TECHNISCHE UNIVERSITÄT CHEMNITZ

Institute of Joining and Assembly
Chair of Welding Engineering
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PROFESSUR SCHWEISSTECHNIK

Theoretical and practical residual stress analysis of nickel waterwall panel welds

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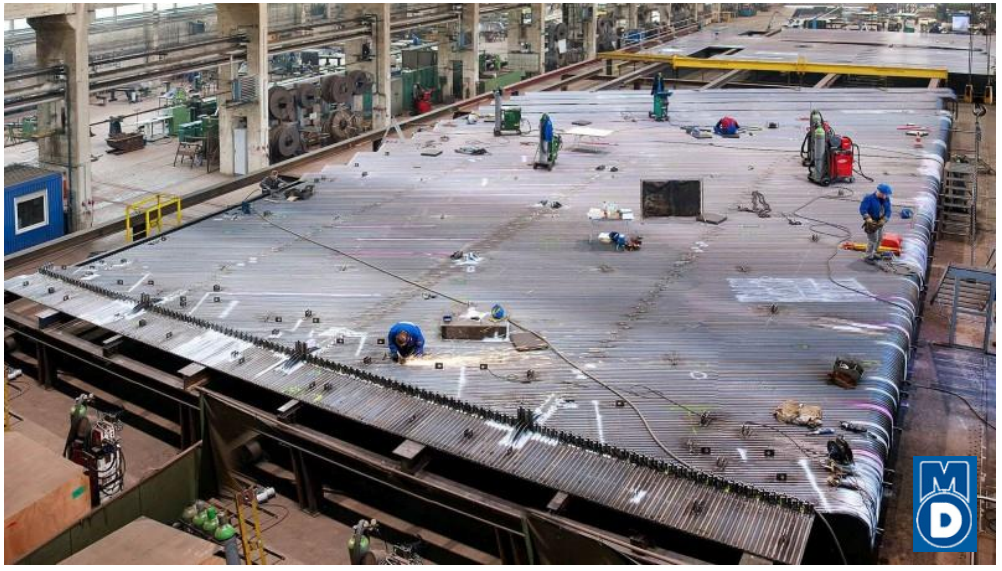
3rd IEA CCC Workshop on A-USC Power Plants , INAIL, Rom

13th to 14th December, 2017

How to realise waterwall panels?

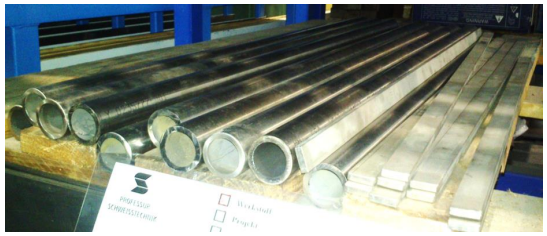
▲fabrication of boiler components

▼fabrication of boiler components (membrane or panels)



Standard way to construct waterwall panels

tube + strip



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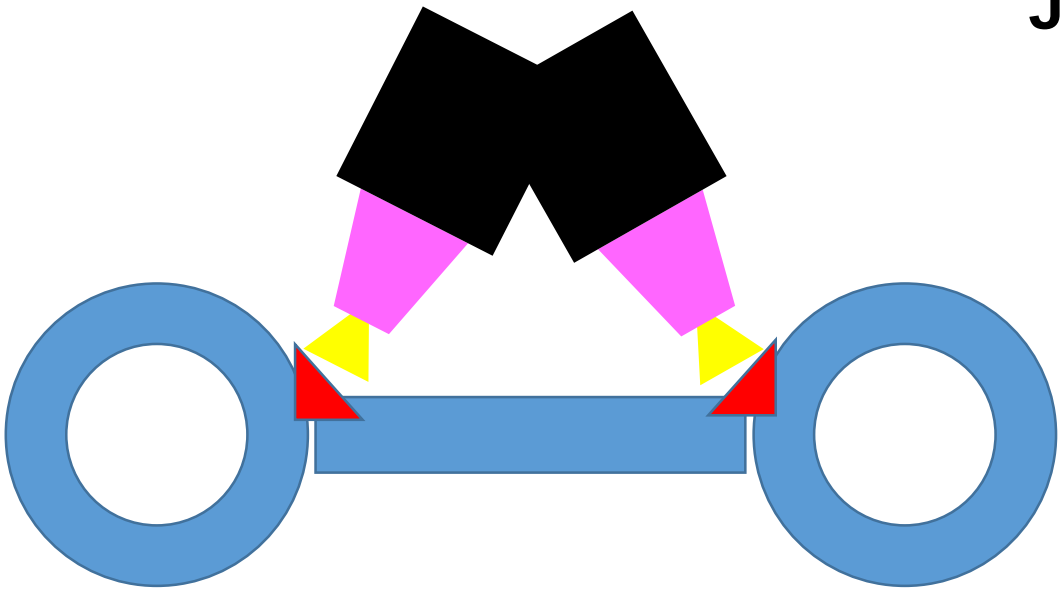
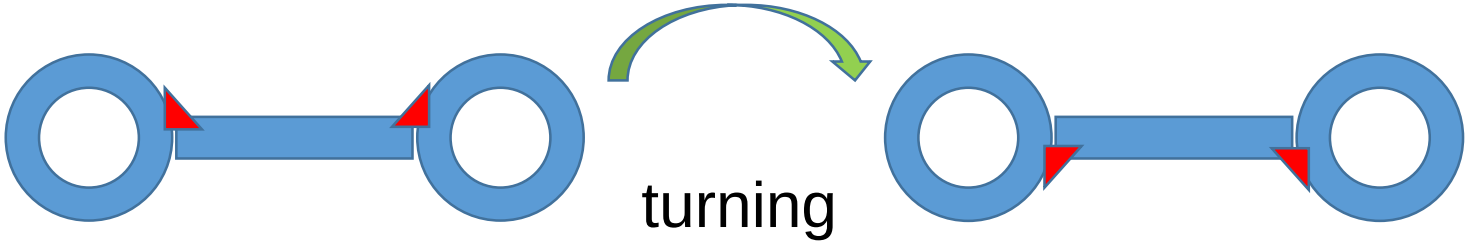
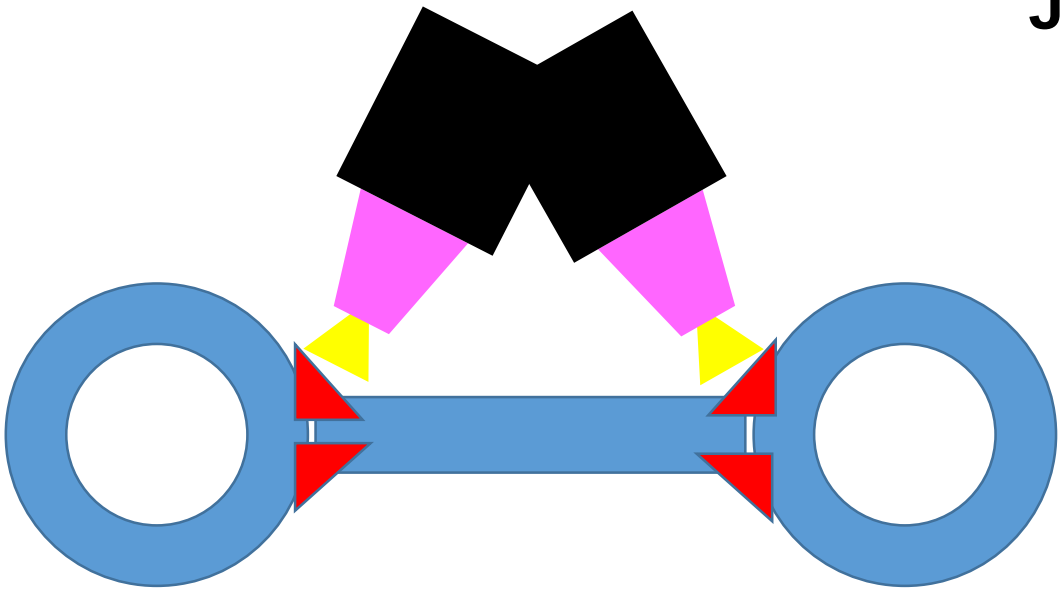


