Impact toughness of steel after electrochemical Hydrogenation

Materials Day 2014

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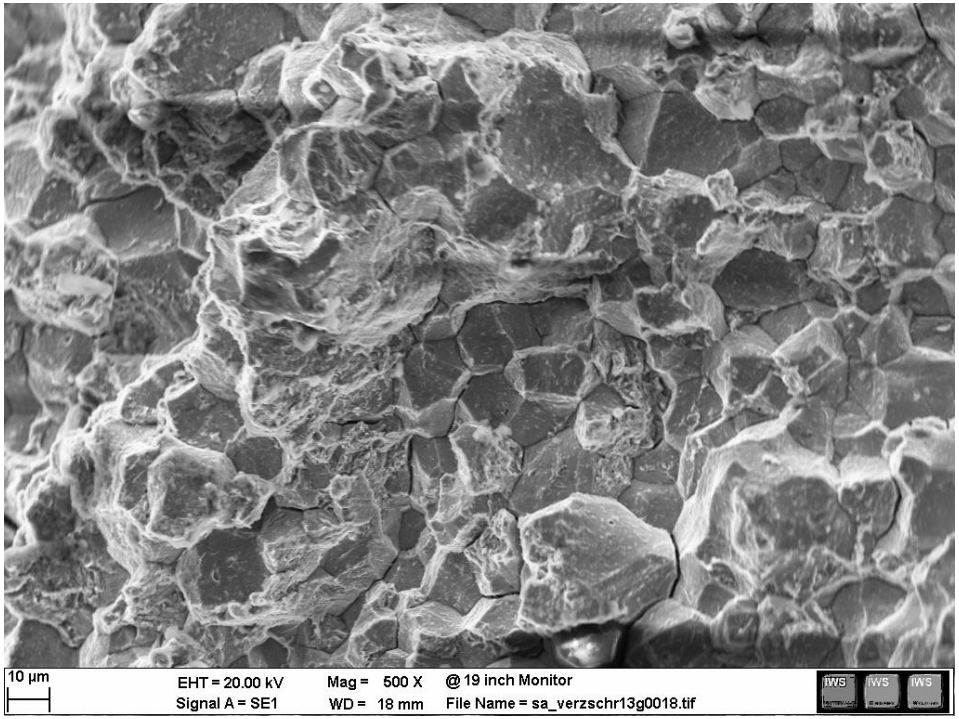
Goal/Motivation

- Artificial reduction of impact toughness of steel samples due to electrochemical hydrogenation (C45E, unalloyed tempering steel)
- Investigation of failure mechanisms/comparison to literature
- Establishing a simple setup and testing method

