

A robotic welding arm is shown in a dark industrial setting, emitting a bright blue and white light from the welding point. The arm is suspended by cables and is positioned over a workpiece.

HUGO ROMER

M2I CONFERENCE
MEETING MATERIALS

12-DEC 2017

NOORDWIJKERHOUT

WIRE & ARC ADDITIVE MANUFACTURING FOR OFFSHORE APPLIANCES



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WIRE & ARC ADDITIVE MANUFACTURING FOR OFFSHORE APPLIANCES

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BACKGROUND

Hugo Romer

- Graduated August 2017 at TU Delft:
 - MSc. Offshore Engineering (Structural Design & Analysis)
 - Huisman R&D WAAM graduation project
- September 2017: Huisman R&D, Advanced Manufacturing
 - Wire & Arc Additive Manufacturing (WAAM)
 - Automated production, incl. robotic welding
- Contact: hromer@huisman-nl.com
- LinkedIn: <https://nl.linkedin.com/in/hugoromer>



BACKGROUND

- Huisman Equipment
- Design, engineering & construction company founded in 1929
- Construction of (large) offshore appliances:
 - Cranes
 - Pipelay Equipment
 - Drilling Equipment
 - Winches
 - Vessel Designs
 - Special Projects



Mast crane



Active heave compensation system



Multi purpose tower
Noble drilling corp.



Blue Piling project
Fistuca BV



Tensioner section
Huisman Konstrukce, Sviadnov, Czech Republic



Crane boom part
Huisman (China) Co., Ltd, Xiamen, People's Republic of China



Cast 2500mt crane hook
Huisman Equipment BV, Schiedam, The Netherlands



Welding of plate components
Huisman (China) Co., Ltd, Xiamen, People's Republic of China



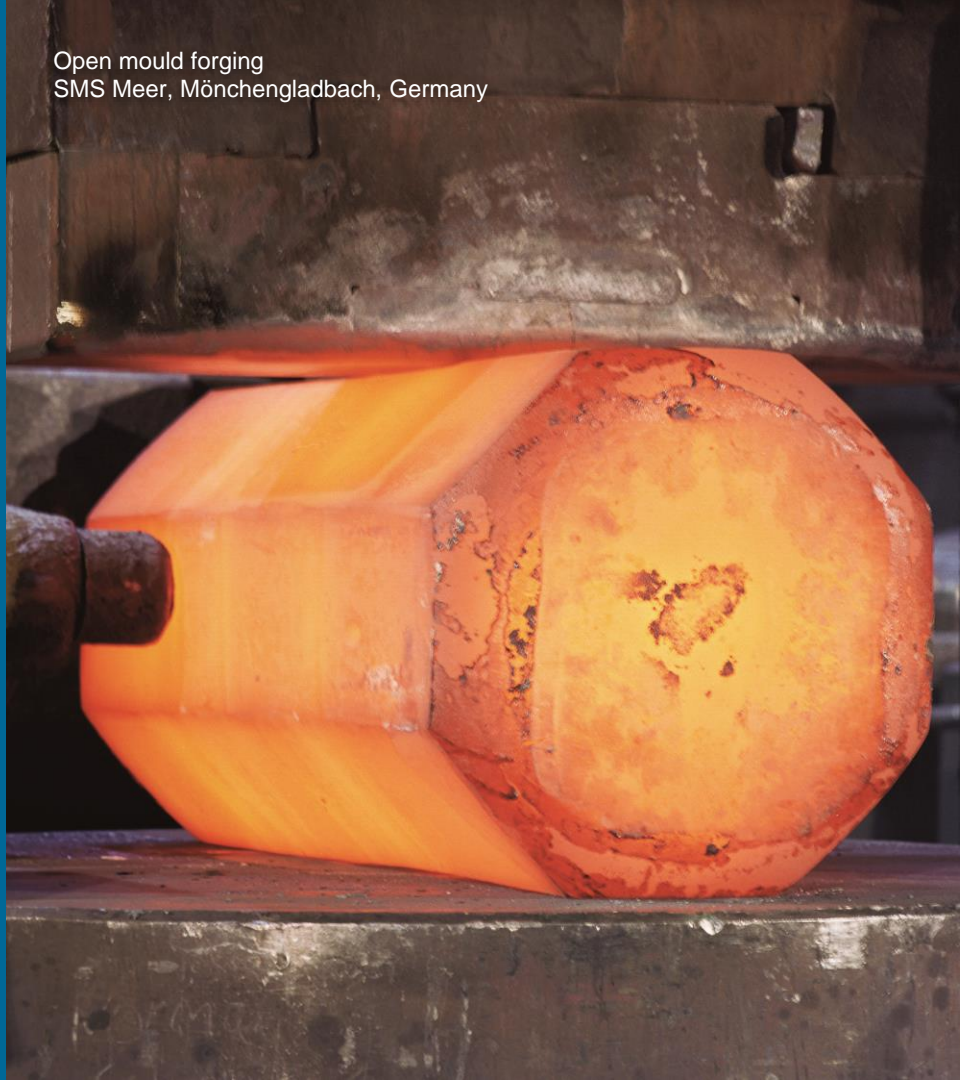
Grinding of welded sections
Huisman Konstrukce, Sviadnov, Czech Republic



Sand die casting
Columbia Steel Casting Co., Inc. Portland OR, United States



Open mould forging
SMS Meer, Mönchengladbach, Germany



BACKGROUND

- Mid to large size parts
- Harsh conditions for end use
 - Strict class rules
- Steels
- Typical material demands:
 - Yield strength: $\sigma_y \geq 690 \text{ MPa}$
 - Elongation: $\epsilon_f \geq 15\%$
 - Impact toughness: $E \geq 27 \text{ J @ } -60^\circ\text{C}$



Introduction to WAAM

INTRODUCING WAAM

- WAAM: Wire & Arc
Additive Manufacturing
- Free-form shaping
- Additive, filament-based process
- High deposition rates
- Wide material availability
- Best compared to large, multipass welds
- Relies on conventional equipment (weld robot)



Weld robot, also used for WAAM
Huisman Konstrukce, Sviadnov, Czech Republic



Deposition rate & weld bead geometry tests
Huisman Konstrukce, Sviadnov, Czech Republic



Wall-shaped (multilayer) WAAM deposition
Huisman Konstrukce, Sviadnov, Czech Republic