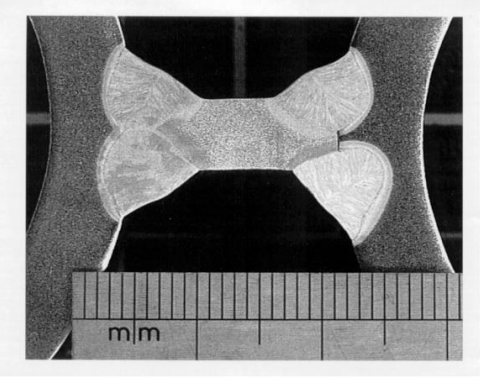
Joining process first side

Standard way to construct waterwall panels





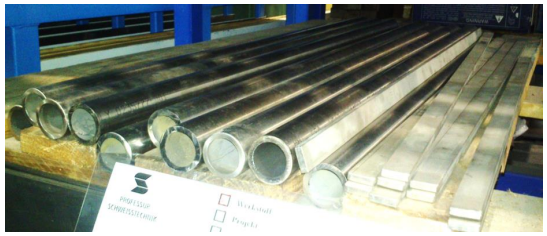
Joining process second side



Alternative Forming strategy - Extrusion

Standard way: connection between tubes and strip

tube + strip



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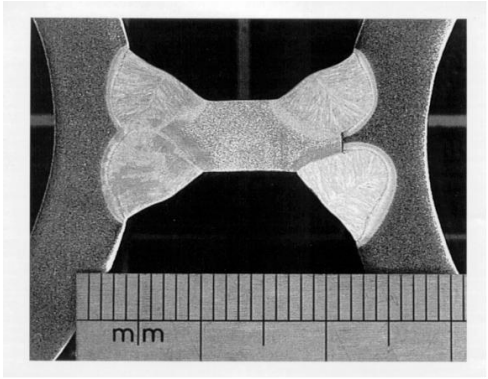
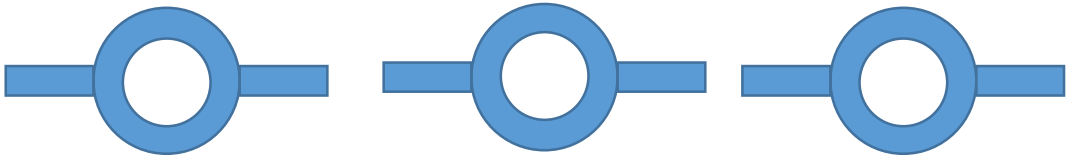


Ongoing/future way: connection of extruded parts



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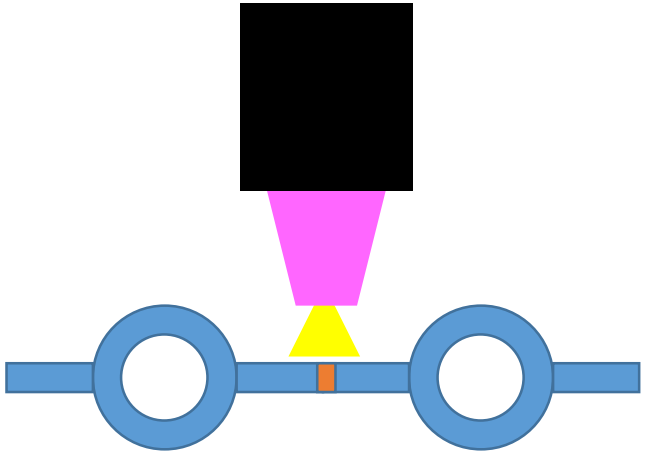
extruded tubes
with strip part

Advantage of extruded parts

- Joining from one side possible
- No turnig of the parts
- Reduced handling and clamping
- Reduced welding time
- Increased quality - the joints are outside the pressurised tube

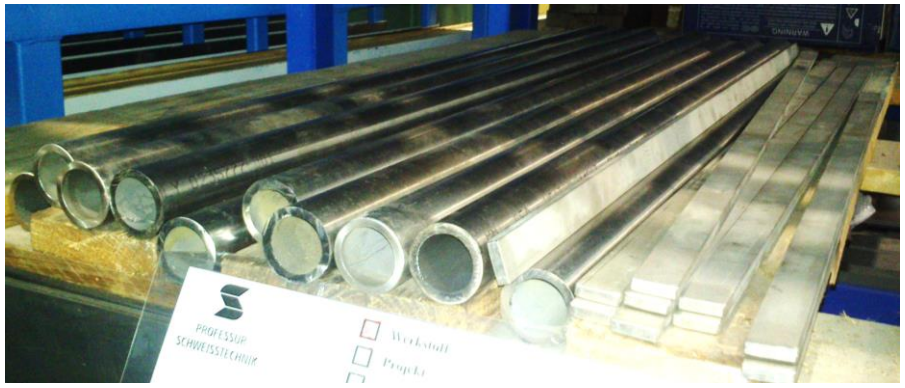


→ two joining geometries

strip to strip

tube to tube

Chemical Composition



in weight %	Ni	Cr	C	Fe	Co	Mo	Nb	Mn	Si	Cu	Al	Ti	P	S
IN 600 (2.4816)	72	15	0.1	10				1	0.5	0.5	0.3	0.3	0.02	0.015
IN 617 (2.4663)	53	21.5	0.075	1.5	12.5	9.25		0.15	0.15	0.4	1.05	0.4	0.01	0.01
NiCr20Mn3Nb (2.4806) IN 82 (filler metal)	73	20	0.02	0.8			2.7	3	0.2					

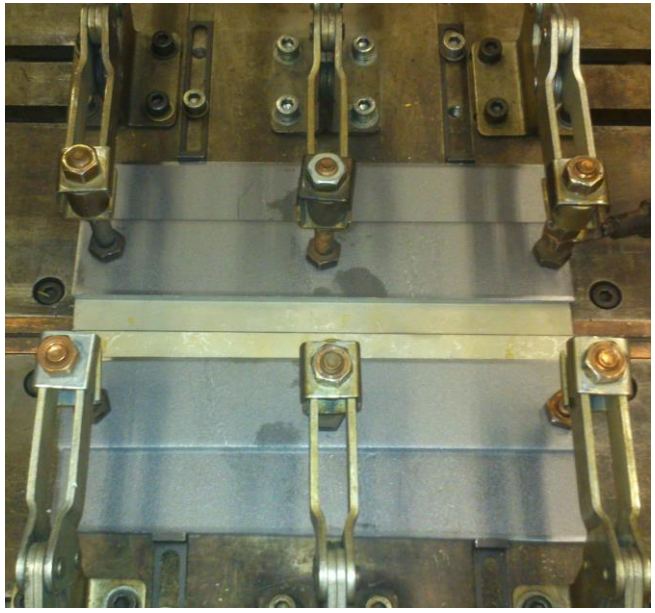
Base Material:

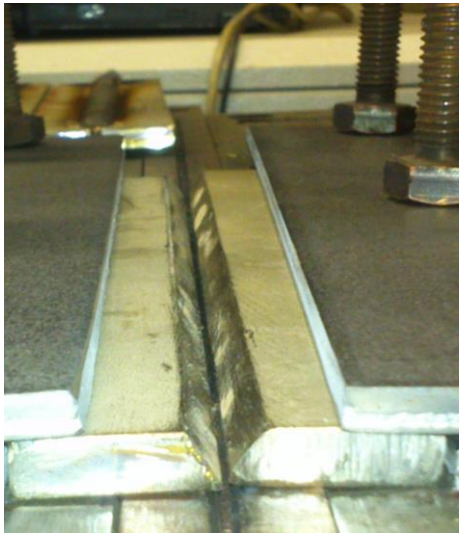
- **IN 600 strip** (width 20 mm, thickness 6 mm)
- IN 617B tube (outer diameter 38mm, wall thickness 6.6mm)

