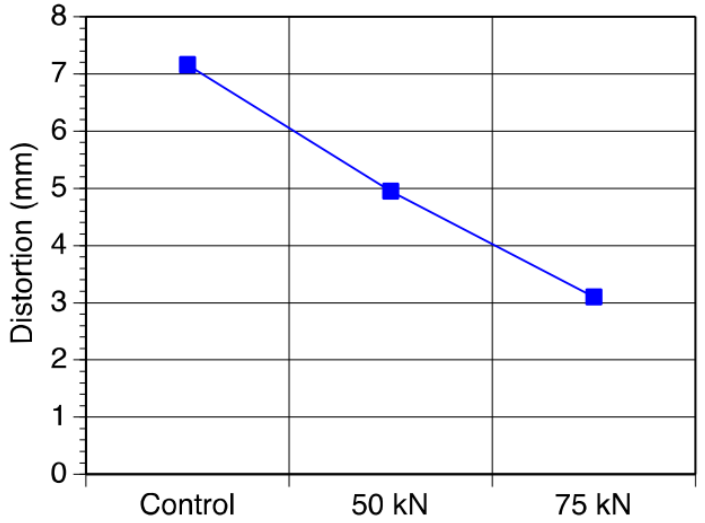
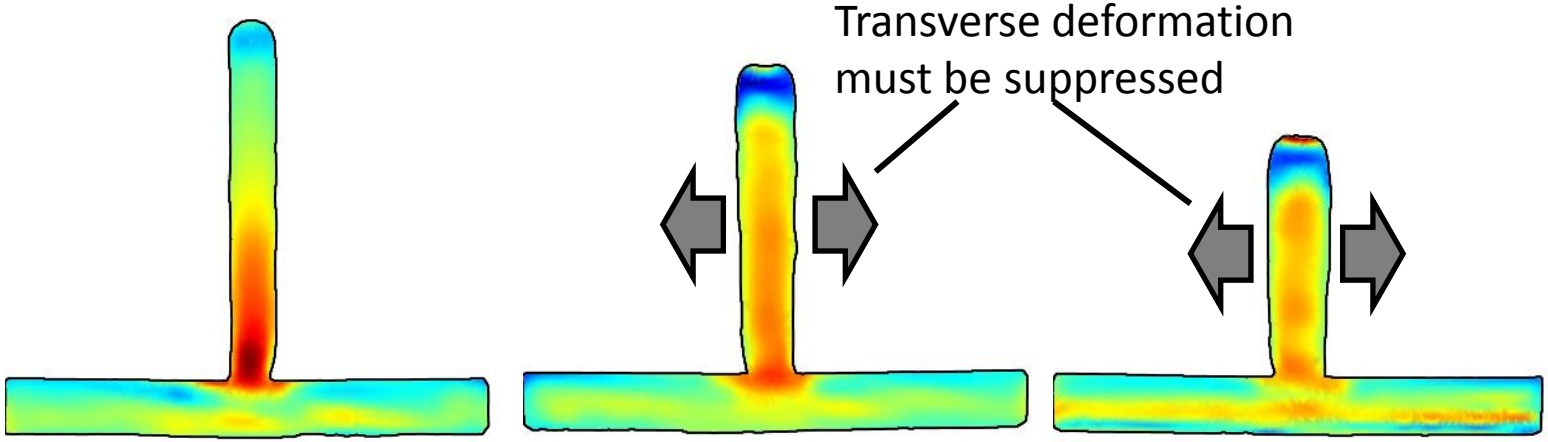