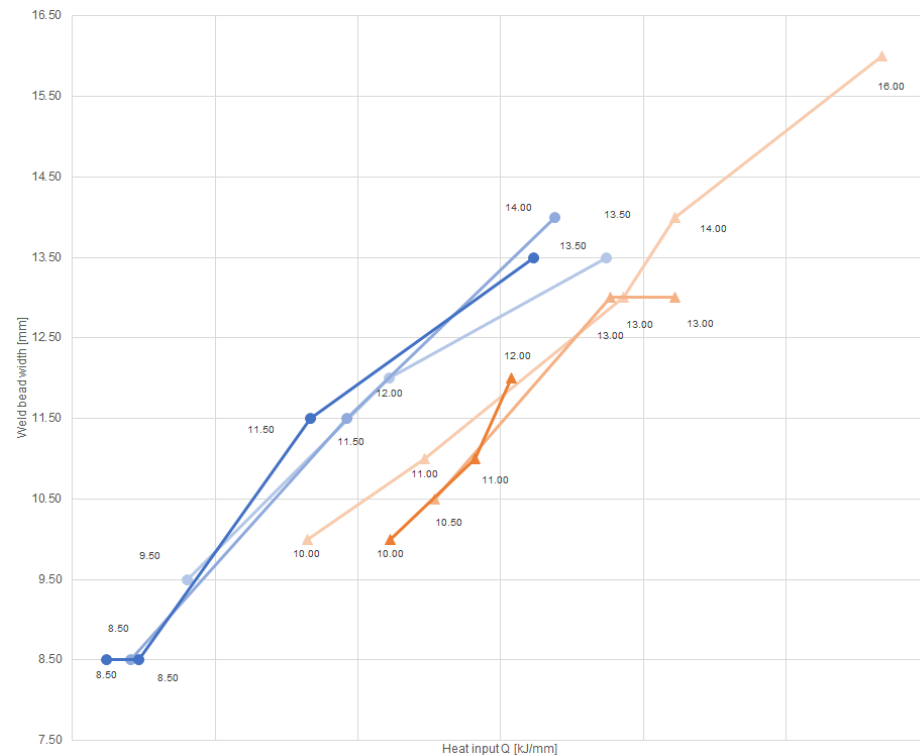
Deposition rate & weld bead geometry tests
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Wall-shaped (multilayer) WAAM deposition
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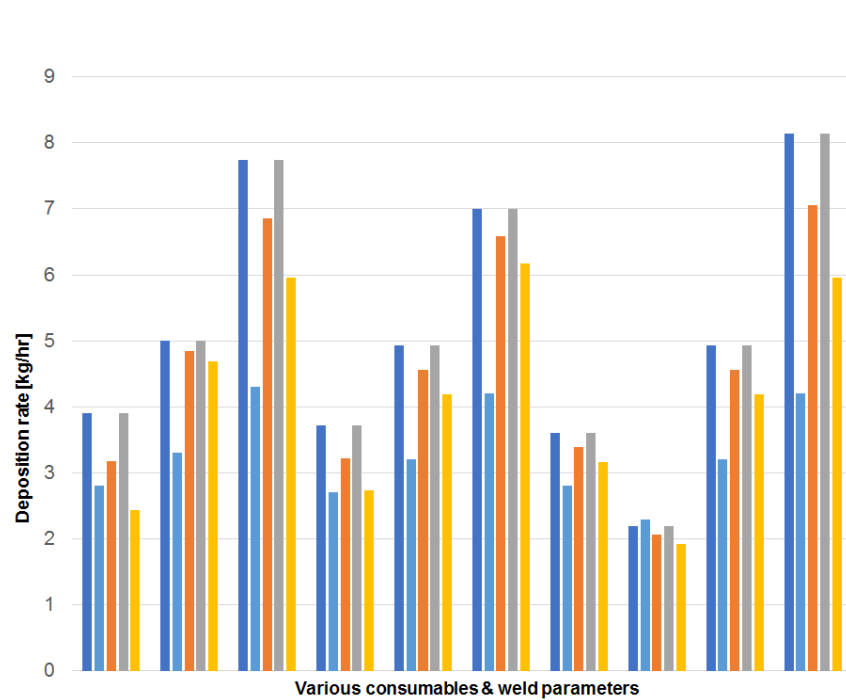
Multipass fillet weld example



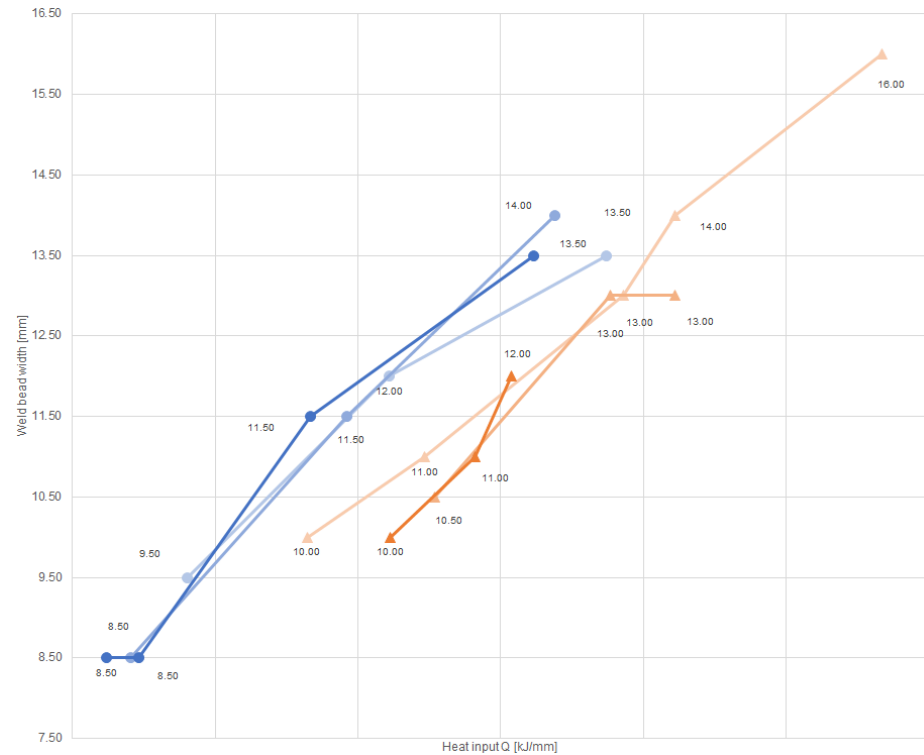
WELD BEAD GEOMETRY



DEPOSITION RATES



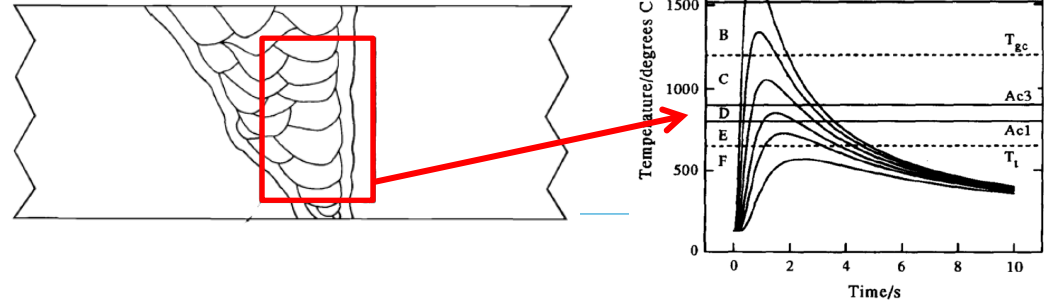
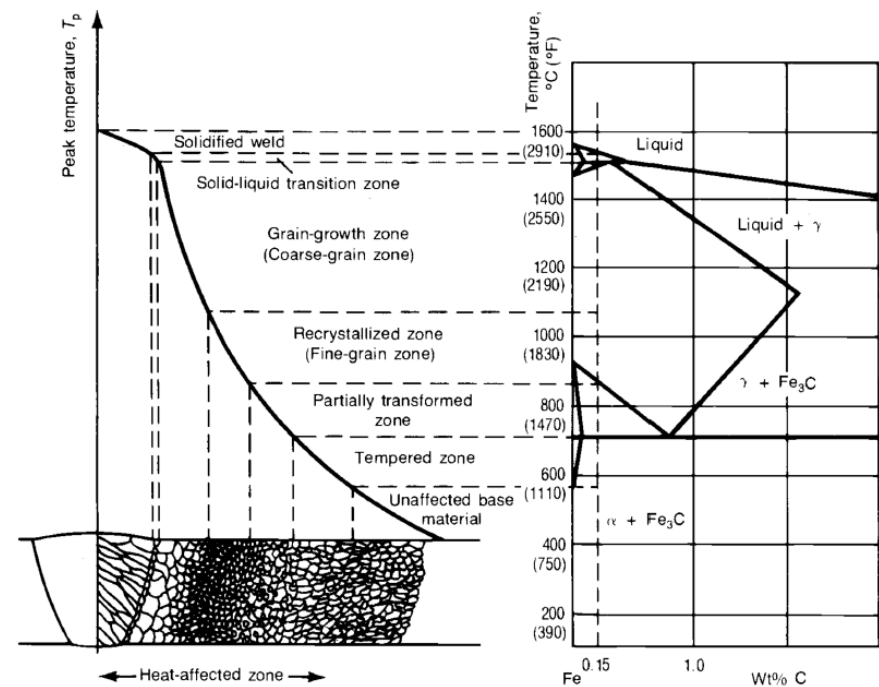
WELD BEAD GEOMETRY



