LPC and Water Spray Quenching

Aachen, 2025
Final Workshop
Christof Ziegler, ALD Vacuum Technologies, Hanau, Germany

This project has received funding from the Research Fund
for Coal and Steel under grant agreement No 101033989

Water spray quenching and heat treatment

- Within the Topgear project, ALD was responsible for the heat treatment of the all parts
- ALD Vacuum Technologies is a well known supplier of fully automated heat treatment systems using the principles of vacuum heat treatment and high pressure gas quenching (LPC and HPGQ)
- For the Topgear project a new approach of quenching was developed and thoroughly investigated:
- The new quenching system is based on water spray quenching (WSQ).
- Since LPC is a well-known and widely applied heat treatment process, the following lecture will focus on the water spray quenching and its results

Content:

- Motivation
- Tasks and device
- Results
  - Hardness response
  - Appearance and microstructure
  - Cooling rates and heat transfer
- Conclusion & outlook

Water spray quenching and heat treatment

Motivation:

- Water spray quenching is an established process since decades in steel making
- High quenching intensities are possible avoiding film boiling stage
- Yet water spray quenching was not introduced to heat treatment of complex shaped components or multilayer loading such as gear transmission parts (e.g. gears, shafts,…) etc.

- Combining water spray quenching with modern heat treatment such as LPC would offer interesting process options or new selection of steel variants
- ALD identified that potential of water spray quenching and successfully combined it with vacuum heat treatment

Water spray quenching and heat treatment

Tasks realized:

- Design, build and commissioning of a suitable test device including right nozzles, fluid supply, safety features, flexibility for different quench performance
- Determine a basic understanding of the performance of WSQ using bolts, gear parts and various steel alloys
- Determine and derive cooling curves and heat transfer coefficient α.
- Identify influence on carburizing, microstructure and hardness values
- Come up with an understanding for a stand-alone quenching chamber in connection with a ALD Syncrotherm® plant

Water spray quenching and heat treatment

Test device (general view)

Water spray quenching and heat treatment

Test device (general view)

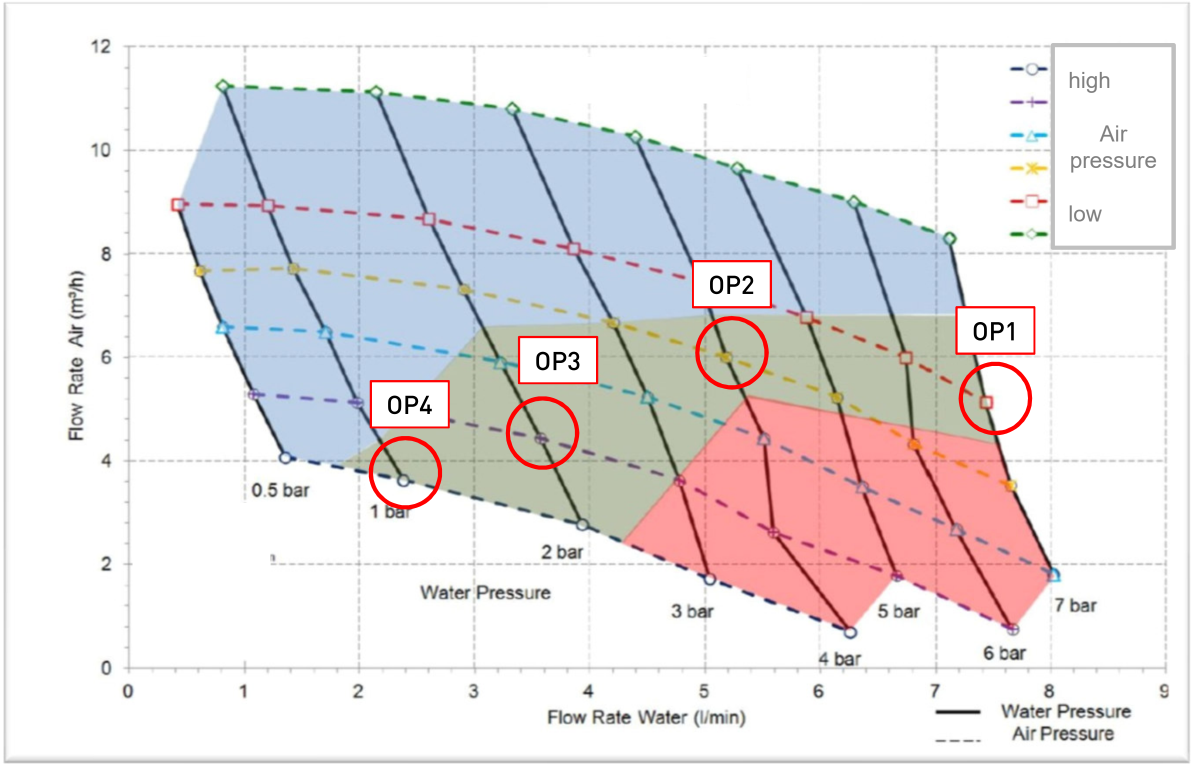
Detailed view:
test part (here: final drive ring) on movable loading tray with nozzle array above <u>and</u> below