Rolling:
Improves Distortion



Transverse deformation must be suppressed

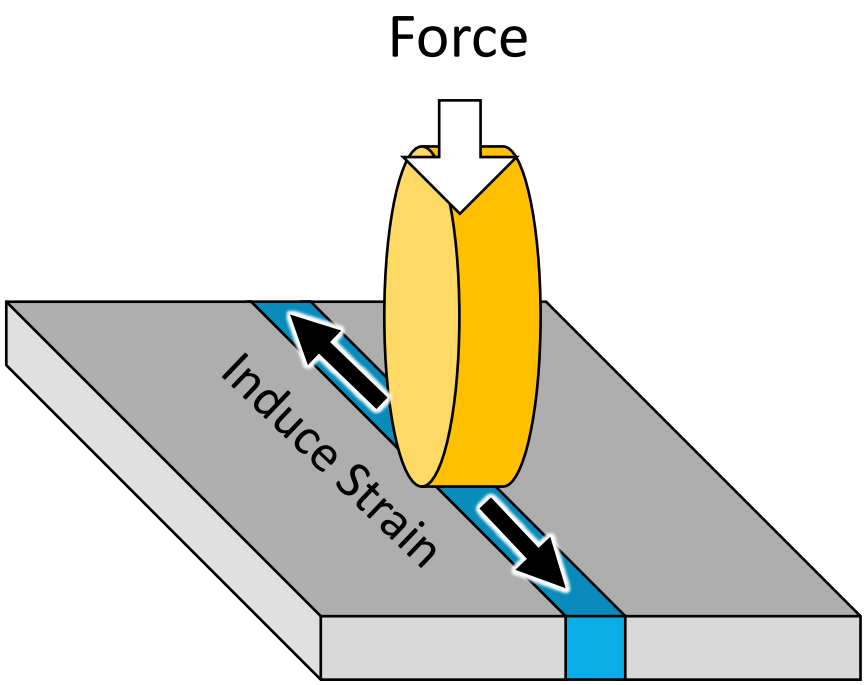


control

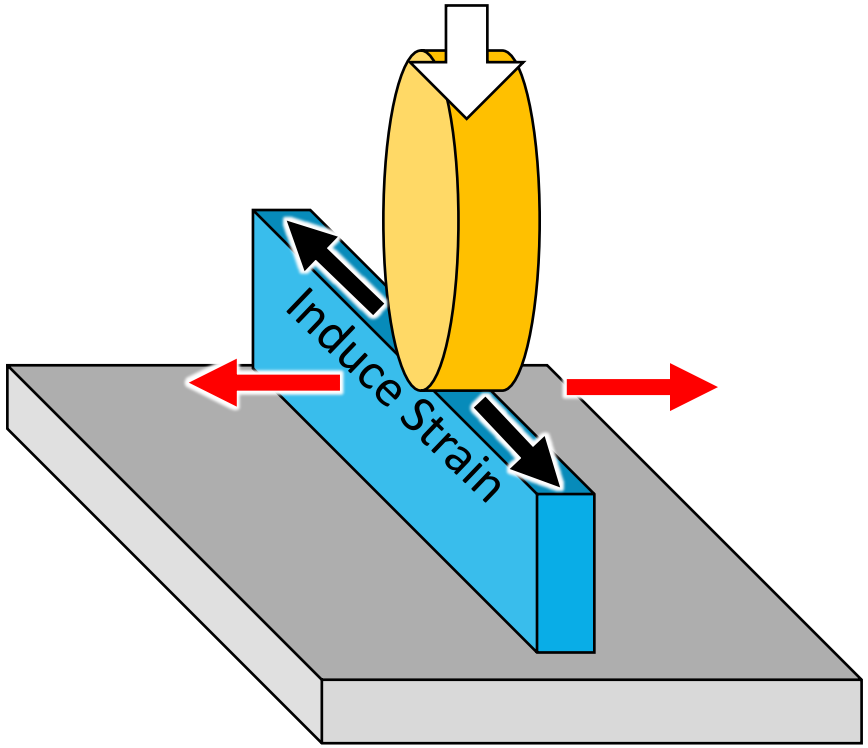
50 kN

75 kN

Solution – Rolling History

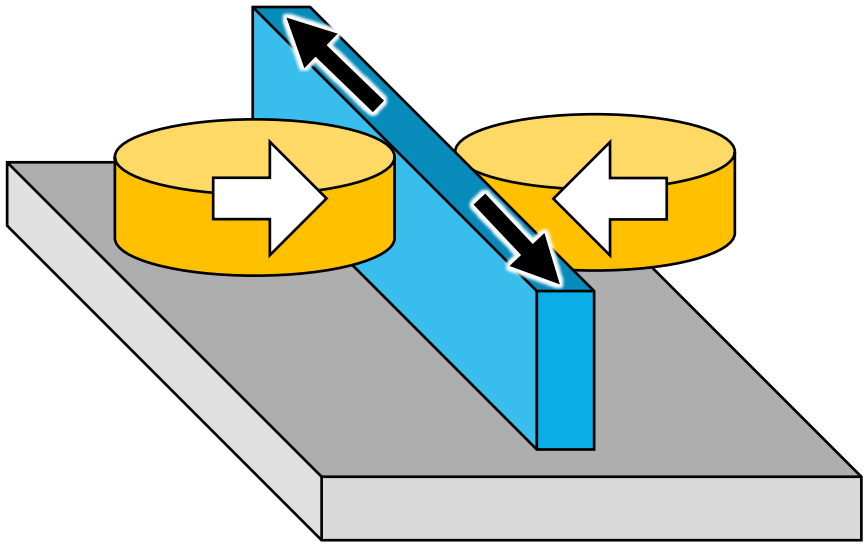


Initial application:
Rolling Butt Welds



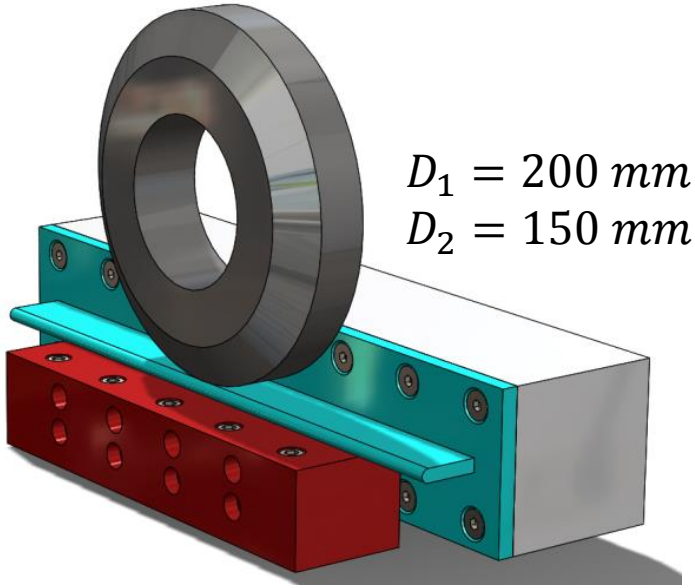
Transfer to:
“Vertical Rolling on WAAM”

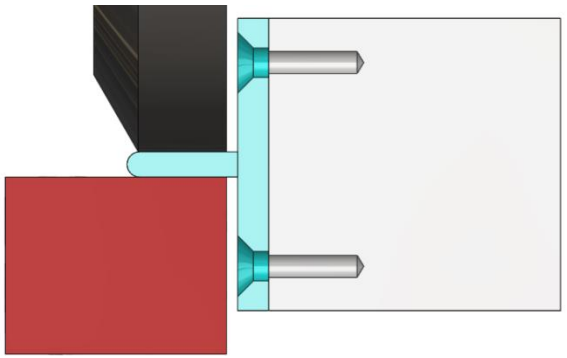
Solution – Rolling
Next Steps



"Pinch Rolling"