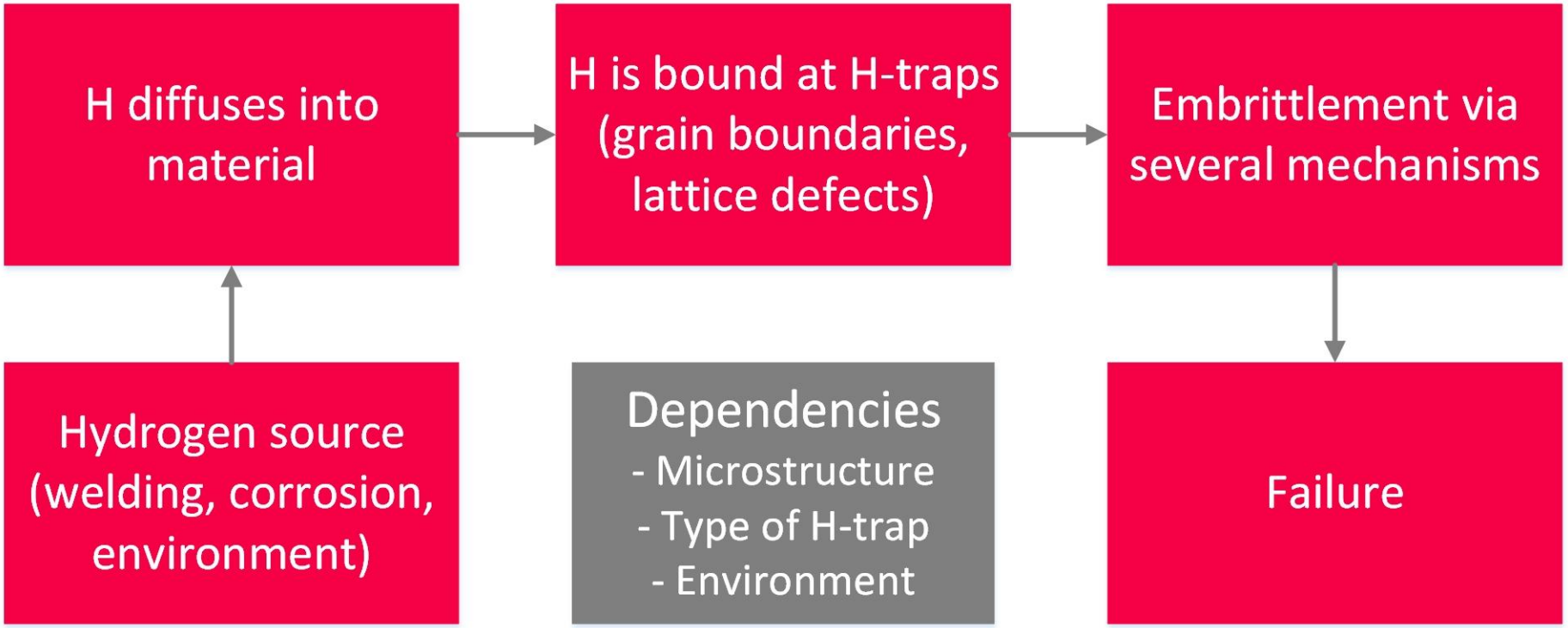
Outline

- Introduction to theory
- Setup & parameters
- Results
- Fractography
- Summary & outlook



Freiberger, Gölles:
Schadensanalyse gebrochener Schrauben, IWS - VI/2013

Theory



Generally: reduced ductility and tensile strength

→ brittle, intergranular fractures

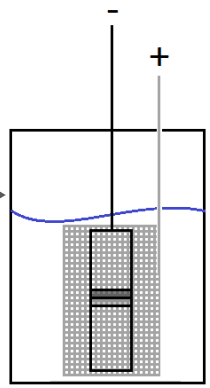
Hydrogen and Charpy-V

- Usually HE is a mid/long-term process similar to Stress Corrosion Cracking
- Higher DBT-temperature
- The tougher the steel, the bigger the difference of CVN energy after Hydrogen charging
- Mobility (effusibility) of H has to be considered
- Dependent on type of steel (microstructure)

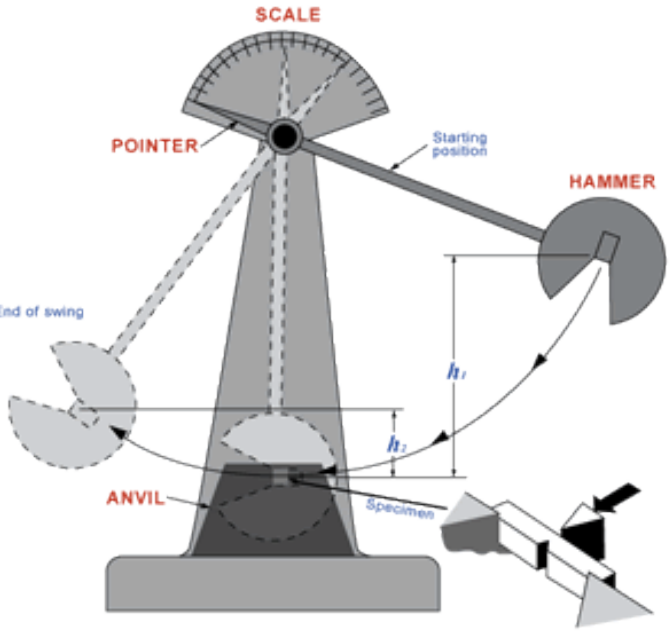
Experiment

Specimen preparation

Hydrogen charging

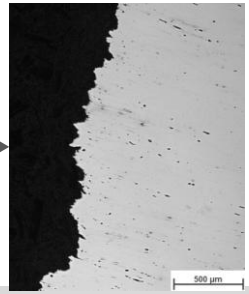


Charpy-V impact



http://atrona.com/img2/CharpyTester.gif (22.10.14)