Filler metal:

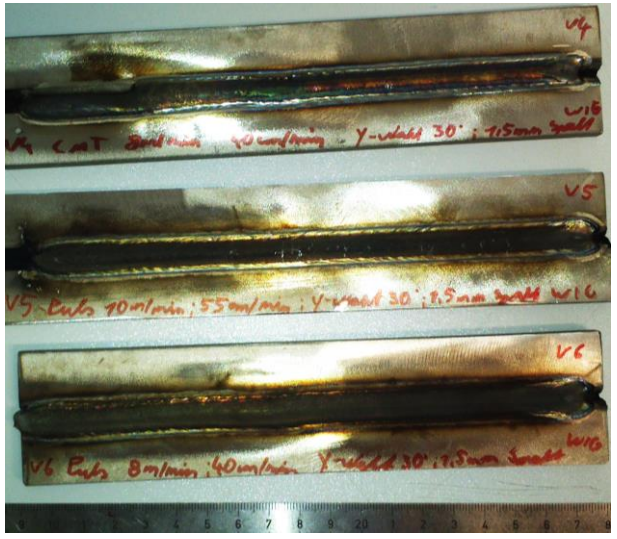
- Inconel 82 (2.4806), diameter of 1.2 mm

Realised clamping and welding system





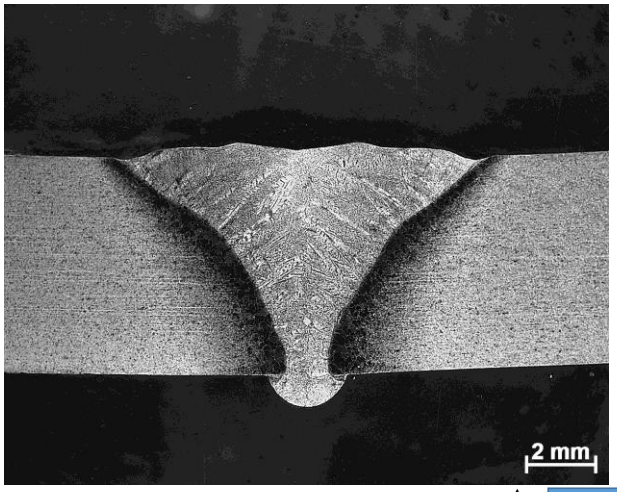
IN 600 strip 250 mm per 20 mm

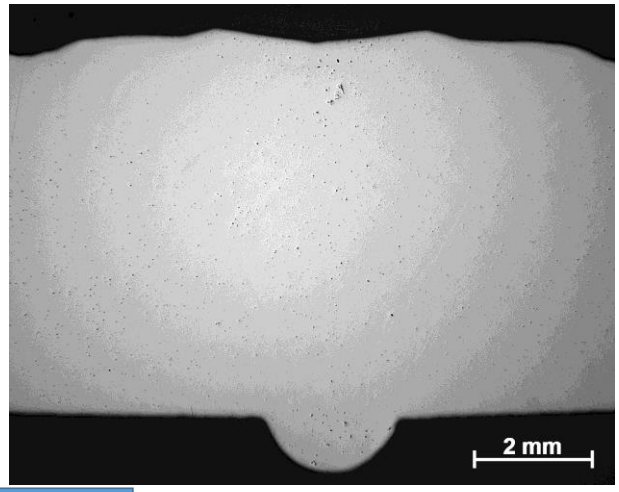


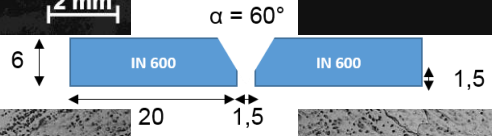
Welding results

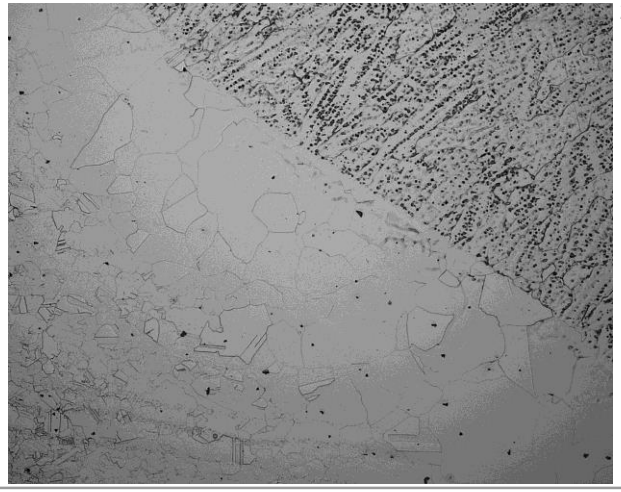
Cross sections MIG-Welding

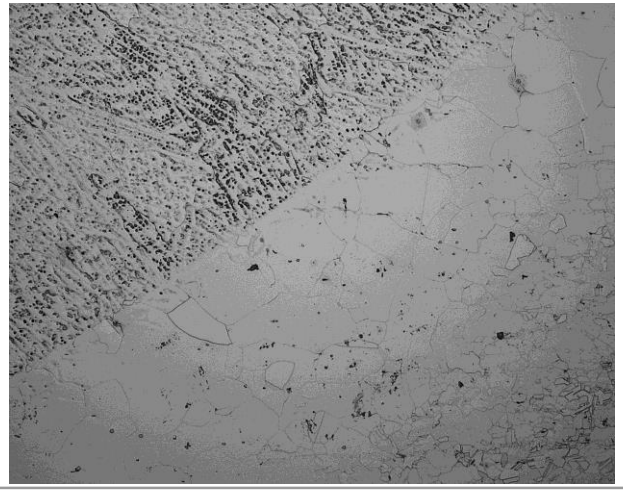
Number	Gap	Shape	speed	Process	Result
V6	1,5	Y (30°, 1.5 mm fillet)	40 cm/min	Pulsed (8m/min)	**good**





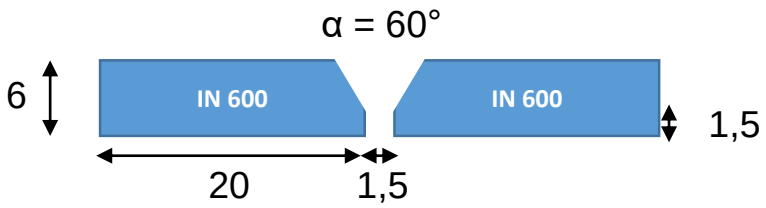






Summary MIG-Welding

- Weld seam preparation is necessary → Y-shape
- defined gap necessary



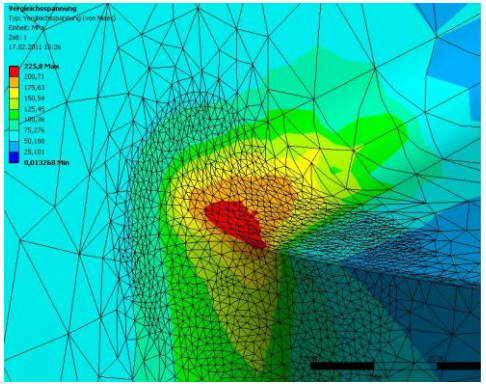
- no hot cracks detected
- Welding speed around 60 cm/min
- hardness reduction in weld seam 10 (HV1)

  filler material optimised for joining process

  → grain structure with little influence

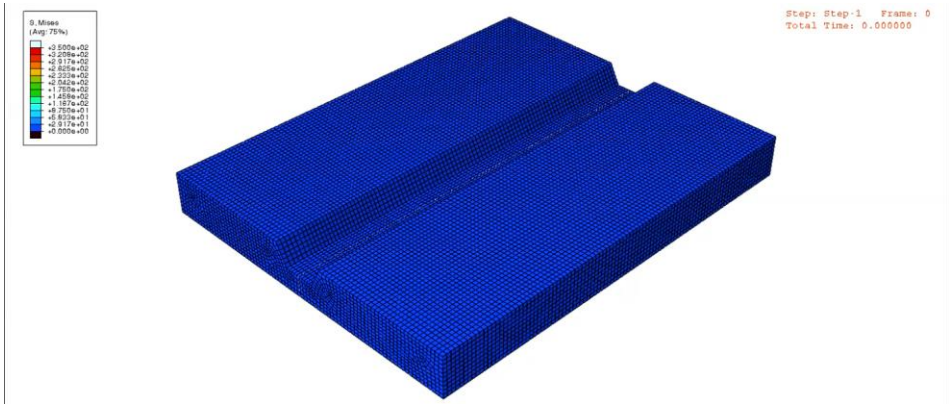
Increase Quality and save time by Finte Element Analysis (FEA)