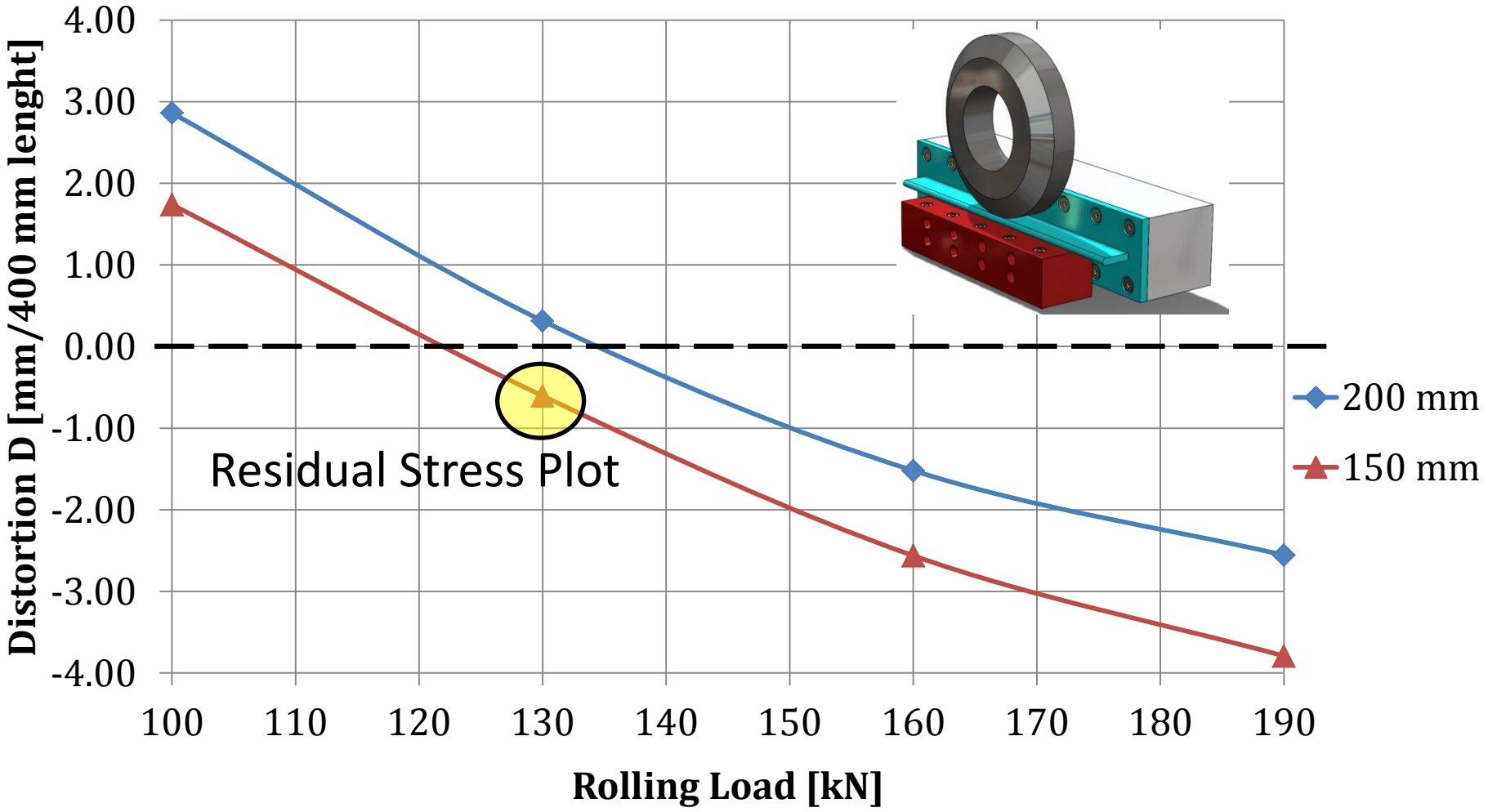
Planned: 2016





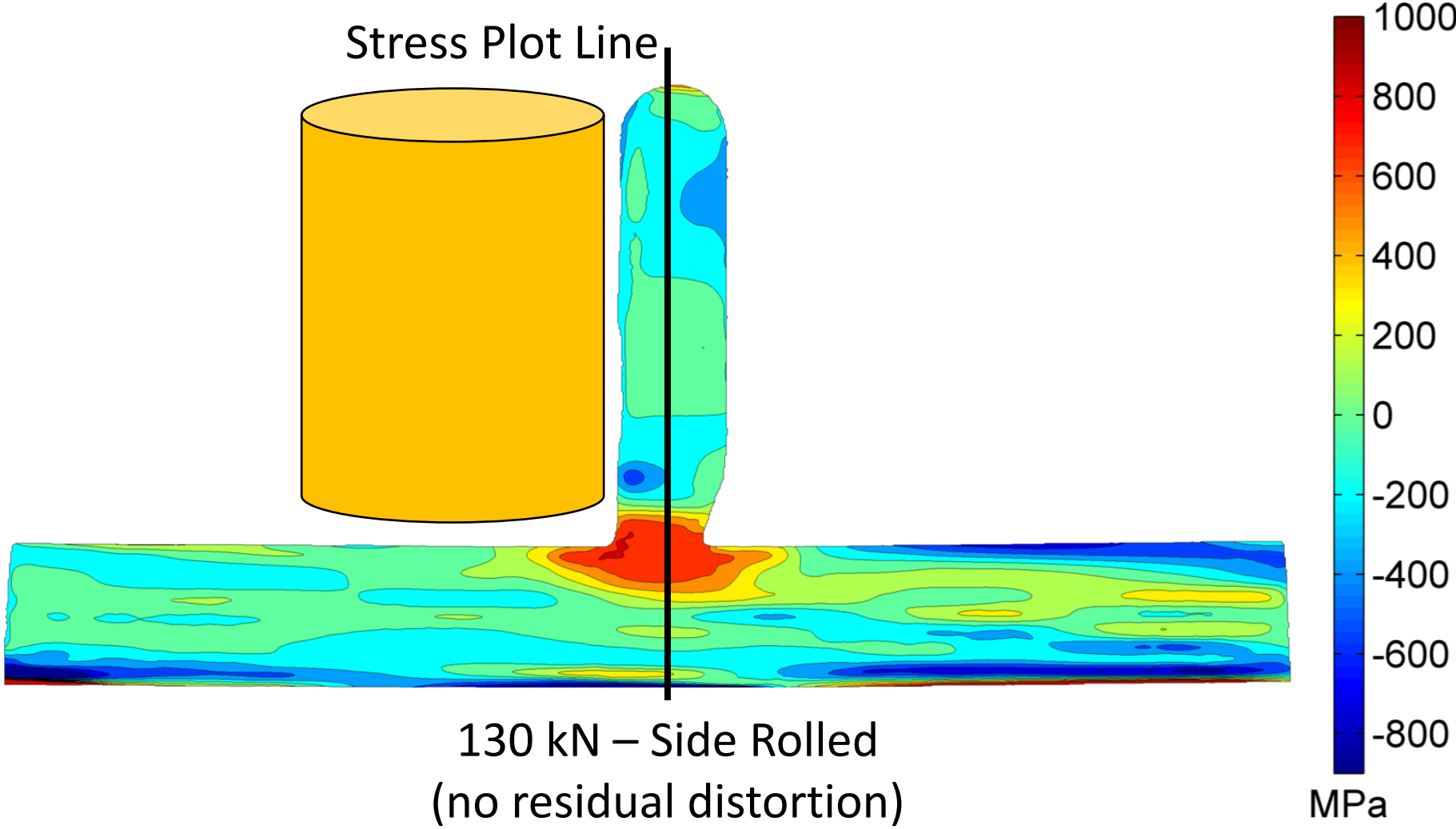
Performed: 2016

Reduction in Distortion



Longitudinal Residual Stress σ_{xx}:

Contour Method (M. Roy - Manchester University)