Nozzle arrays (9 no) can be adjusted independently regarding distance, flow and pressure of water and air

Water is circulated water, a loss to steam / vapour was not encountered

Water spray quenching and heat treatment

Characteristic curves for nozzles with different operation points (OP)



OP1: intensive

OP4: most soft

Water spray quenching and heat treatment

Results – hardness I:

- First results showed promising and repeatable results

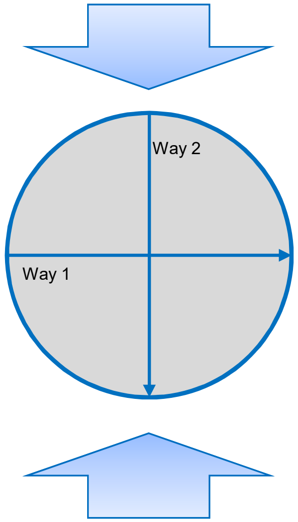
	OP 2		water immersion		OP 3 (softer)		OP 2 (orientation across)		He 18bar	N2 18bar
bolt pairs	1	6	2	5	3	8	4	7		
15mm from surface	441	448	432	435	434	437	429	437	(336)	(295)
core, 50mm	420	447	421	411	412	418	416	406		
bolts 16MnCr5; L=100; D= 25mm										

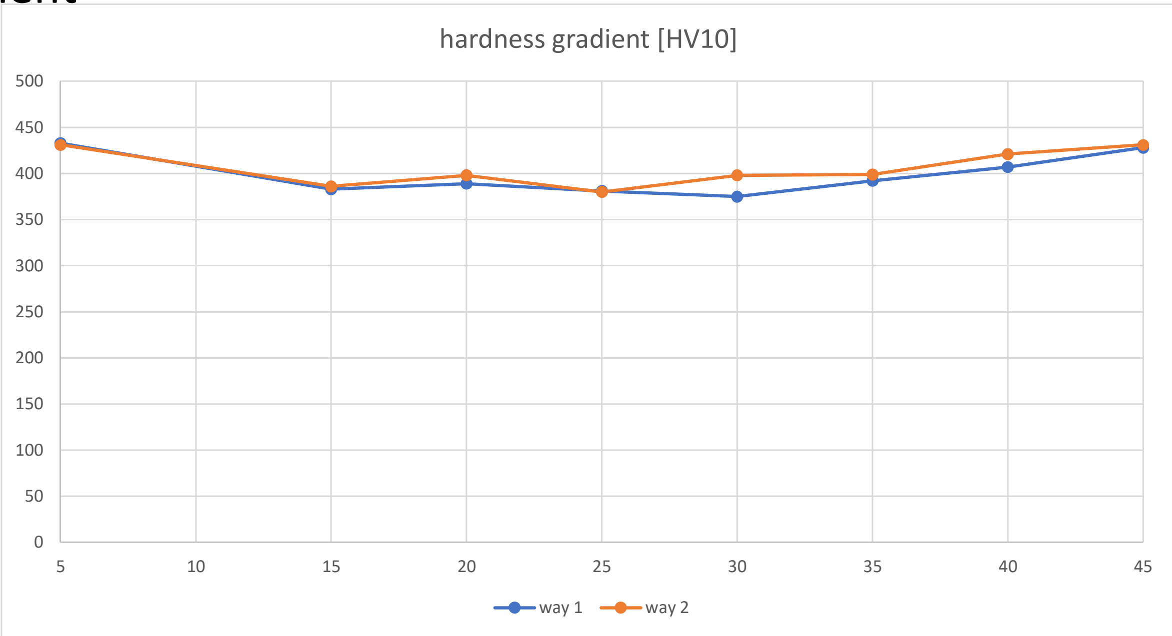
quenched from 930°C; hardness in HV10; ALD Standard bolt 16Mncr5; OP = operation point of nozzle; OP1=strongest, OP4 softest