FEA



Process and material simulation

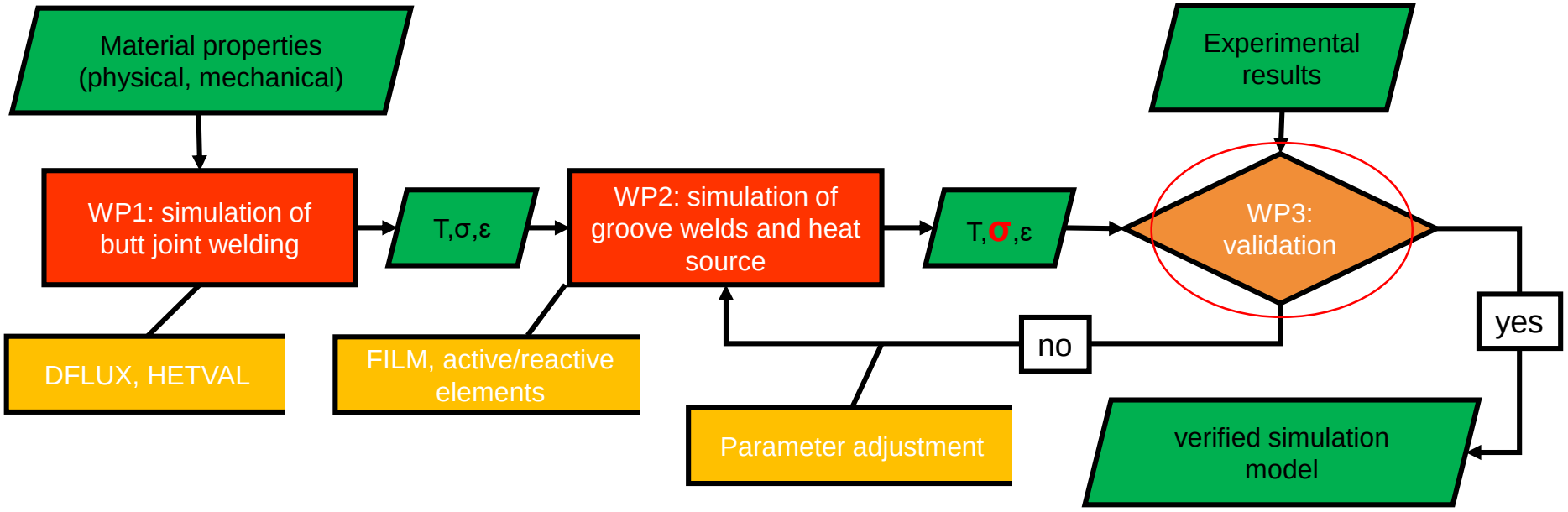
Simulation of groove welds – resulting stress



„low“ heat input

„high“ heat input

work-flow chart of FEA



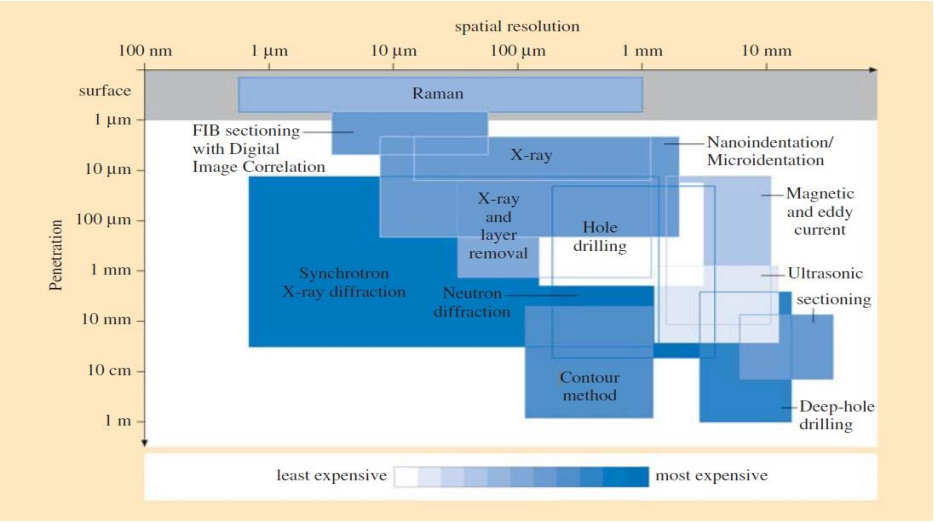
Some specific material properties still unclear

→ Measurements and Round Robin test

on residual stress measurement (temperature and time)

Residual stresses measuring techniques

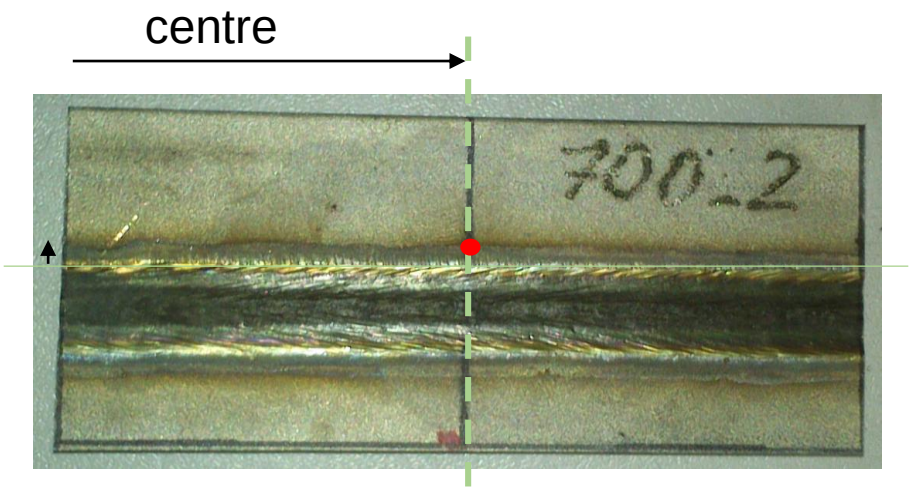
- **Non-destructive**
  - X-ray diffraction method
  - Synchrotron diffraction
  - Neutron diffraction
  - Magnetic method
  - Ultrasonic method
- **Semi-destructive**
  - Centre-hole drilling method
  - Ring core method
  - Deep-hole driling method
- **Destructive**
  - Layer removal method
  - Contour method
  - Splitting method



[02]

