TUHH
Hamburg University of Technology

Institute for Ship Structural Design and Analysis

M-10

Sören Ehlers
Prof. DSc. (Tech) / Institutsleiter

Ship Structural Design & Analysis

Maritime Systeme

Institute for Ship Structural Design and Analysis (M-10)

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Hamburg University of Technology

Sören Ehlers: Design and analysis of ships and offshore structures

Teaching

- Fundamentals of engineering design
- Ship structural design I, II and III
- Introduction to ship structural analysis
- Arctic technology

Research

- Analytical, numerical and experimental structural analysis
- Structural analysis and design under extreme conditions
- Fatigue of Ships and Offshore structures
- Design of Ships and Structures for polar regions
- Structural optimisation

Ship Structural Design & Analysis

Maritime Systeme

Marine Technology Students at TUHH

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Teaching in the current situation:

- Teaching is primarily online with live or pre-recorded presentations

Registered students 2020:

- Quite a drop in recent years
- New Master students: 8
- New Bachelor students: 18
- Total registered students: 71

- **General trend is a decreasing amount of students in mechanical engineering**
- **Especially for Marine Technology I feel that we fail to communicate the diversity and cutting-edge technology we deal with. Often the one associates naval architecture with steel and iron work of heavy labor at a yard alone**

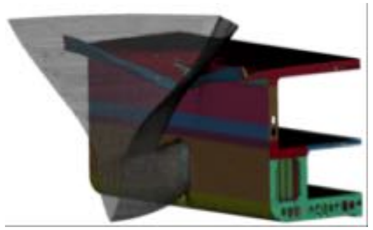
Research Areas

Fatigue/fracture mechanics
- Detail design
- New cutting and welding methods
- New materials
- Production and in-service influences on fatigue and fracture behavior

Ice loads
- Ice-structure interaction
- Ice-pressure-distribution
- Thin sections
- Friction testing

Nonlinear Waves under Solid Ice
- Nonlinear wave propagation
- Dispersion of waves
- Swell conditions
- Ice breakup mechanism

Numerical Simulations
- Component design
- Structural optimization
- Fatigue assessment
- Material models
- Simulation of collision and grounding



Research Areas

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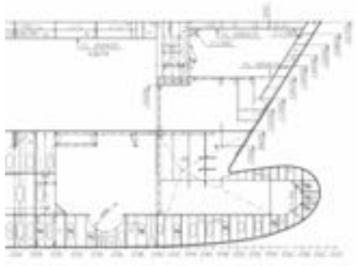
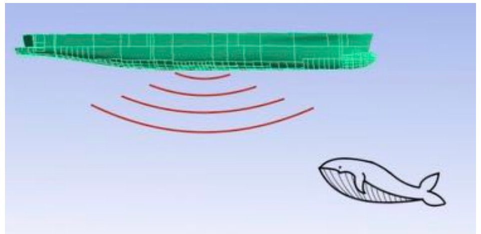
Residual stresses and laser scanning
- Hole-drilling rosette method
- Weld surface geometry scanning
- Plate deformation

Ship structural design for ice loads
- Ice-structure interaction
- Ice-pressure-distribution
- Thin sections
- Friction testing



Structural behavior
- Design of ships and equipment
- Collision and grounding
- Production and in-service influences on structural strength
- Influence of corrosion

Ship acoustics
- Sound sources
- Sound propagation through structures
- Sound radiation into water



Ship Structural
Design & Analysis

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Fatigue strength and residual stresses

Ship Structural Design & Analysis

Motivation

- Vielseitige Schadensfälle für Schiffe und Offshore Strukturen [1]
- Oft kombinierte Schäden [2]
- Ein Großteil der Schäden sind auf schlechtes design und operative Fehler zurückzuführen [2]
- Materialwahl kann Schäden beeinflussen [3]

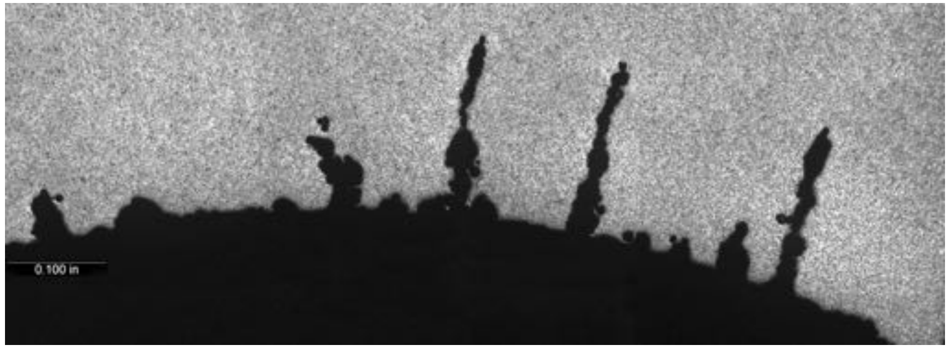
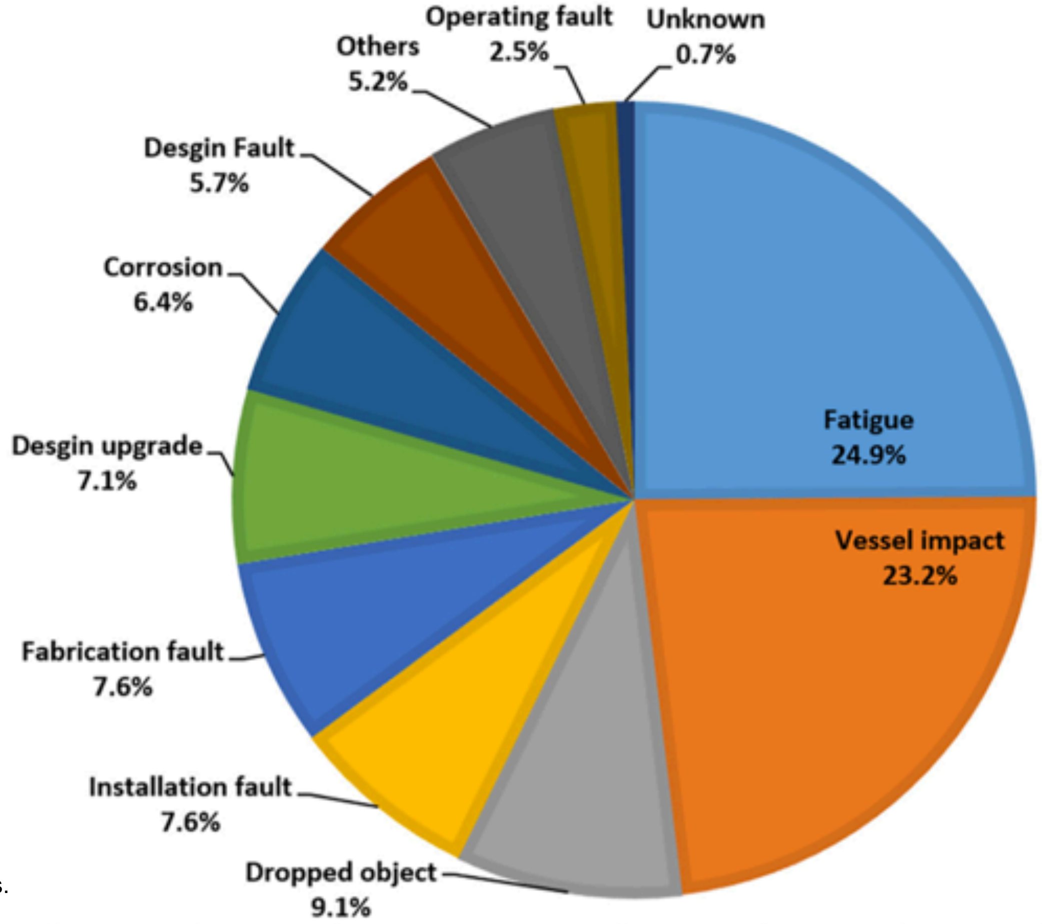


Image © Structural Integrity Associates, Inc.

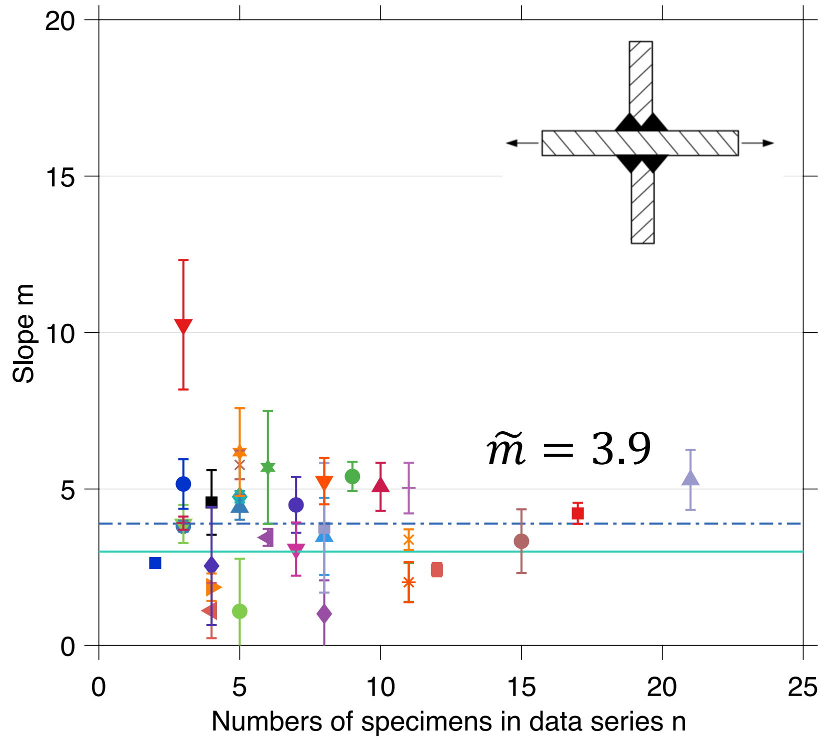
Dokumentierte Schäden in Offshore Strukturen [1]

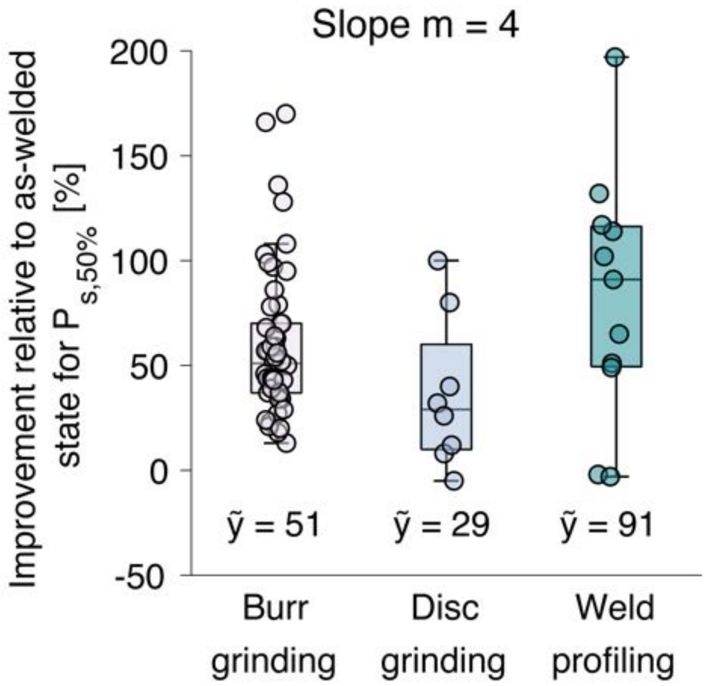


Ref.:
[1] A. Dehghani, F. Aslani, A review on defects in steel offshore structures and developed strengthening techniques. Structures, 20 (2019) 635-657. https://doi.org/10.1016/j.istruc.2019.06.002
[2] S.J. Price, R.B. Figueira, Corrosion Protection Systems and Fatigue Corrosion in Offshore Wind Structures: Current Status and Future Perspectives. Coatings, 7 (2017). https://doi.org/10.3390/coatings7020025
[3] V. Igwemezie, A. Mehmanparast, A. Kolios, Materials selection for XL wind turbine support structures: A corrosion-fatigue perspective. Marine Structures, 61 (2018) 381-397. https://doi.org/10.1016/j.marstruc.2018.06.008

Post-weld improvement and retrofitting

- TIG-dressing as a repair method up to 2.3 mm crack depth without reduction in fatigue strength [1]
- Recent results on TIG-dressing and grinding support and assessment based on a slope m = 4 [2,3]
- Higher fatigue strength improvement for weld profiling than for burr grinding and disc grinding [2]
- Highest improvement for combination of grinding and peening [3]





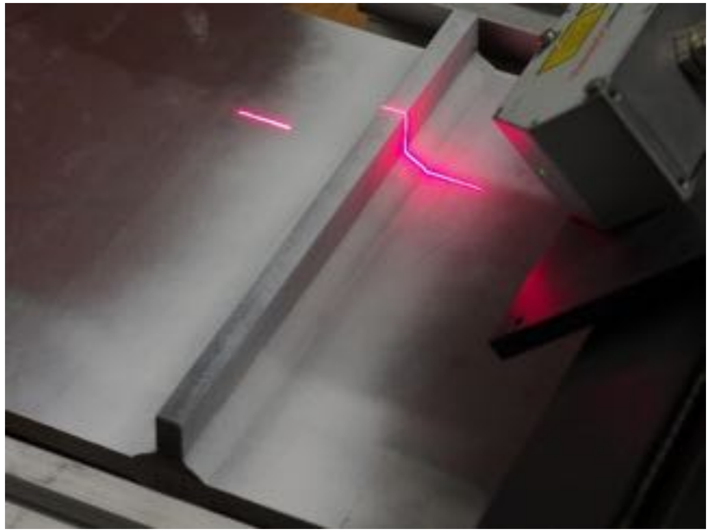
Ref.:

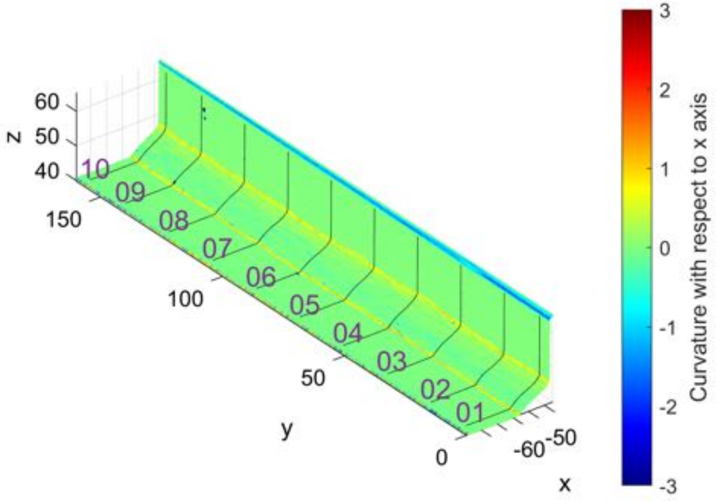
[1] Al-Karawi et al., Fatigue crack repair in welded structures via tungsten inert gas remelting and high frequency mechanical impact. Journal of Constructional Steel Research, 172 (2020). https://doi.org/10.1016/j.jcsr.2020.106200

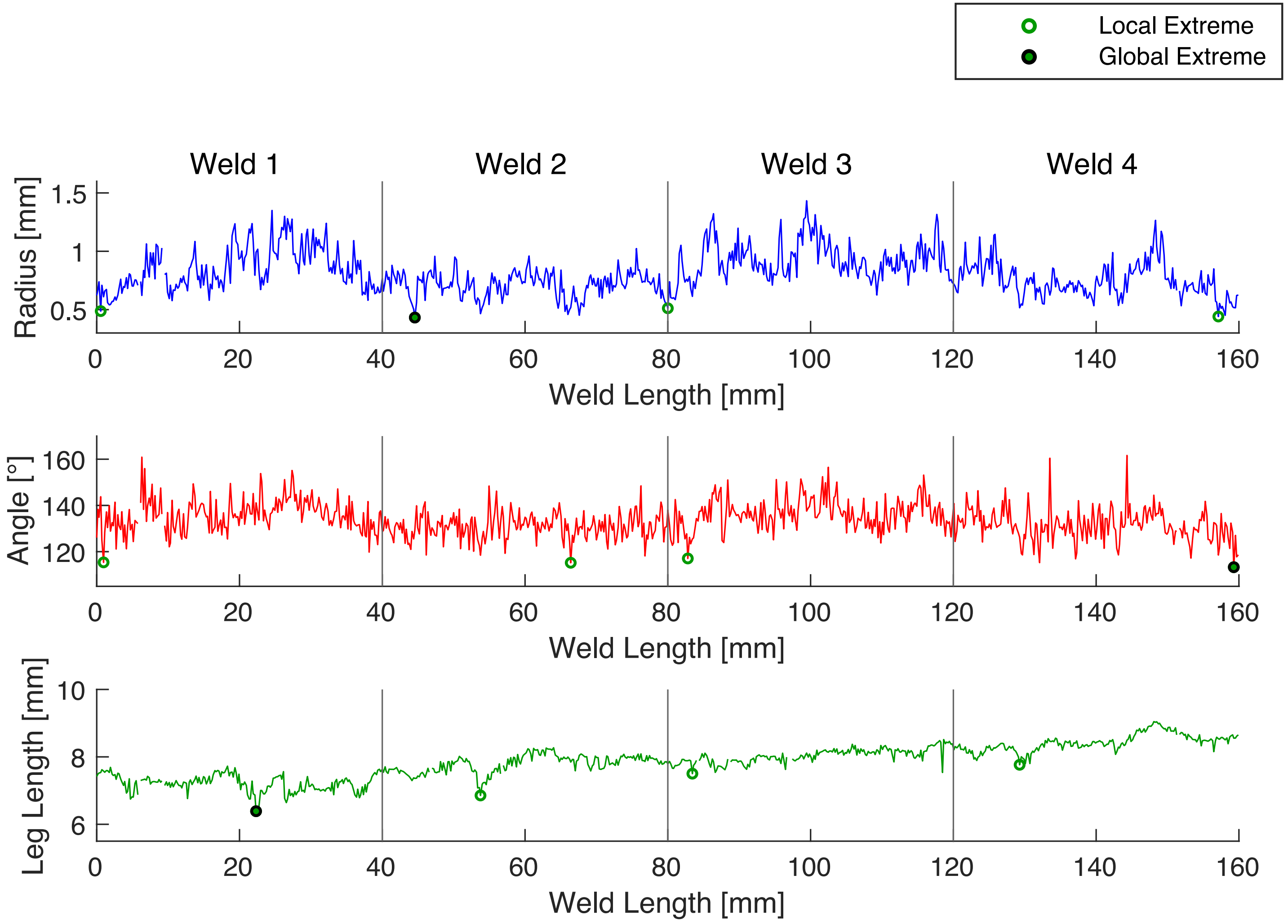
[2] Braun & Wang, A review of fatigue test data on weld toe grinding and weld profiling. International Journal of Fatigue, submitted for publication (2020)

[3] Ahola et al., Fatigue strength assessment of ground fillet-welded joints using 4R method. International Journal of Fatigue, 142 (2021). https://doi.org/10.1016/j.ijfatigue.2020.105916

Weld geometry assessment

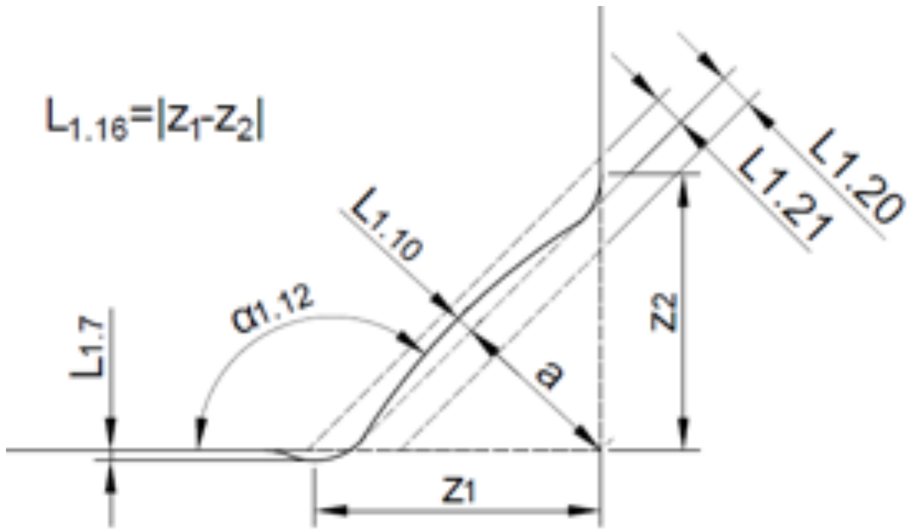


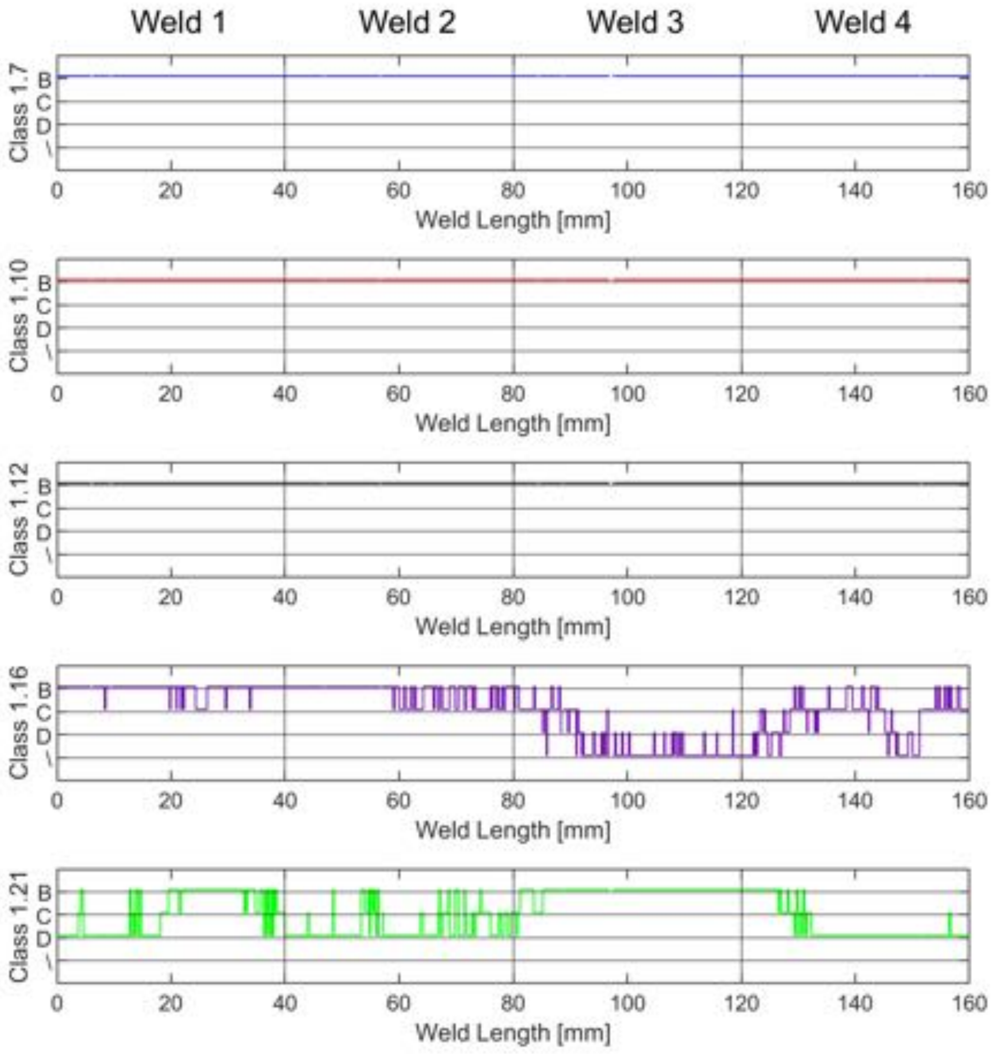




Ref.: Renken et al. (2020). An algorithm for statistical evaluation of weld toe geometries using laser triangulation, under preparation.