- Motivation to continue !

Results – hardness II:

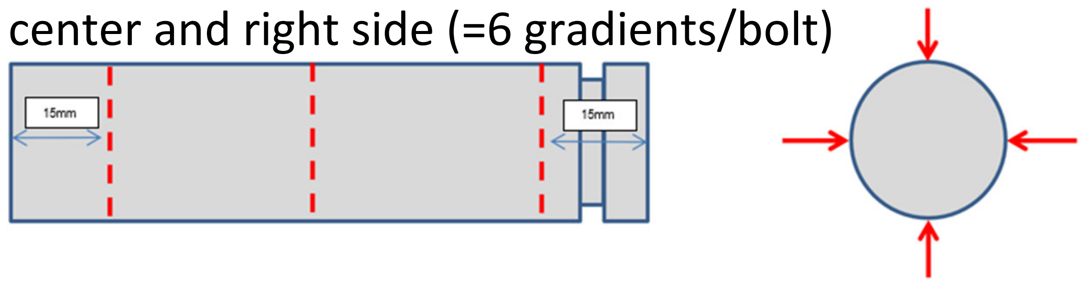
- Hardness uniformity in bolt (D=50mm; L=100mm; m=1,5kg; 18CrNiMo76)
- Measured crosswise as gradient





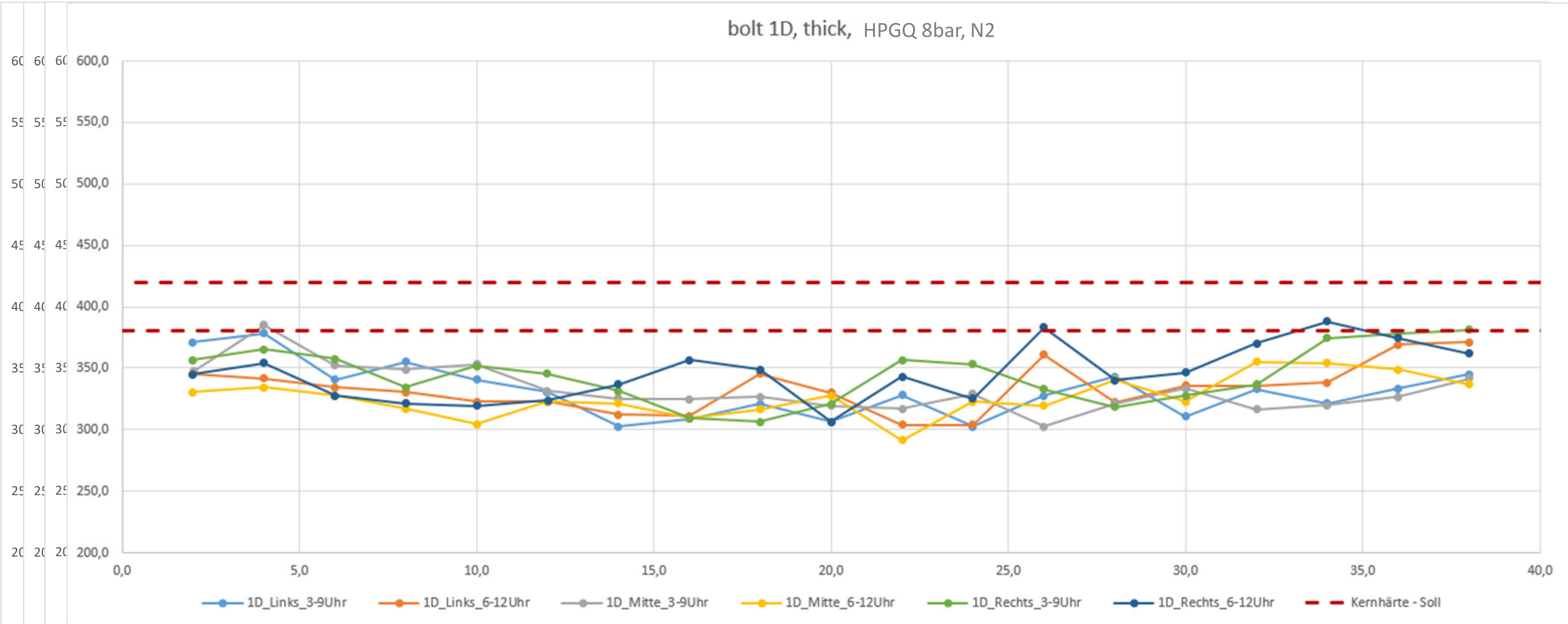
Results – hardness III :