Position residual stress measurement Round Robin Test

1 mm adjacent to fusion line



Round Robin Test

Measuring techniques

X-Ray diffraction method XRD

2 Partners

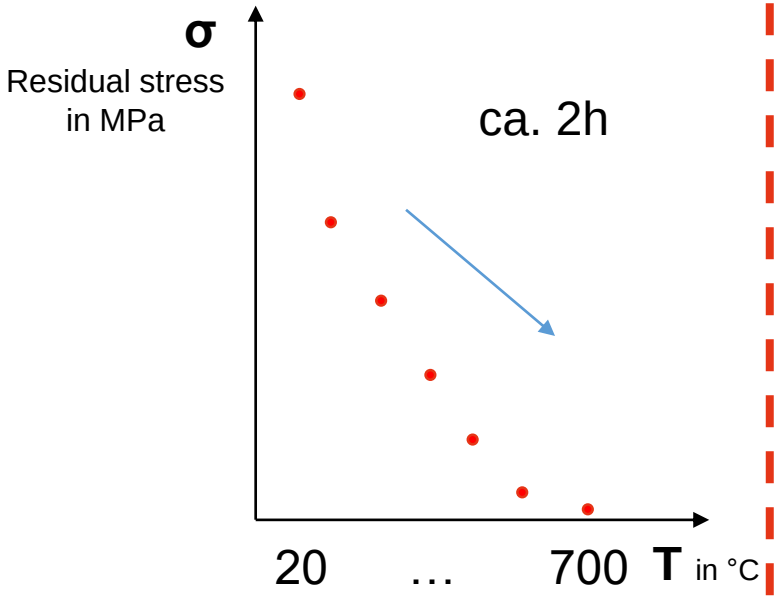
Centre-hole drilling method

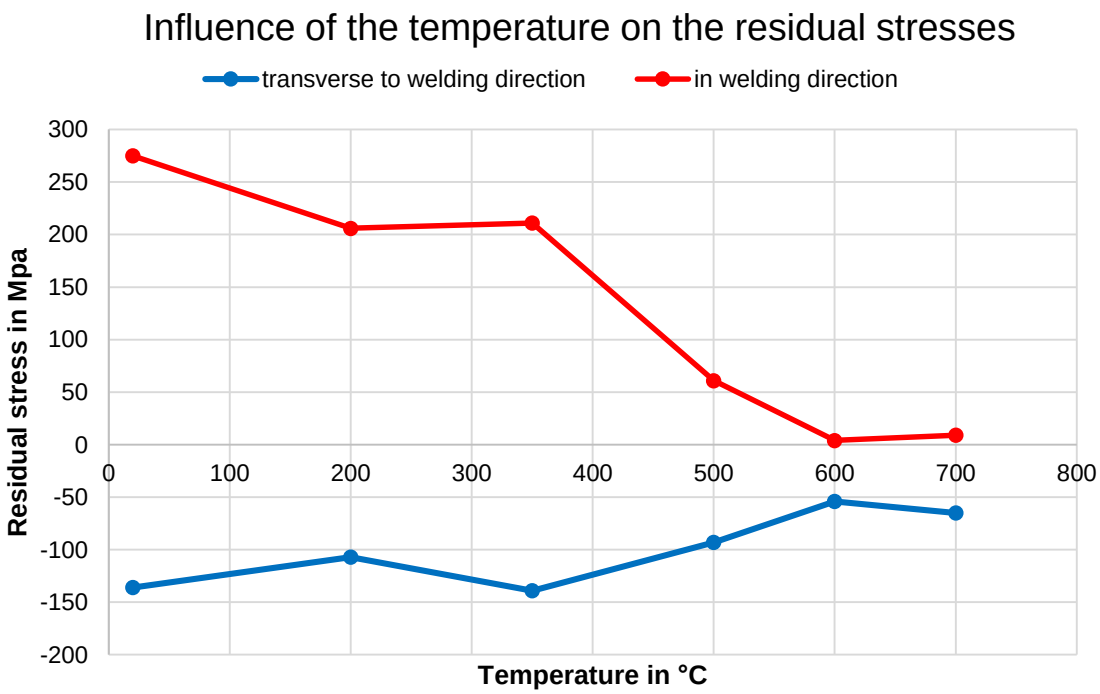
3 Partners

Ultrasonic method

1 Partner

XRD TU Chemnitz
- Influence of Post weld heat treatment



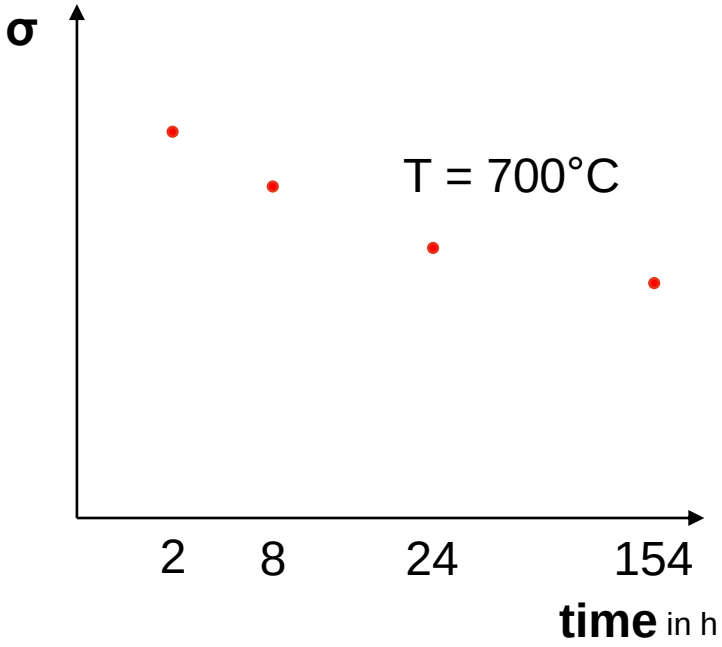


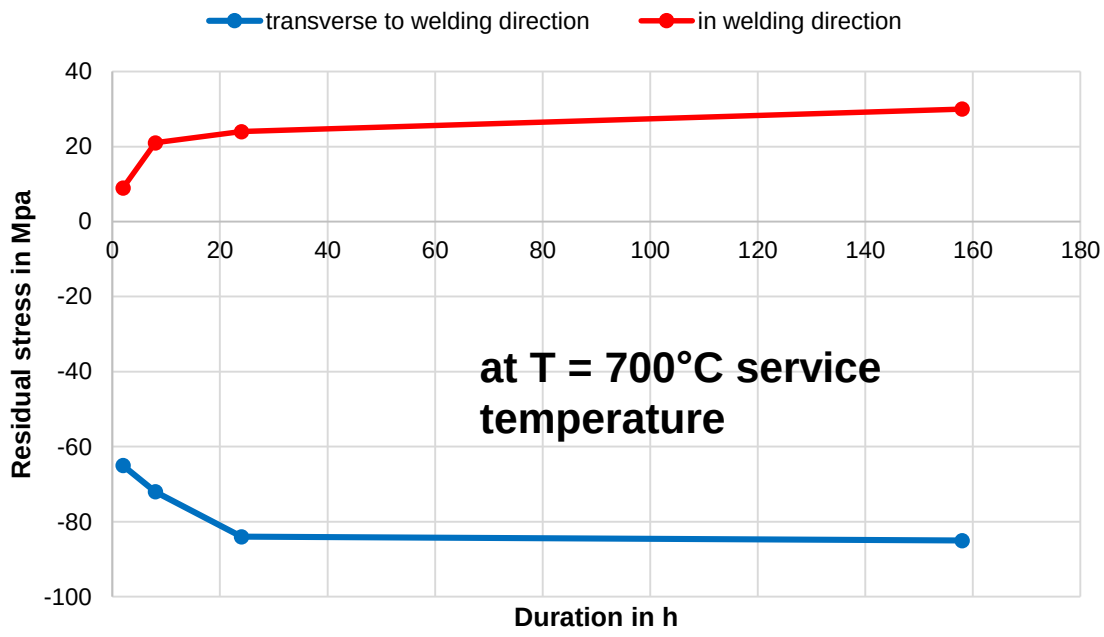
residual stress via **X-Ray diffraction (XRD)**