Fractography

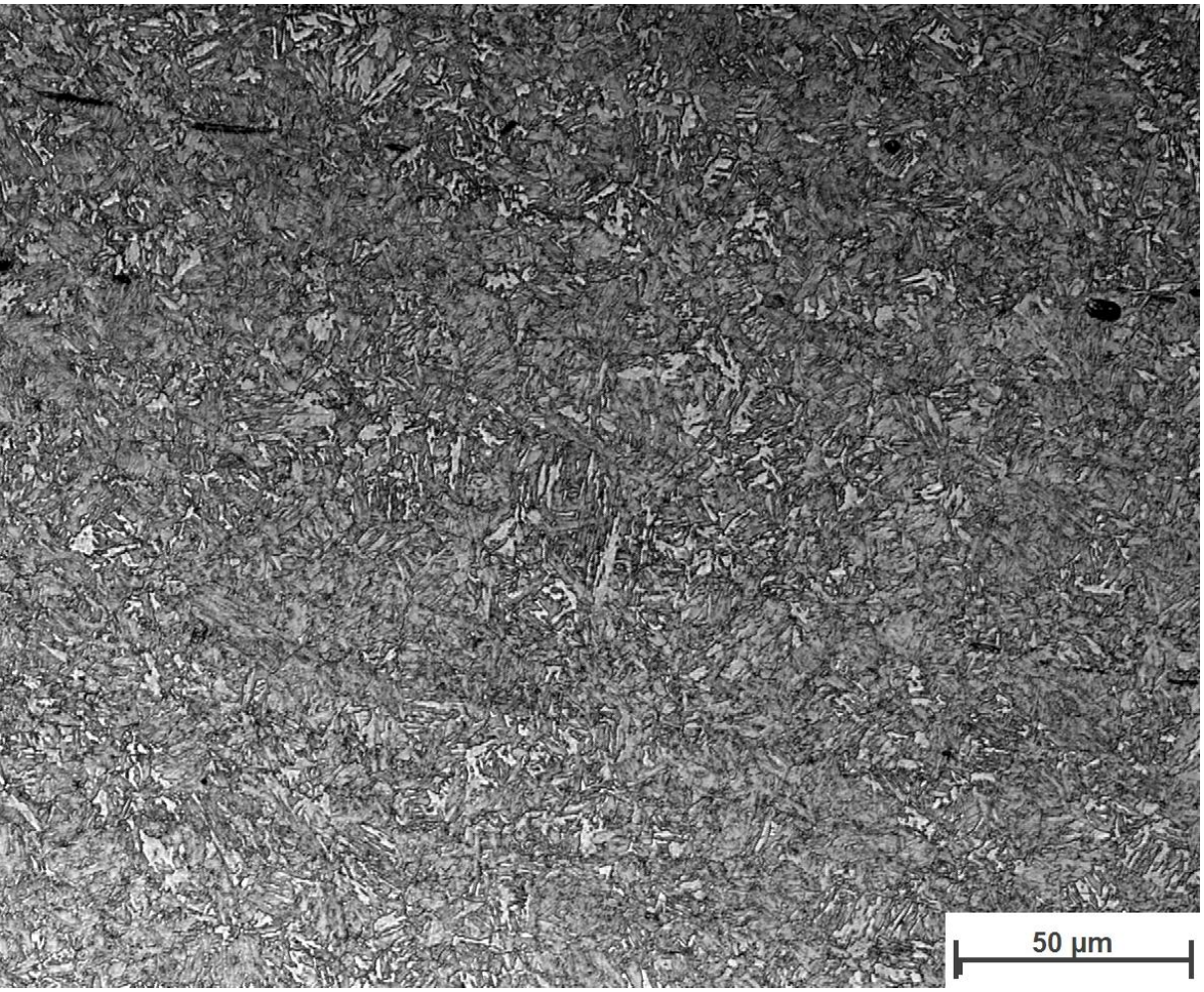


Specimen preparation C45E steel

C	Si	Mn	S
0,45	0,25	0,65	<0,03

- Charpy-V-Notch samples (10x10x55mm)
- Hardening temperature 850°C; 0,5h; quenched in water
- Tempered at 600°C; 1h; cooled in air
- Grinded (K120) for uniform surface
- H-Loading according to setup
- 2 Lots of heat treatment
  (Lot A and B)