- Hardness response comparison between different case hardening steels and different quenching
- Two bolt sizes (D=20 and D=40; L = 100mm; mass ~0,5..1 kg)
- Alloy 1 = 27MnCr5; Alloy 2 = 20NiCrMo2 (opposite side of hardenability)
- All quenched at same water spray intensity and compare to HPGQ
- Again cross gradient measurement
- Checked on left side of bolt (+15mm); center and right side (=6 gradients/bolt)



Water spray quenching and heat treatment

Results – hardness IIIa 27MnCr5 [HV10] :



Water spray quenching and heat treatment

Results – hardness IIIa 27MnCr5:

	bolt 1 thin LPC WSQ	bolt 1B thick LPC WSQ	bolt 1C thin LPC HPGQ	bolt 1D thick LPC HPGQ	
Average over all values	474	466	360	336	HV 10
Maximum value	548	540	406	388	HV 10
Minimum value	410	409	308	291	HV 10
Range	138	131	98	97	HV 10
Standard deviation	30	30	22	21	HV 10
Median value over all	476	461	359	333	HV 10

Results – hardness IIIb 20NiCrMo2:

	bolt 2 thin LPC WSQ	bolt 2B thick LPC WSQ	bolt 2C thin LPC HPGQ	bolt 2D thick LPC HPGQ	bolt 2E thick LPC HPGQ	bolt 2F thin LPC HPGQ	
Average over all values	333	336	253	247	255	273	HV 10
Maximum value	423	398	282	274	317	313	HV 10
Minimum value	269	283	237	226	238	241	HV 10
Range	154	115	45	48	79	71	HV 10
Standard deviation	31	25	11	9	12	14	HV 10
Median value over all	324	333	251	248	253	271	HV 10

Additional comparison: Bolt 2G; thin, WSQ with higher quenching intensity = approx. +20..25HV10 against bolt 2
Range is higher on low alloyed steel due to steeper gradient of hardenability!

Water spray quenching and heat treatment

Results – hardness IV :