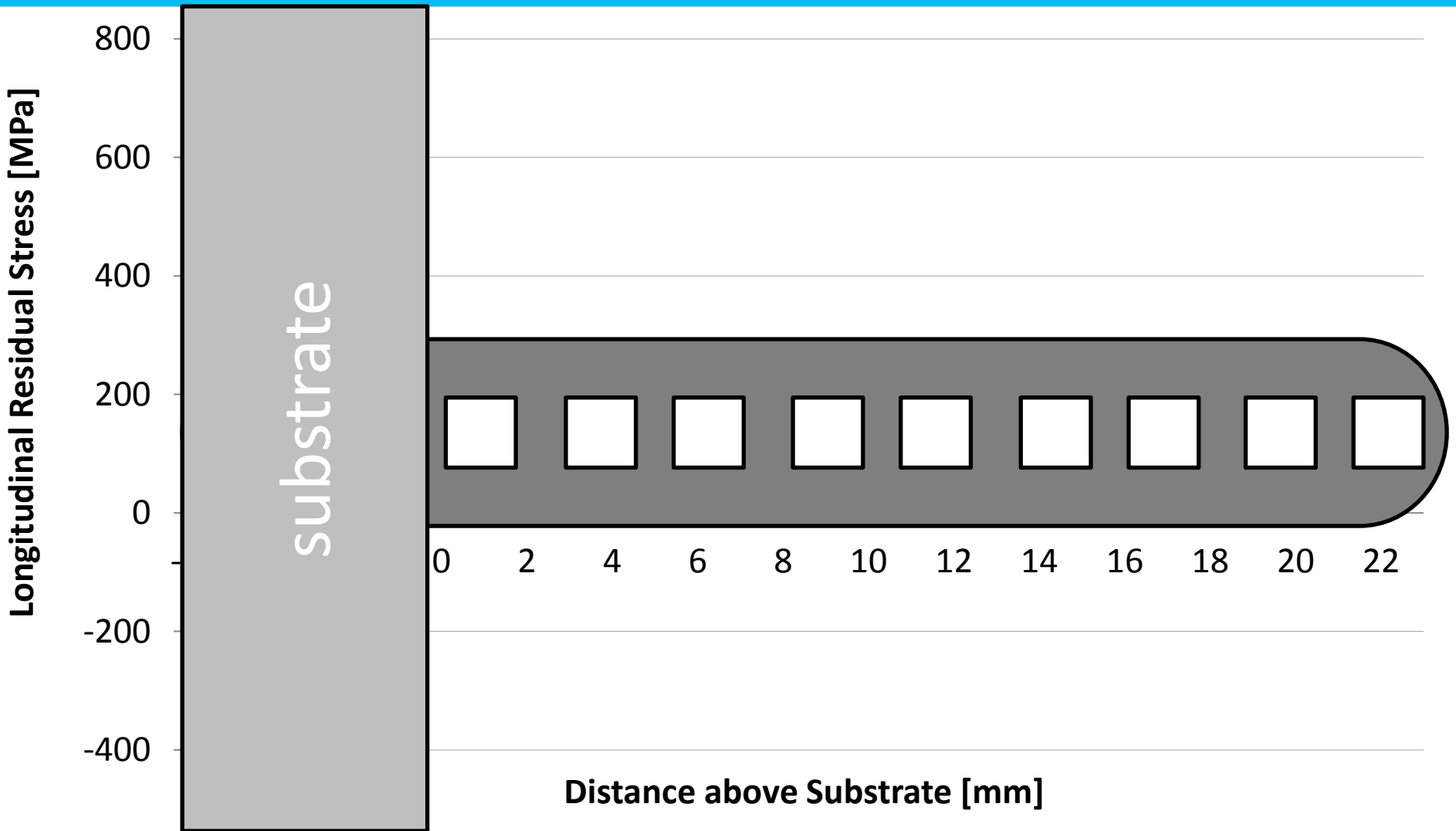


130 kN – Side Rolled
(no residual distortion)

Longitudinal Residual Stress σ_{xx}:

Neutron Diffraction (J. Hönnige - ENGIN-X @ ISIS)

Contour Method (M. Roy - Manchester University)



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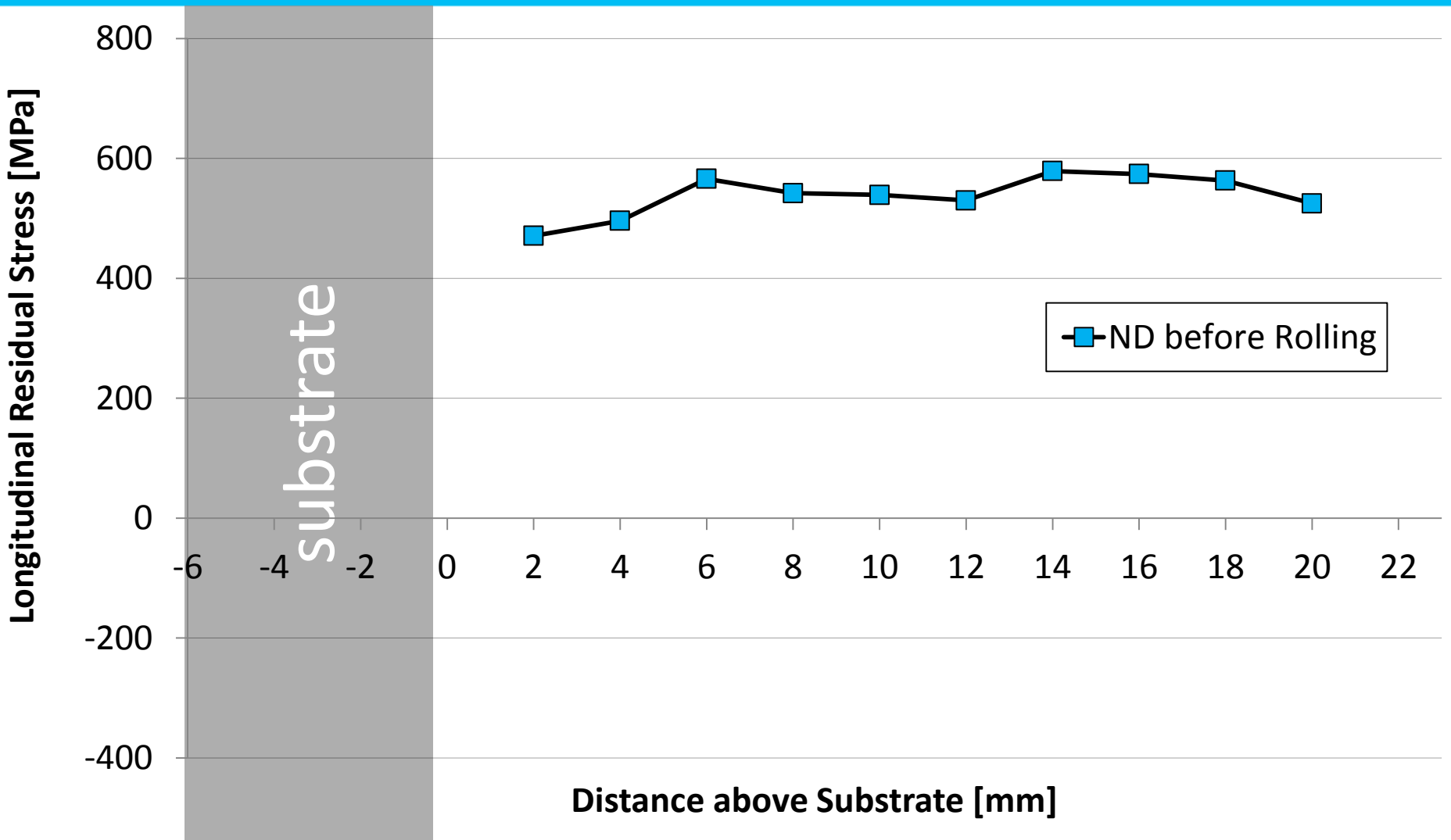