Weld geometry assessment



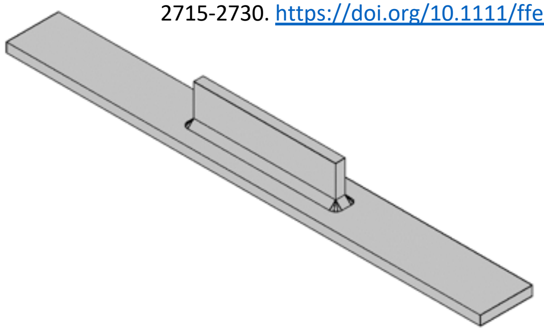


- IIW Round Robin study on weld geometry measurement systems & algorithm
- First results published [1]
- Higher measurement effort leads to more locations that do not fulfil ISO5817 requirements [2]

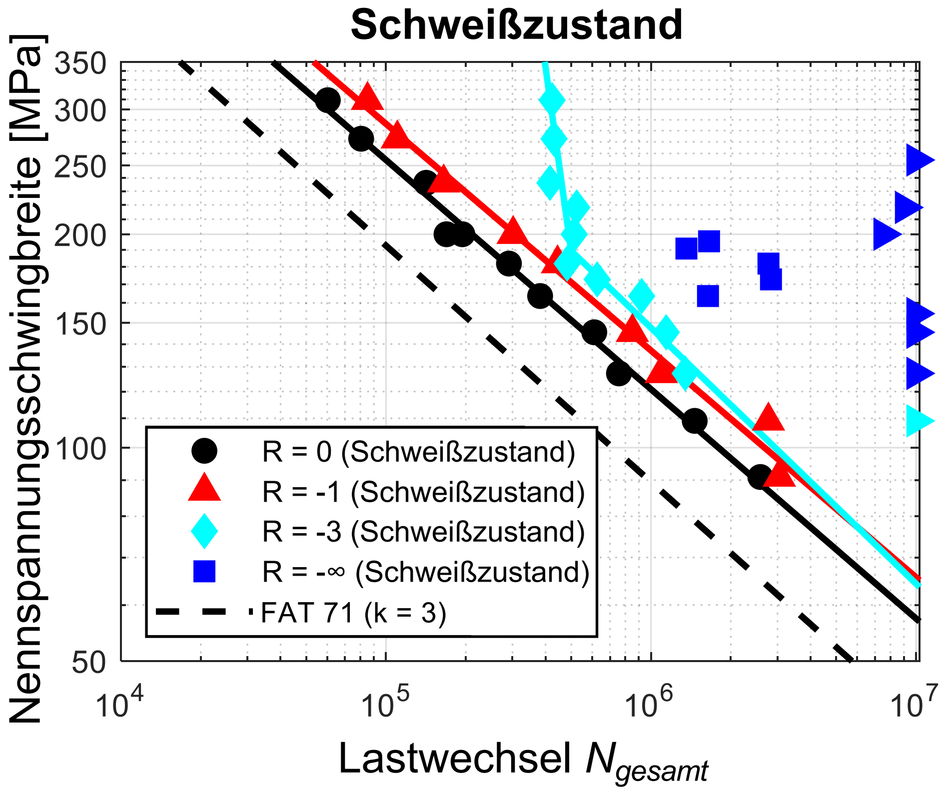
Ref.:
[1] Schubnell et al. (2020). Influence of the optical measurement technique and evaluation approach on the determination of local weld geometry parameters for different weld types. Welding in the World, 64(2), 301-316. https://doi.org/10.1007/s40194-019-00830-0
[2] Renken et al. (2020). An algorithm for statistical evaluation of weld toe geometries using laser triangulation, under preparation.

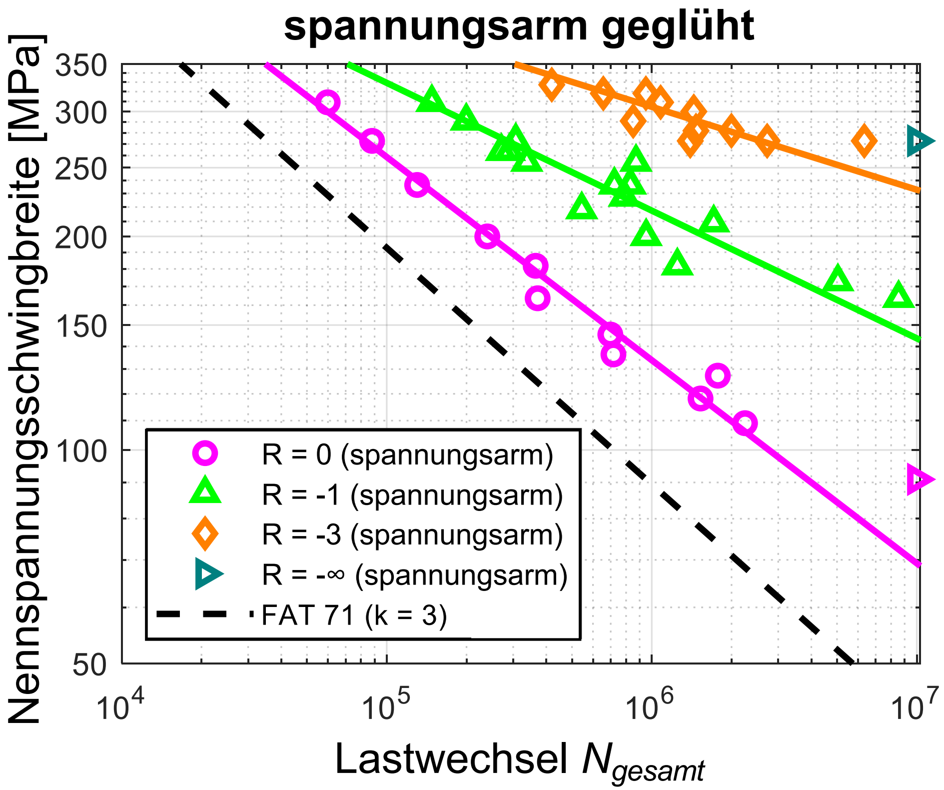
Fatigue strength assessment considering residual stresses

Ref.: N. Friedrich, Experimental investigation on the influence of welding residual stresses on fatigue for two different weld geometries. Fatigue Fract Eng M, 43 (2020) 2715-2730. https://doi.org/10.1111/ffe.13339



- Gesamtlebensdauer-Wöhlerlinien
- deutlicher Eigenspannungseinfluss





Schweißsimulation

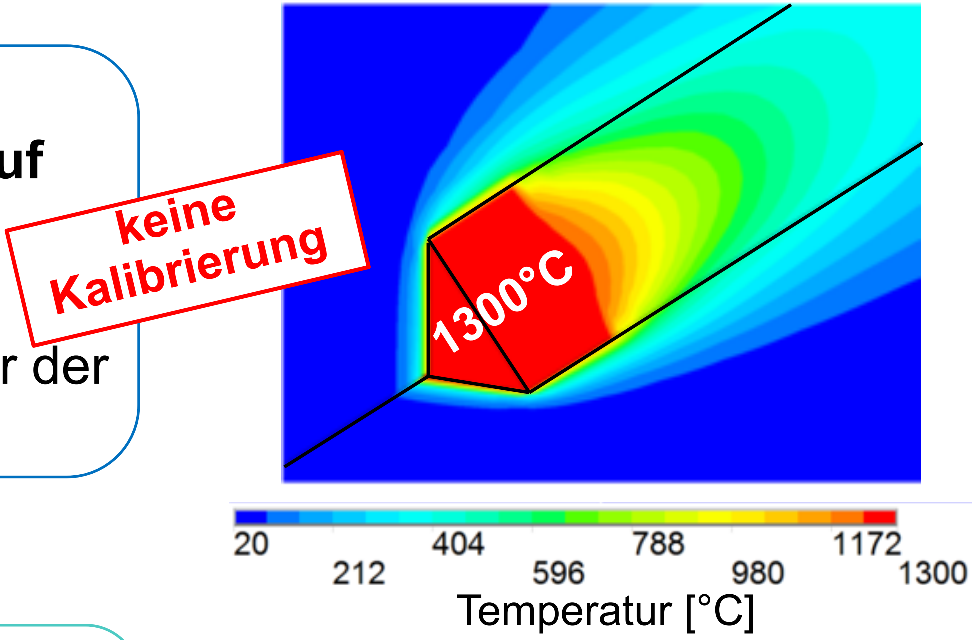
Vereinfachter FE-Simulationsansatz

(1) transiente thermische Analyse

Last: **einheitliche Temperatur auf Nahtquerschnitt**

⬇

Ergebnis: Temperaturverteilung über der Zeit



(2) elastisch-plastische Strukturrechnung

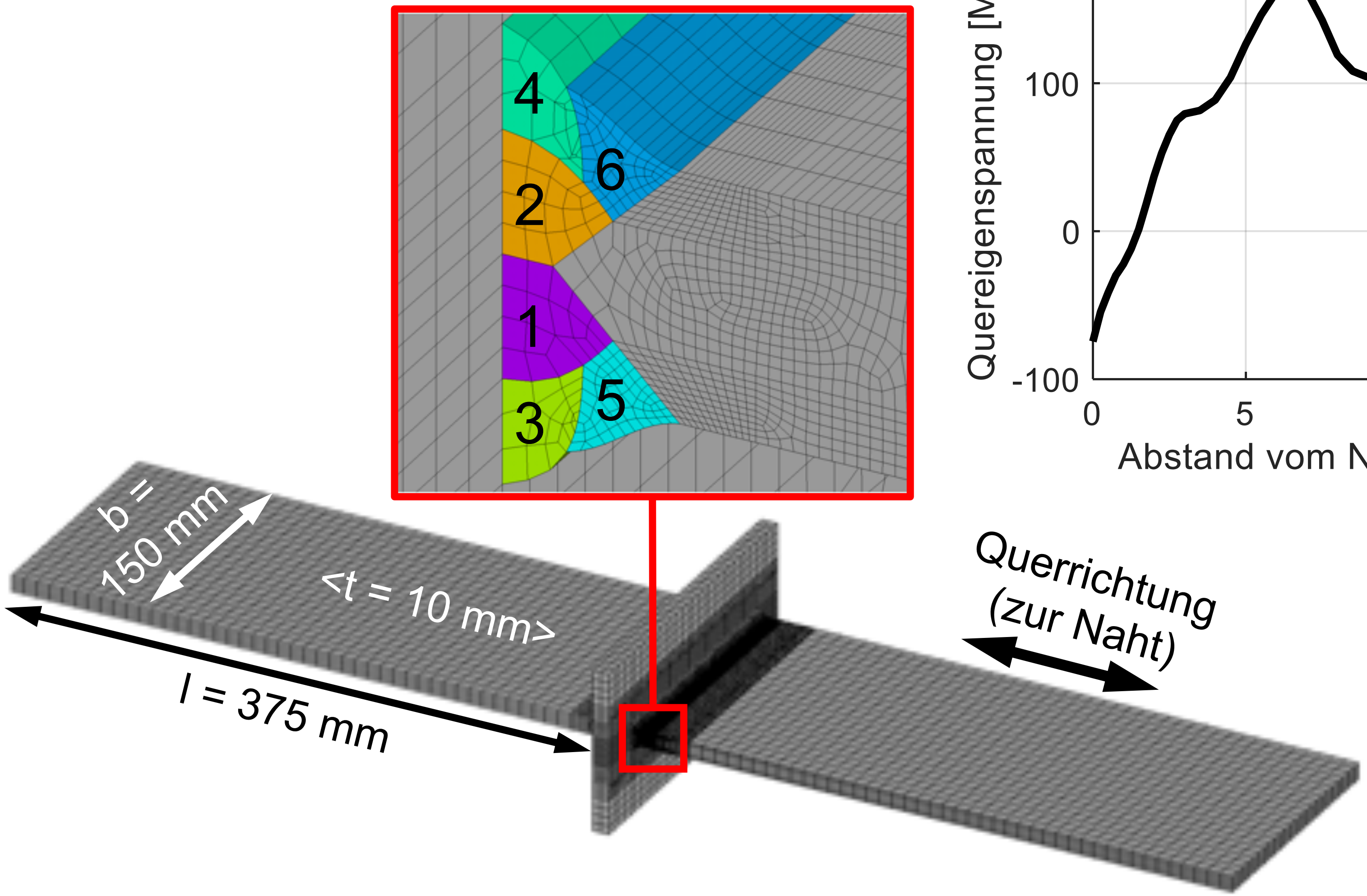
Last: Temperauren aus (1)

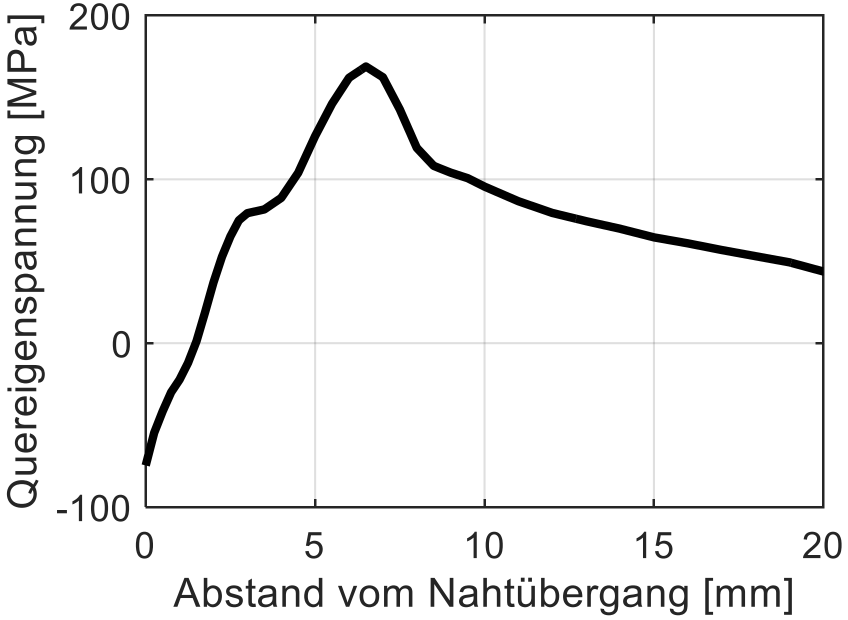
⬇

Ergebnis: Eigenspannung und Verzug

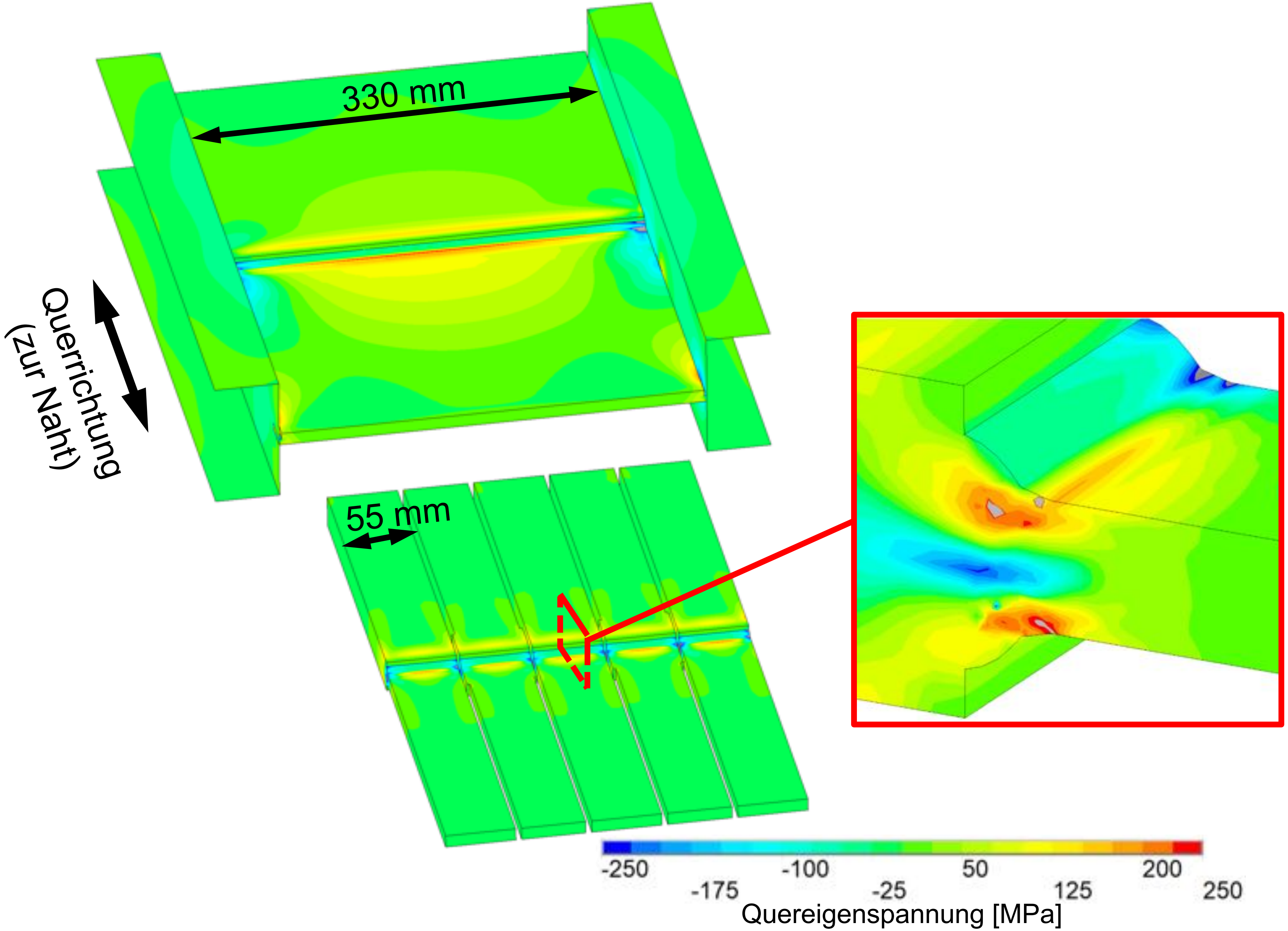
Schweißsimulation

- angewendet auf fiktive Kleinprobe mit Kreuzstoß
- angenommener Werkstoff: S355





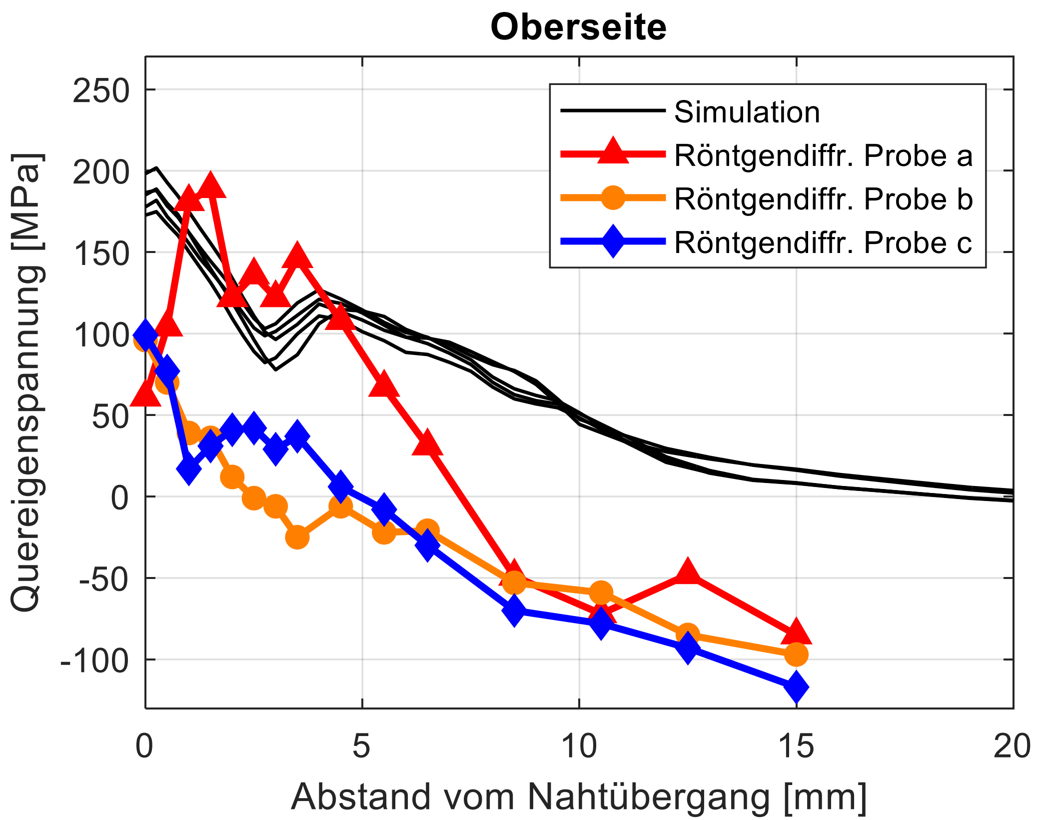
Schweißsimulation



Eigenspannungsmessung

Eigenspannungsmessungen:

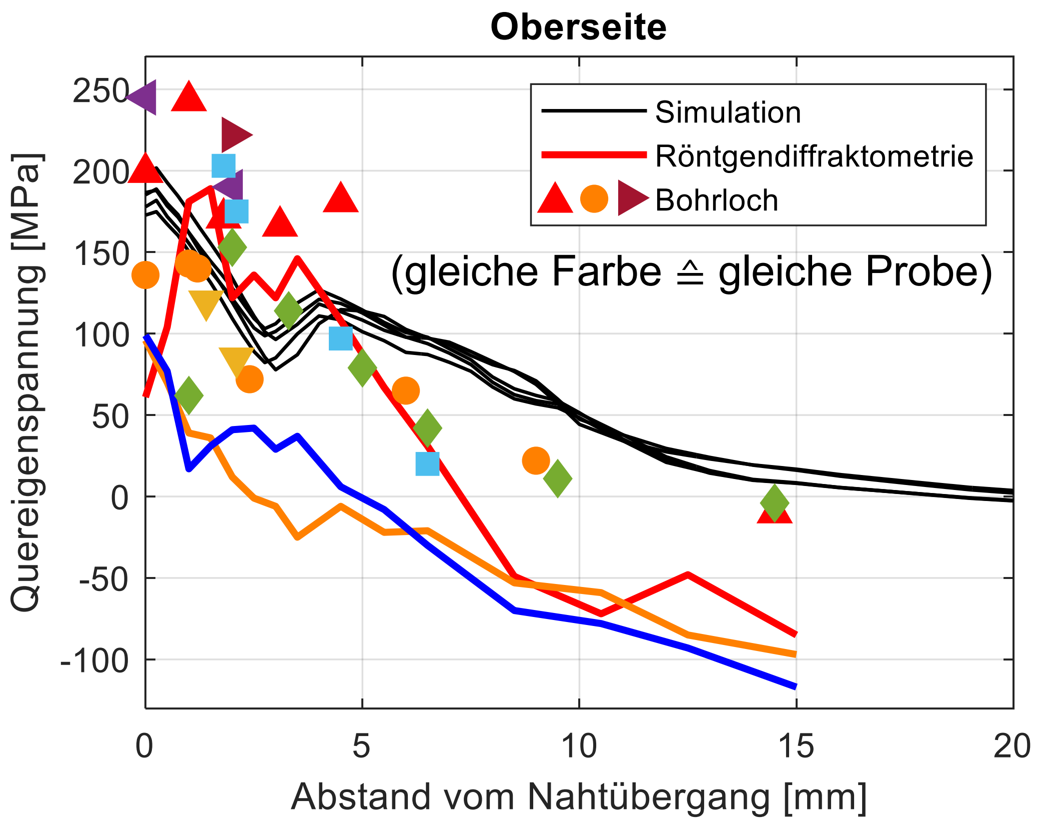
- **Röntgendiffraktometrie** (*ifs* TU-Braunschweig)
- Messtiefe bis ~ 5 µm
- auf 3 Proben



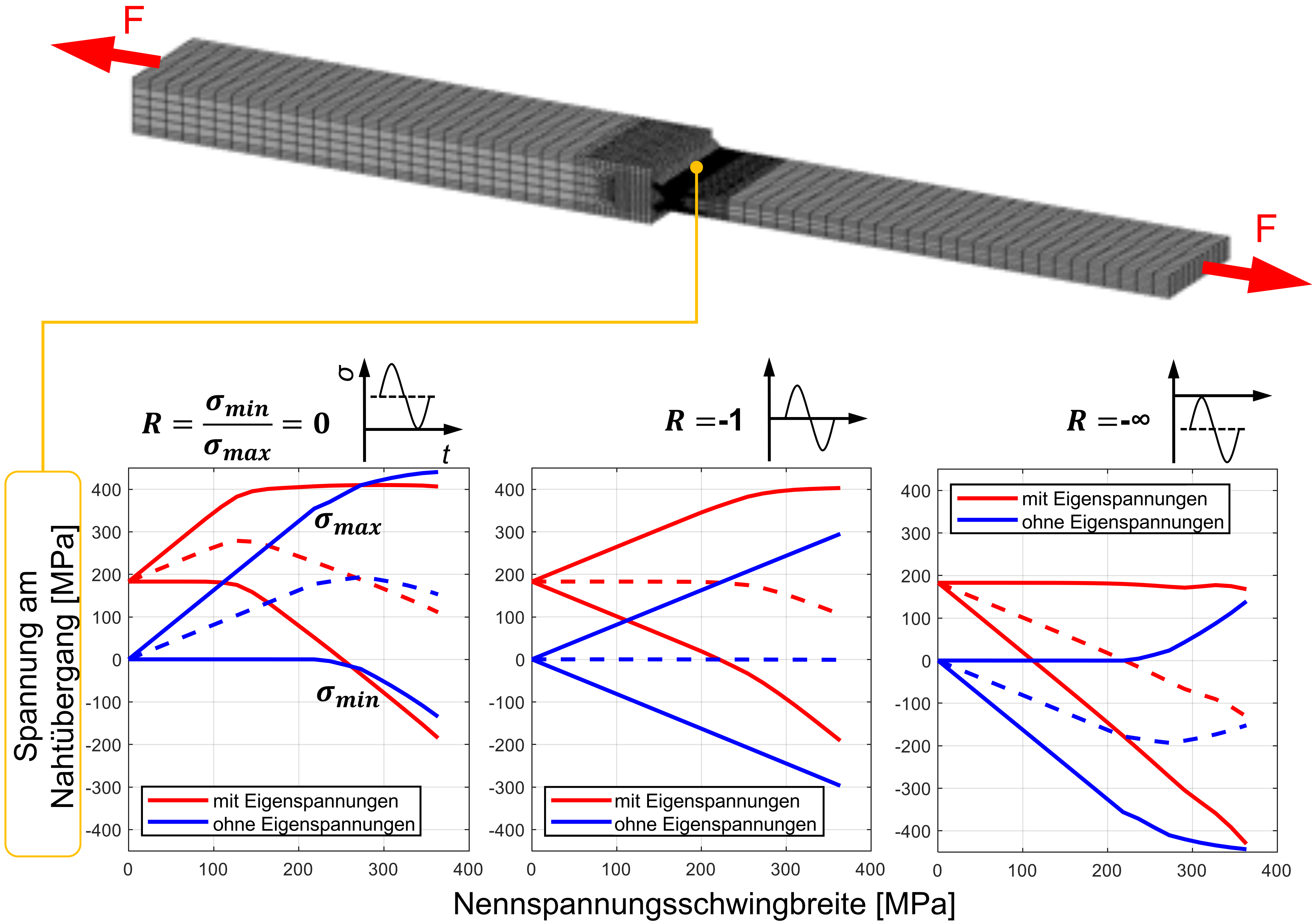
Eigenspannungsmessung

Eigenspannungsmessungen:

- **Bohrlochverfahren**
- Auswertung unter Annahme konstanter Eigenspannungen bis 1 mm Tiefe

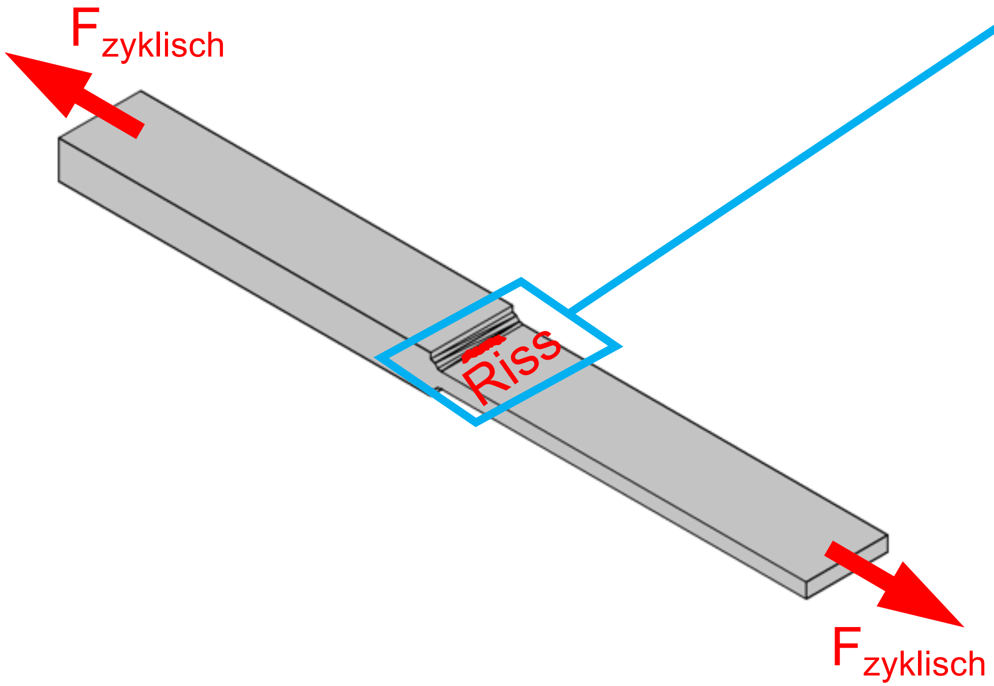


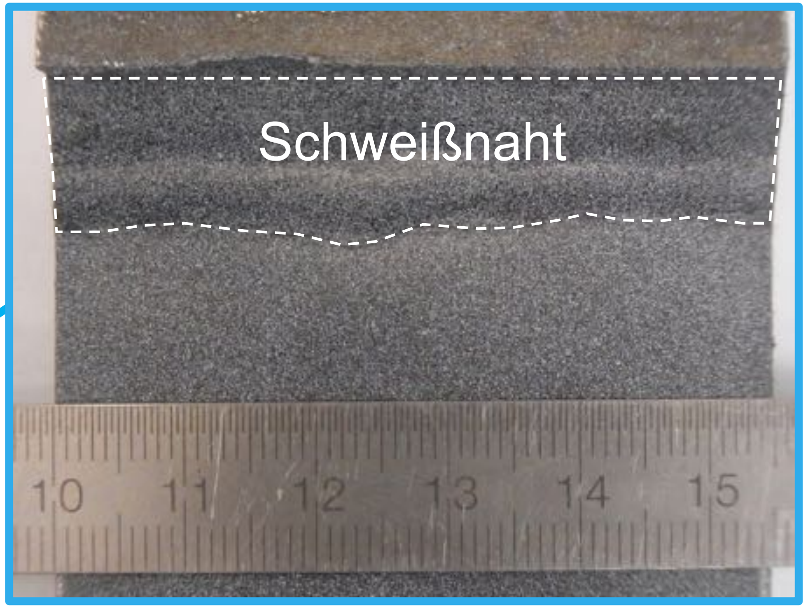
Überlagerung mit äußerer Last

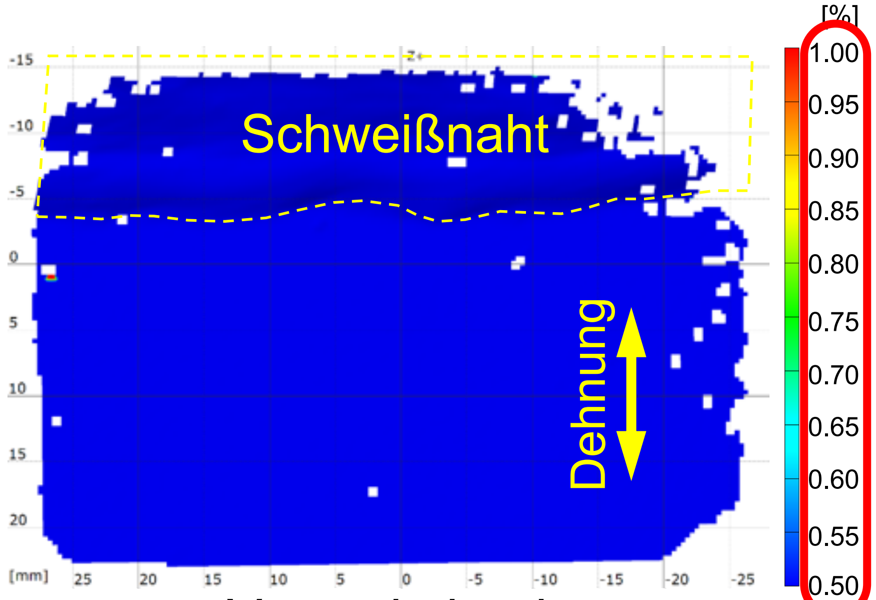


Schwingversuche – Risserkennung

Risserkennung mittels digitaler Bildkorrelation

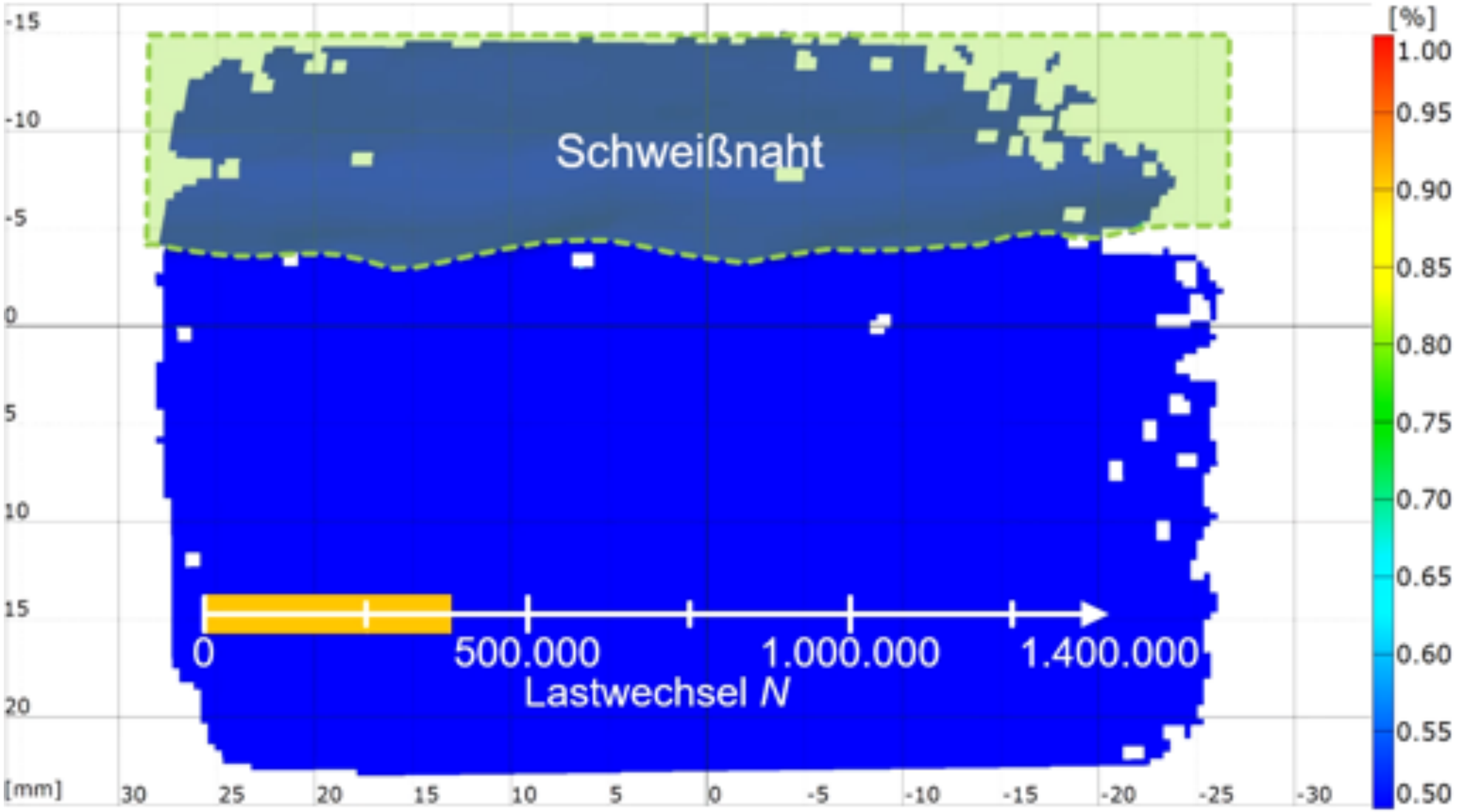




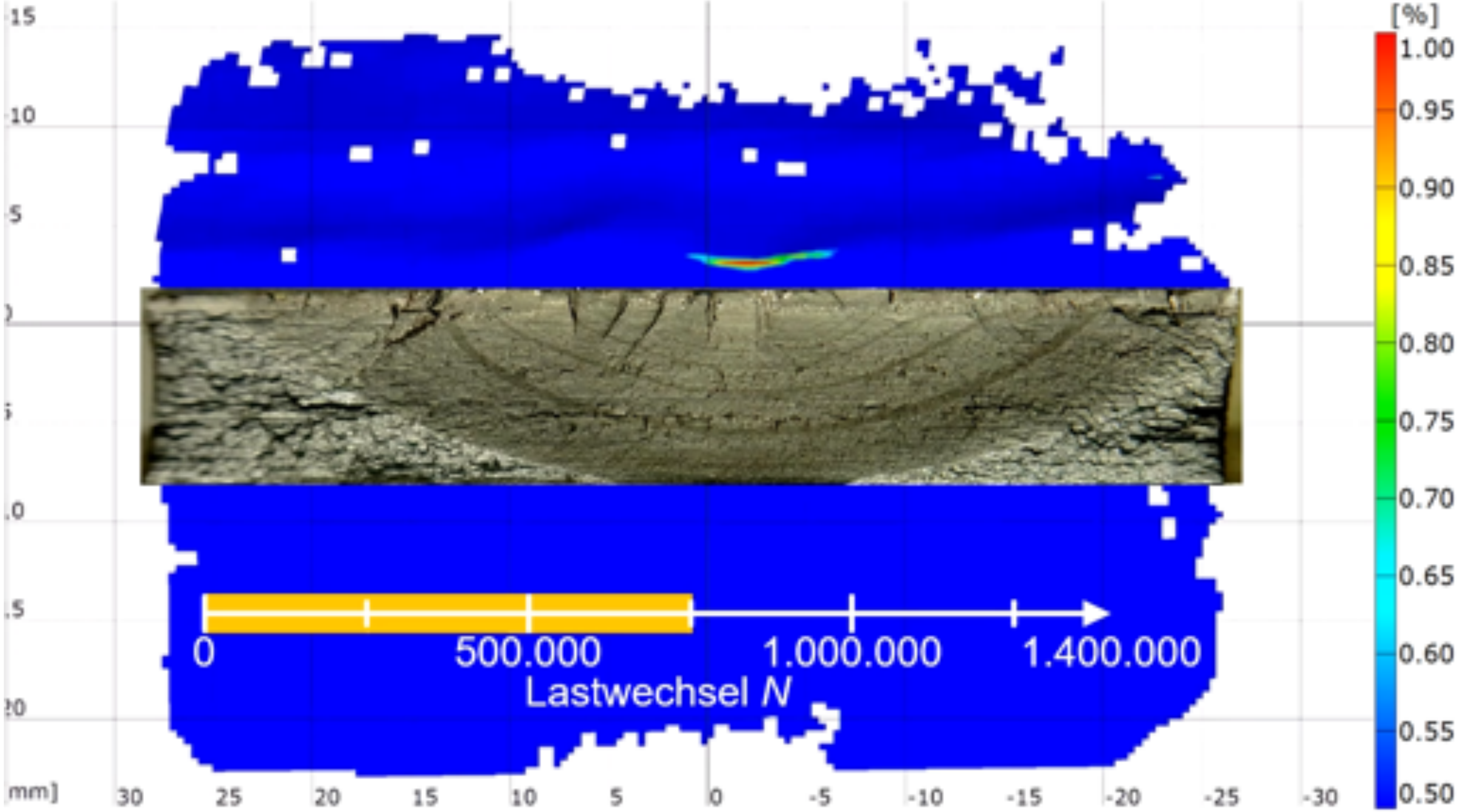


Versuchsbeginn

7. Schwingversuche – Risserkennung



Schwingversuche – Risserkennung



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Ice-structure interaction and temperature effects

Ship Structural Design & Analysis

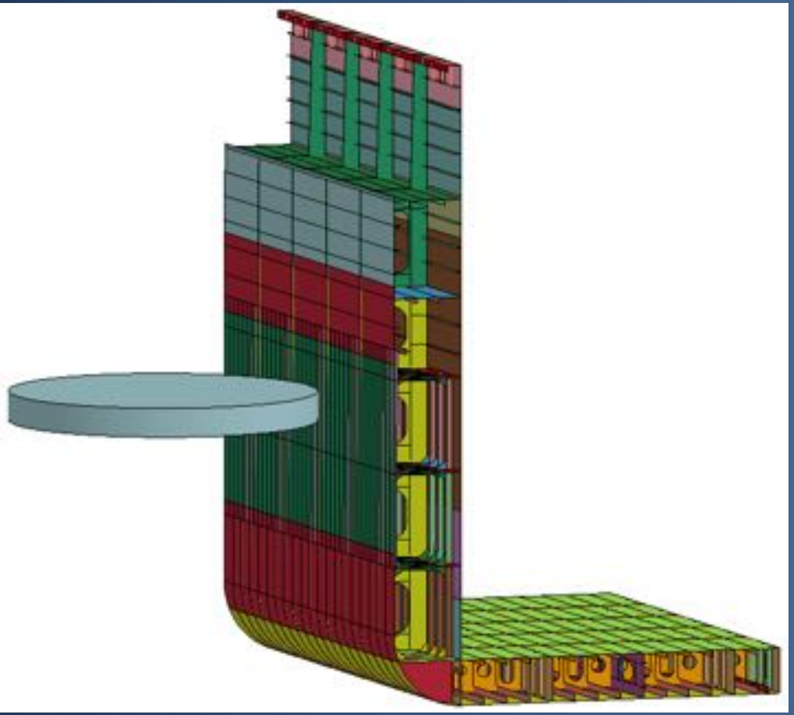
Collision scenario

<u>Ice Floe:</u>

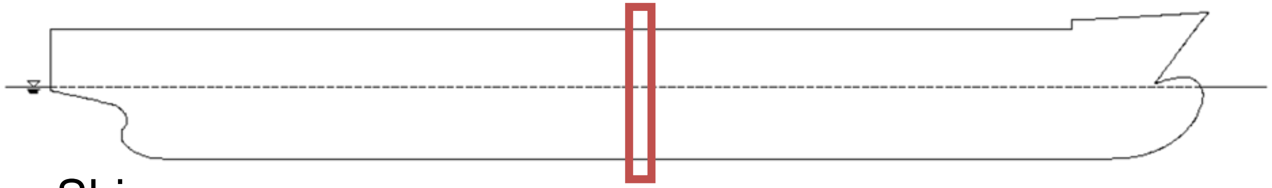
- Diameter d = 8.5 m
- Thickness t = 0.8 m (acc. FSICR)

- Total mass for a circular plate:

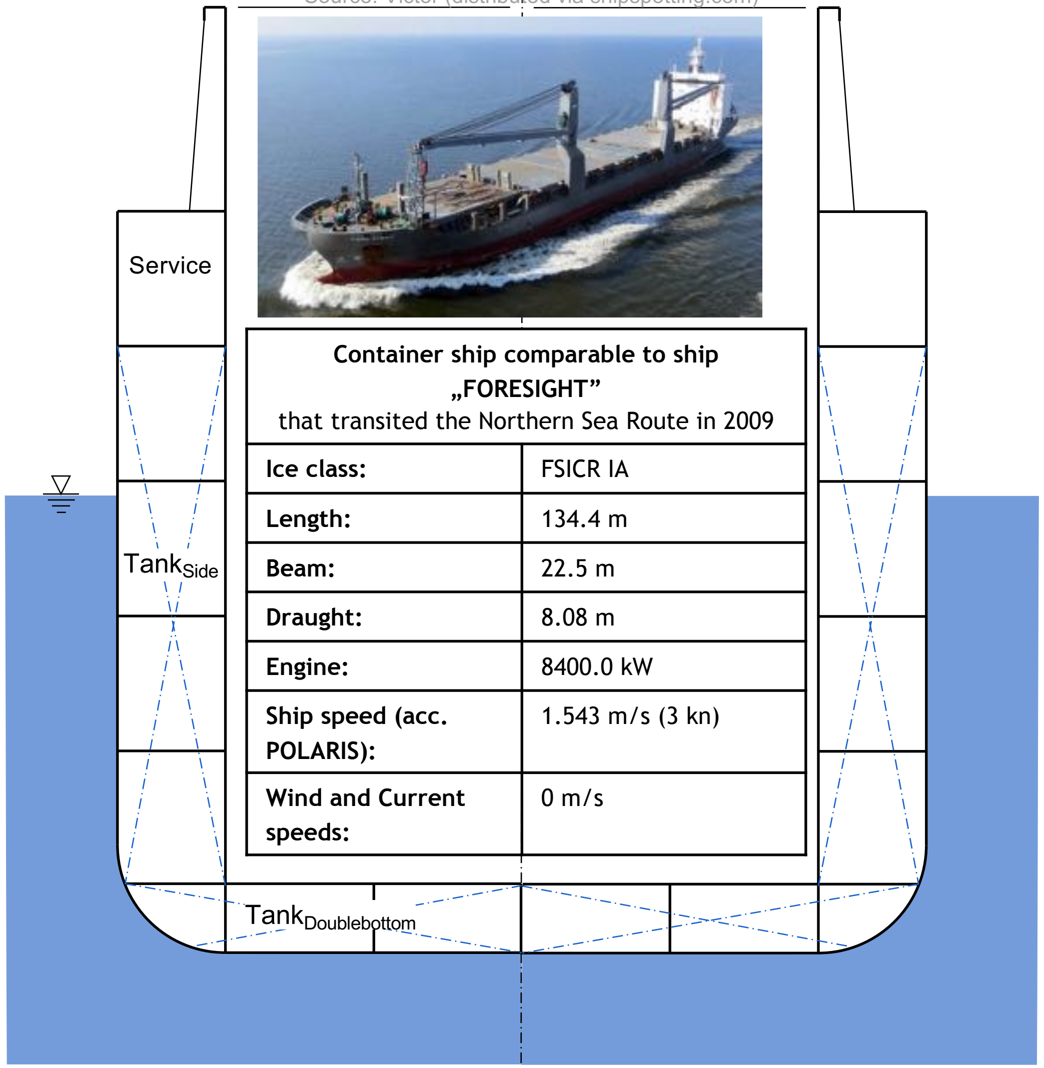
→ $m_{total} = m_{floe} + m_{hydro} = 82.6\ t$



<u>Ship:</u>



Source: Victor (distributed via shipspotting.com)



Container ship comparable to ship „FORESIGHT" that transited the Northern Sea Route in 2009	
Ice class:	FSICR IA
Length:	134.4 m
Beam:	22.5 m
Draught:	8.08 m
Engine:	8400.0 kW
Ship speed (acc. POLARIS):	1.543 m/s (3 kn)
Wind and Current speeds:	0 m/s

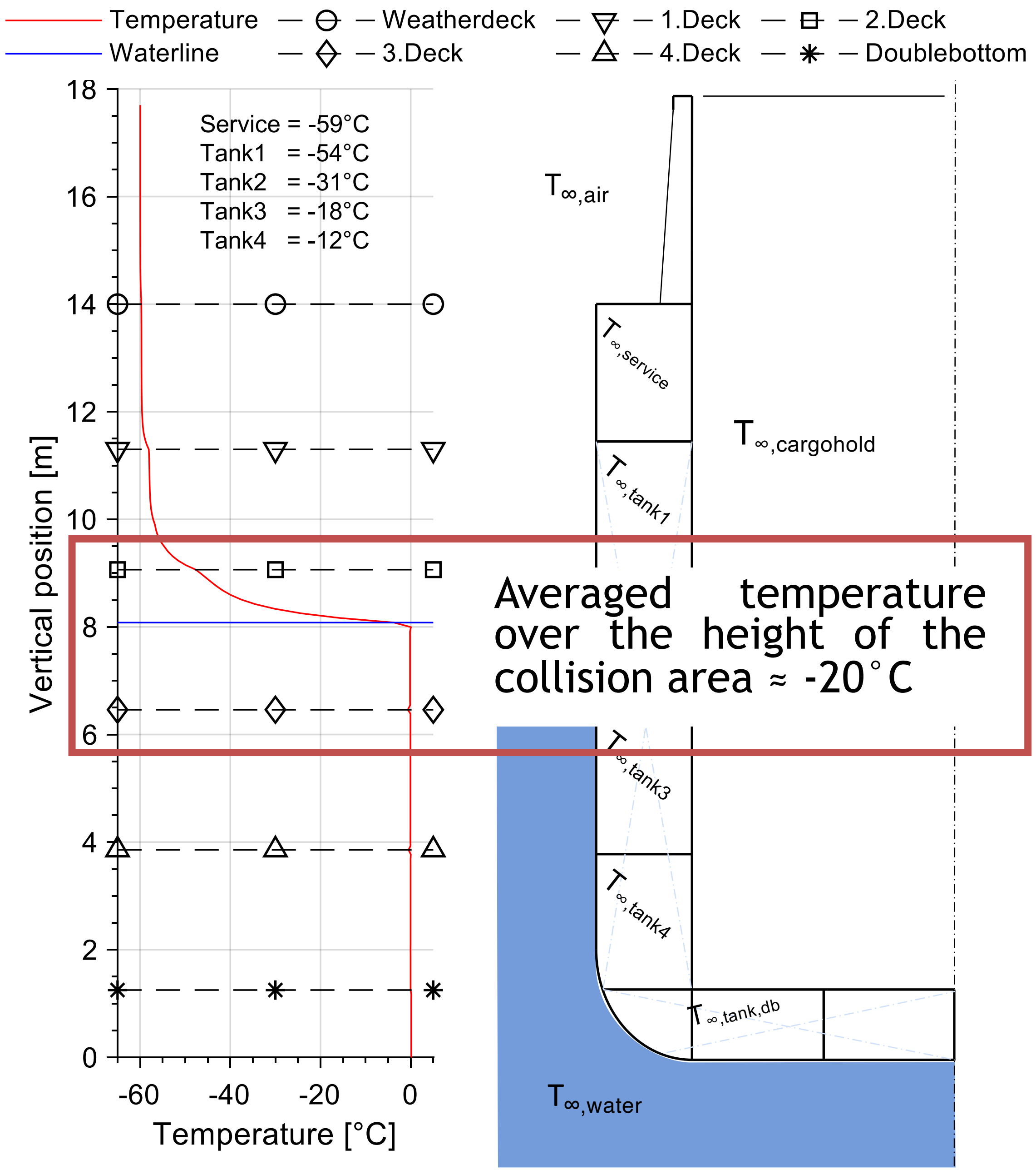
Heat transfer

How cold could a ship structure can actually become in winter?

- In the rules and guidelines of the classification societies -60 °C can be found as the lowest temperature for material tests on steels used in shipbuilding. This value corresponds well with different temperature measurements where extreme values below -50 °C were measured in the area of the Northern Sea Route.

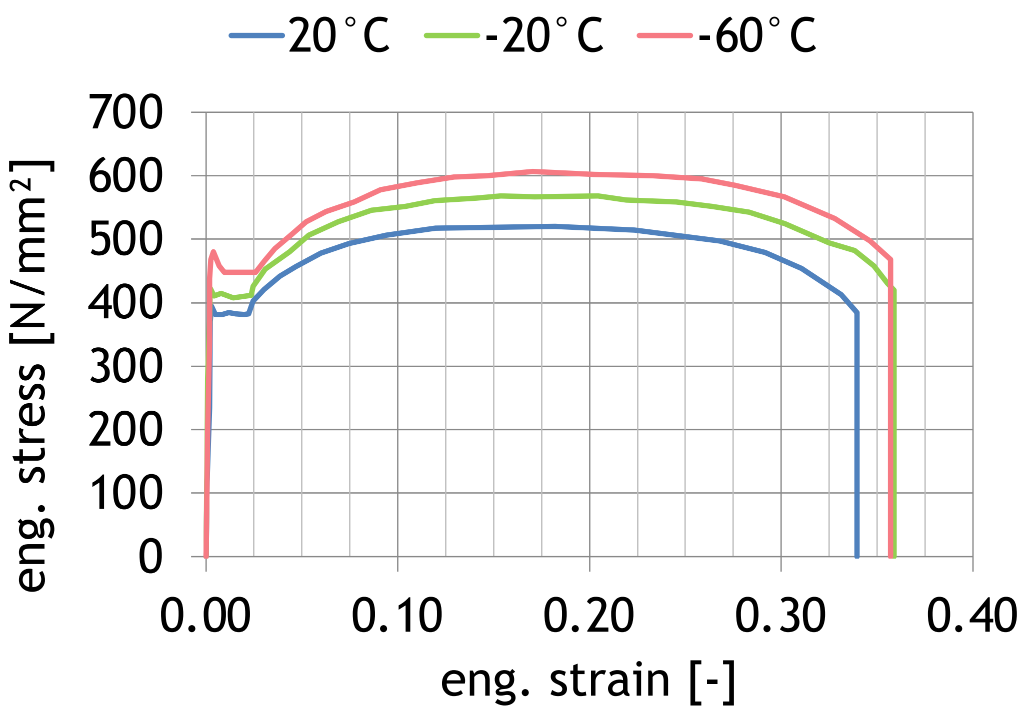
- In contrast, liquid seawater cannot become colder than -2 °C

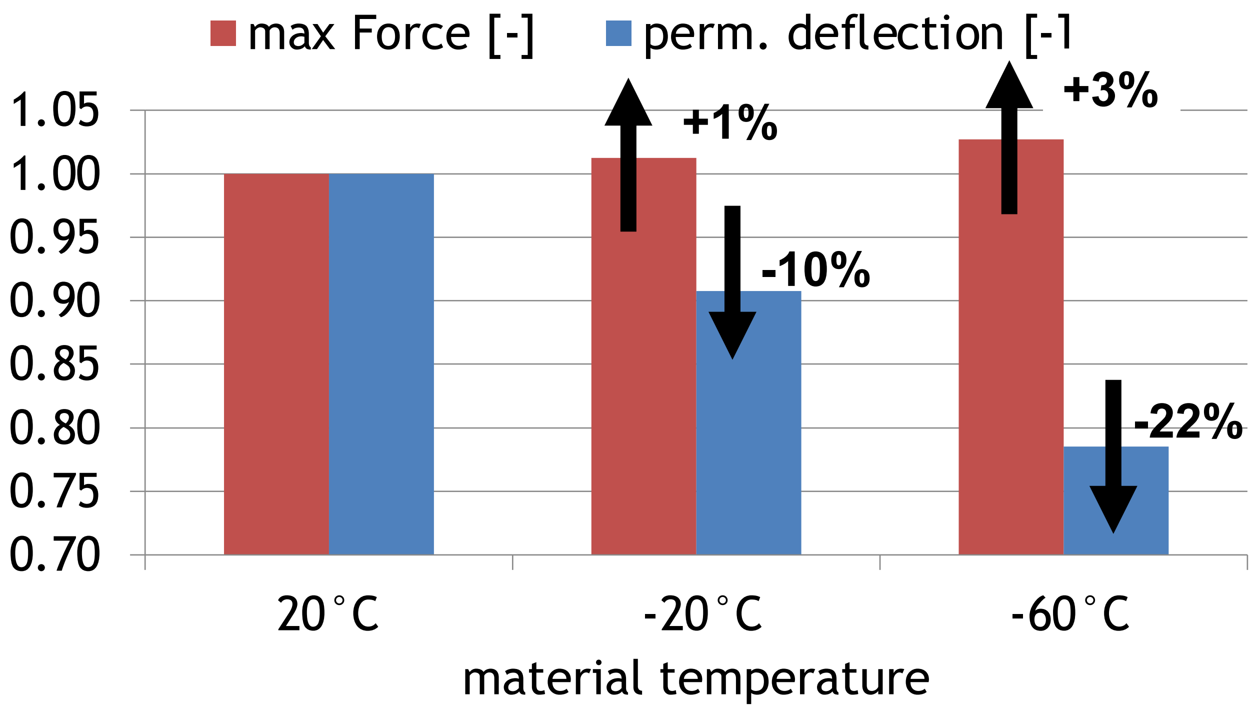
Ref.: Kubiczek et al. (2019). *Simulation of temperature distribution in ship structures for the determination of temperature- dependent material properties,* 12th European LS-DYNA Conference Koblenz.



Averaged temperature over the height of the collision area ≈ -20°C

Temperature dependent material properties and the effect on the structural response in case of collision



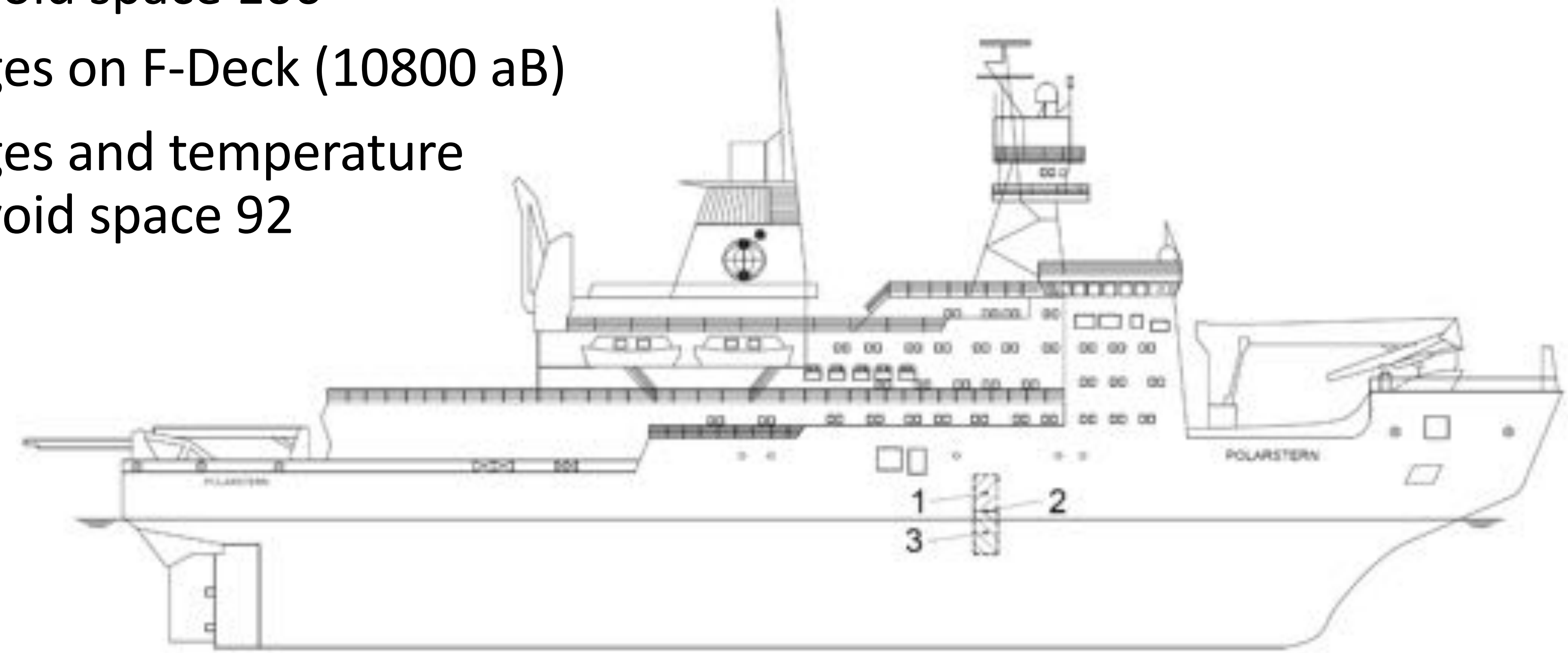


→ neglecting the structural temperature leads to a conservative overestimation of the permanent deflection.

→ consideration of extreme values leads to an underestimation of the permanent deflection because the structure is assumed to be too stiff.

Measurement locations on board Polarstern

- Strain gauges and temperature sensors in void space 100
- Strain gauges on F-Deck (10800 aB)
- Strain gauges and temperature sensors in void space 92

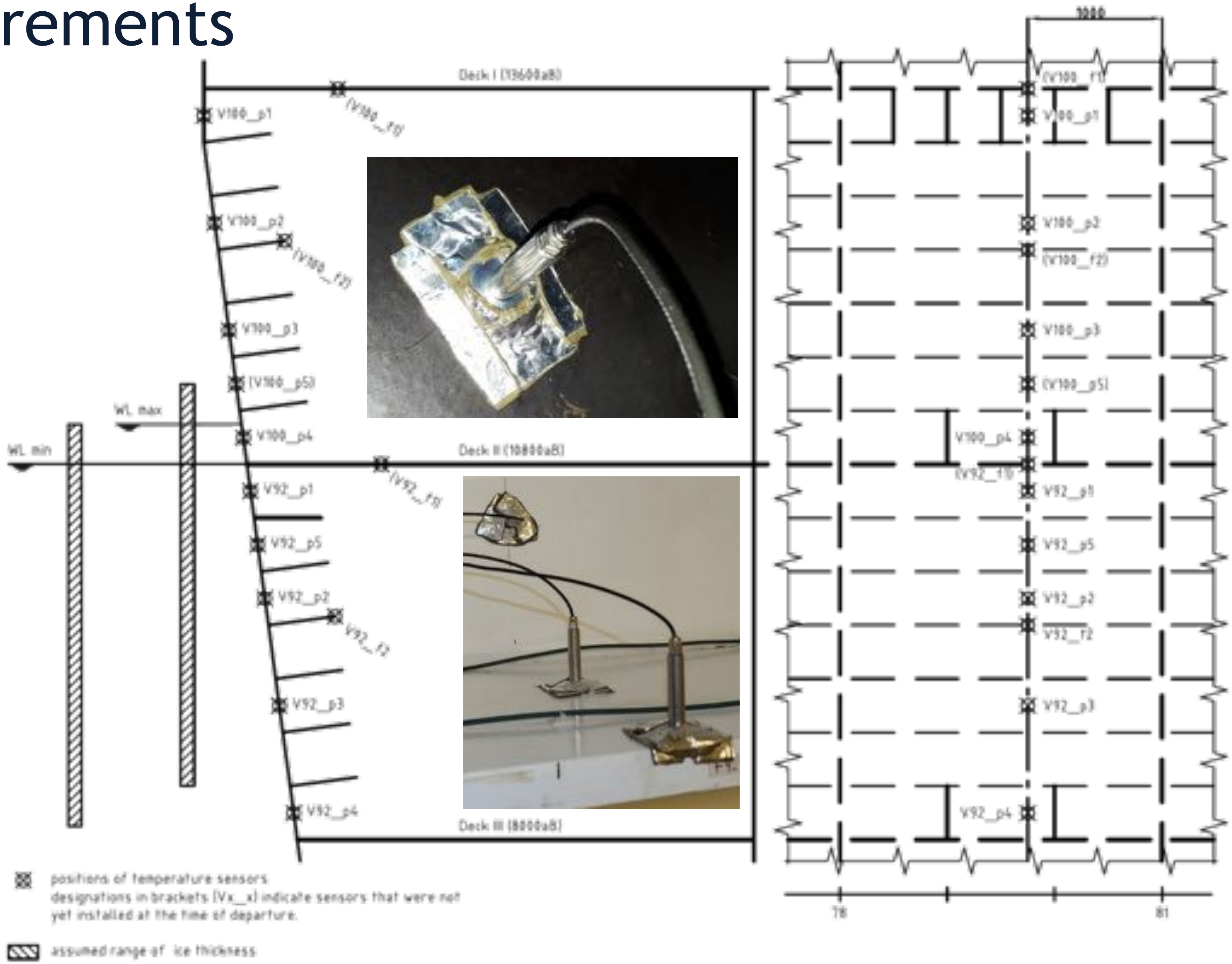


Temperature measurements

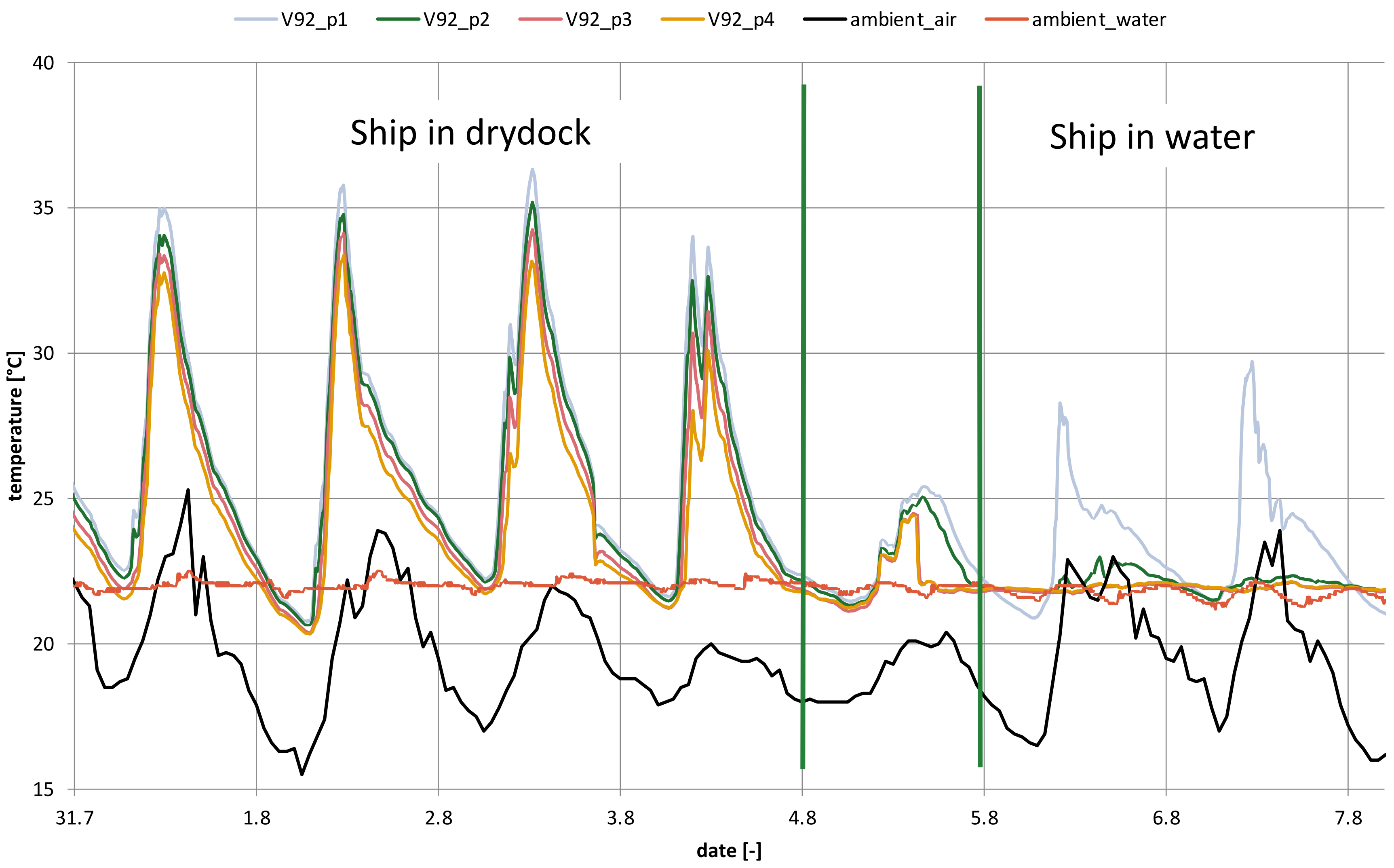
- Temperature measurement on steel structure with PT1000 sensors every 5 minutes