Material characteristics

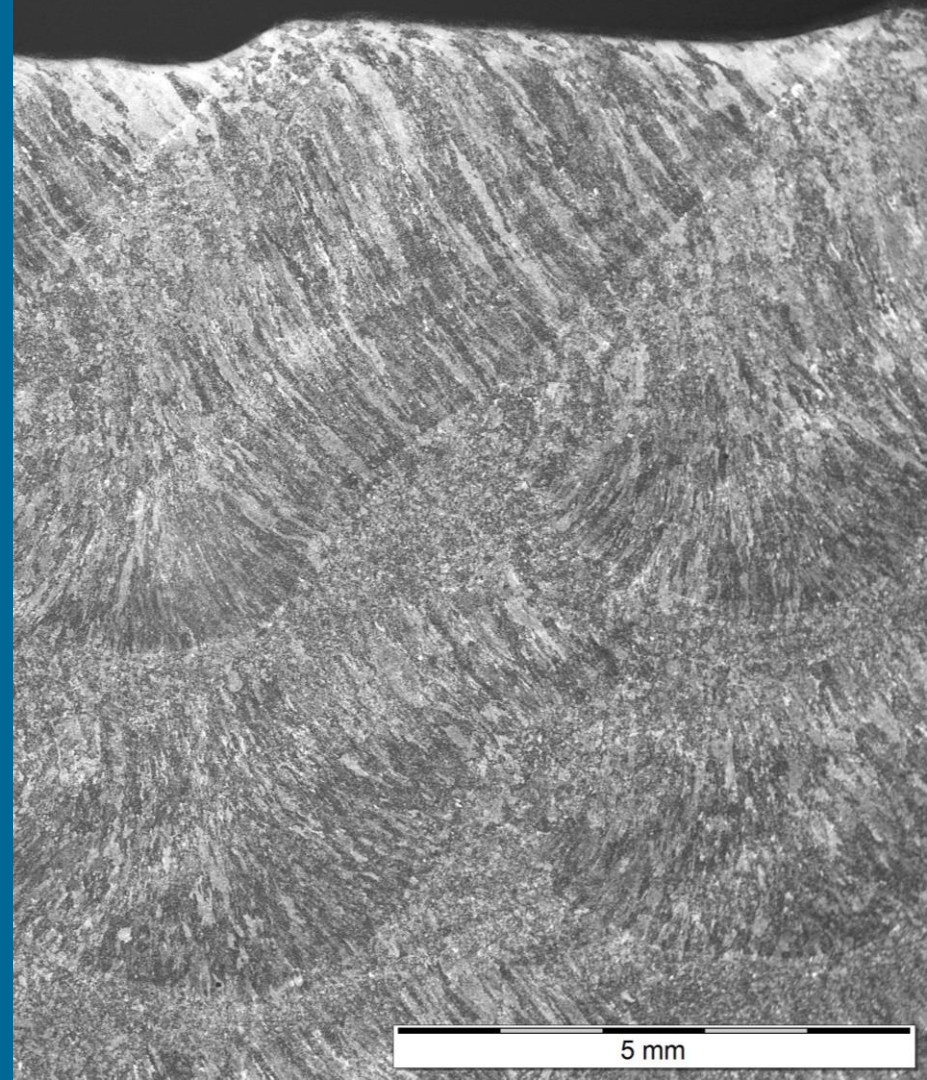
MACRO & MICROSCOPIC CHARACTERISTICS

- HAZs + annealed material
- Dendritic grain growth, grown metal grains (heat treatment)
- Consistent material structure
- Risk of defects:
 - Gas inclusions (small compared to cast)
 - Lack of fusion
 - Trailing slag

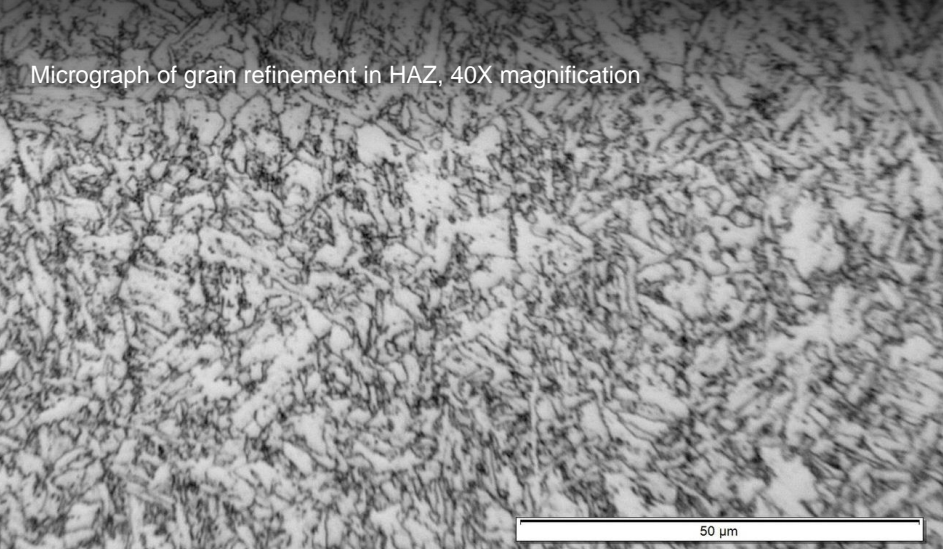


MACRO & MICROSCOPIC CHARACTERISTICS

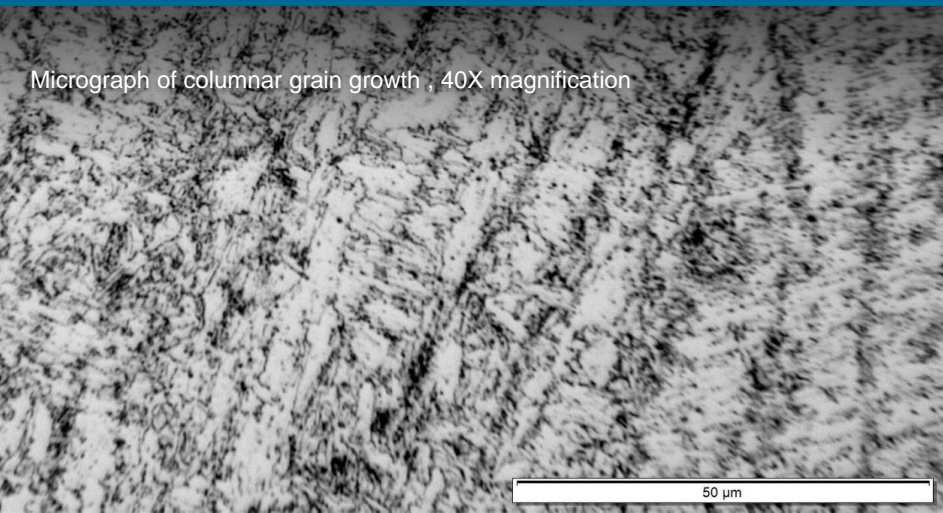
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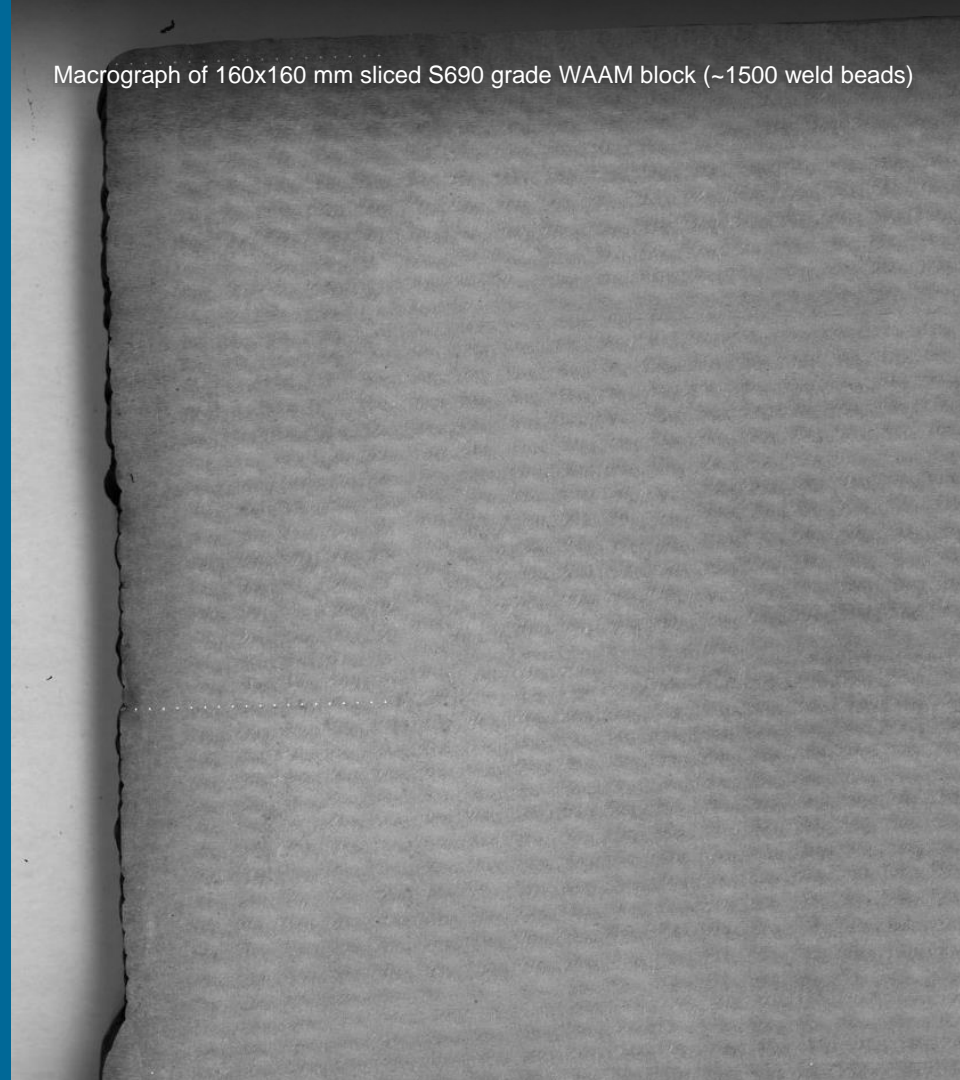
Micrograph of grain refinement in HAZ, 40X magnification