Residual Stress:
Neutron Diffraction (ENGIN-X @ ISIS)
Contour Method (Manchester University)

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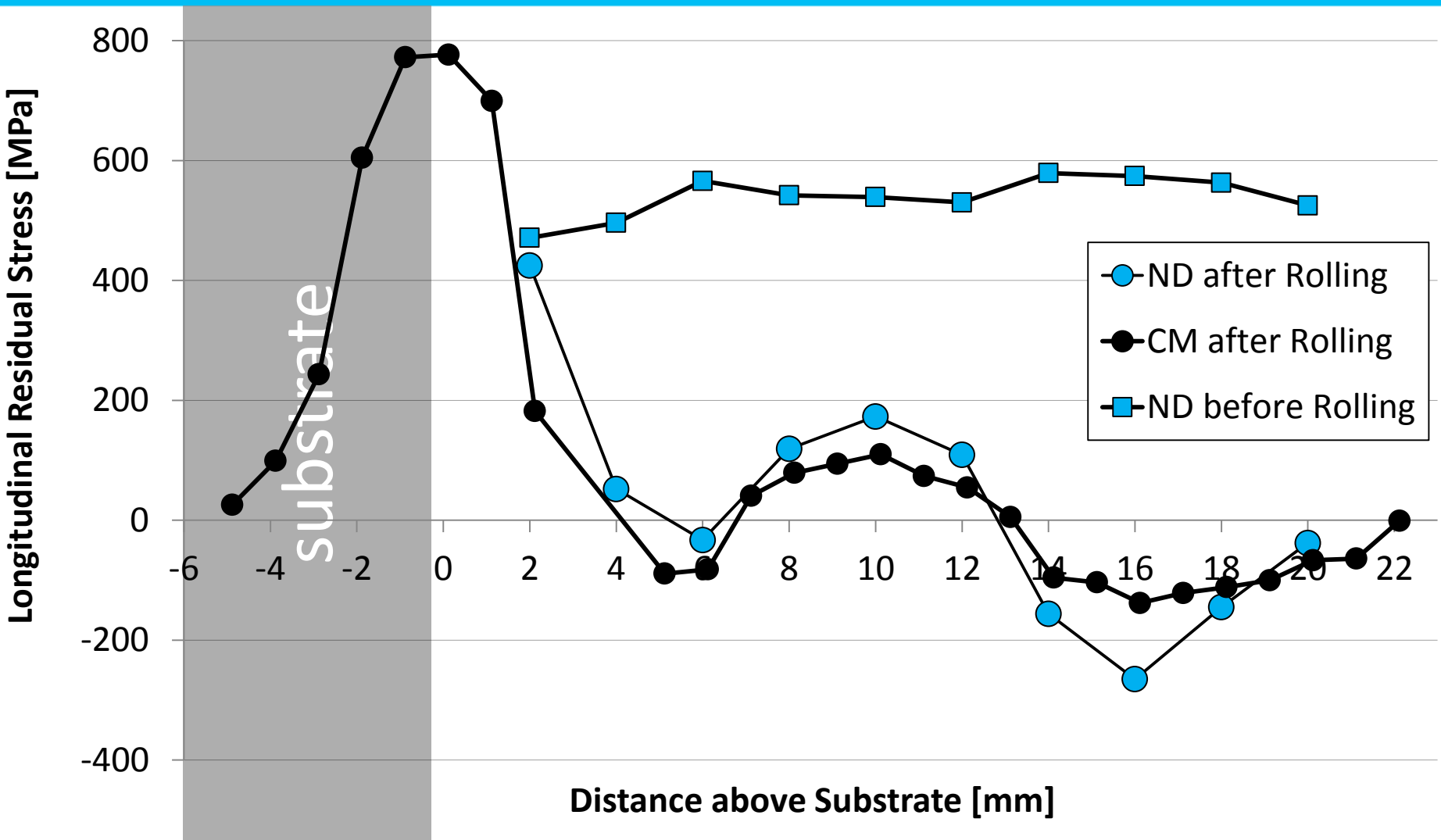
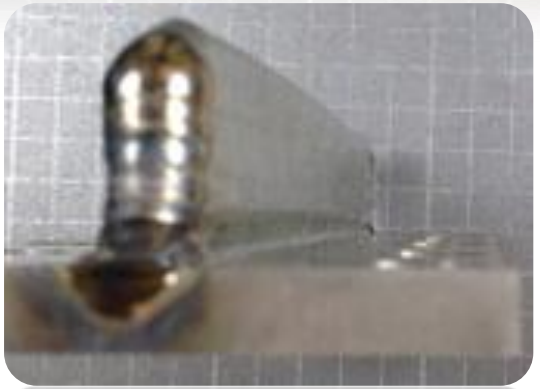
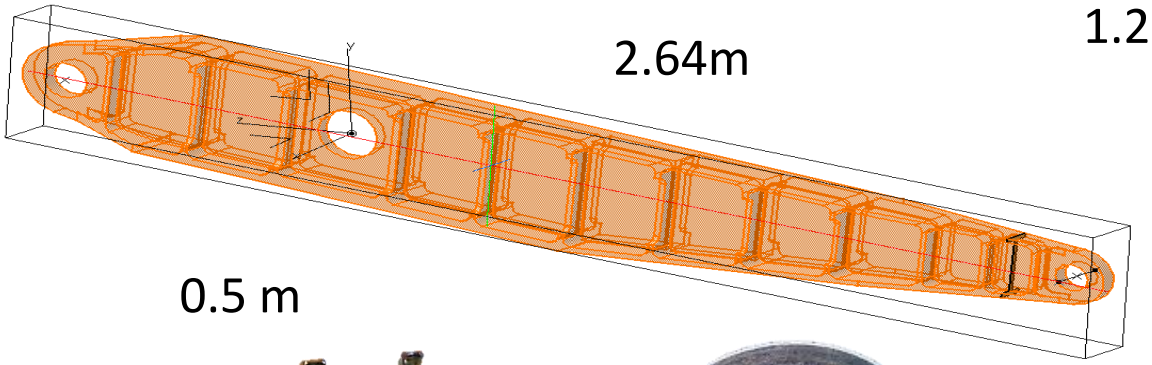
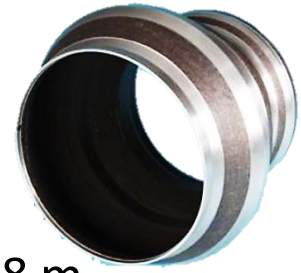