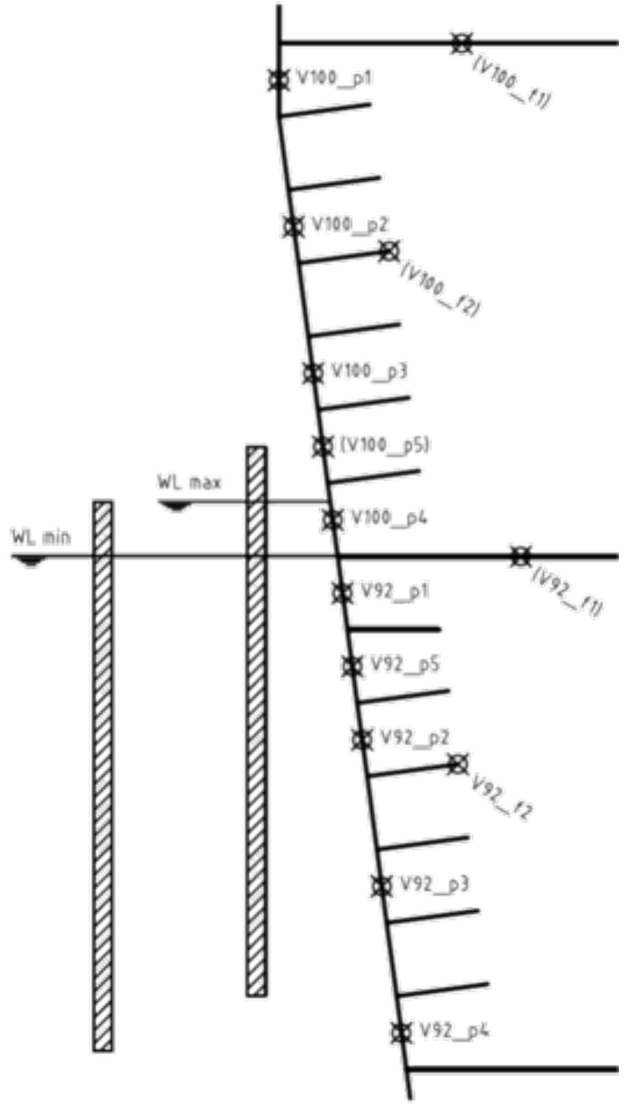
Data provided by the ship's weather station:

- Measurement of water temperature 5m below waterline
- Measurement of air temperature 29m above waterline



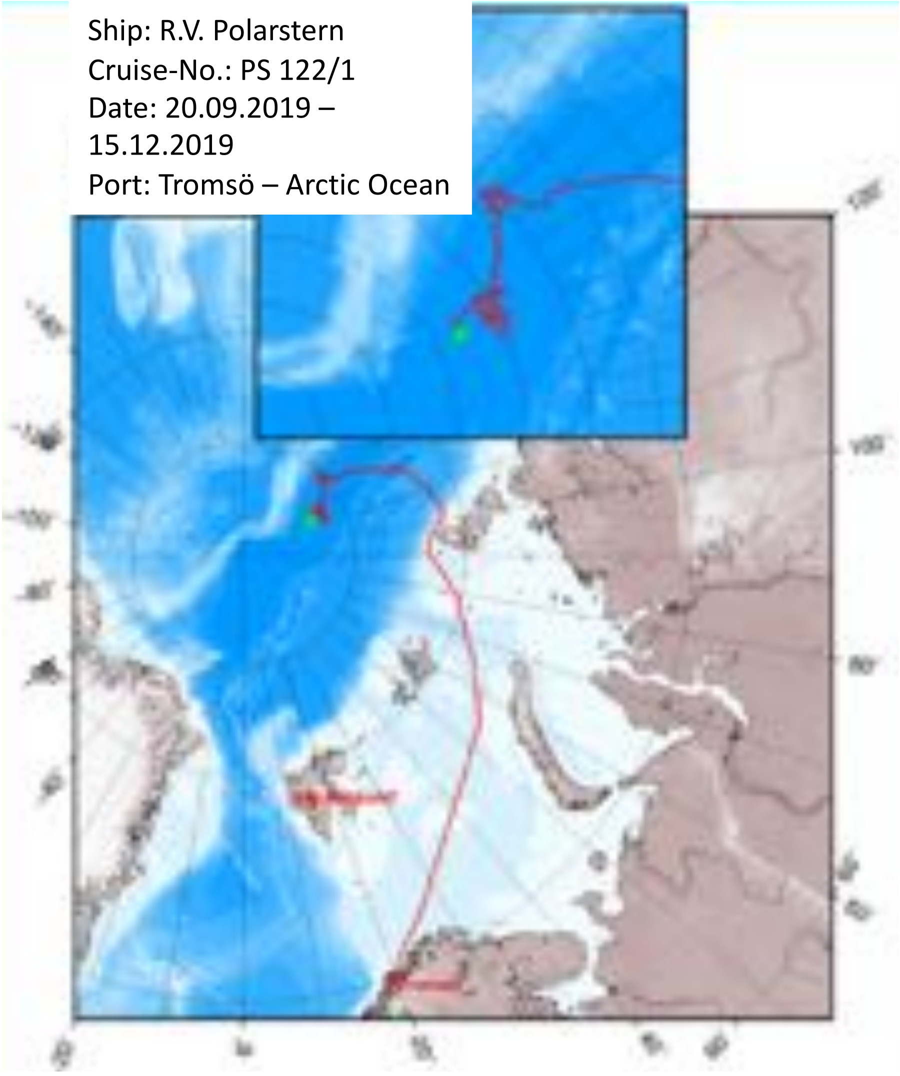
Temperature measurements



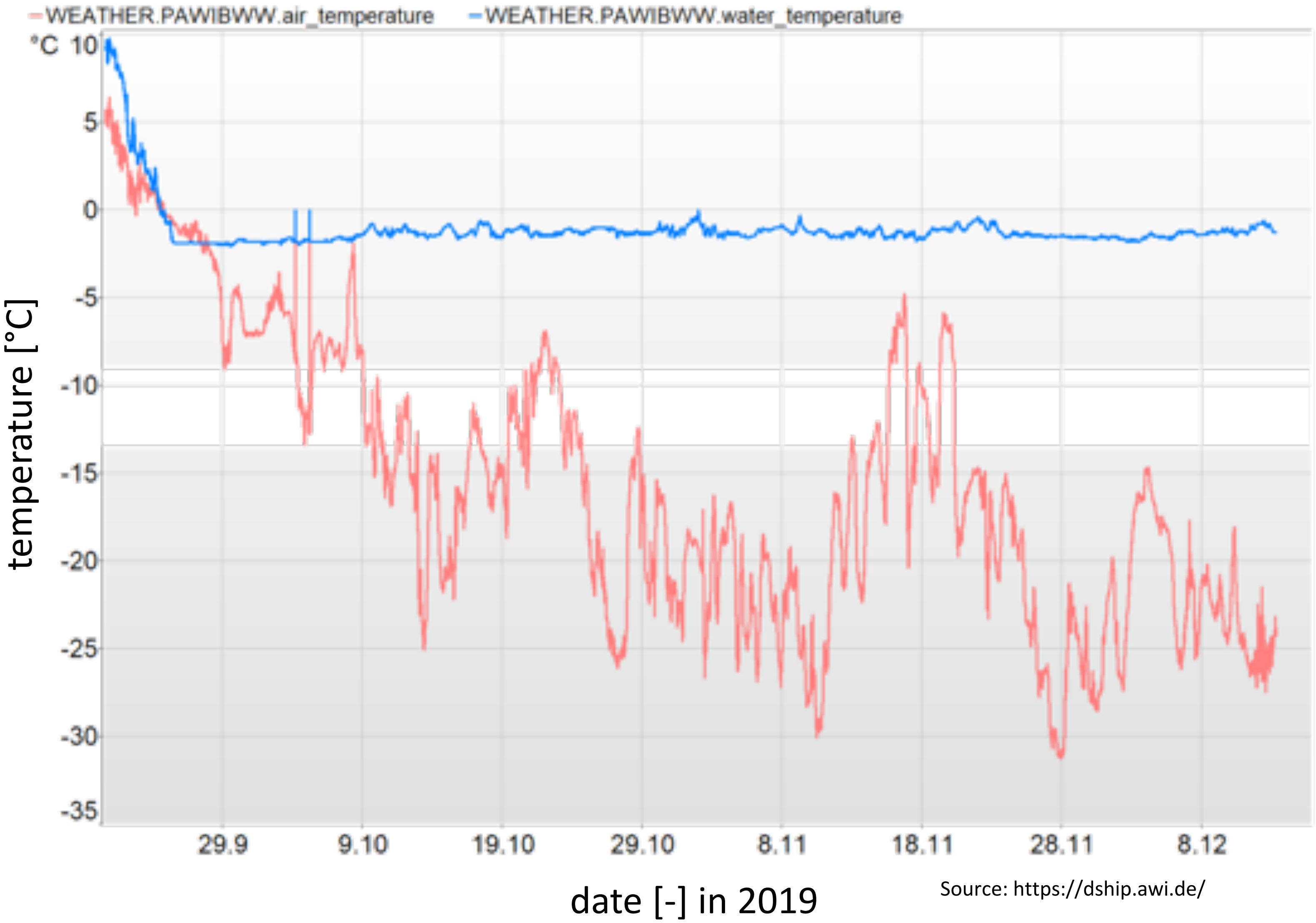


Temperature measurements

Ship: R.V. Polarstern
Cruise-No.: PS 122/1
Date: 20.09.2019 – 15.12.2019
Port: Tromsö – Arctic Ocean



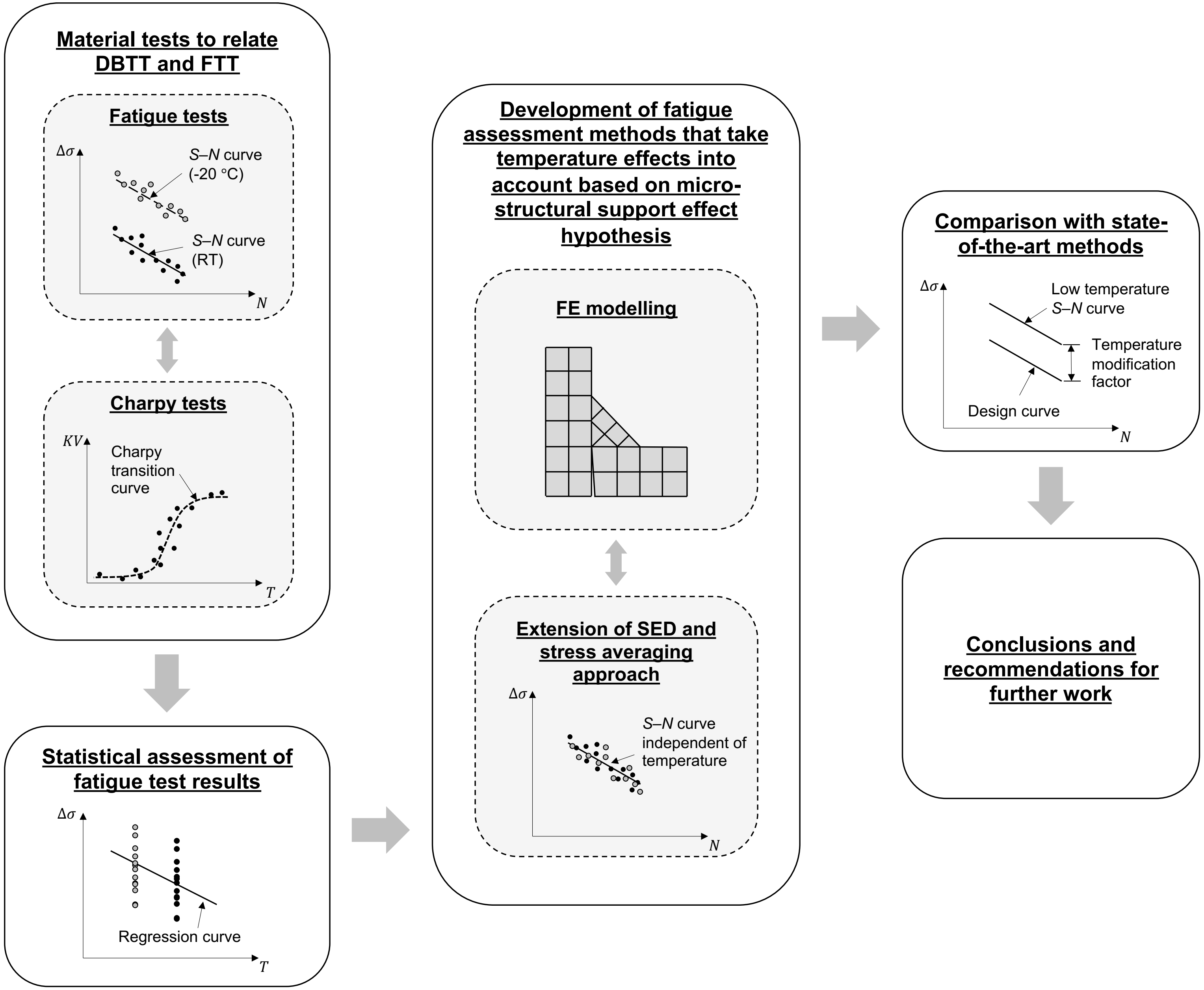
Source: http://www.awi.de



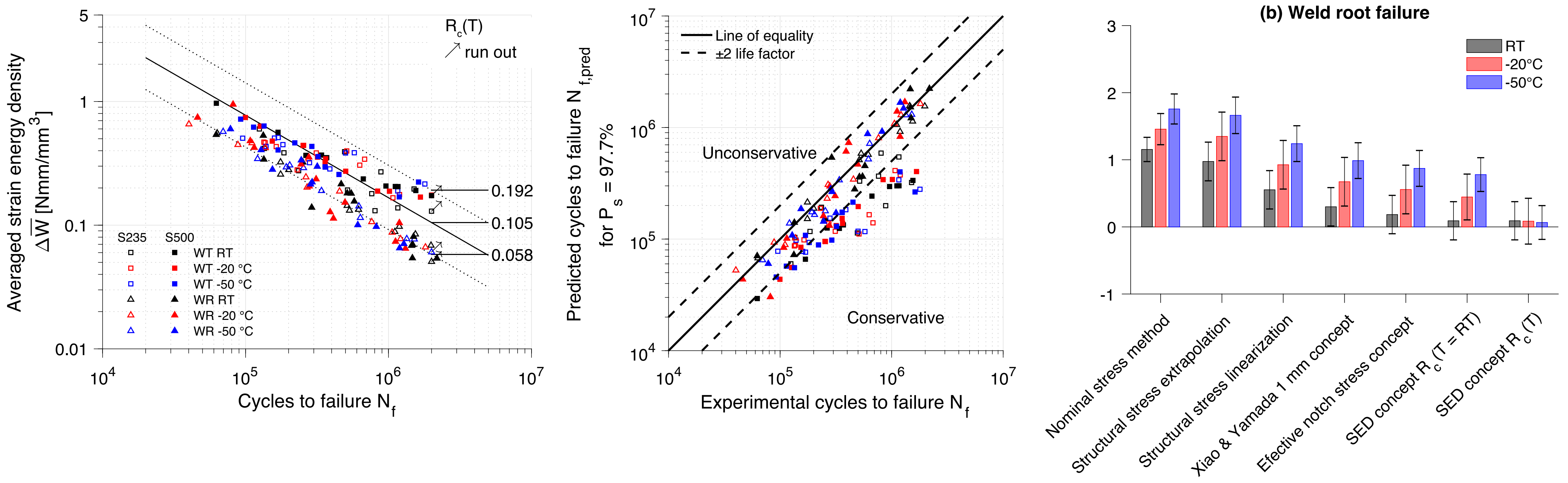
Source: https://dship.awi.de/

Research approach

- Two steels
- Three weld details
- Two methods

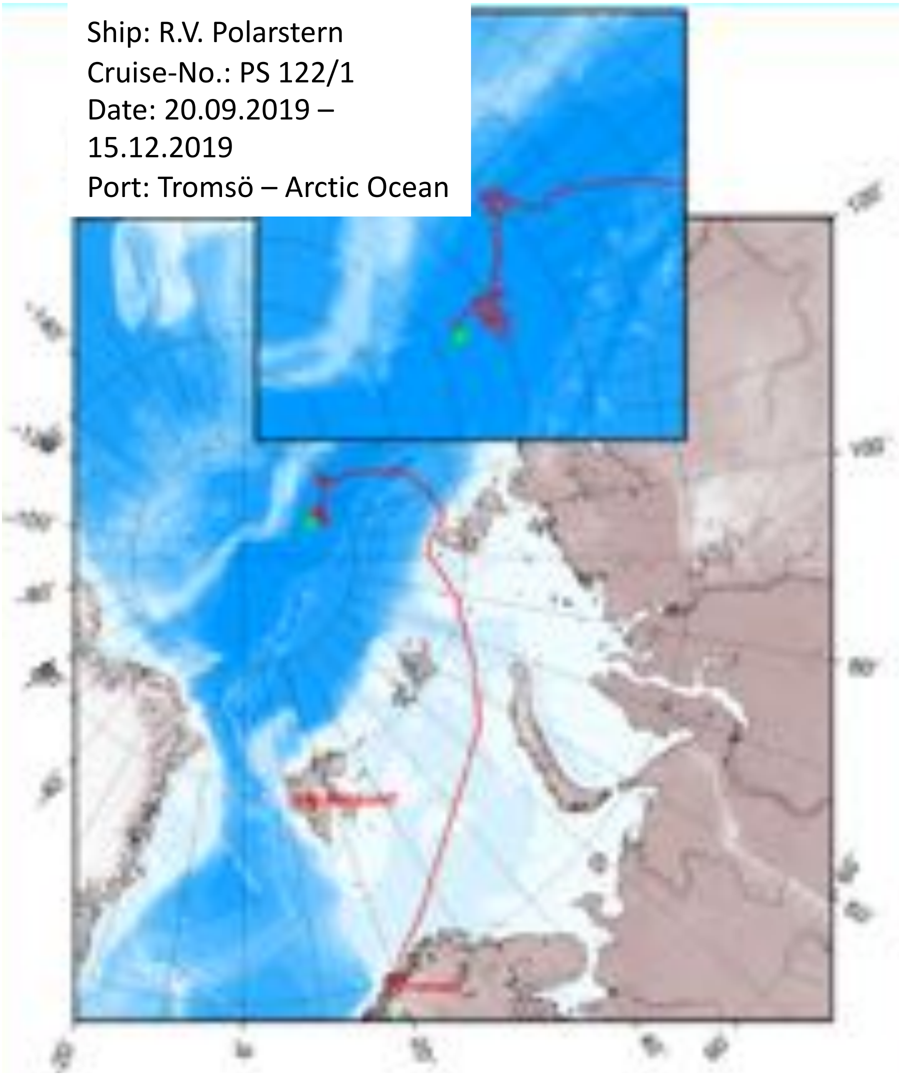


Results for SED method and comparison with state-of-the-art methods

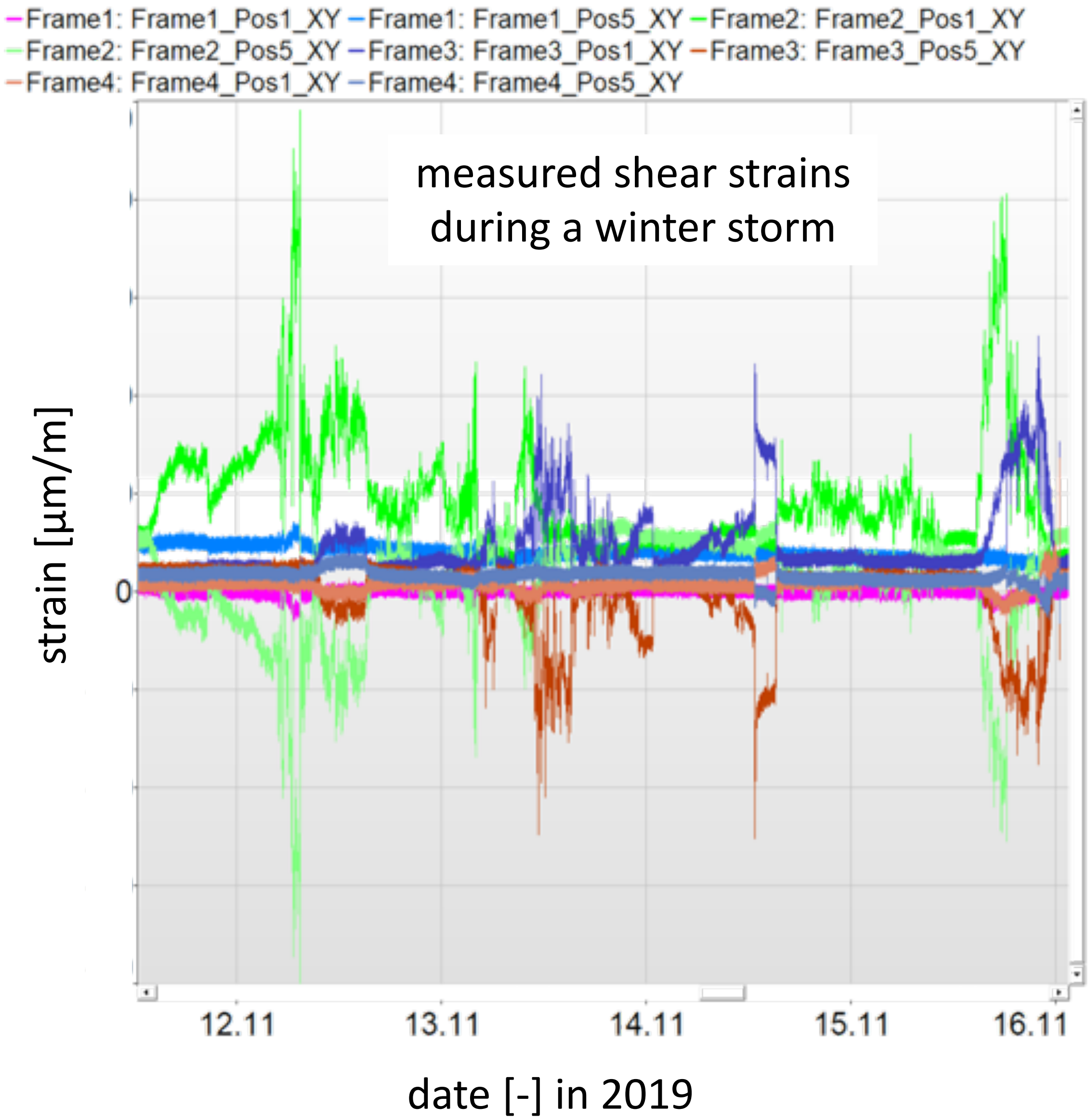


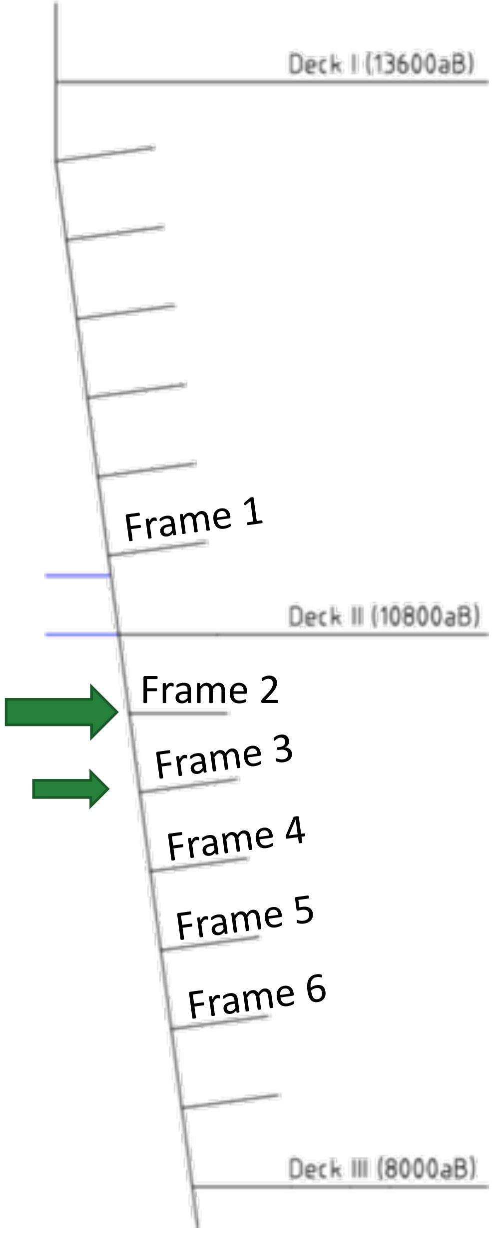
Ice load measurements

Ship: R.V. Polarstern
Cruise-No.: PS 122/1
Date: 20.09.2019 – 15.12.2019
Port: Tromsö – Arctic Ocean