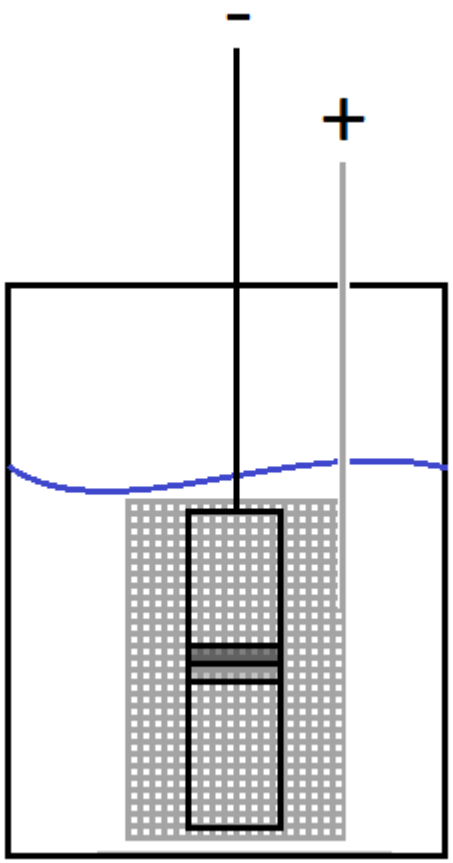
Microstructure



Tempered martensite and bainite

Hydrogen charging

- Potentiostat: Autolab PGSTAT128N
- Cathode: Charpy-V specimen
- Anode: Pt-plated grid-electrode
- Alumel wire
- Electrolyte: H_2SO_4 (0,5M)
- Additive: Thiourea (CH_4N_2S)