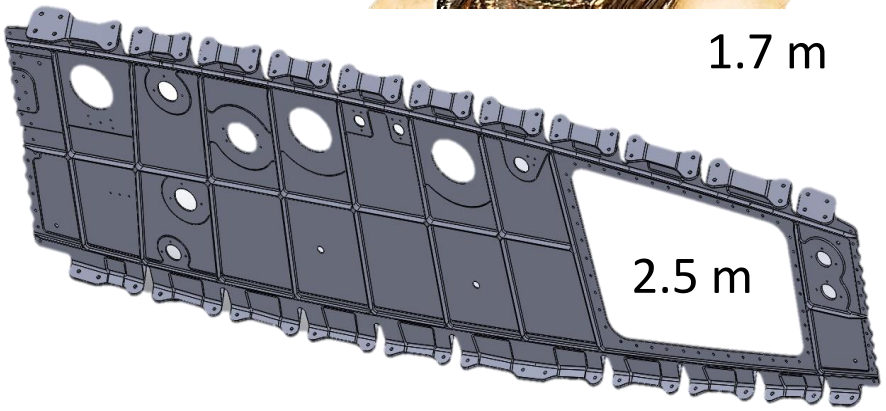
Lab Scale



Real Candidate Parts?

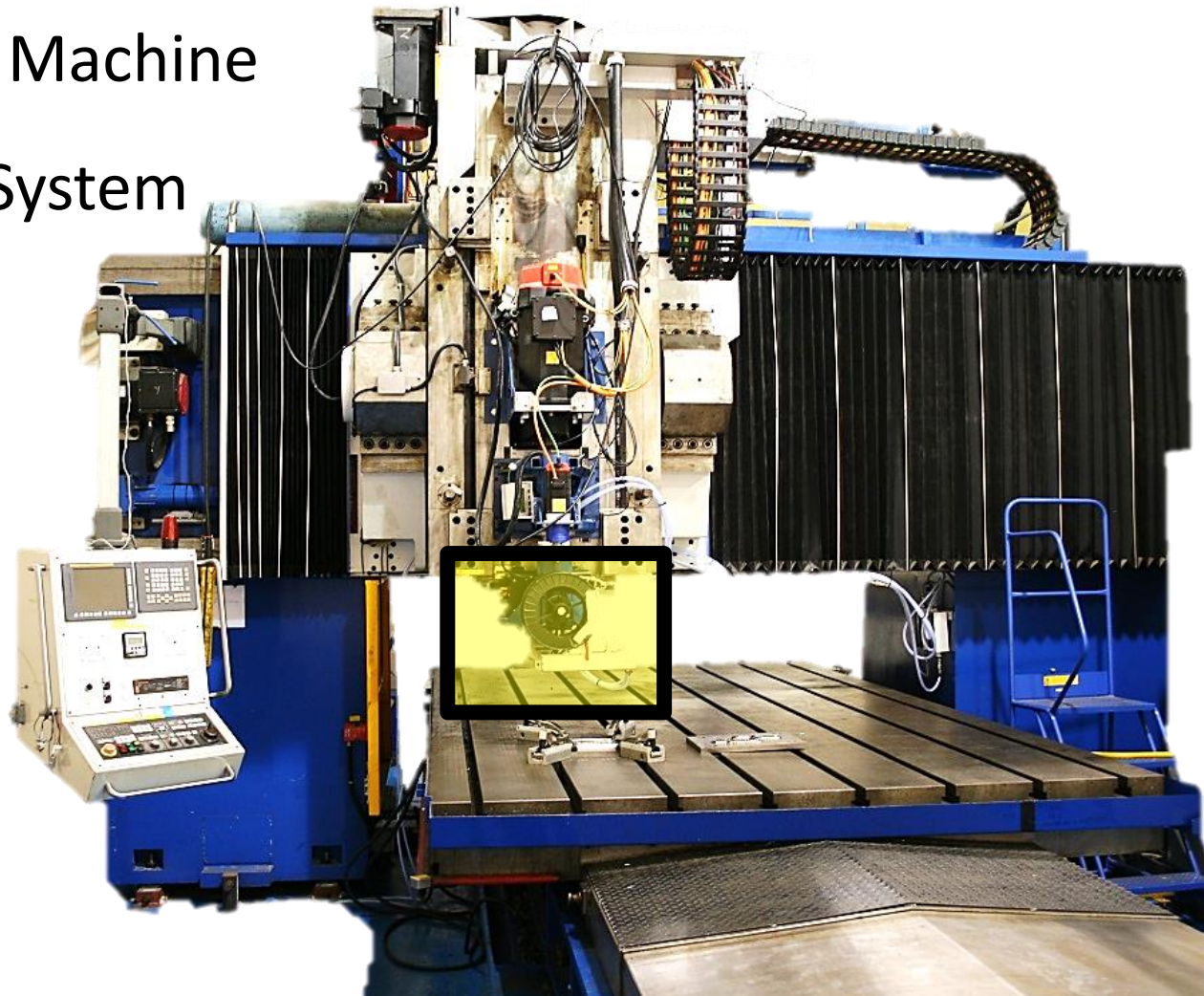




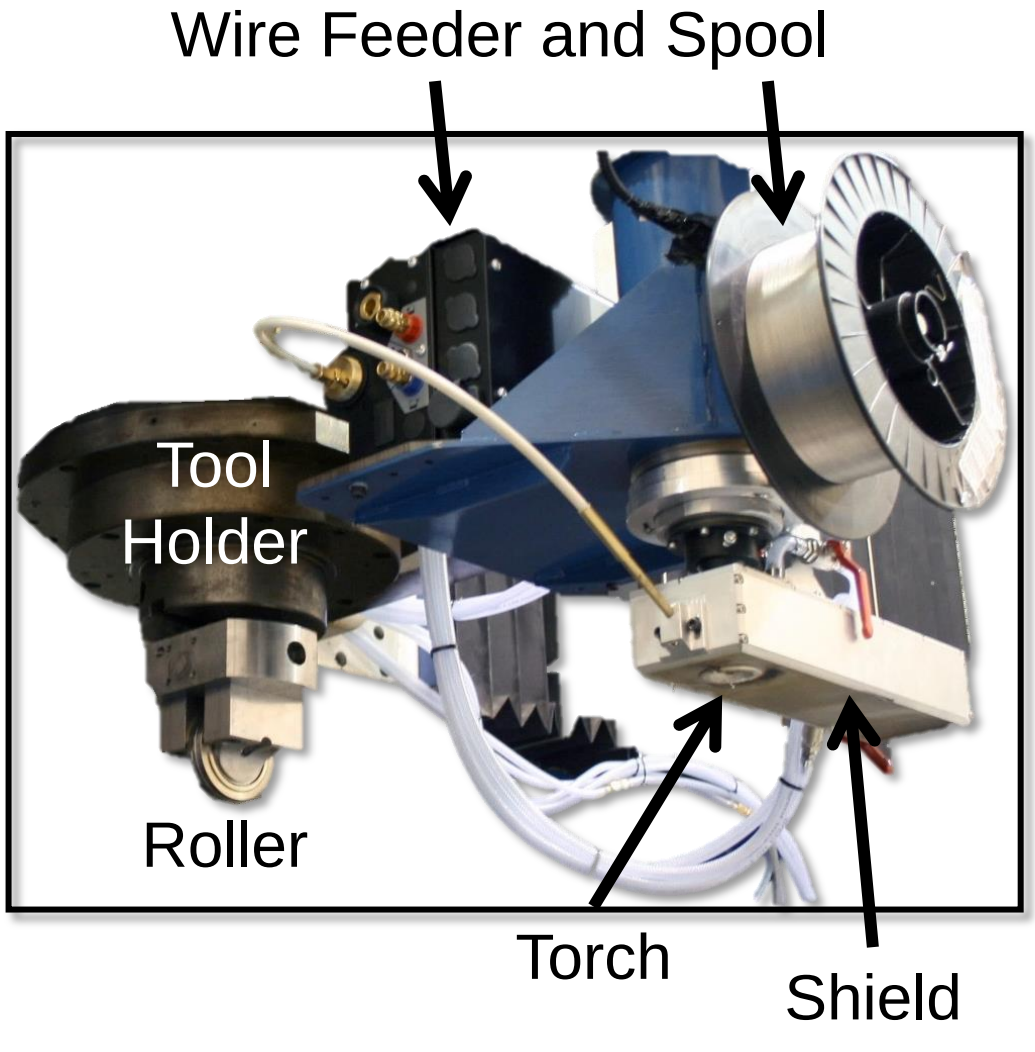


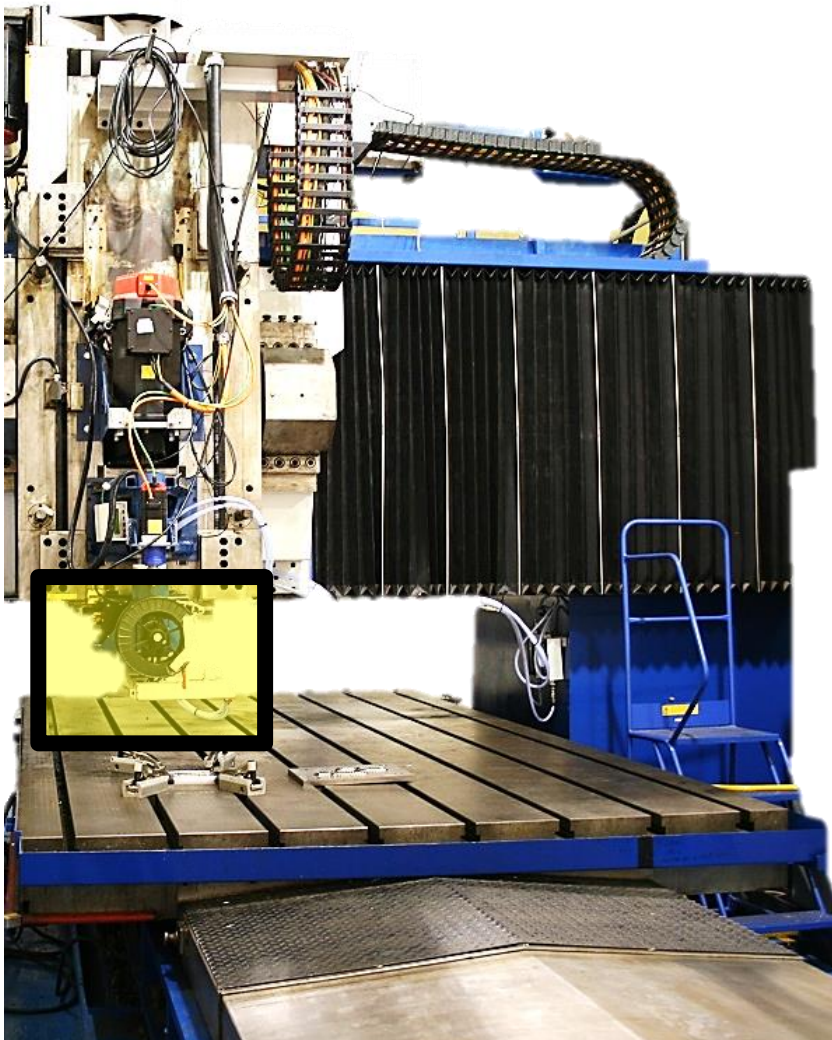
Rolling Assisted WAAM

- CNC Milling & FSW Machine