Source: http://www.awi.de

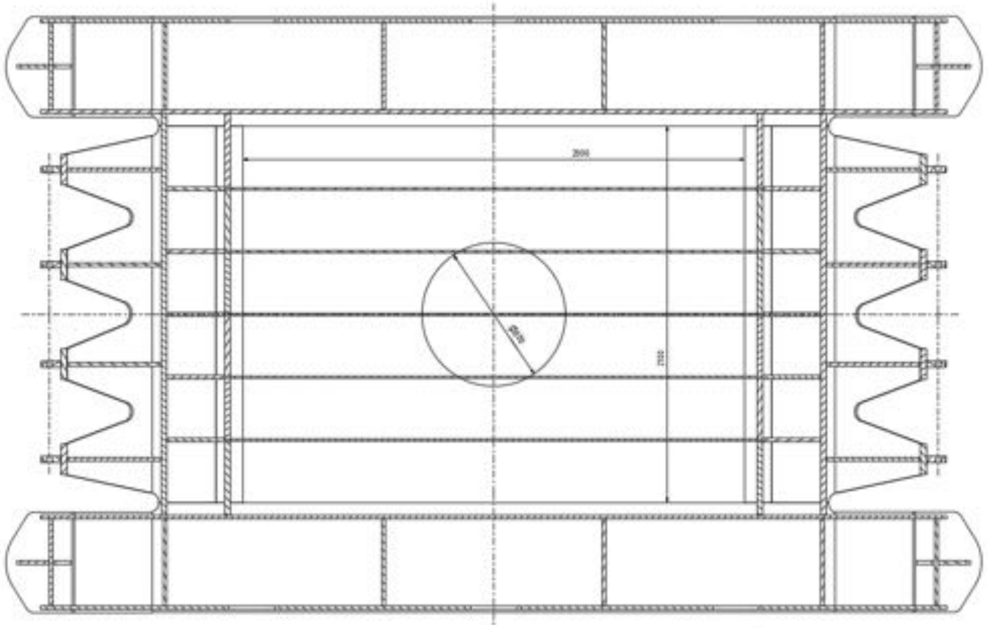




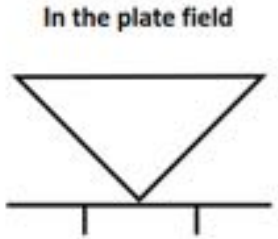
I. Test Program large scale tests

Test setup for the deformable structures

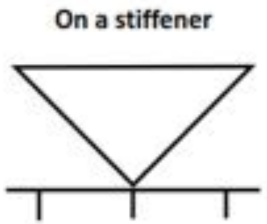
Panel 2



Panel 1



Panel 2 & 3



Panel 1

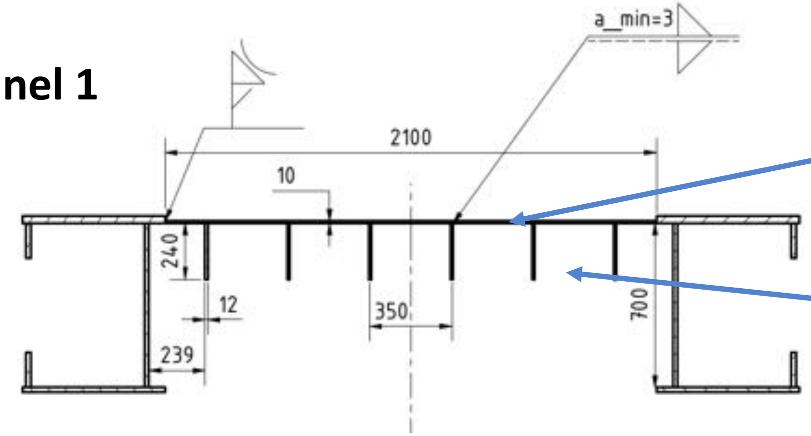
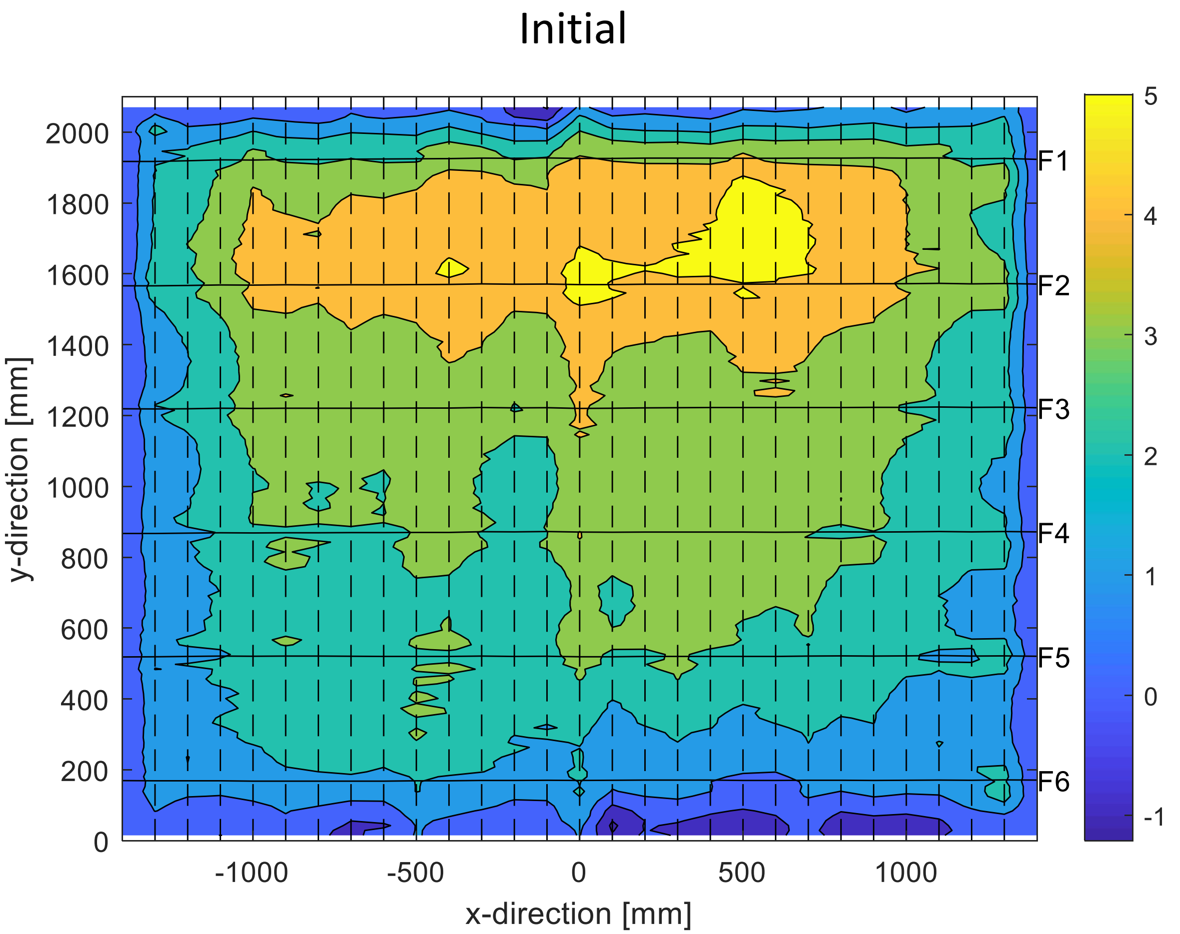


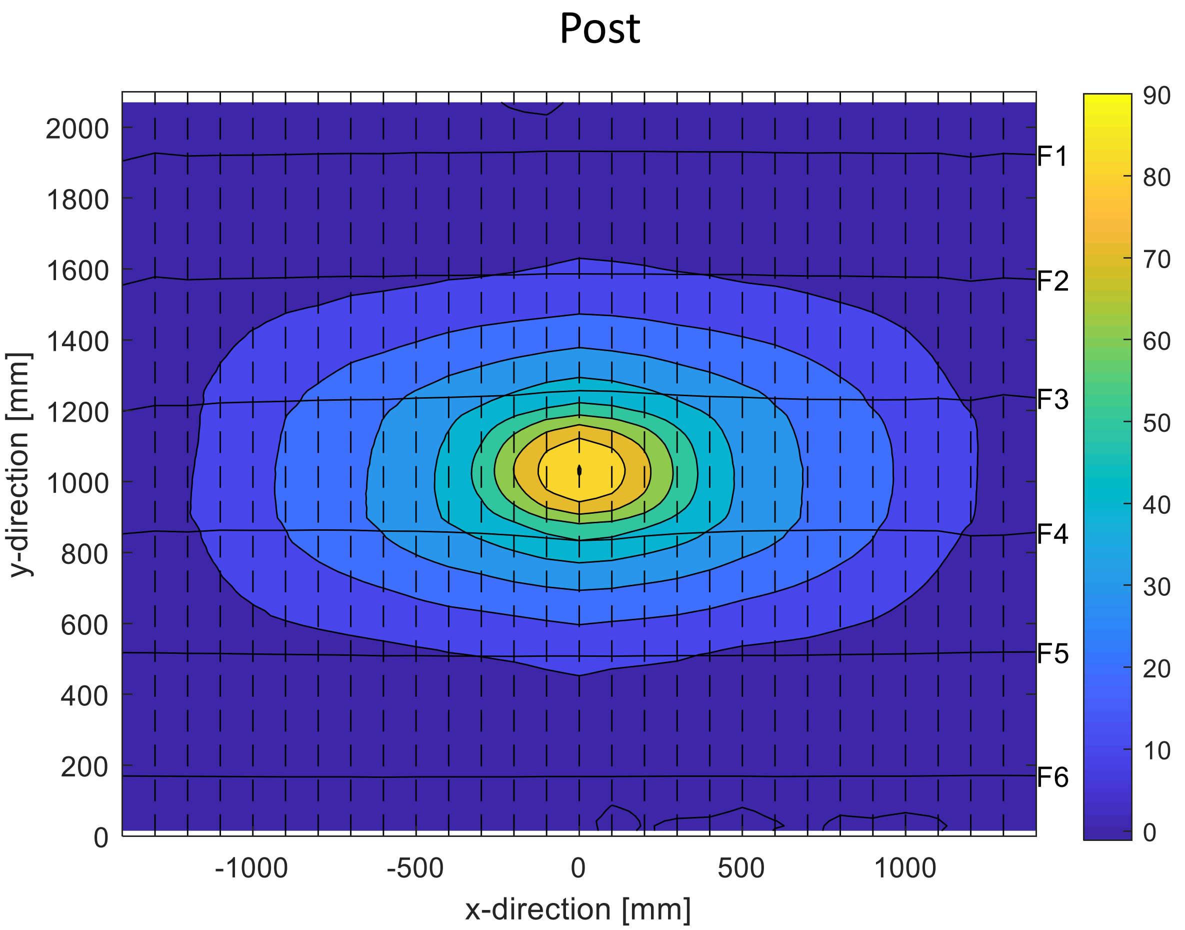
Plate thickness 10 mm

Spacing: 350 mm
FB 240 x 12

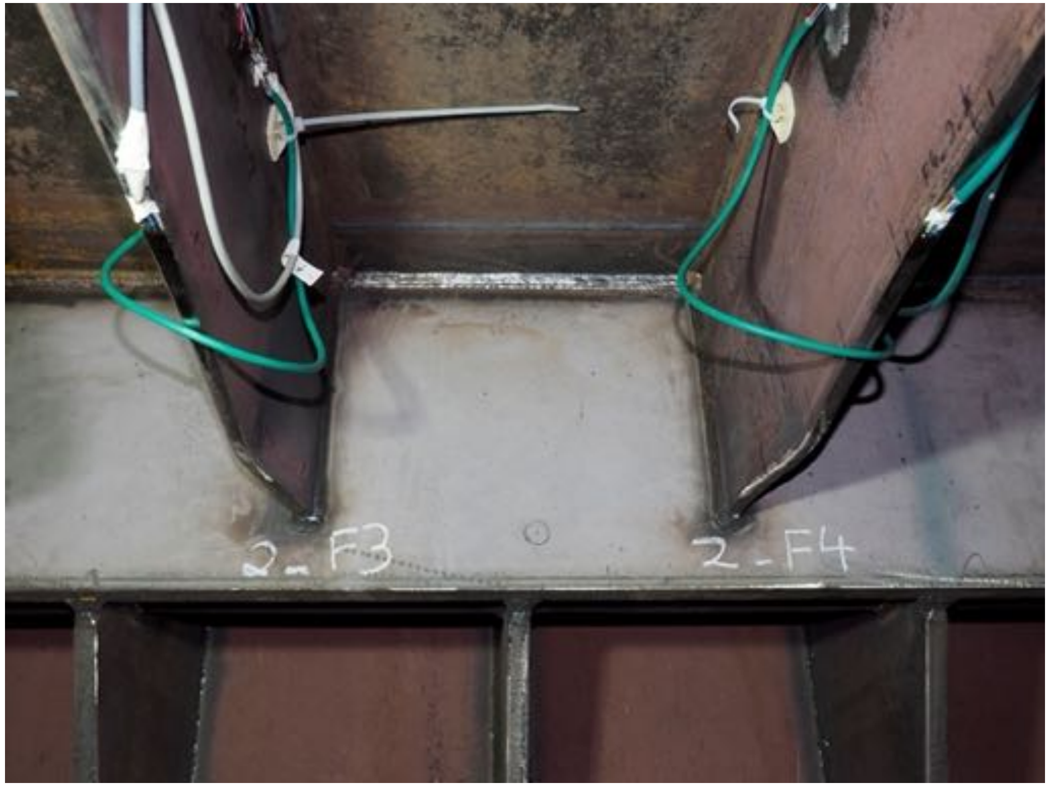
Force curve of the brittle test run against Panel 1

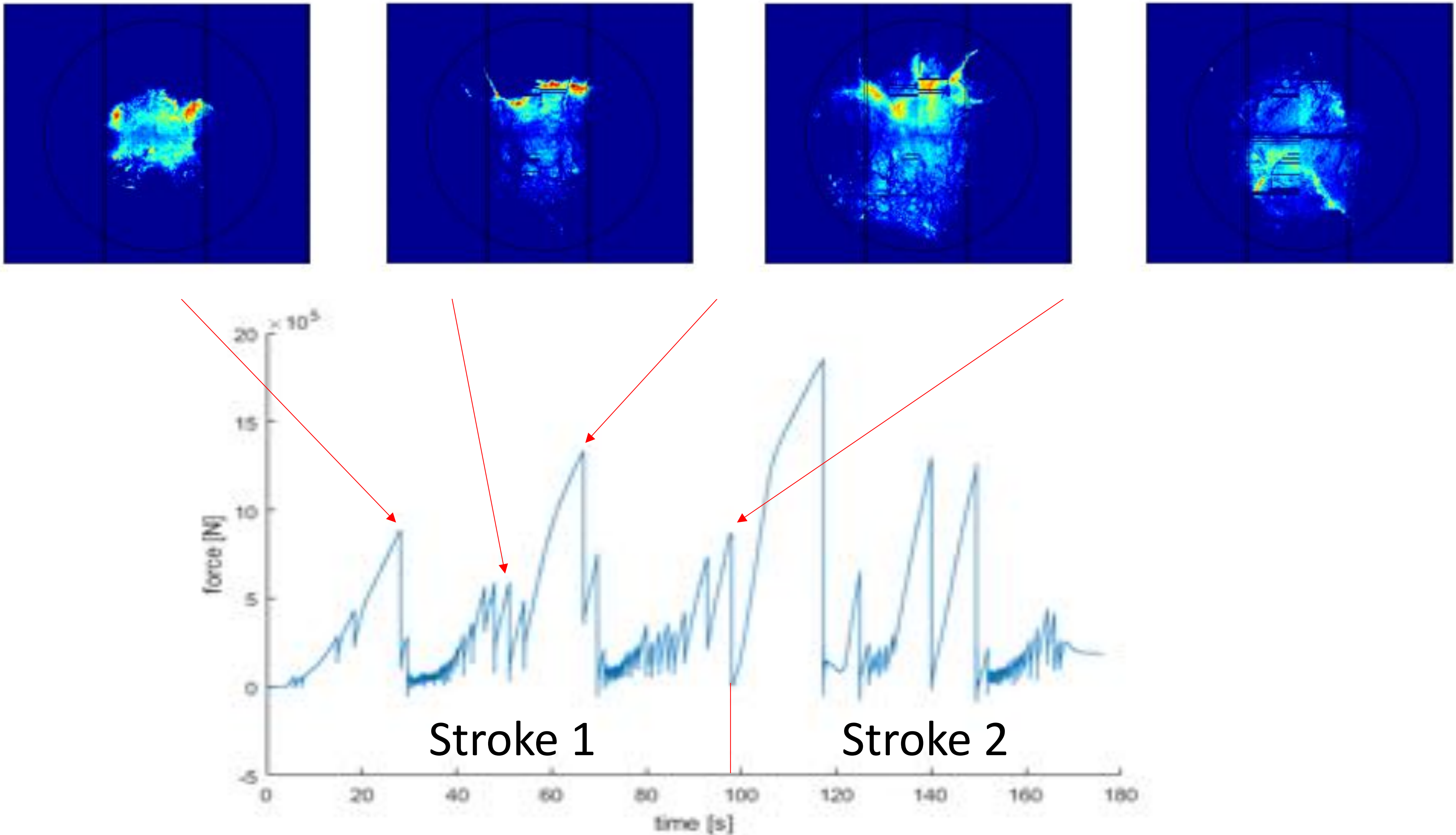
Deformation of the panel



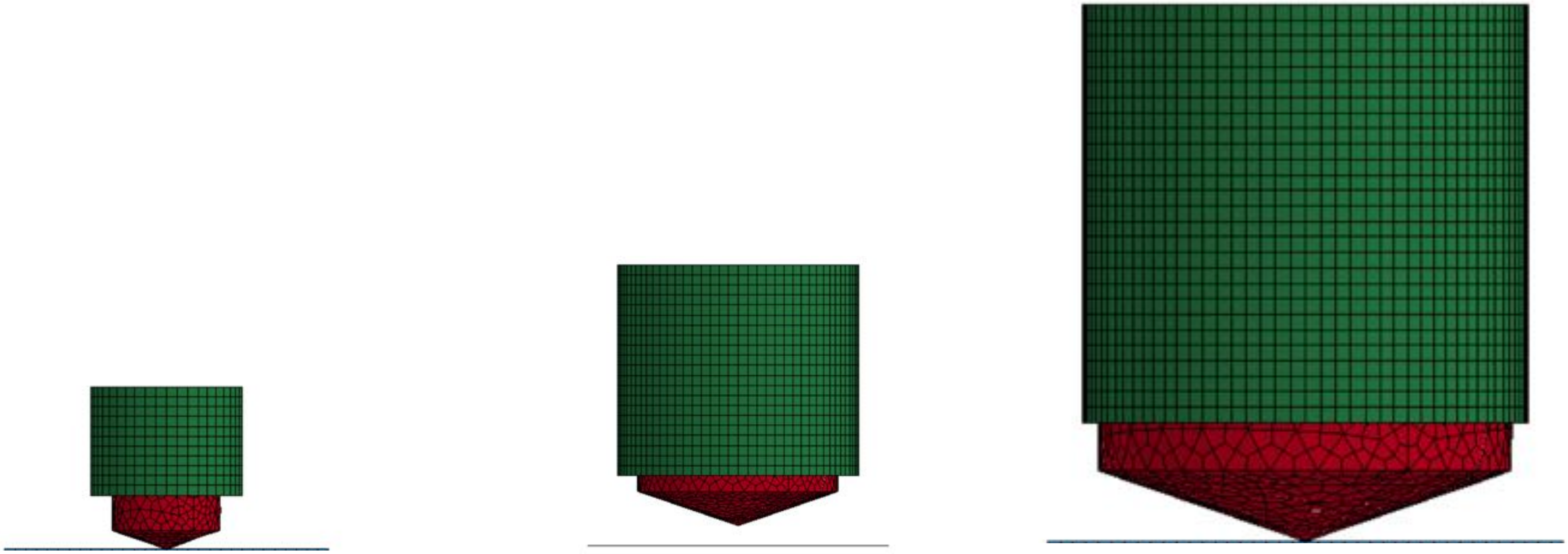


Deformation of the stiffeners



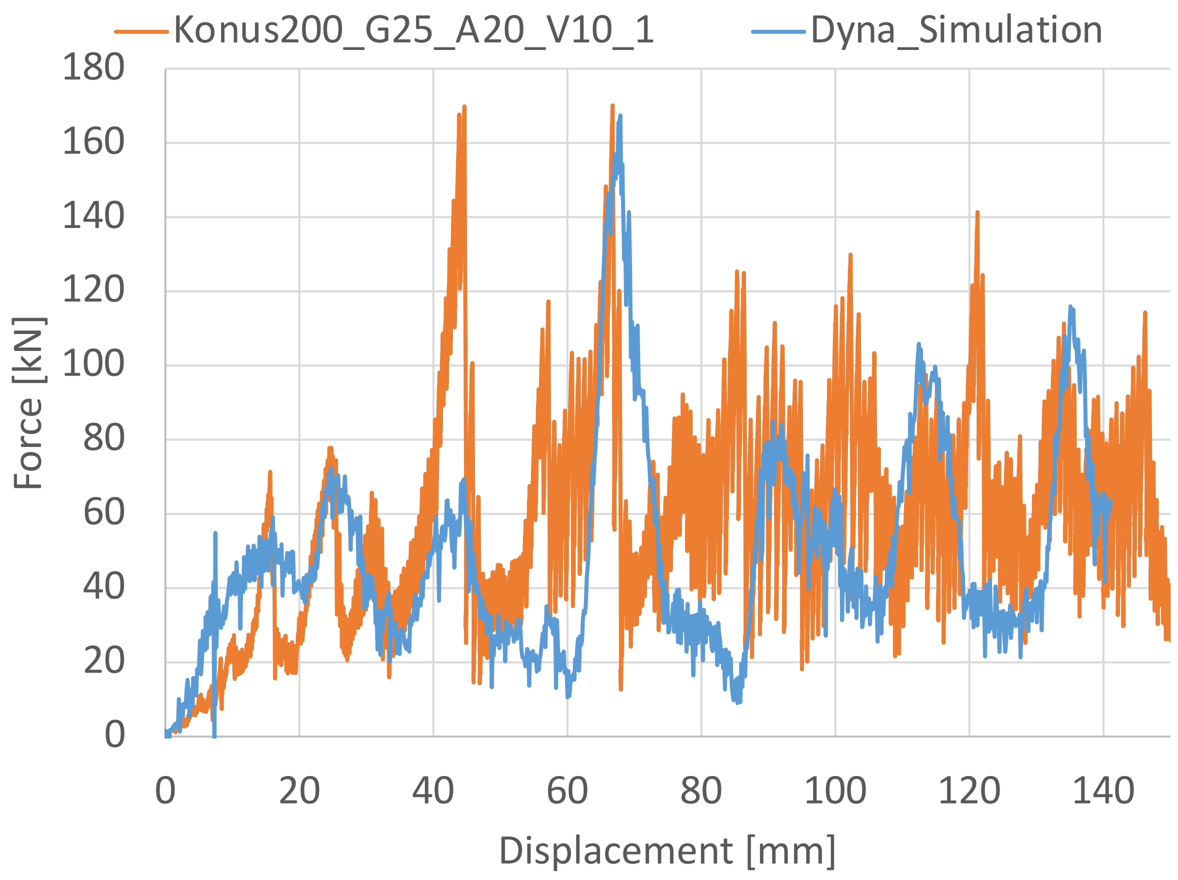

× 10^5
20
15
10
5
0
-5
force [N]
0
20
40
60
80
100
120
140
160
180
time [s]
Stroke 1
Stroke 2