→ **longitudinal 275 MPa**

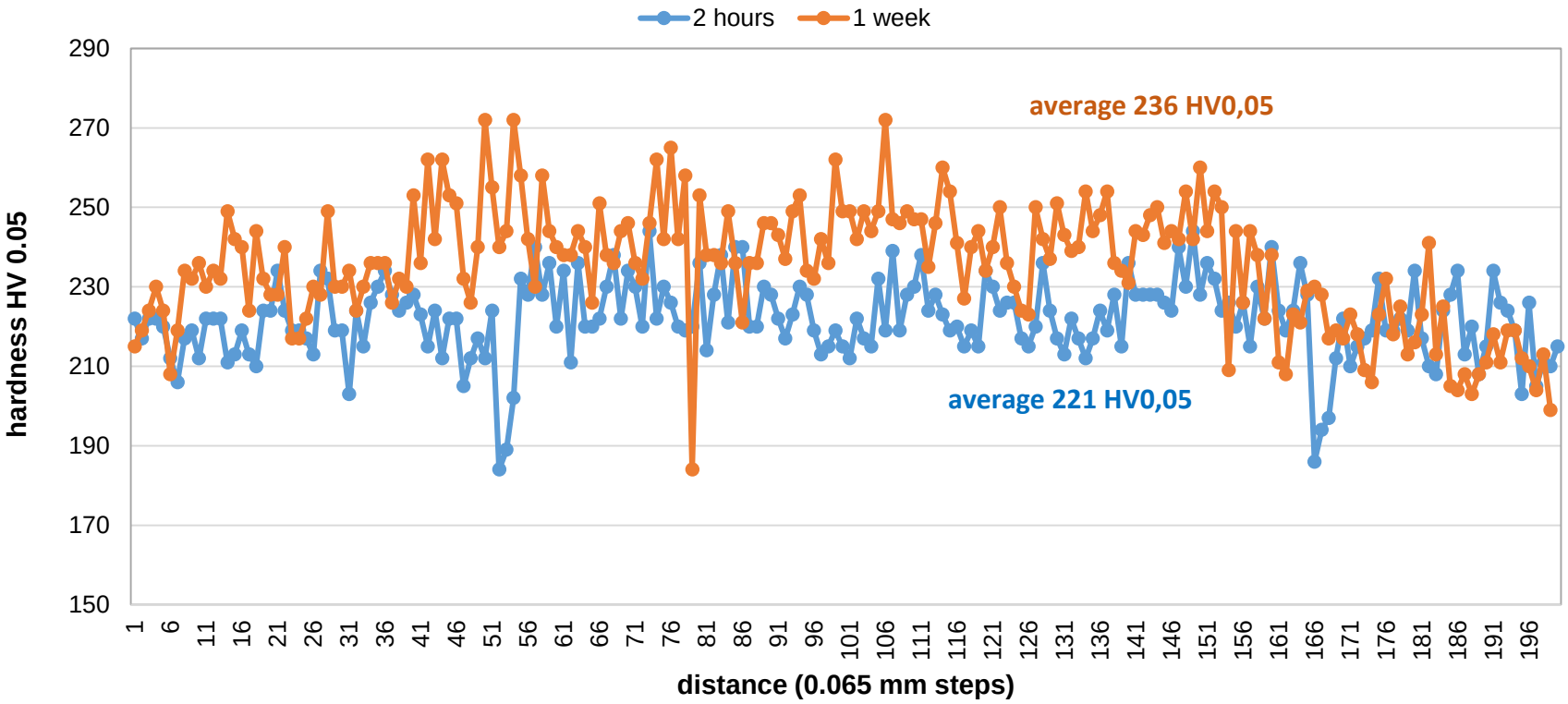
→ **transversal -136 MPa**

XRD TU Chemnitz
- Influence of operating time at 700 °C service temperature





Reason of increase of residual stress at T=700°C



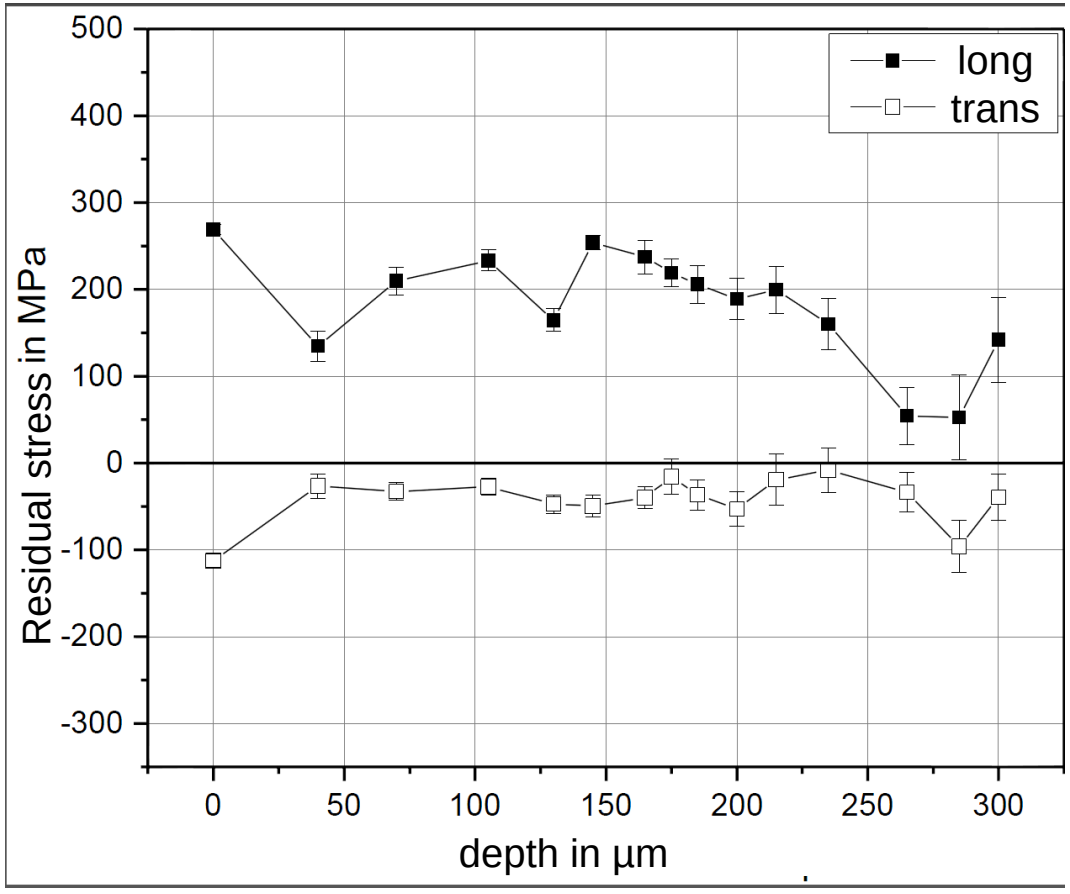
Mechanism **„Negative Creep“**

Microstructure: - Nb and Ti carbides as well NbCrN excluded inside as well as around grain boundaries
- formation of gamma prime phase (above T=500°C)
- δ-ferrite in the wed metal and HAZ