- Integrated WAAM System



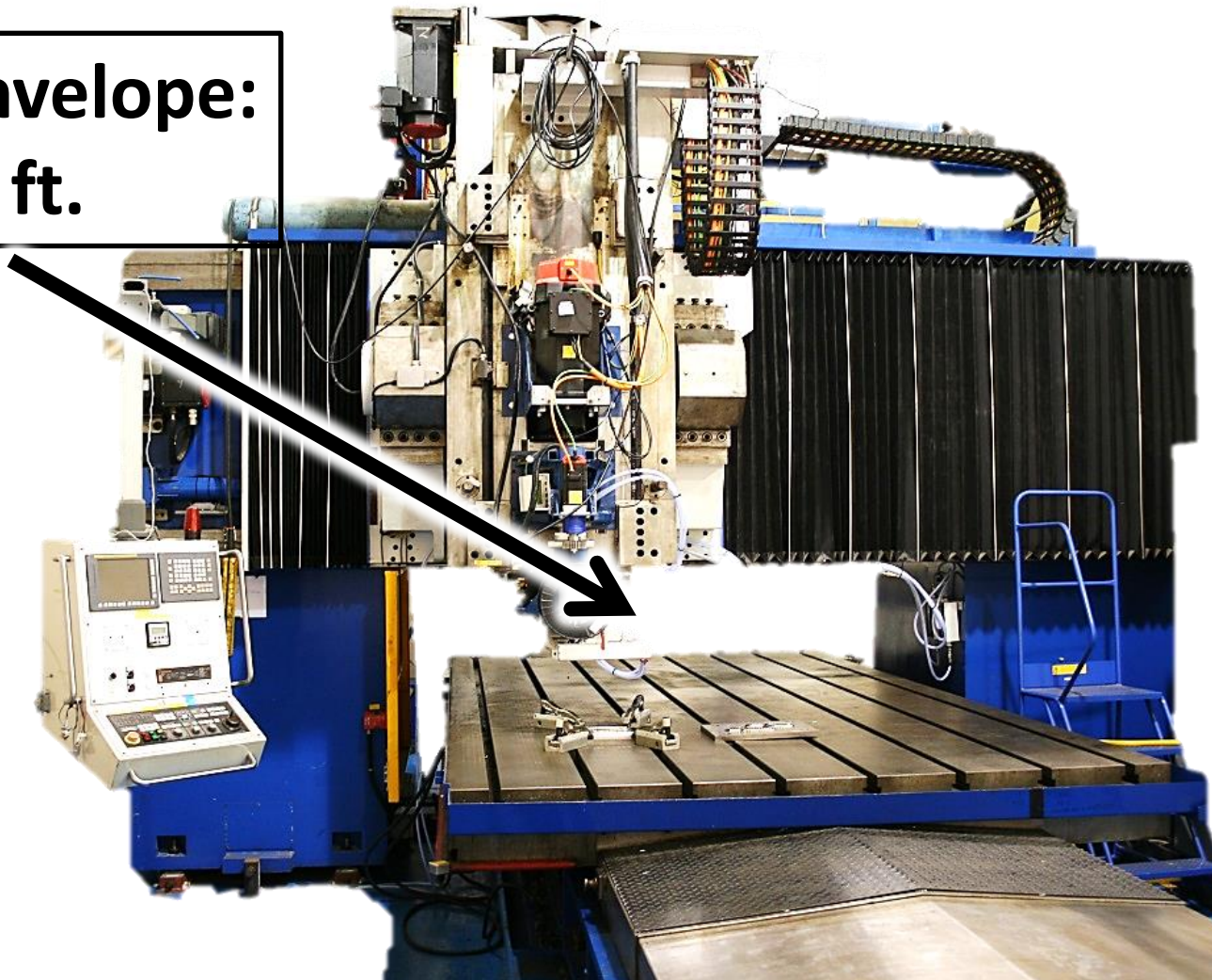
Rolling Assisted WAAM





Rolling Assisted WAAM

Max. Working Envelope:
14 x 6 x 2.5 ft.



Rolling Assisted
Wire + Arc Additive Manufacture
of Meter-Scale Aerospace Components