Ice-Extrusion Test simulations

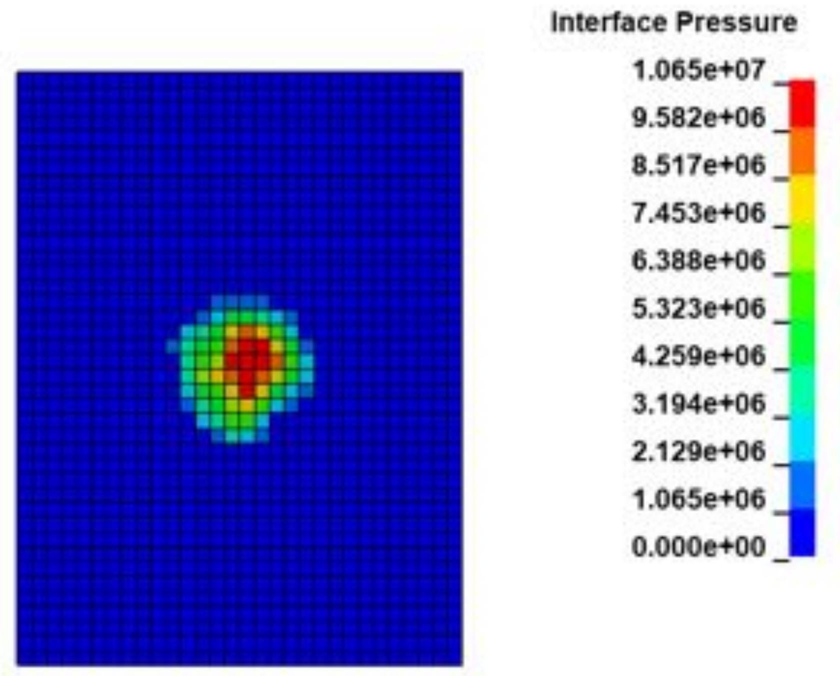


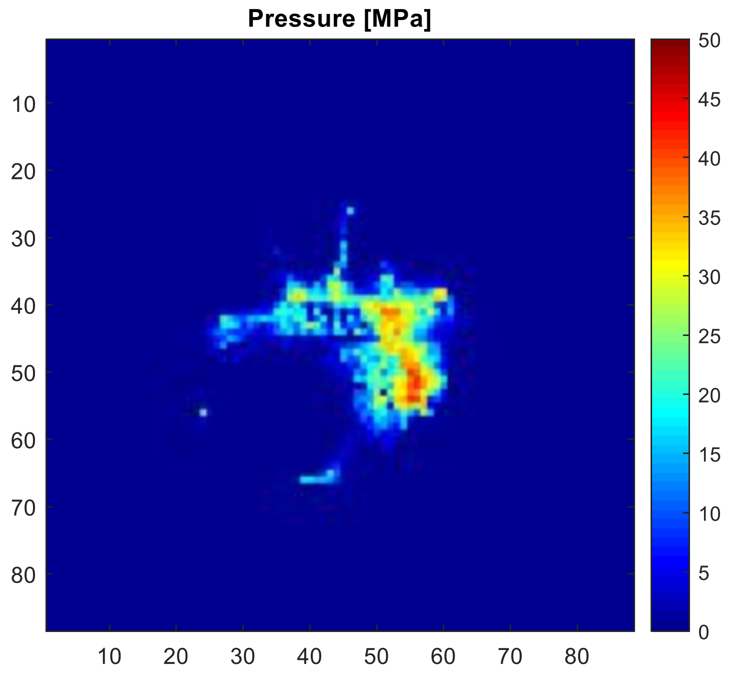
D=100 Cone 100	D=200 Cone 200	D=800 Cone 800

Results Ice-Extrusion Tests



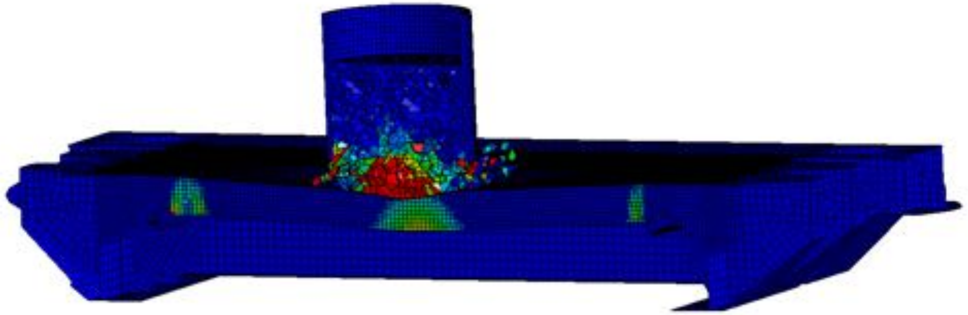
Ice Pessures - Cone 200



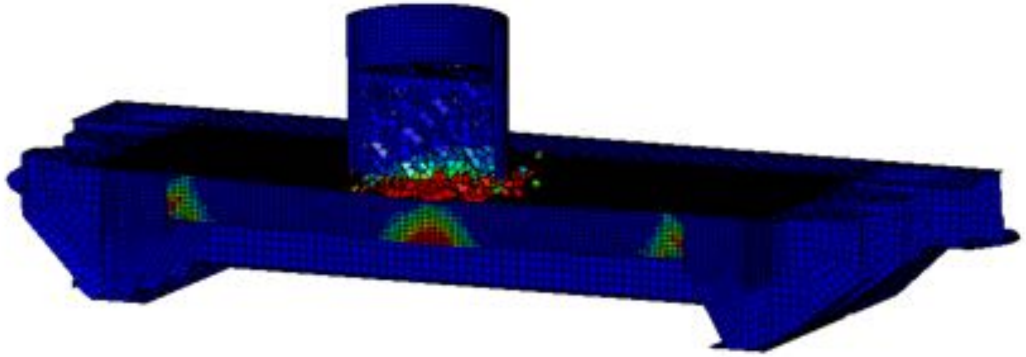


The loaded area of the LS-Dyna simulation is currently larger than measured. Accordingly, the contact pressures (F/loaded area) are underestimated. The maximum pressures of the simulation are in the magnitude of **30 to 50 MPa**. This in accordance with the TekScan results.

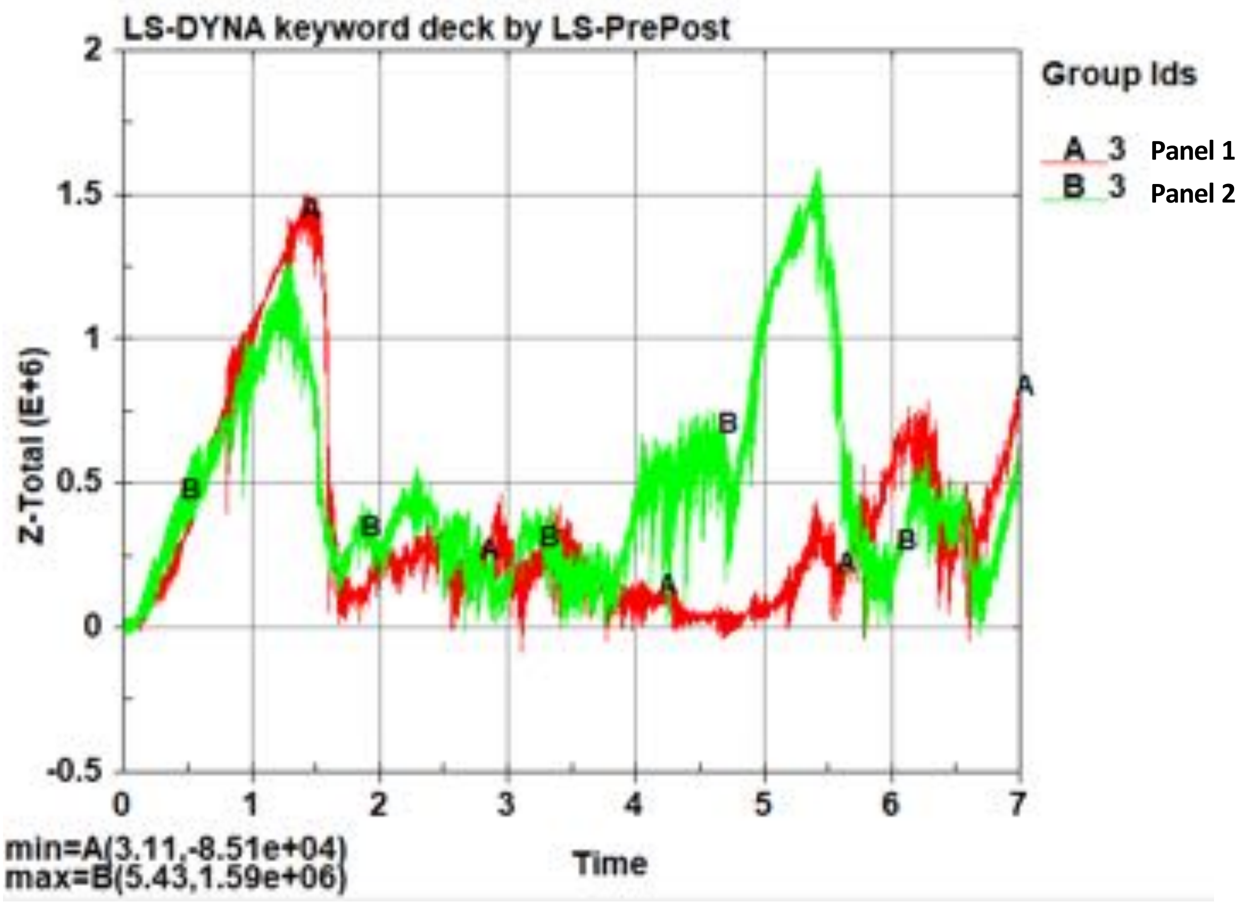
Application to the large scale extrusion tests



Panel 1



Panel 2



Hamburg University of Technology

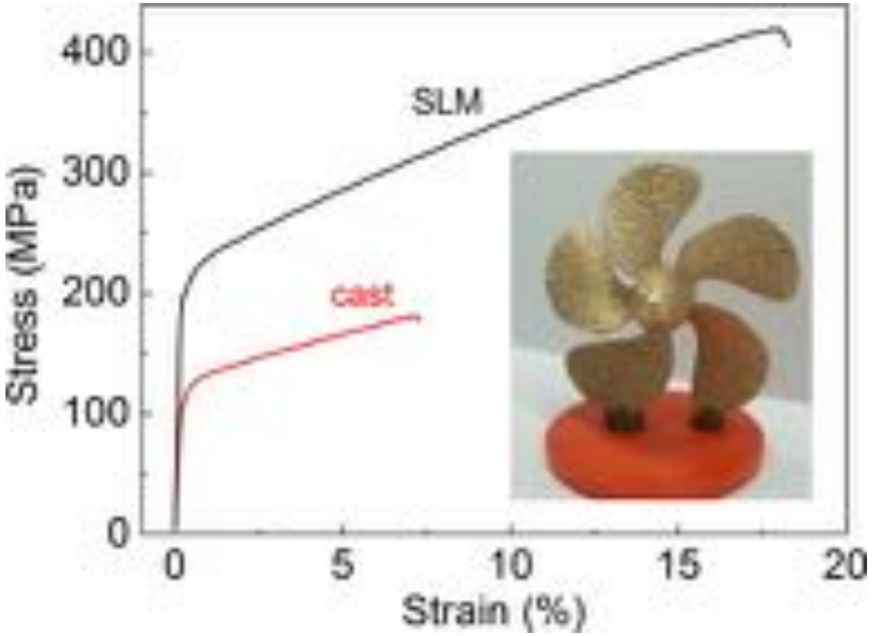
Untersuchung der Schwingfestigkeit hybrid additiv und subtraktiv gefertigter Proben aus AISI 316L

M. Braun, S. Hellberg, I. Kryukov, S. Böhm, R. E. Wu, S. Ehlers, S. Sheikhi

Ship Structural Design & Analysis

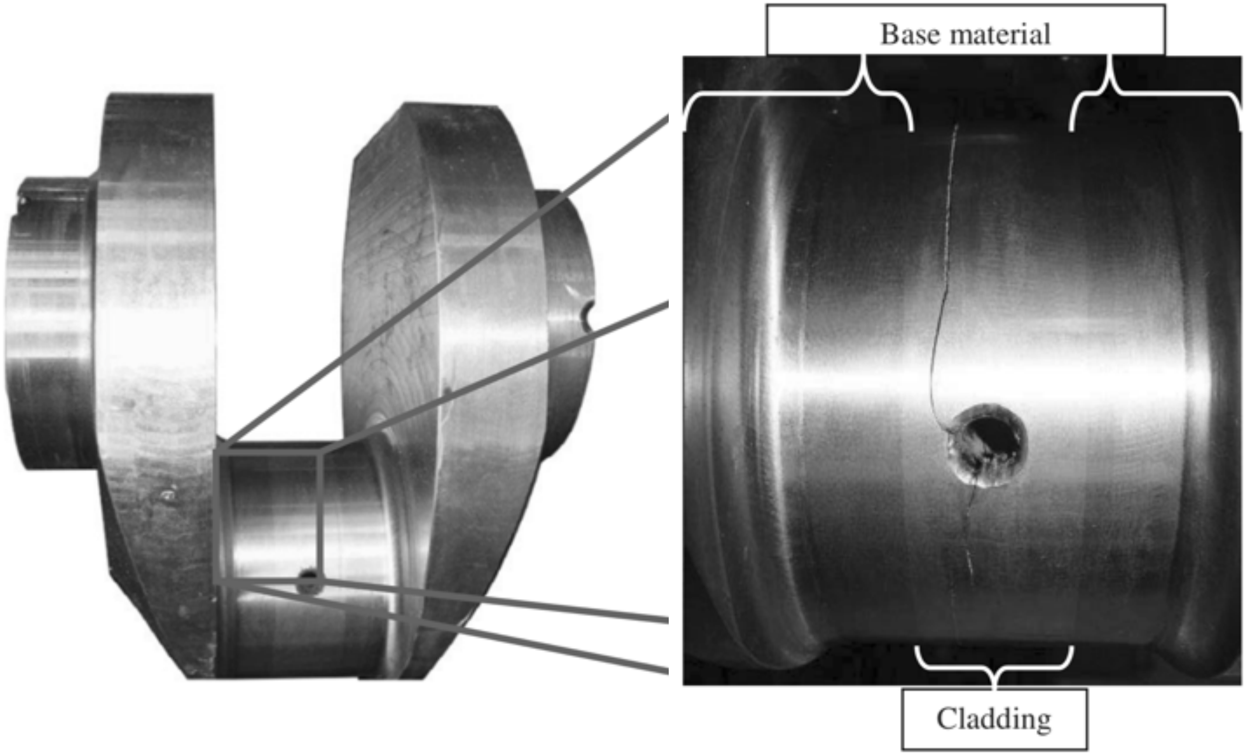
Motivation

SLM Cu-10Sn bronze propeller



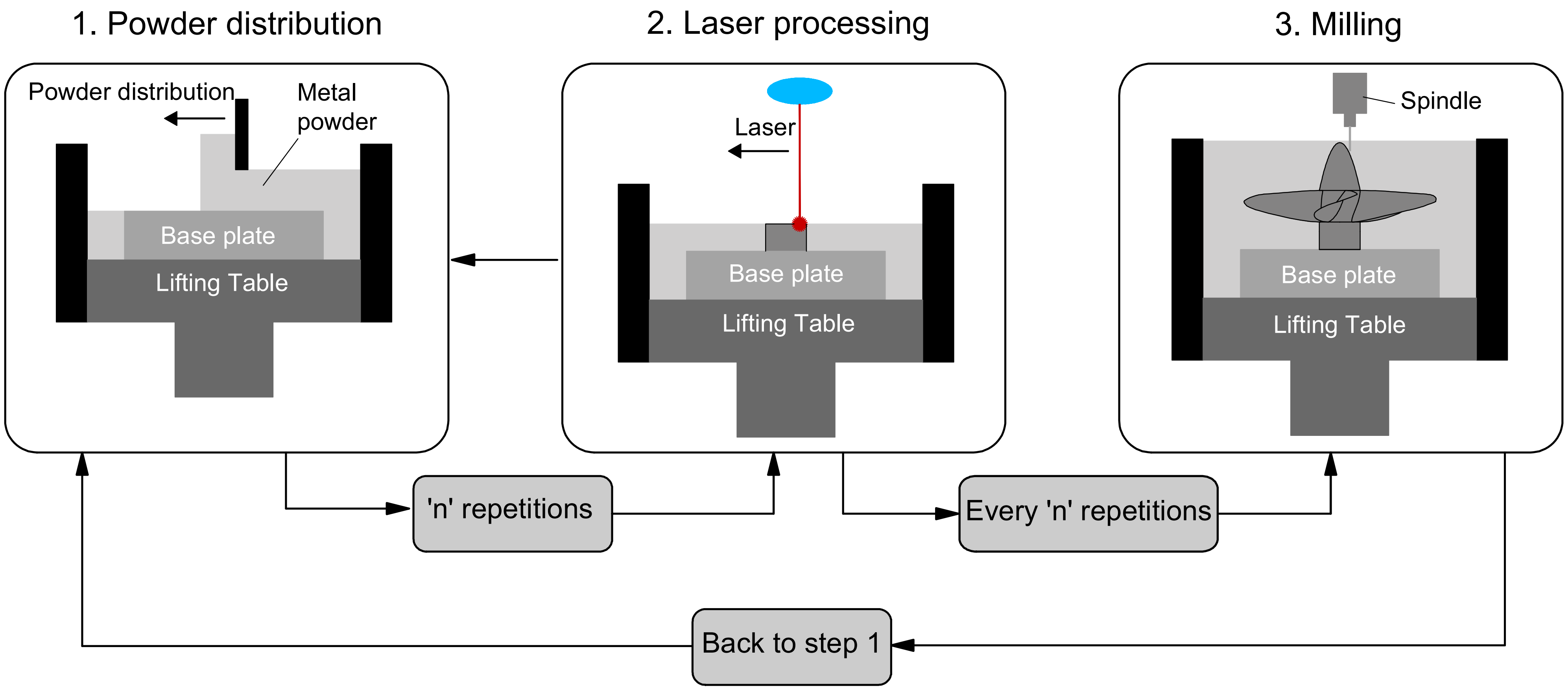
Ref.: Scudino et al. (2015)

Crankshaft of medium-speed four-stroke diesel engine



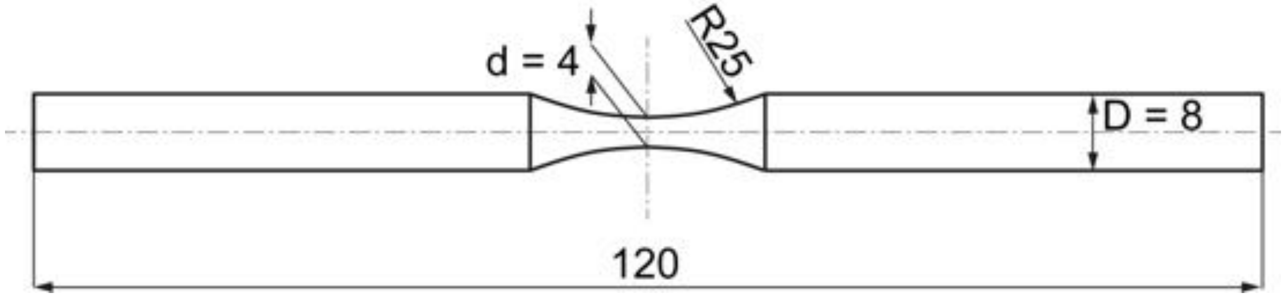
Ref.: Köhler et al. (2011)