→ **Increase of hardness and resulting residual stresses**

Source 280, 317, 486, …

XRD with chemical etching Partner 1 - Influence of depth



measurement point

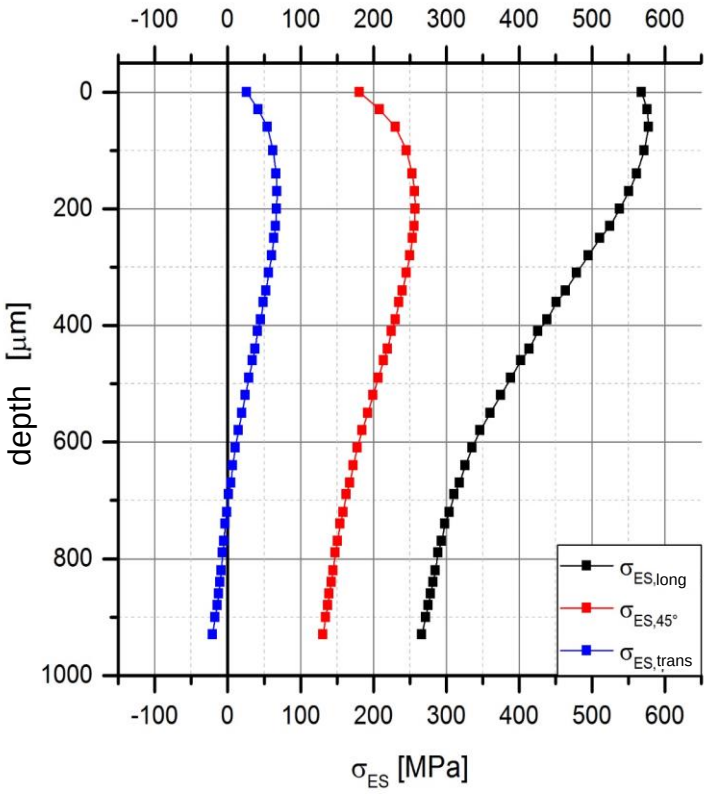
Residual stresses are nearly on the same level with increasing depth

→ **longitudinal 281 MPa**

→ **transversal -112 MPa**

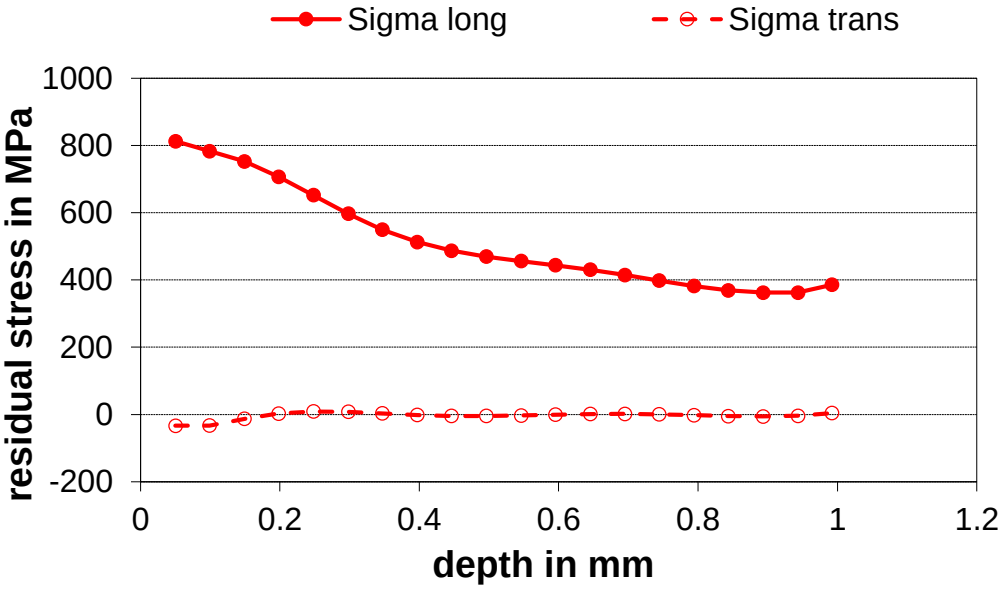
centre-hole drilling method with strain gauge

Partner 2



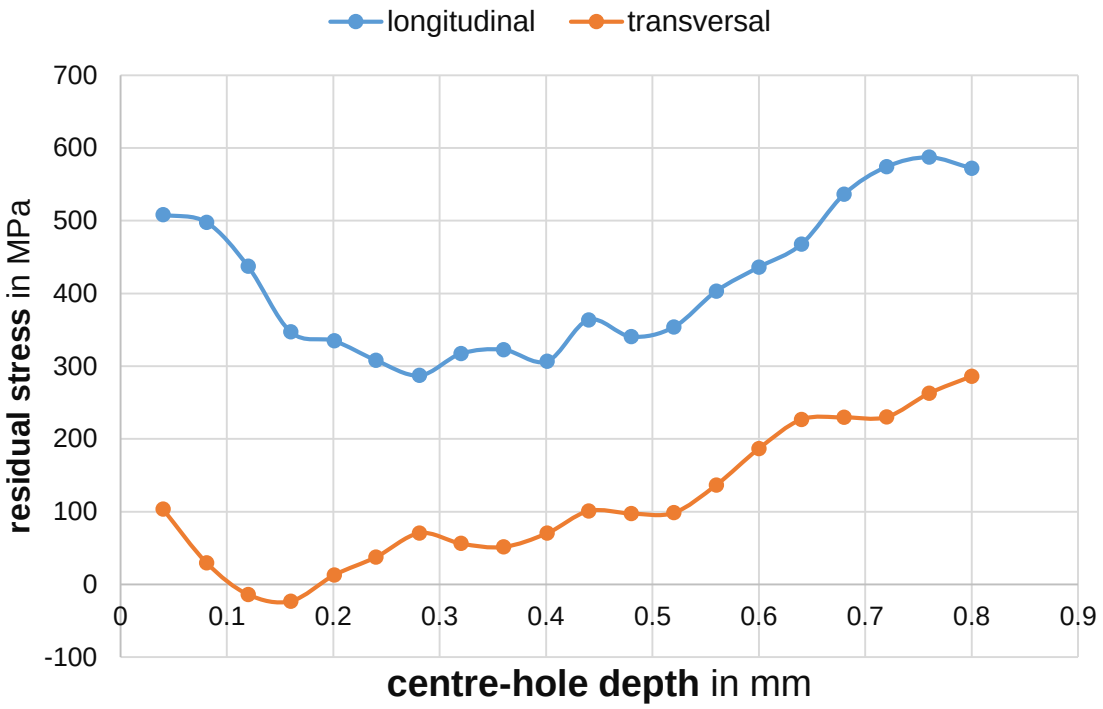
→ longitudinal 567 MPa
→ transversal 26 MPa

Partner 3

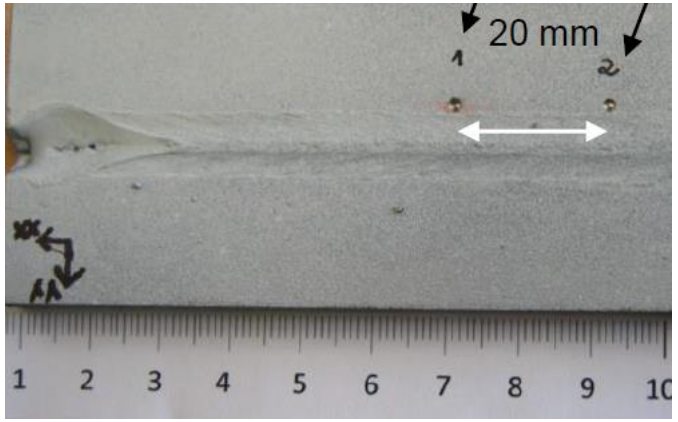


→ longitudinal 813 MPa
→ transversal -34 MPa

centre-hole drilling method with electronic speckle pattern interferometry – Partner 4