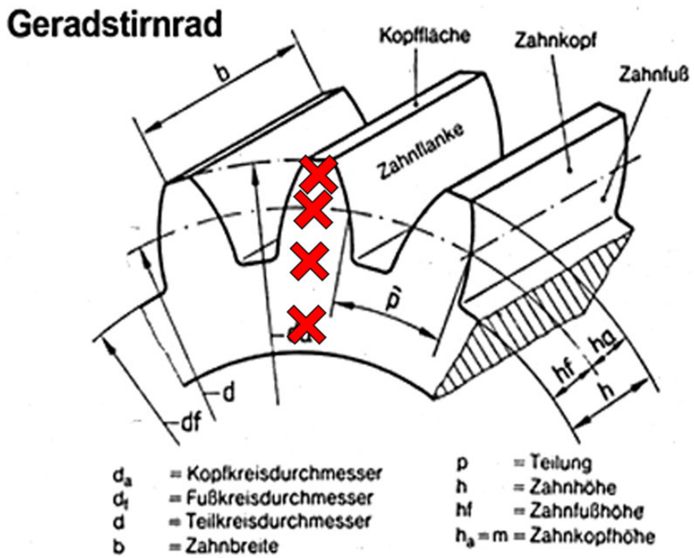
- Hardness response on gear parts

- Quenched from 930°C
- No LPC
- Medium intensity of WSQ (OP2)

Water spray quenching and heat treatment

Results – hardness IV :

- Hardness response on gear parts, 4 positions measured



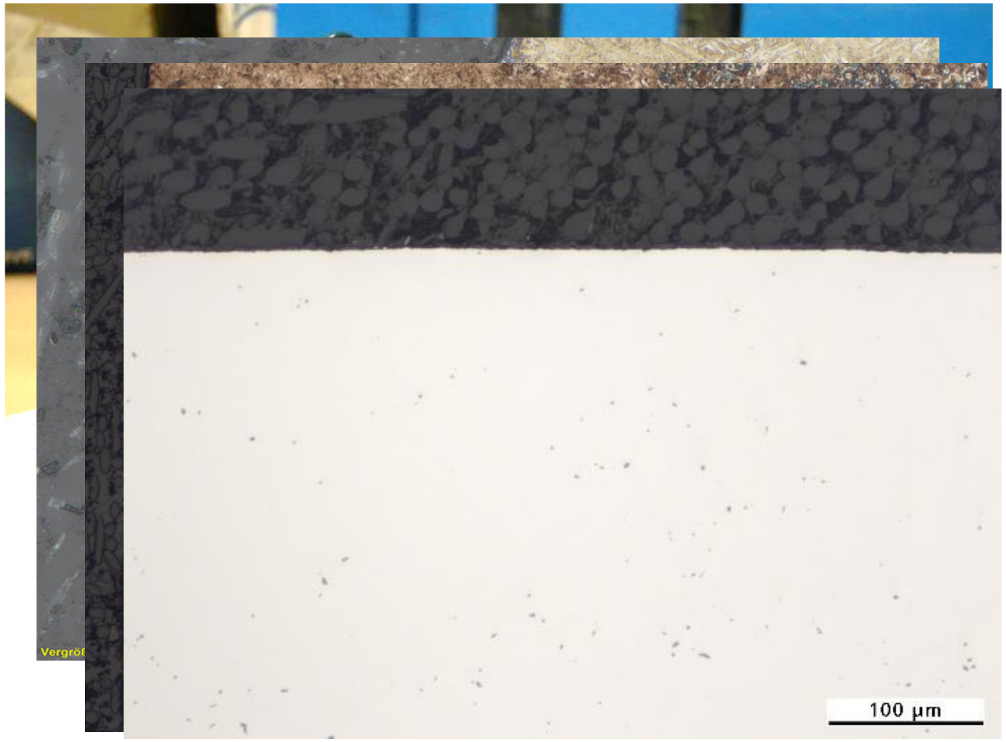
Position	Small (20MnCr5)	FDR (20MnCr5)	Ring (18CrNiMo76)
¼	510	454	445
½	497	456	440
Tooth root	521	461	441
core	521	423	442

Core hardness 5mm below tooth root dia.
Steel composition determined by inhouse GDOES

Water spray quenching and heat treatment

Results – appearance and microstructure

- Parts coming from LPC going to WSQ showed a smooth yet greyer surface appearance
- No IGO was found
- No scale
- No decarburization
- No RA, no other defects
- CHD was as expected