Micrograph of columnar grain growth, 40X magnification



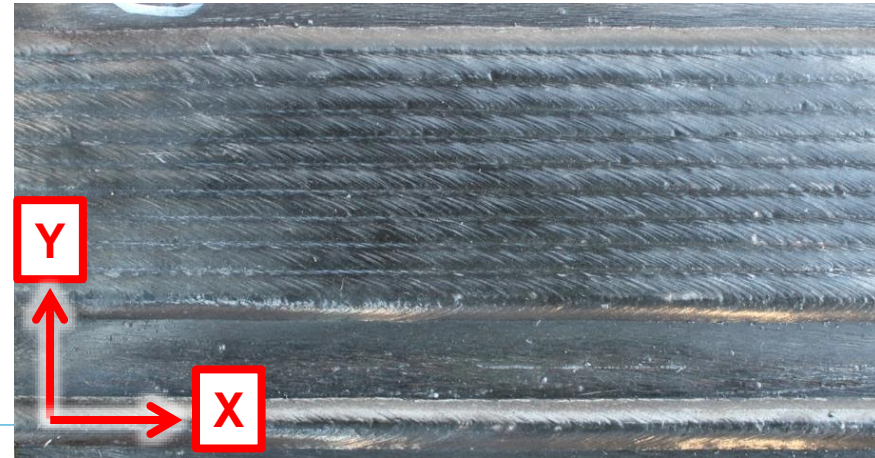
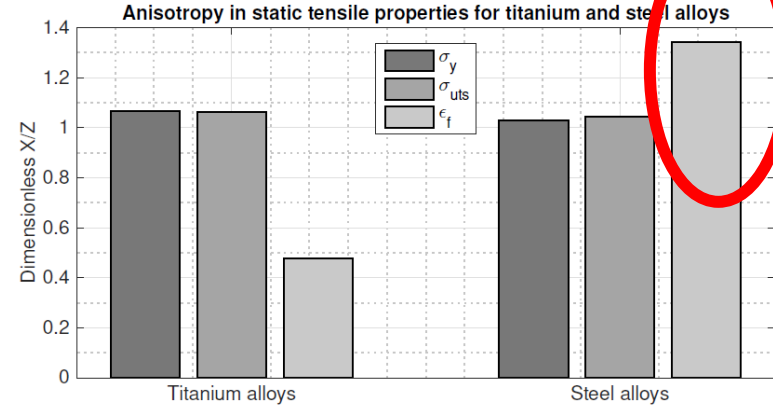
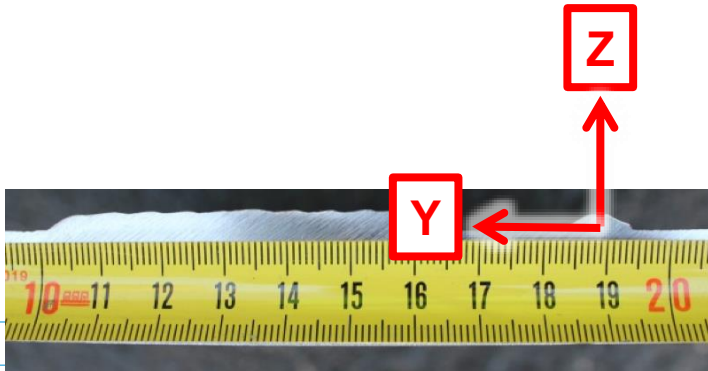
Macrograph of 160x160 mm sliced S690 grade WAAM block (~1500 weld beads)



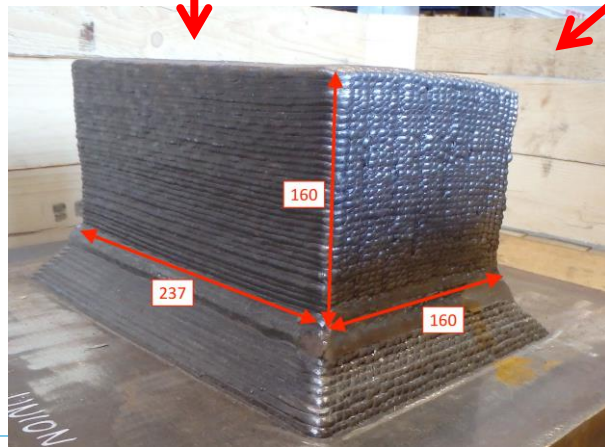
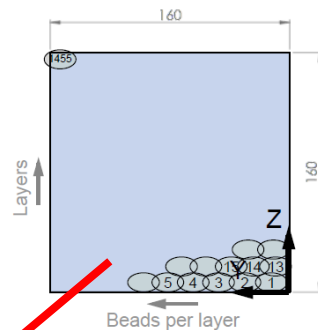
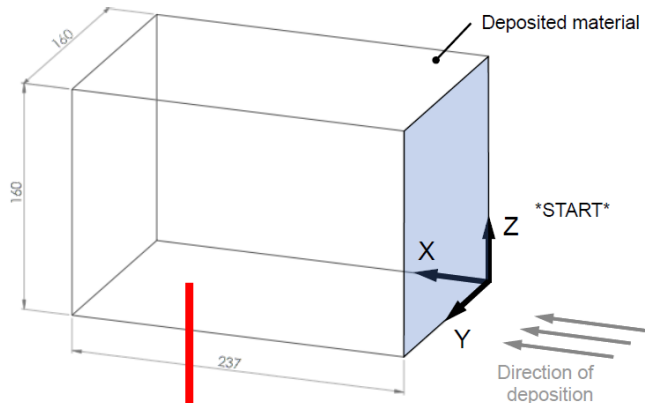
Anisotropic aspects