Optical measurement of surface displacements



→ **longitudinal 503 MPa**
→ **transversal 67 MPa**

Summary comparison residual stress measurements

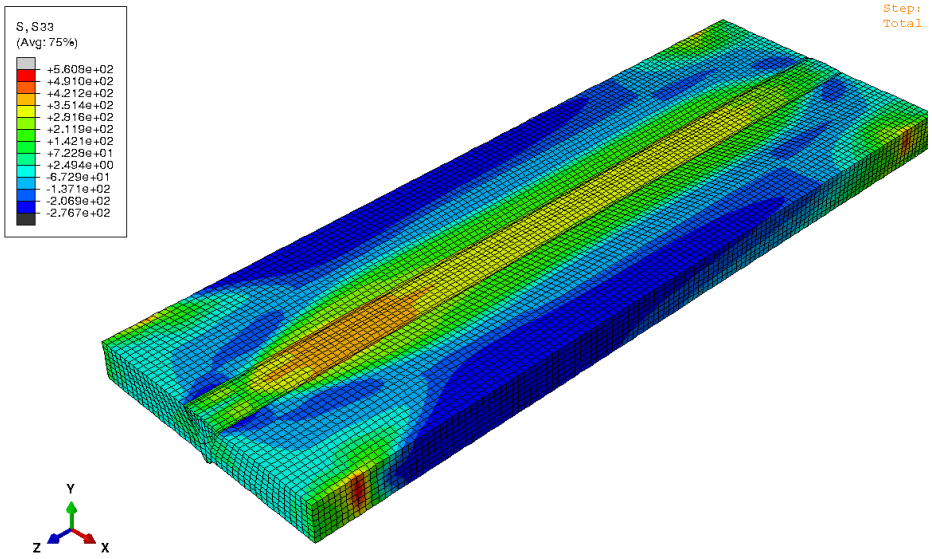
Results Round Robin

Institution	**TU Chemnitz**	**Partner 1**		**Partner 2**	**Partner 3**	**Partner 4**	**Partner 5**
method	XRD	XRD	XRD, chemical etching	centre-hole and strain gauge	centre-hole and strain gauge	centre-hole and electronic speckle pattern interferometry	ultrasonic method
residual stress longitudinal - in welding direction in MPa	275	270	281	567	813	503	sample to small
residual stress transversal- transverse to welding direction in MPa	-136	-37	-112	26	-34	67	sample to small

Tensile strength of Alloy 600: 550 MPa

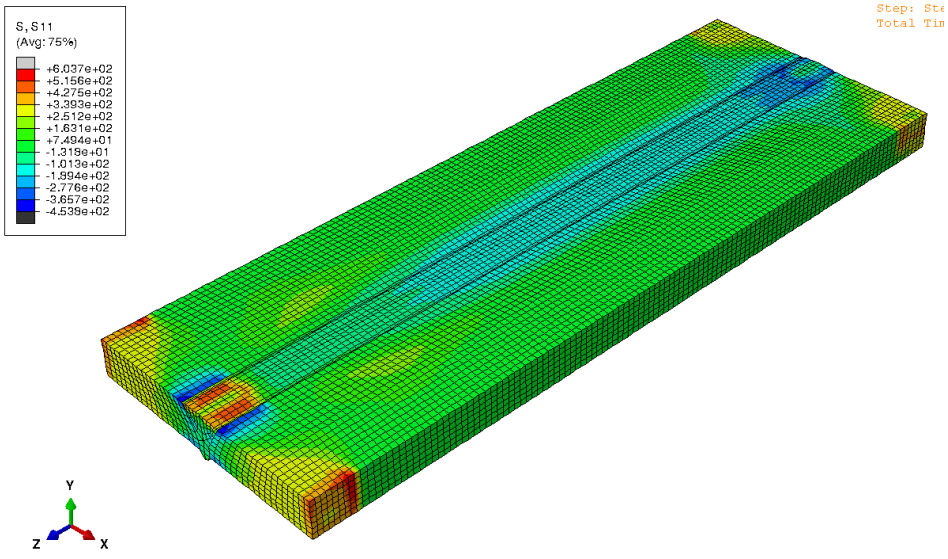
- XRD has same level of results
- Centre-hole drilling method two till three times higher
  → adaption of the stress-strain-level from linear to real necessary
- Ultrasonic method useable but not for our sample geometry

Simulation of groove welds – residual stresses



Longitudinal residual stress

Residual stresses around 250 MPa



Transversal residual stress

Residual stresses around -140 MPa

→ Simulation model is verified and useable for ongoing experiments and developments

Do you have questions?

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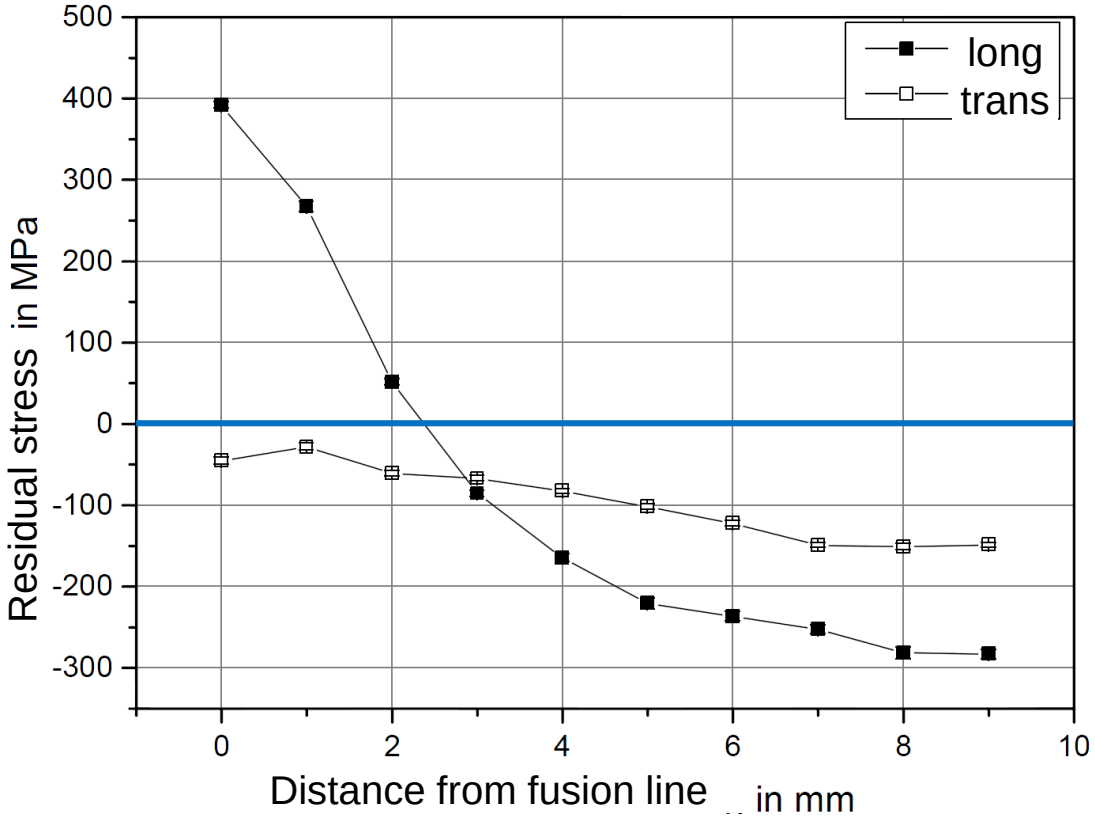
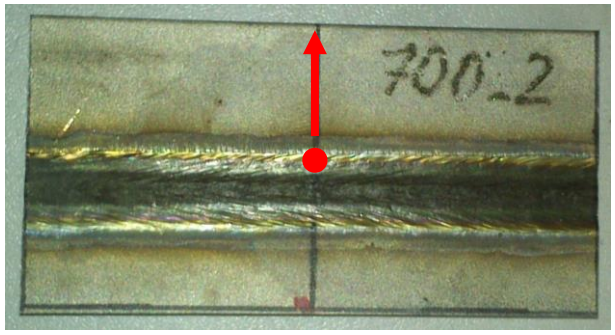
XRD Partner 1
- Influence of distance from the fusion line





measurement direction

Residual stresses decrease with increasing distance from the fusion line

→ **longitudinal 270 MPa**

→ **transversal -37 MPa**

Comparison of different FEA Models at DP 700

	Model TUC	Model DEKRA	Experimental results
Dimension	3D	2D	
Integration of weld geometry	Yes	Yes	
Simulation of weld temperature	Yes	Yes	
longitudinal residual stress	+250	+260	+275
Transverse residual stress	-140	+255	-140