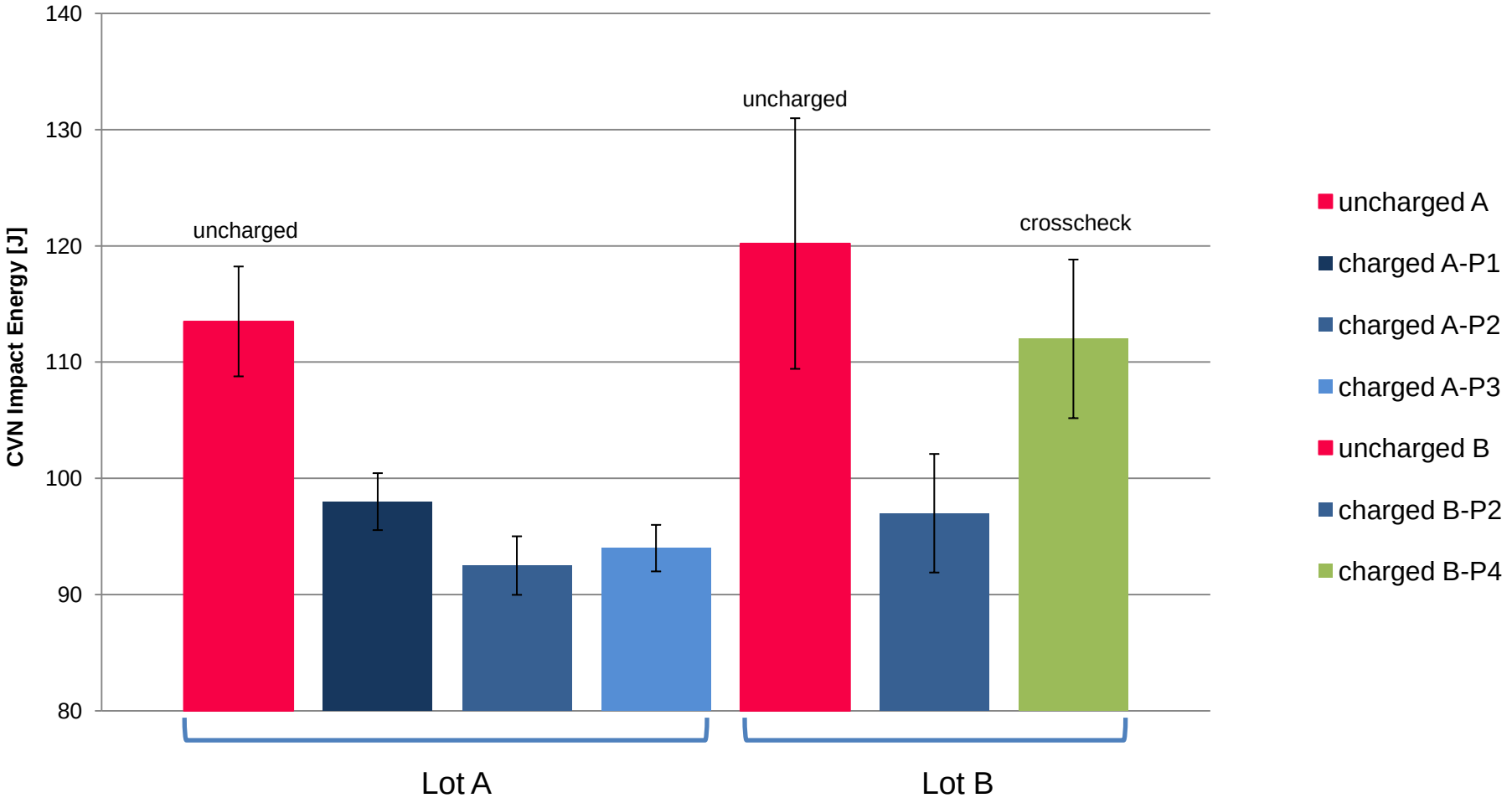


$$H_3O^+ + e^- \rightarrow H_{ads} + H_2O$$

Parameters for H-Charging

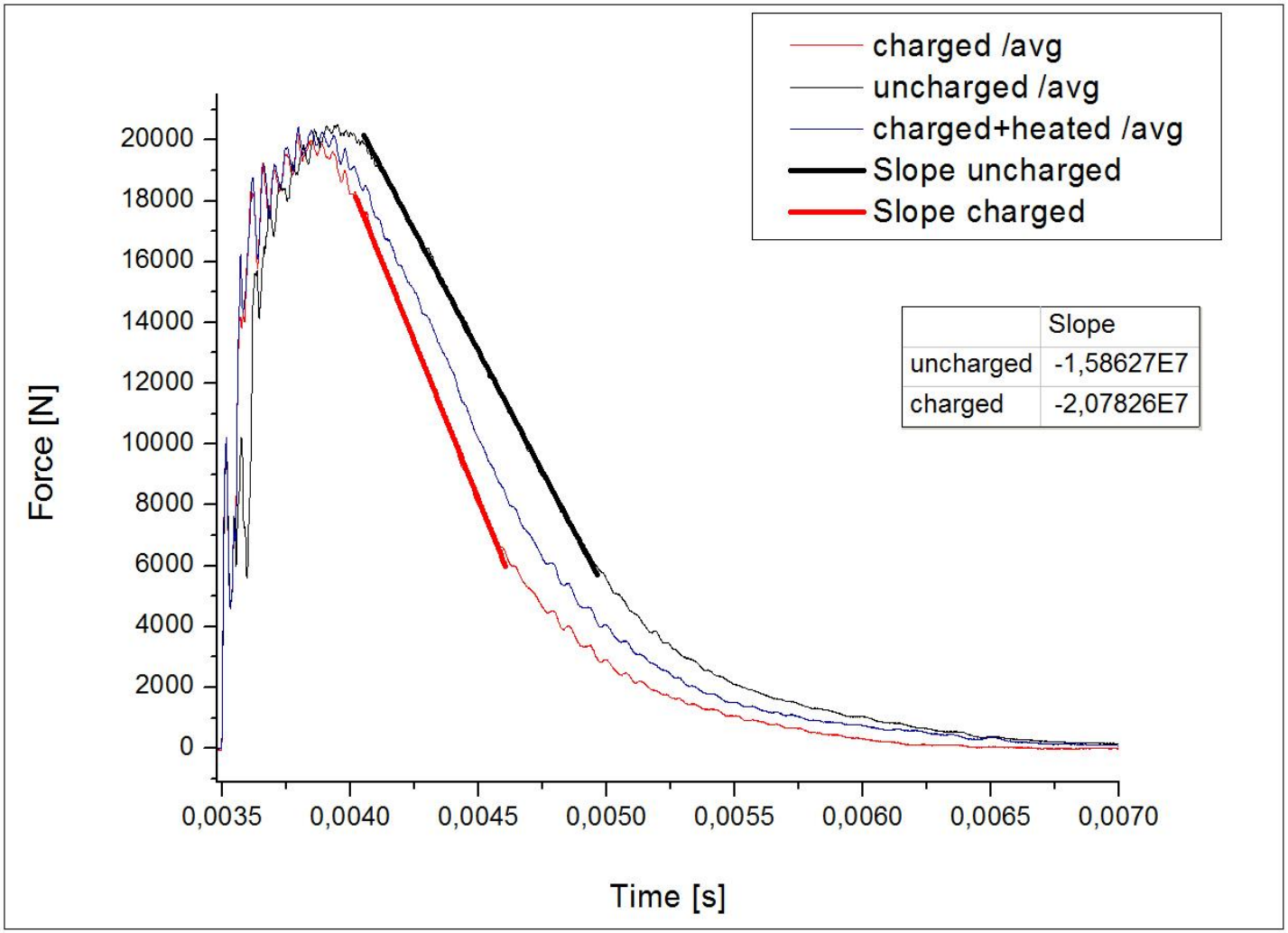
	U	P1	P2	P3	P4
Current [mA/cm²]	0	33	20	20	20
Time [h]	0	1	1	3	1
Thiourea [mg/L]	0	0	10	10	10
Heat treatment [°C;h]	-	-	-	-	250; 12