Water spray quenching and heat treatment

Results – cooling speed

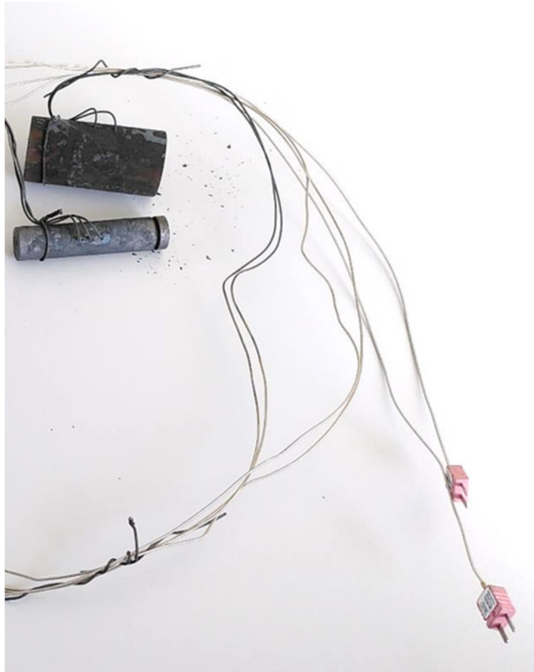
- 2 bolts (D=25 and D=40mm) equipped with thermocouples in 3, 7 and 12mm
- Live measurement with furnace tracker
- Quenched from ~930°C
- Aim:

✓ Understand cooling speed

✓ Heat transfer coefficient

✓ Validate hardness against TTT diagram

✓ Change in quench intensity on cooling rates

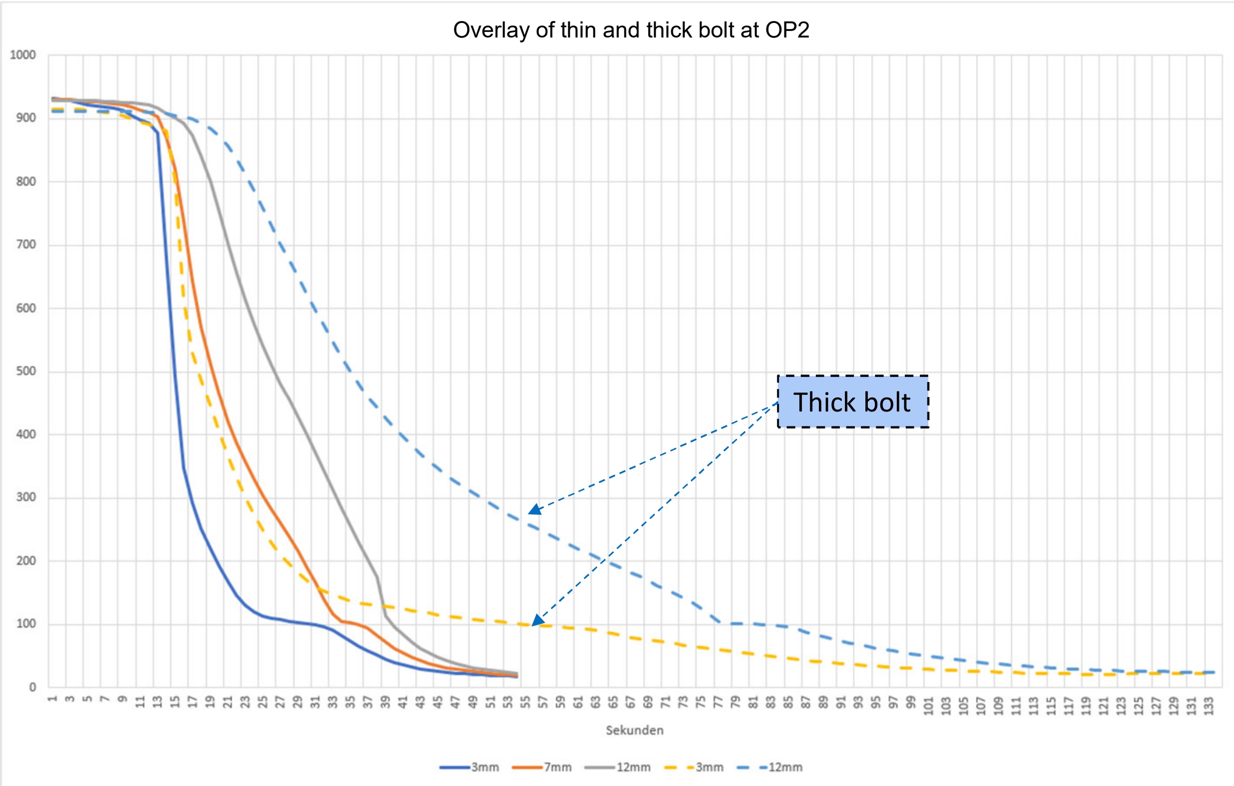


Water spray quenching and heat treatment

Results – cooling speed I

- Two bolts thin and thick with same intensity

- ▶ Clear difference between the 2 bolts (thick / thin)
- ▶ Hardness results match to TTT-diagramm