ANISOTROPY

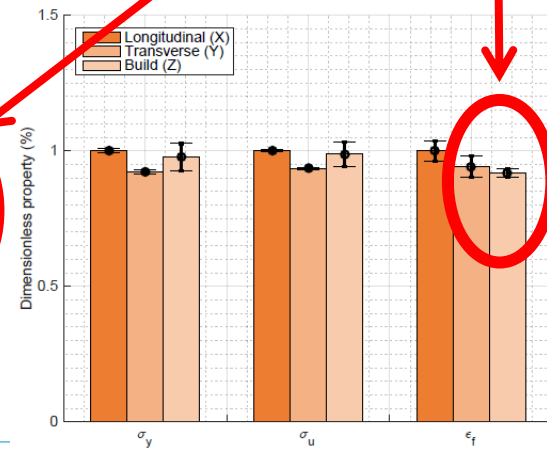
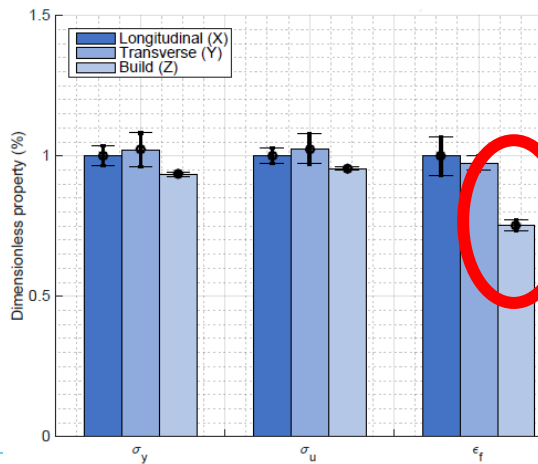
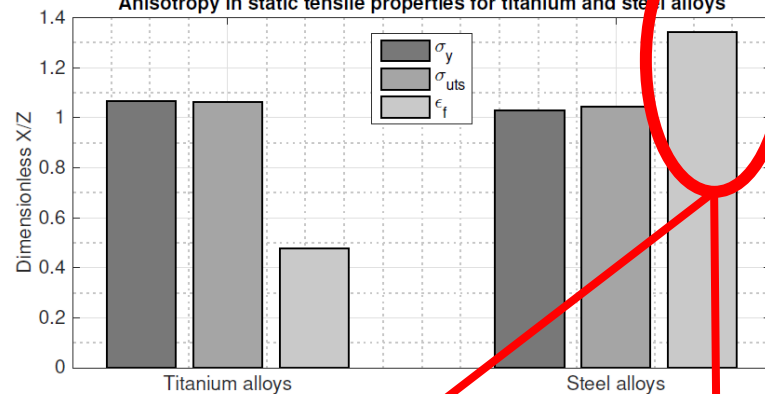
- Filament character of WAAM suggests anisotropy to be expected
- Metal dependent: Ti-6Al-4V versus HSLA steels
- Alloy dependent: see next slide (two S690 grade consumables)



STOP



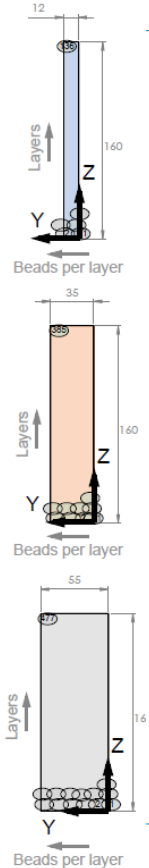
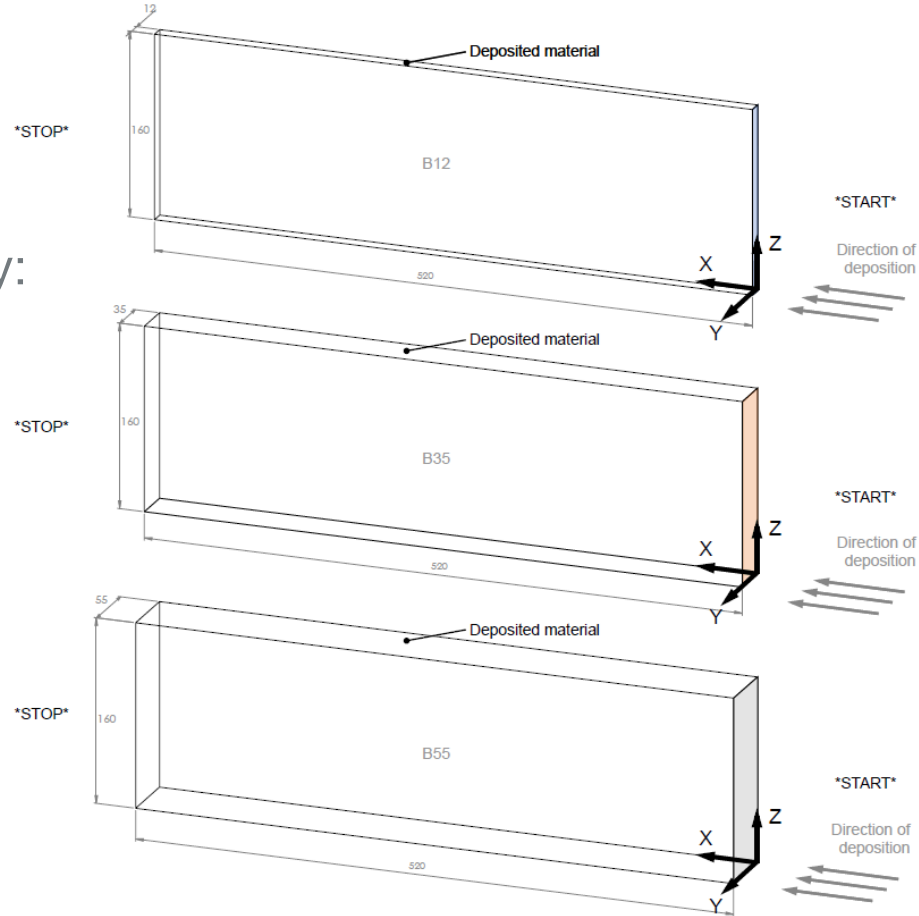
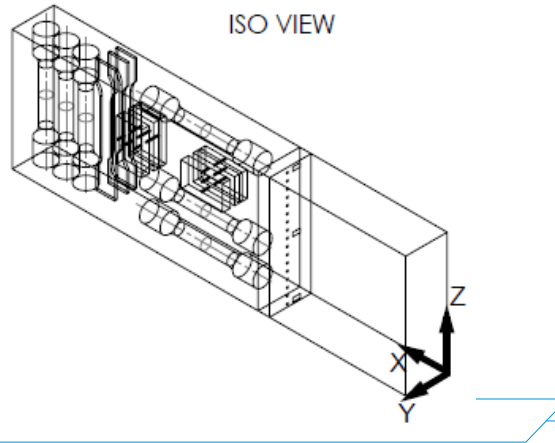
Anisotropy in static tensile properties for titanium and steel alloys