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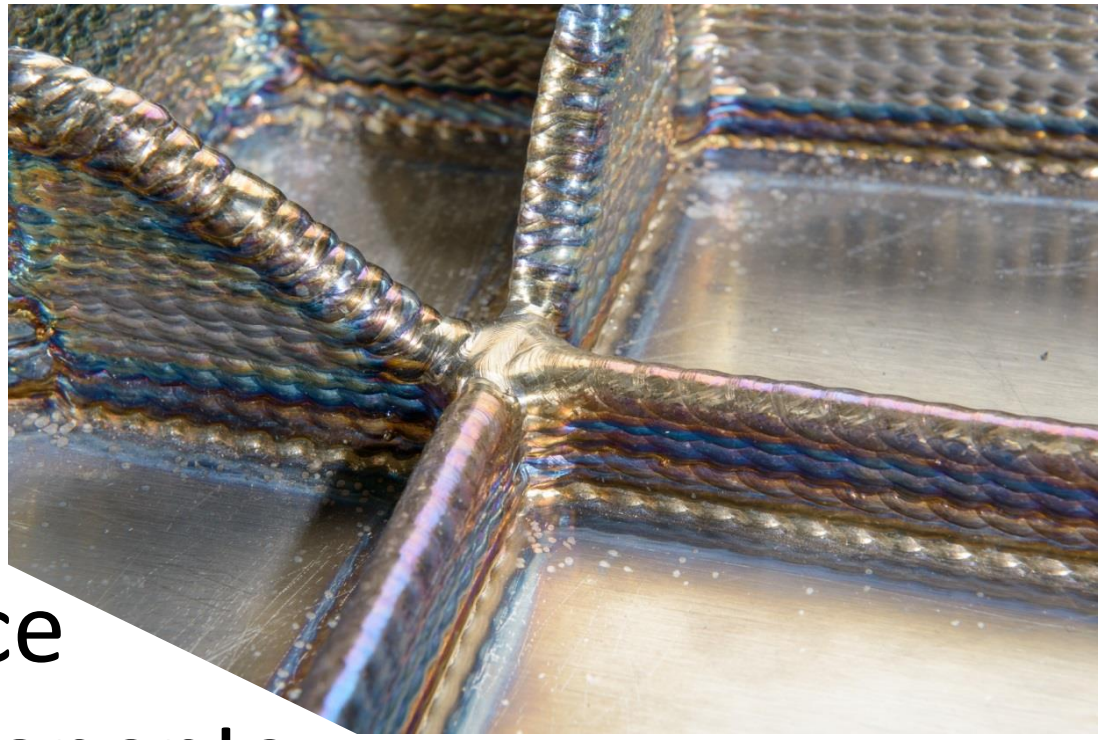
WAAM



Large Scale
Near Net Shape
High Performance
Structural Components

www.WAAMMat.com

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