Hybrid additive and subtractive manufacturing



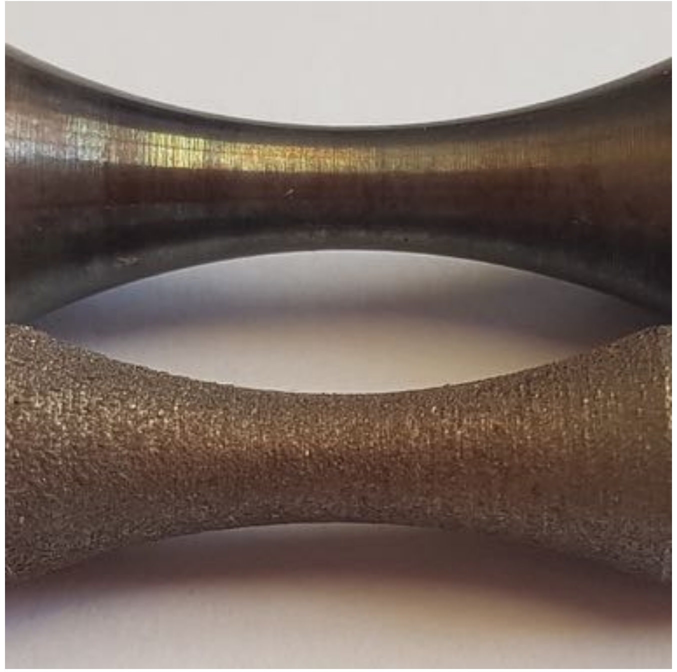
Specimen preparation

- Material: 316L
- Renishaw AM250-System
- 200W Ytterbium fibre laser
- Argon atmosphere
- Layer thickness: 40 µm
- Specimens shape acc. to ASTM E466-15
- Built in vertical direction



© Renishaw

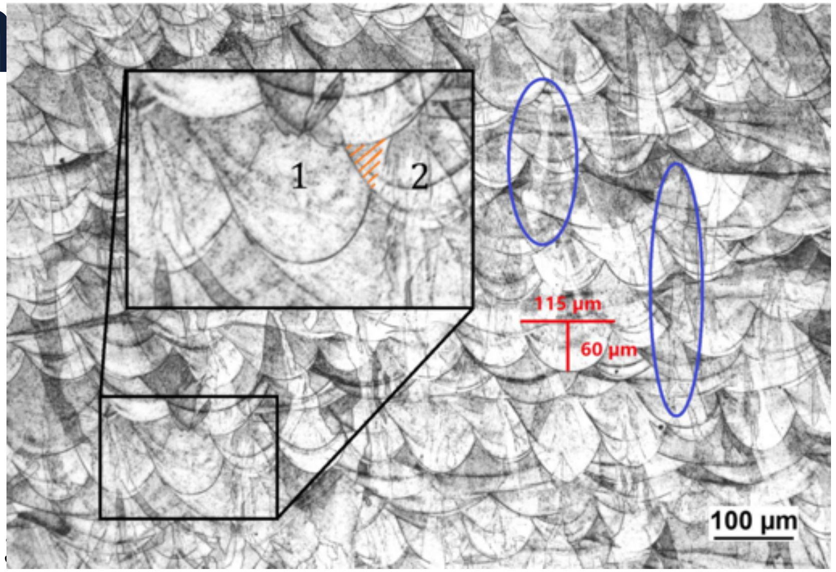
Test program

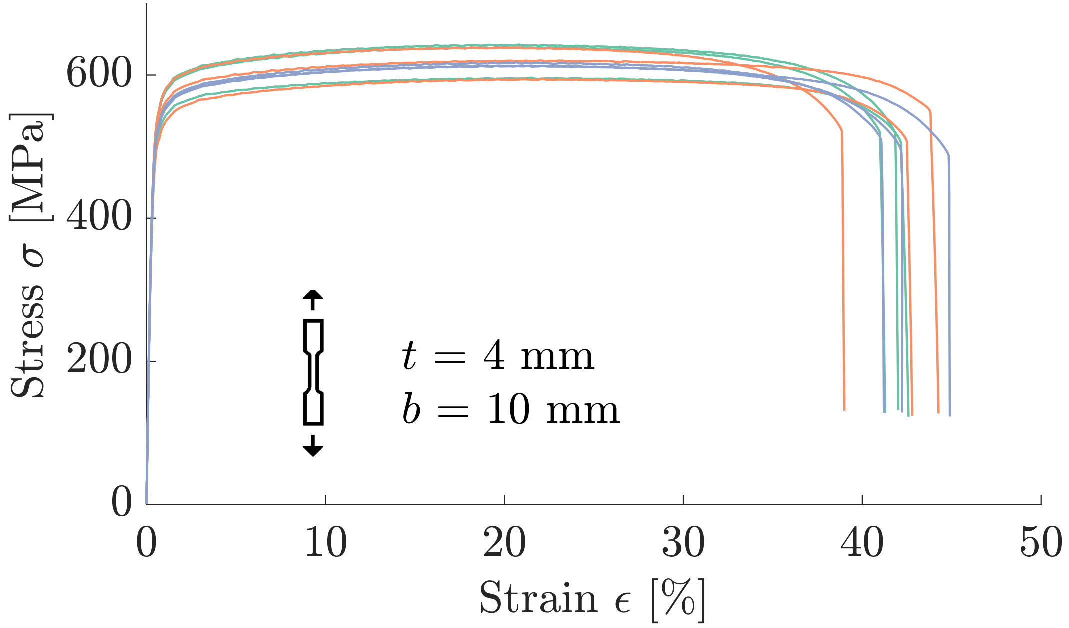


Condition	As-built	Heat-treated	Machined + Heat-treated
Heat treatment	–	2h @ 650 °C (furnace cooled)	2h @ 650 °C (furnace cooled)
Machining	–	–	1 mm thickness reduction by turning

Material characterisation

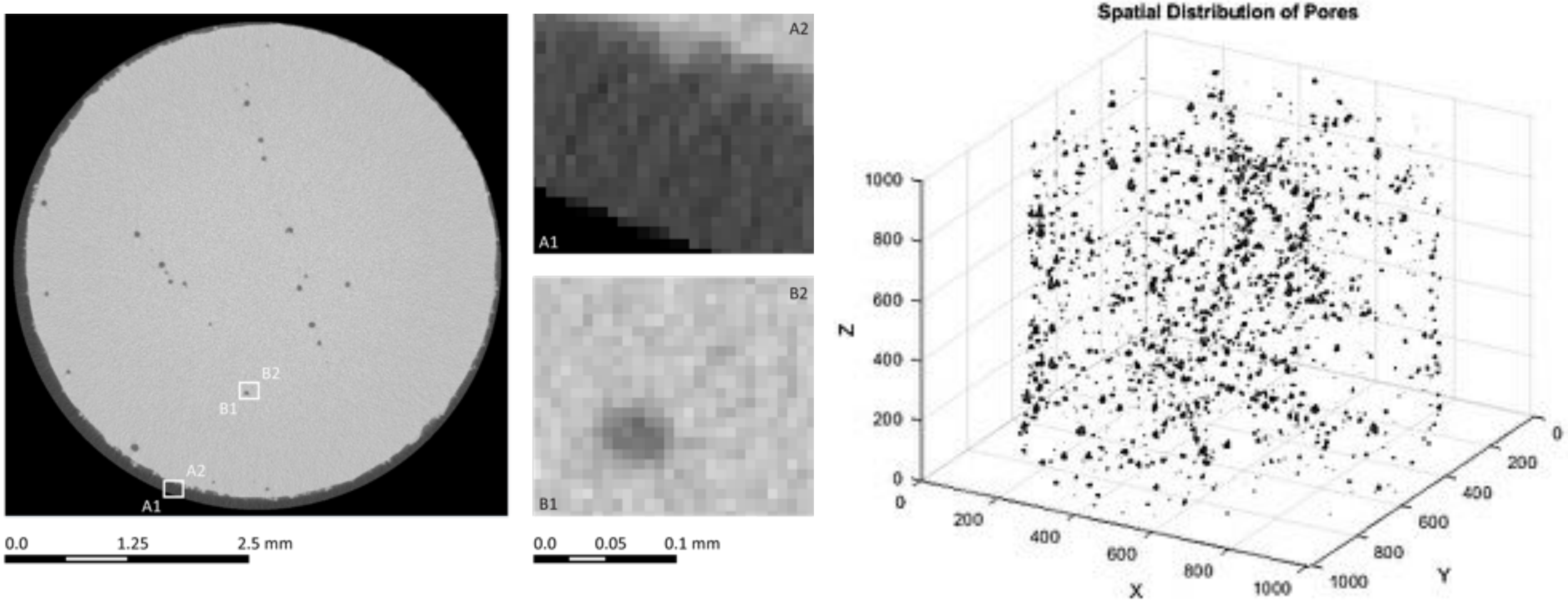
- High strength and ductility
- Grains partially extend over several layers



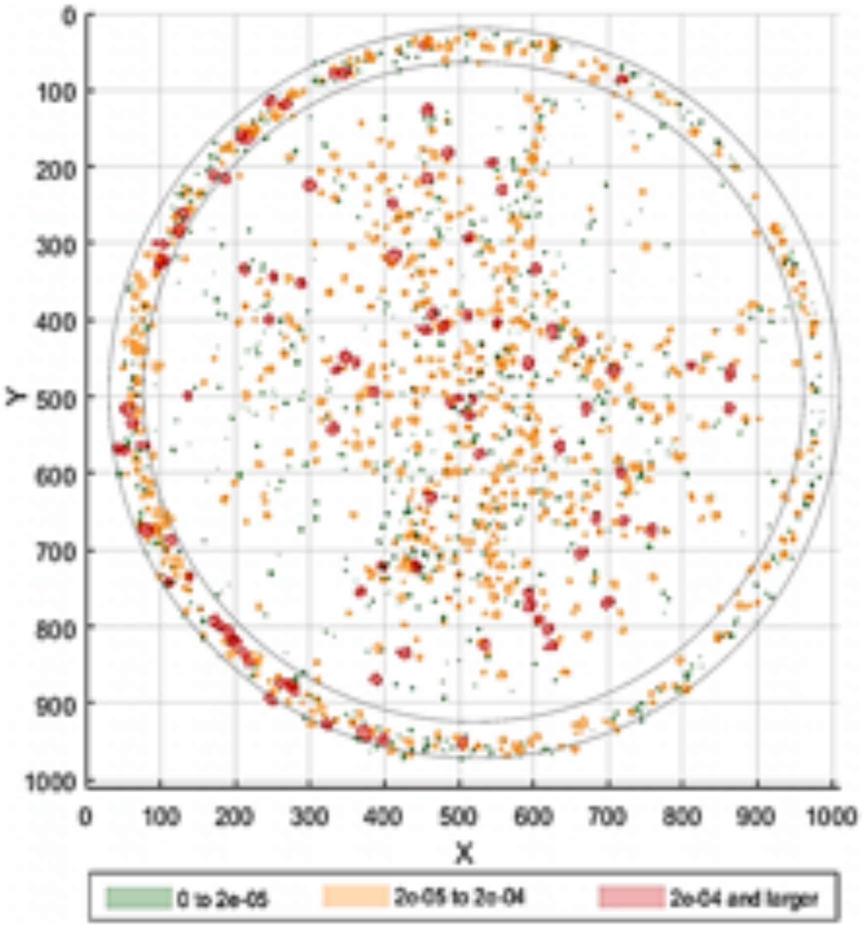


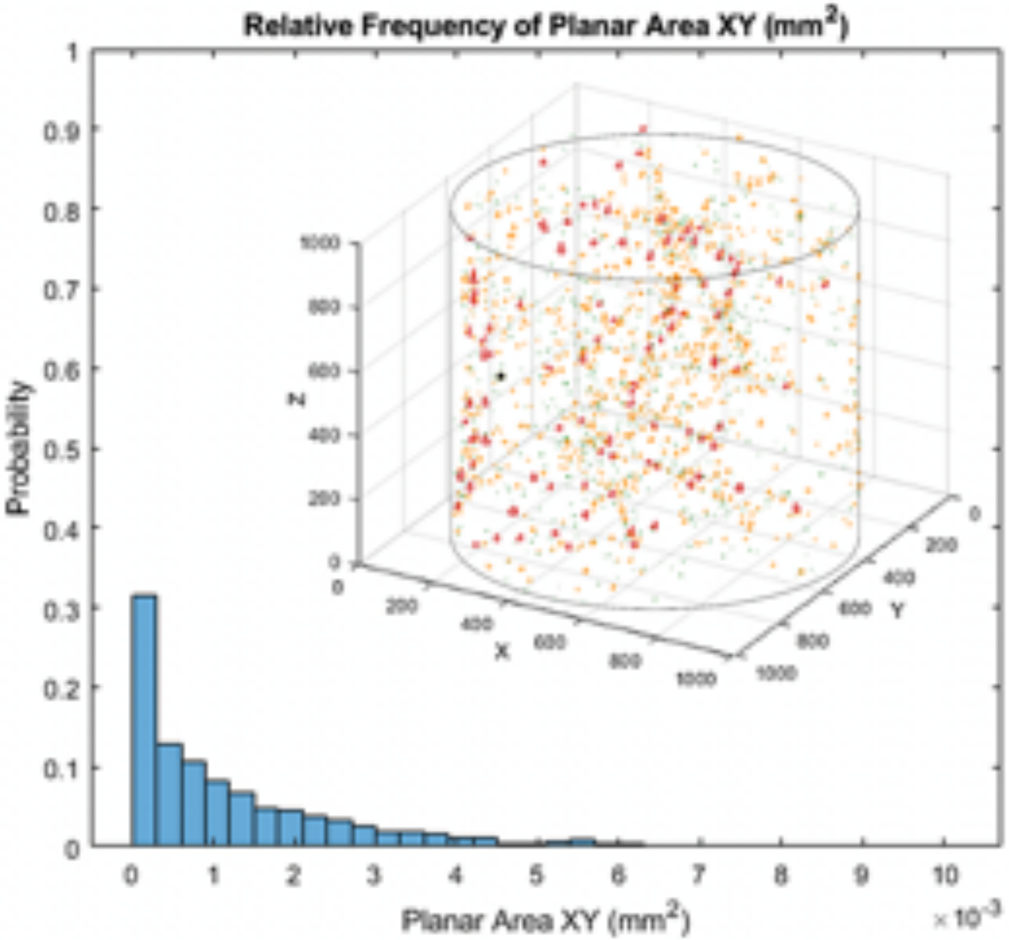
Orientation [°]	σ_{YS} [MPa]	σ_{UTS} [%]	ϵ_f
0	492	612	42.5
0	523	638	41.2
0	523	642	41.9
45	517	620	44.2
45	486	594	42.7
45	525	638	38.9
90	510	617	41.1
90	506	613	44.3
90	504	596	41.8
⌀	510	619	42.2

Computer tomography scan



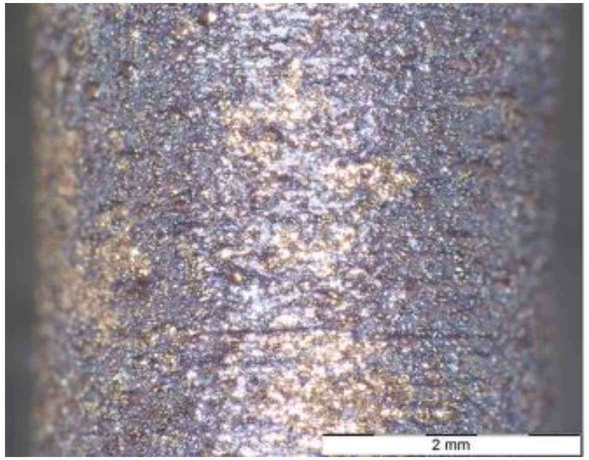
Computer tomography scan

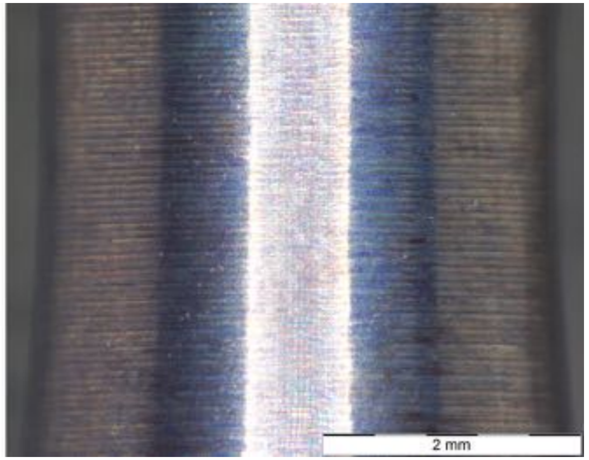




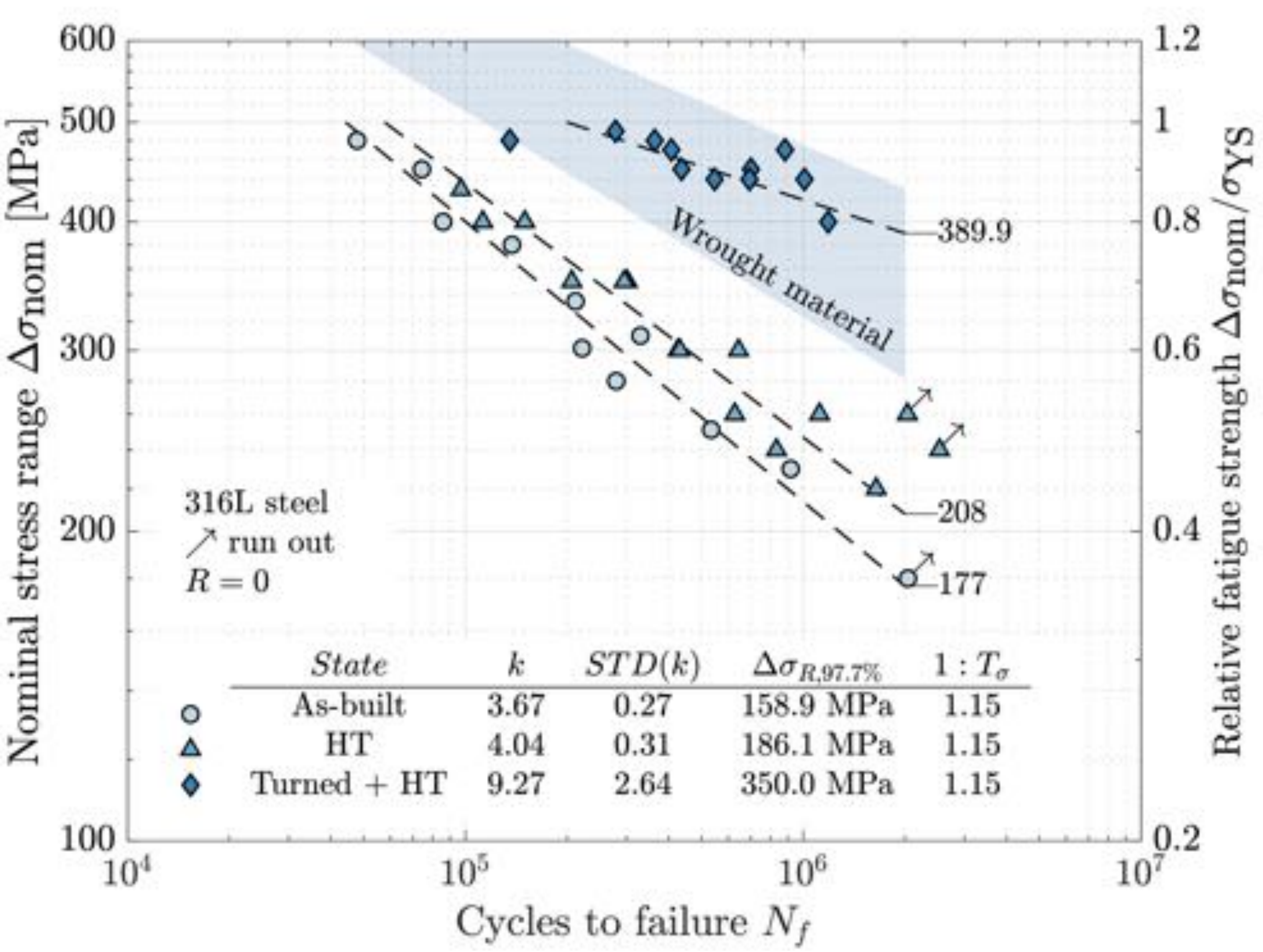
Post-treatment of selective laser melted parts

	Unbehandelt	Bearbeitet
Rautiefe R_t	41,929 ± 0,065	5,062 ± 0,063
Mittenrauwert R_a	6,295 ± 0,041	1,024 ± 0,005





Fatigue test results



Effect of surface roughness

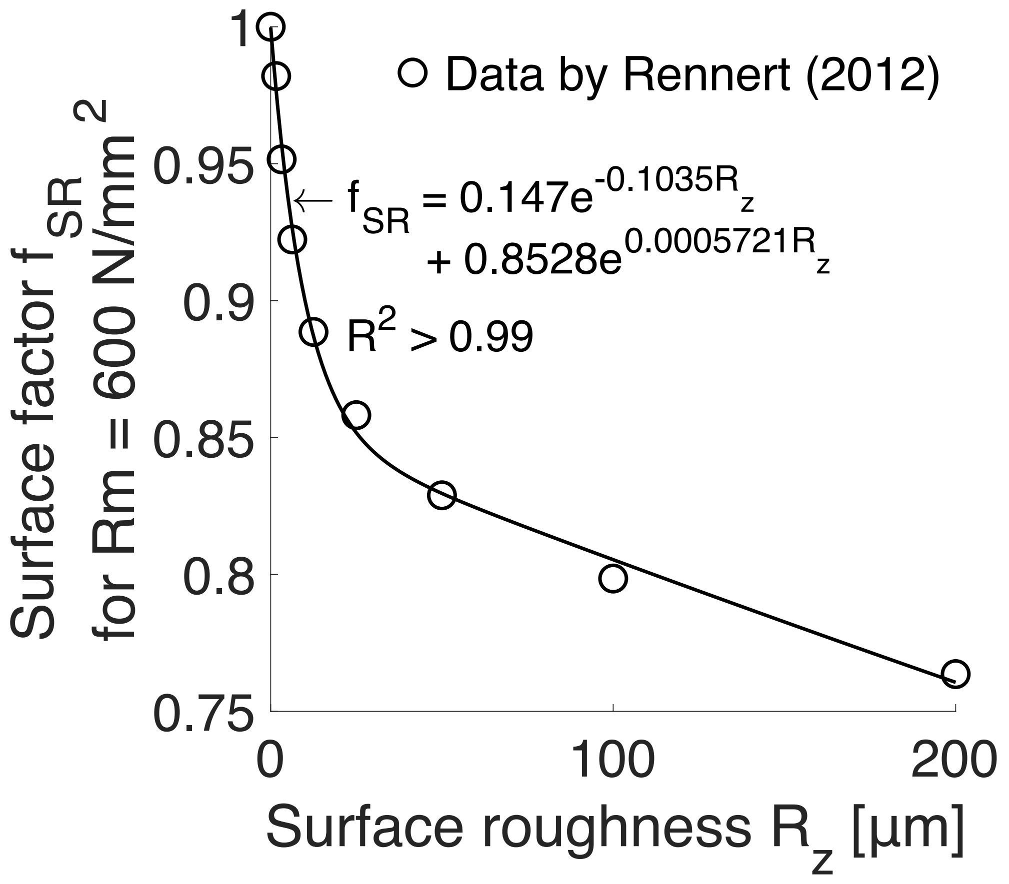
- Surface roughness as-built:

$R_a \approx 6.3\ \mu m \rightarrow R_z = 20 - 55\ \mu m$

- Surface roughness machined:

$R_a \approx 1.0\ \mu m \rightarrow R_z = 4 - 16\ \mu m$

- Estimated difference: ≈10%



Ref.: Rennert, R. (Ed.) (2012): FKM Richtlinie

Thank you for your attention!