Product shape & volume effects

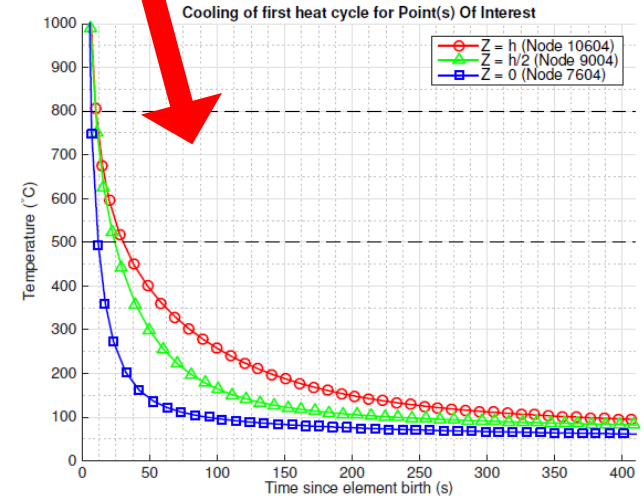
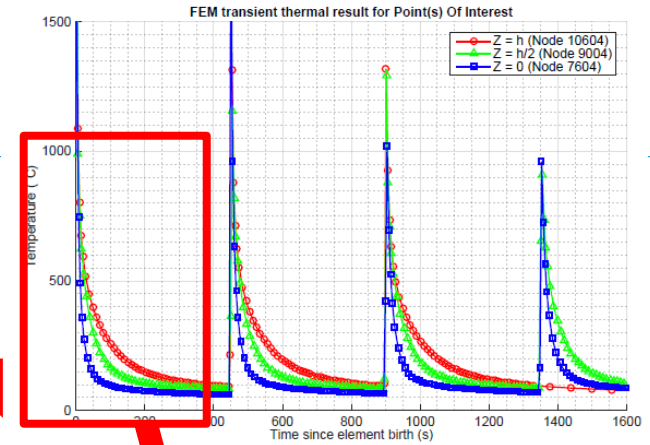
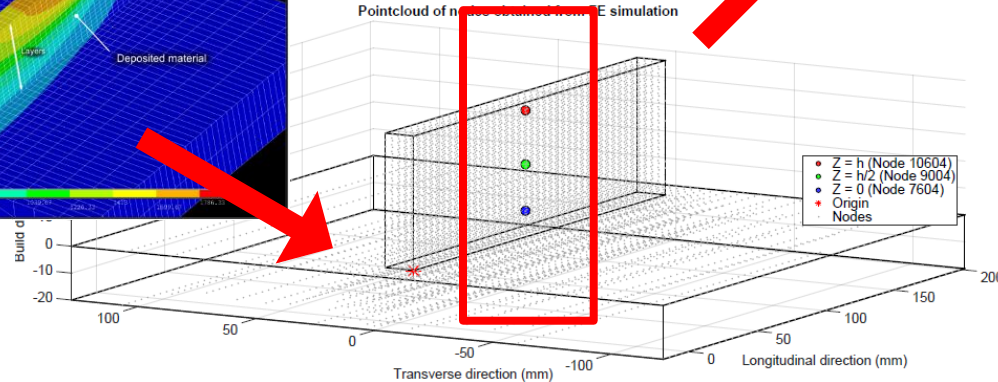
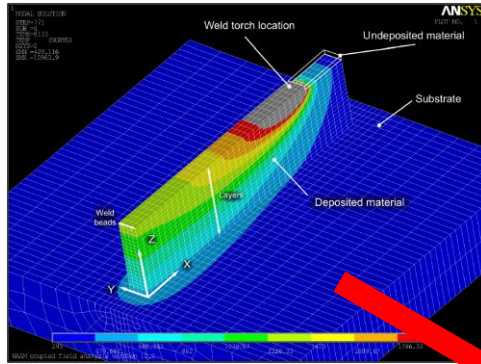
GEOMETRY EFFECT ON MATERIAL PROPERTIES

- Product geometry co-defines material properties
- Cooling rates influenced by:
 - Product volume
 - Product shape

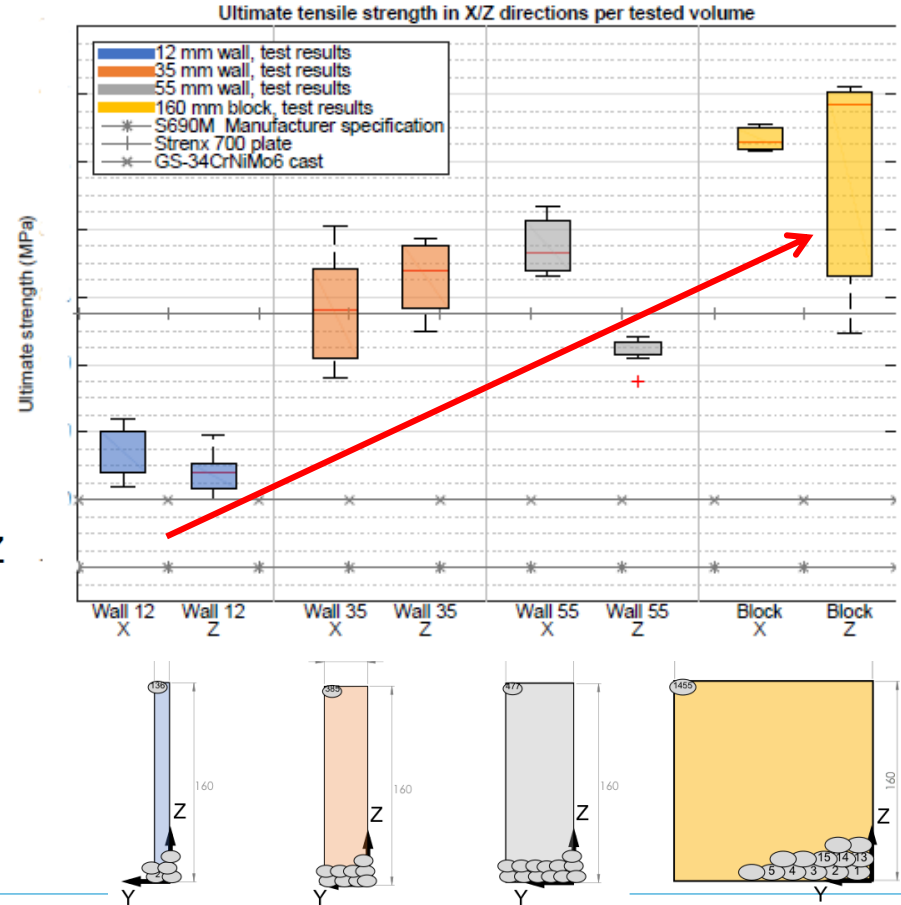
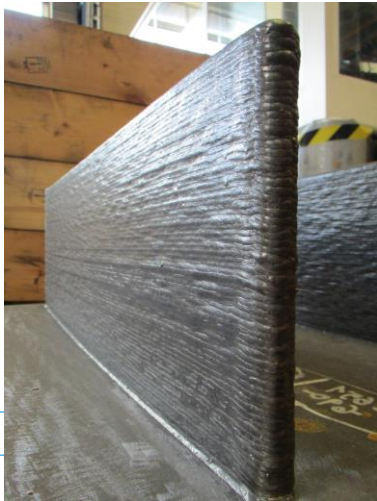
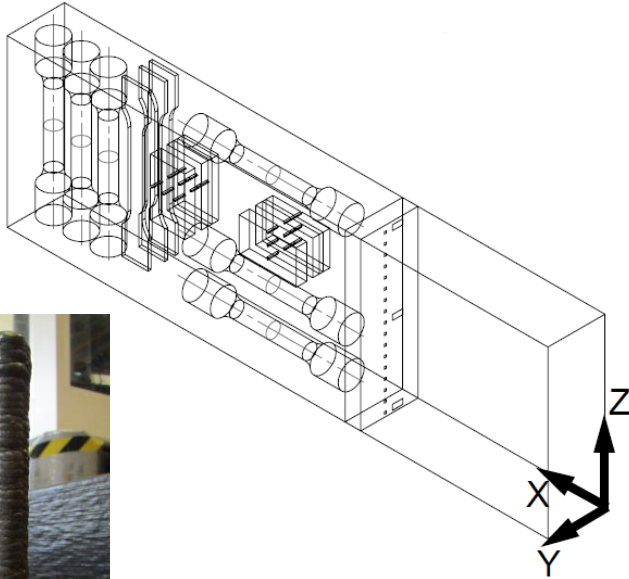