Results of Charpy-V-notch test



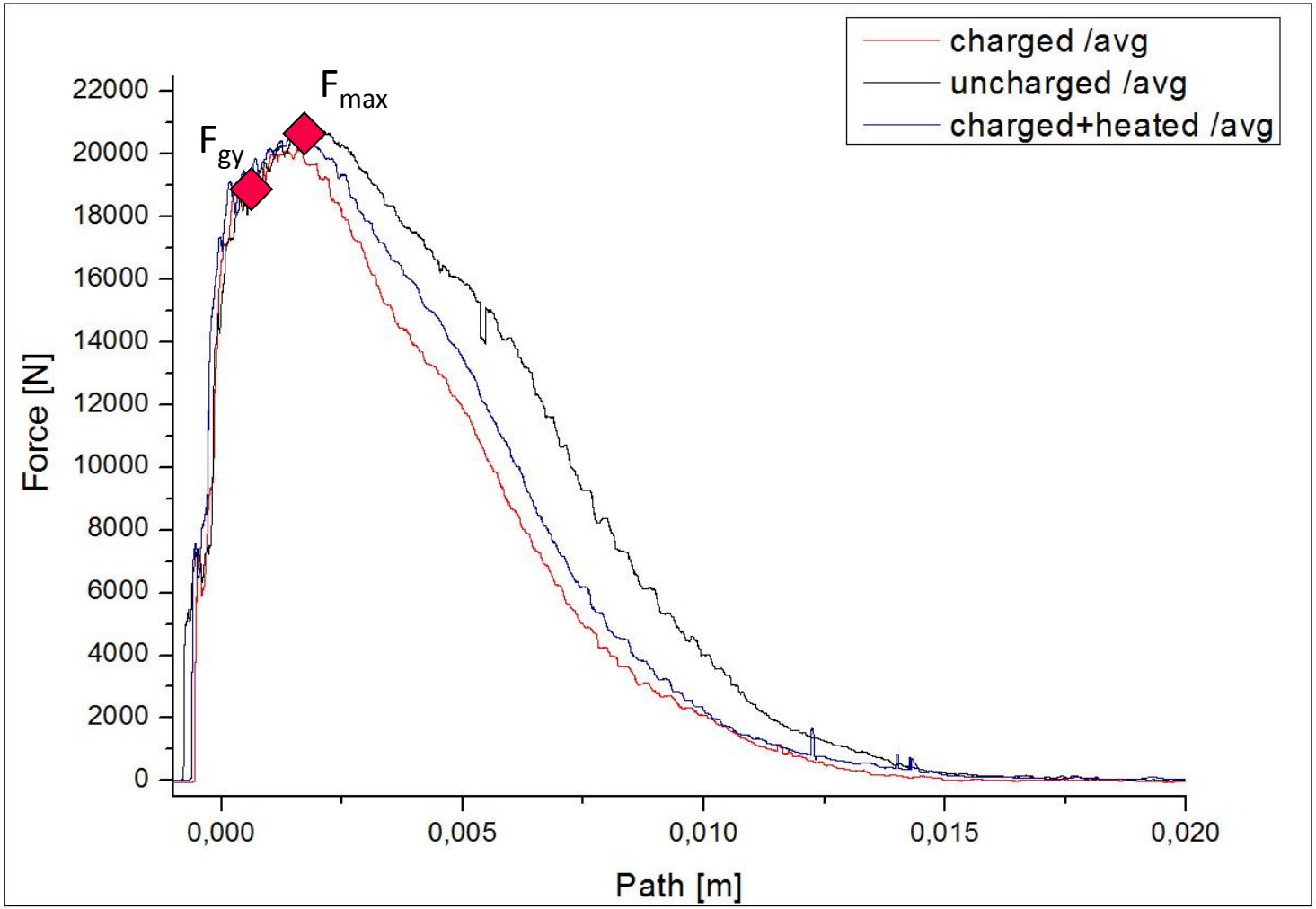
n = 5 T = RT (~22°C) 1 excluded for uncharged A and B-P4 each