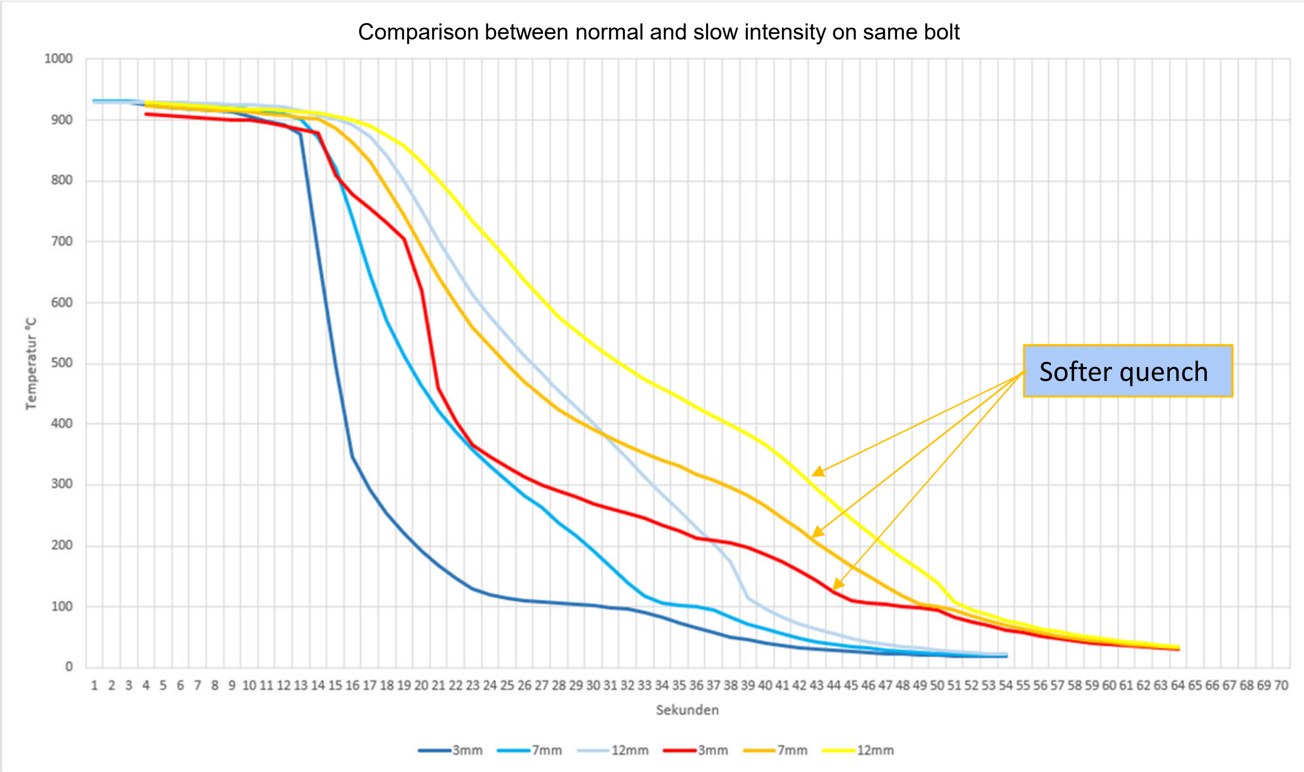


Water spray quenching and heat treatment

Results – cooling speed II

- Same bolt – different quenching intensity

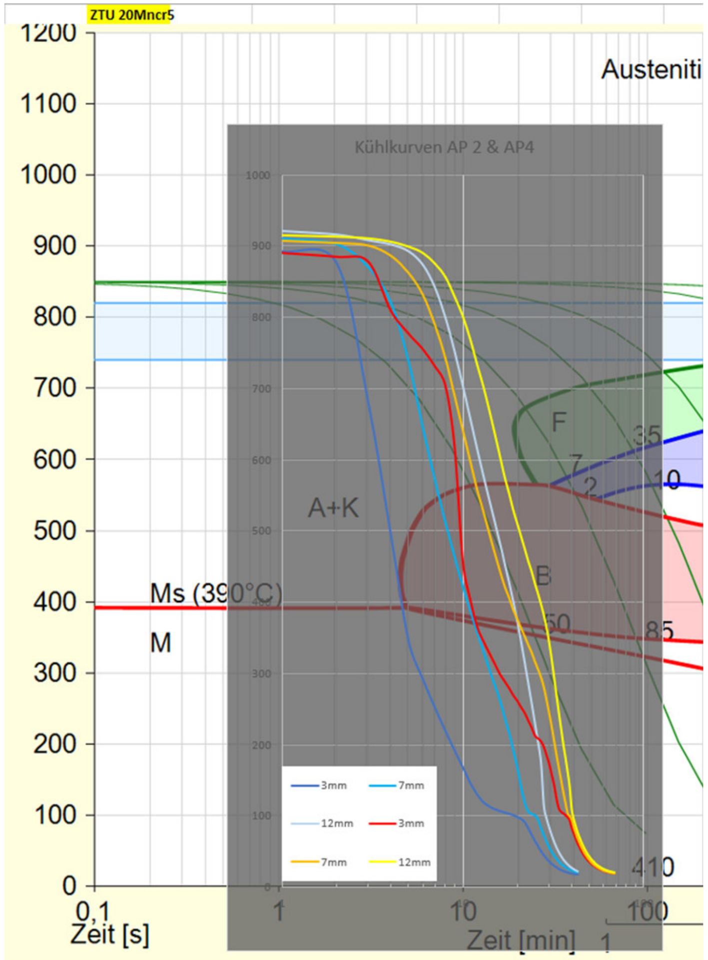
- ►different cooling speeds possible
- ►quenching intensity can be adjusted
- ►dynamic quenching possible



Water spray quenching and heat treatment

Results – cooling speed III

- A numerical model was set up to assess the α-value and validate with the real cooling curves
- Results at ALD bolt showed a HTC α of up to 4.000 W/m²K (oil: 1.500-2.500)
- Cooling rates and hardness found match to TTT diagram



TTT diagram by Dr. Sommer Navimat 9

Water spray quenching and heat treatment

Results – cooling speed IV

- Example: billet (steel)
- L=250mm; D=60mm; M~5,5kg
- LPC at 950°C

- ►Handwarm in ~140sec

Water spray quenching and heat treatment

Current status / Outlook:

- Design and develop connection to ALDs Syncrotherm® one piece flow heat treatment system for complete automation and industrial application
- Investigate bulk loads and further materials
- Await further results from *TOPGEAR* project (e.g. machinability, fatigue bending, tribology, …)
- Investigate further industrial application

Water spray quenching and heat treatment

Summary

- Water spray quenching proves to be a suitable option for intensive quenching
- Combination of low pressure heat treatment and WSQ is possible
- Adaption of quench performance is possible
- New fields of application are conceivable like low alloyed steels, free cutting steels or titanium (?)

Thank you for your attention!

www.topgear-project.eu

This project has received funding from the Research Fund
for Coal and Steel under grant agreement No 101033989