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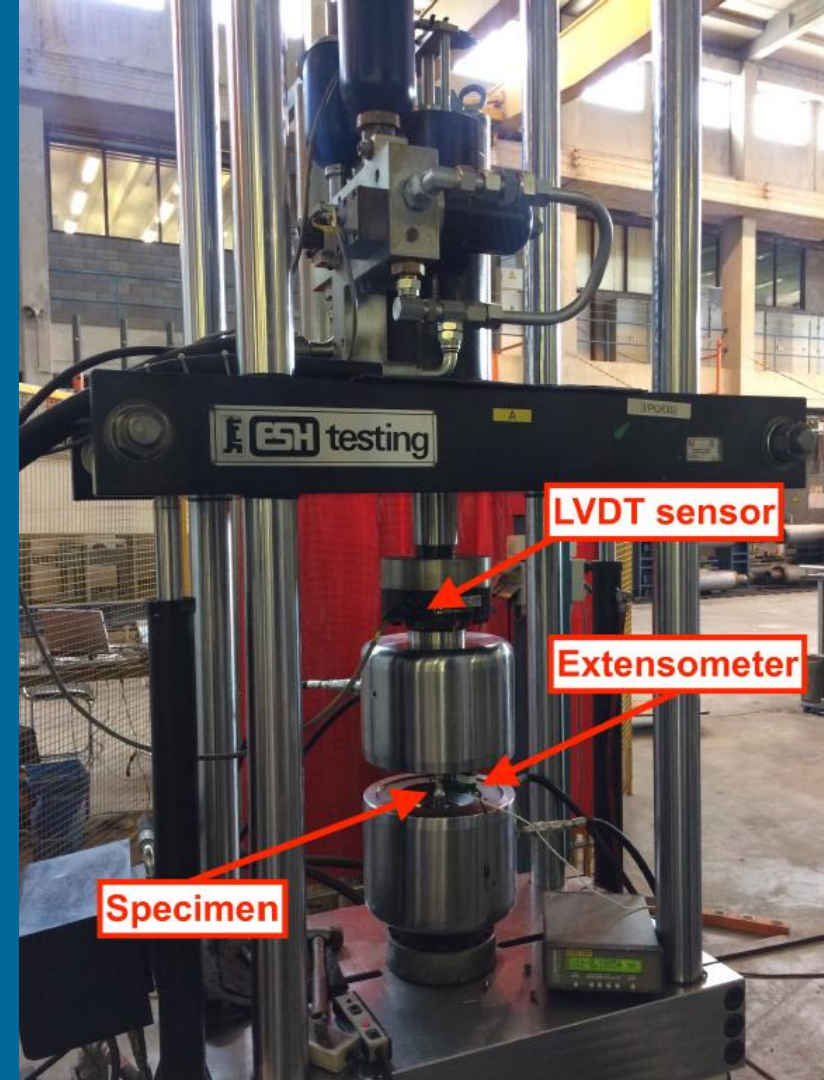
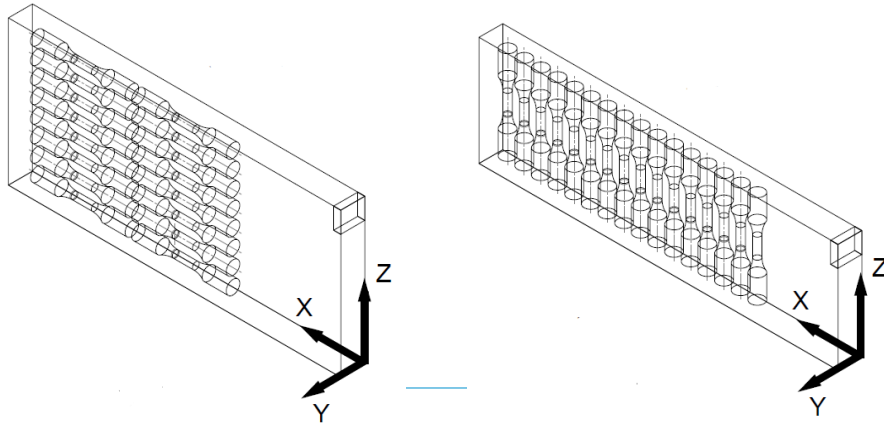
GEOMETRY EFFECT ON MATERIAL PROPERTIES



Fatigue assessment

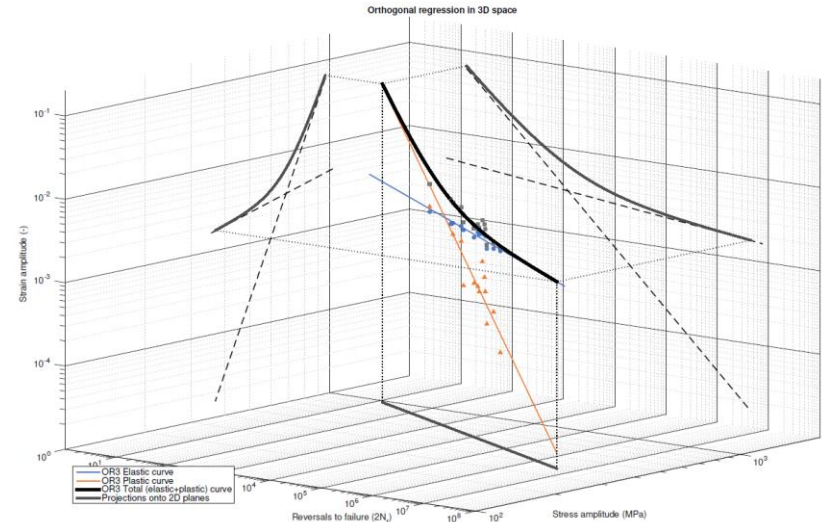
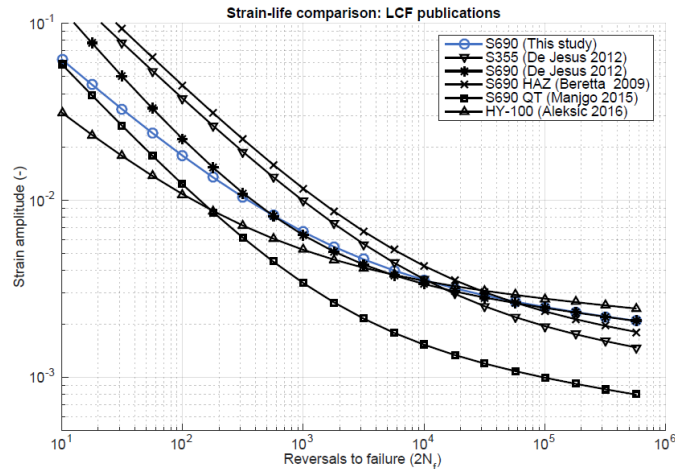
FATIGUE PERFORMANCE

- Low-cycle fatigue assessment
- ASTM E606 strain-controlled cyclic uniaxial tensile tests ($R = -1.0$)
- Smooth polished uniform cylindrical gauge specimens (D10)



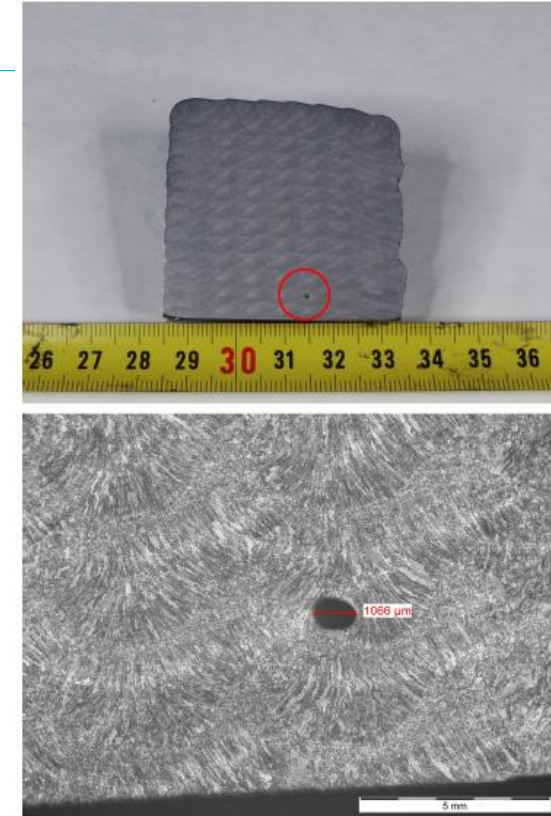
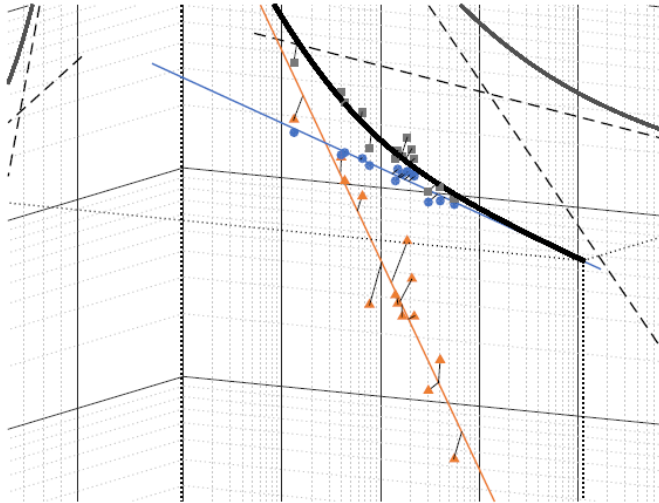
FATIGUE PERFORMANCE

- No distinguishable anisotropic effects
- LCF Performance comparable to base material of similar steel grade
- Weld-induced defects contribution



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Future of WAAM at Huisman

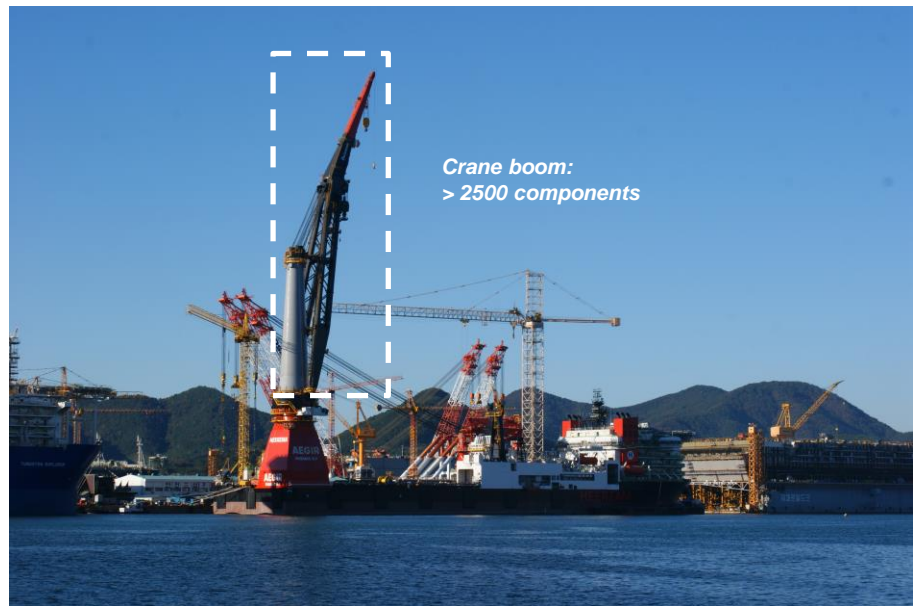
FUTURE OF WAAM AT HUISMAN

- We consider WAAM as a serious addition to our current production processes
- We are taking steps to move forward accordingly
- Phases:
 1. Select suitable components
 2. Define appropriate project steps
 3. Identify challenges and required knowledge
 4. Involve project partners



FUTURE OF WAAM AT HUISMAN (1): SELECT SUITABLE COMPONENTS

- Determine manufacturing costs and delivery time for various production techniques:
 - Castings
 - Forgings
 - Welding rolled elements with minimum weld volume
 - Fully welded (WAAM)
 - Hybrid: rolled elements and WAAM

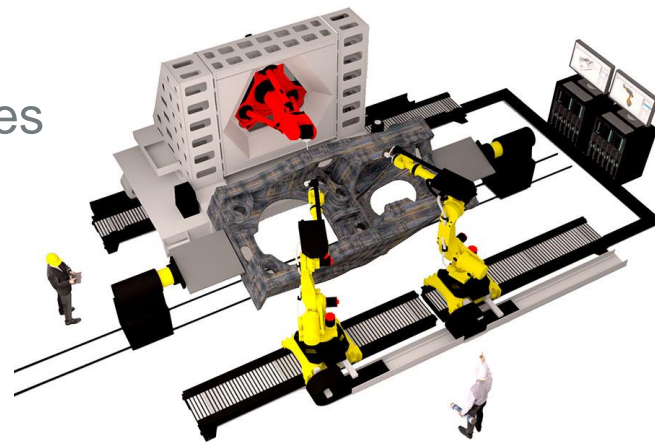


1. Design of component
2. Selection base and weld metals
3. Design manufacturing process
4. Prepare inspection and test plan
5. Make weld procedures
6. Manufacturing
7. Testing
8. Evaluation



FUTURE OF WAAM AT HUISMAN (3): IDENTIFY CHALLENGES AND REQUIRED KNOWLEDGE

- Geometrical accuracy
- Residual stress
- In-line NDT
- Evidence of quality
- Integration of production, pre and postprocesses (welding, machining, NDT, PWHT, dimensional survey)
- Efficiency:
 - High deposition rate
 - Minimizing intermediate cleaning
 - Minimizing machining
 - Identifying defects during manufacturing
 - Minimizing handling
 - Avoiding PWHT



LASIMM Project
<http://lasimm.eu>

FUTURE OF WAAM AT HUISMAN (4): INVOLVE PROJECT PARTNERS

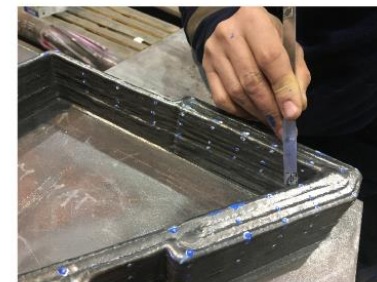
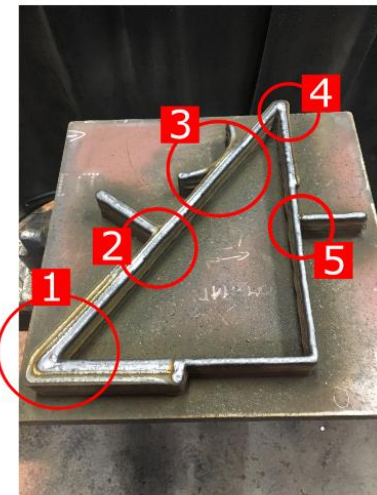
1. Robot suppliers
2. Weld consumable suppliers
3. Gas suppliers
4. 3D scanning
5. NDT experts
6. Machining experts
7. Process simulation
8. Test laboratories
9. Third party inspectors



First WAAM hook by Huisman
Huisman Equipment BV, Schiedam, The Netherlands



Huisman



10-NOV-2017
"WAAM 4-shape"
Produced in HK

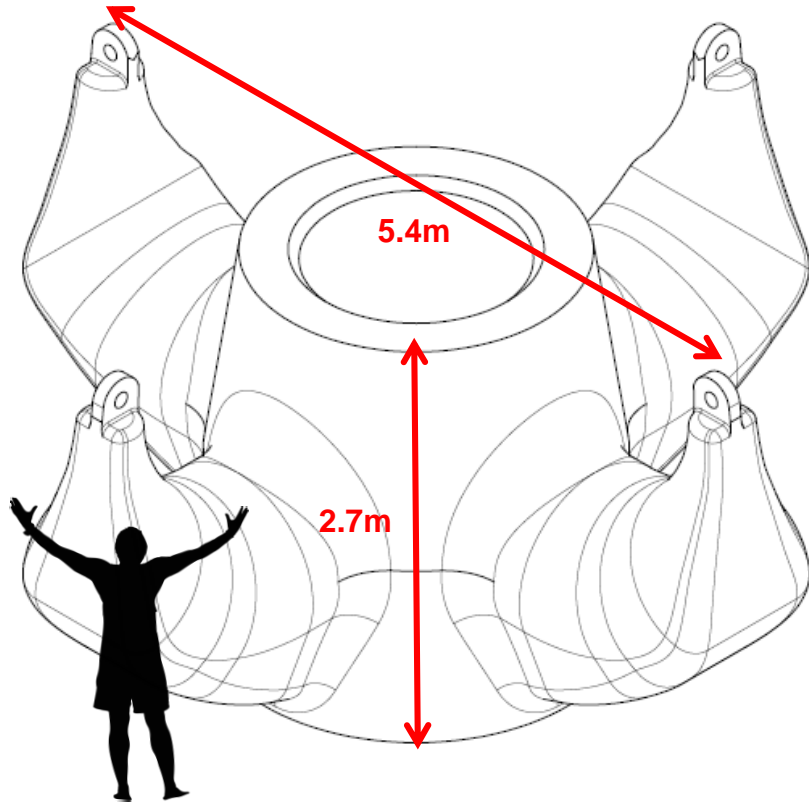


Production process: Wire & Arc Additive Manufacturing (WAAM)

Pictures: geometrical trials, S690 steel

More information: Hugo Romer
hromer@huisman-nl.com

Design of 10,000mt 4-prong hook
Huisman Equipment BV, Schiedam, The Netherlands



Casting of 4-prong hook
Lifting capacity: 10,000mt





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