Instrumented Charpy-V / F-t

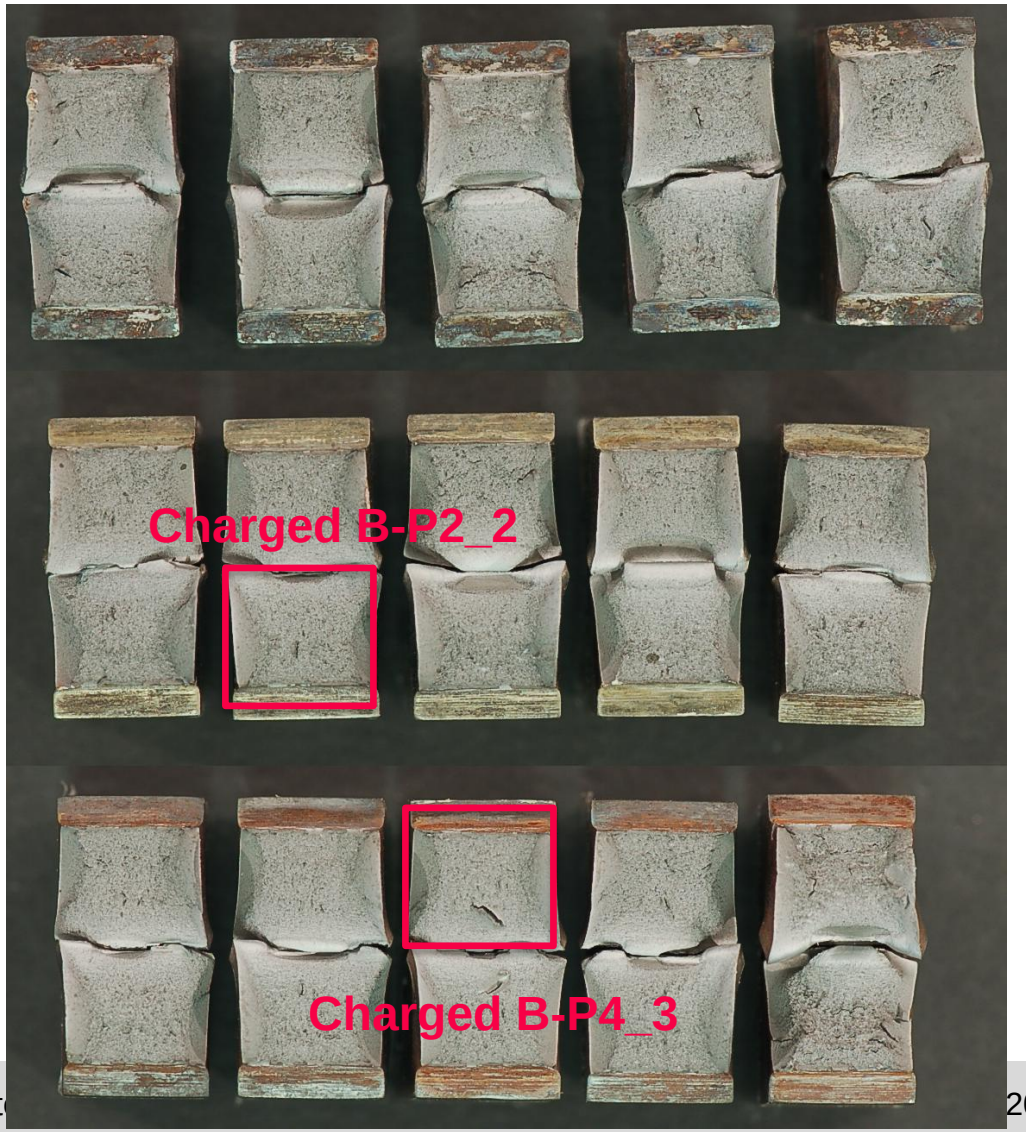


	Slope
uncharged	-1,58627E7
charged	-2,07826E7

Instrumented Charpy-V / F-s



Fractography

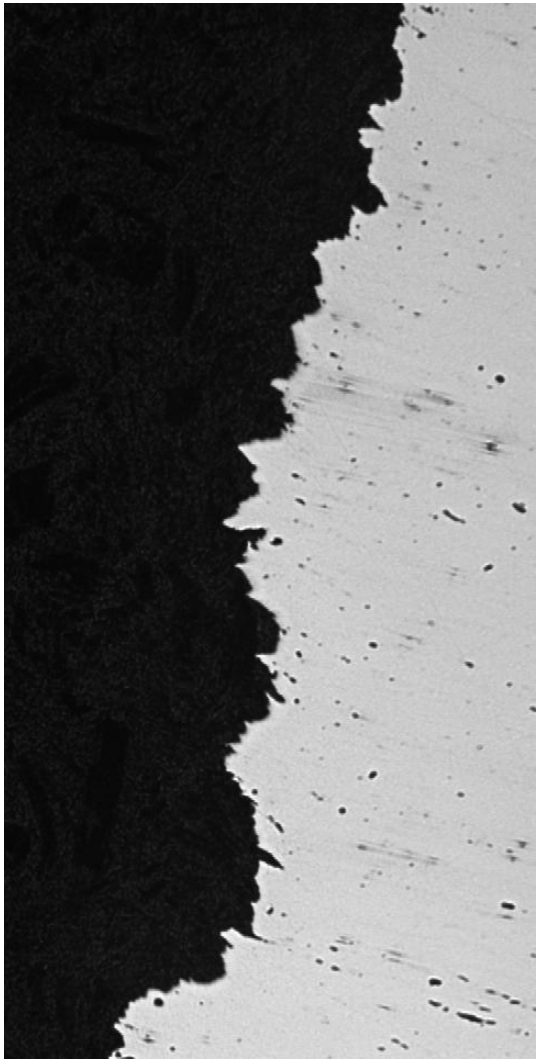


uncharged

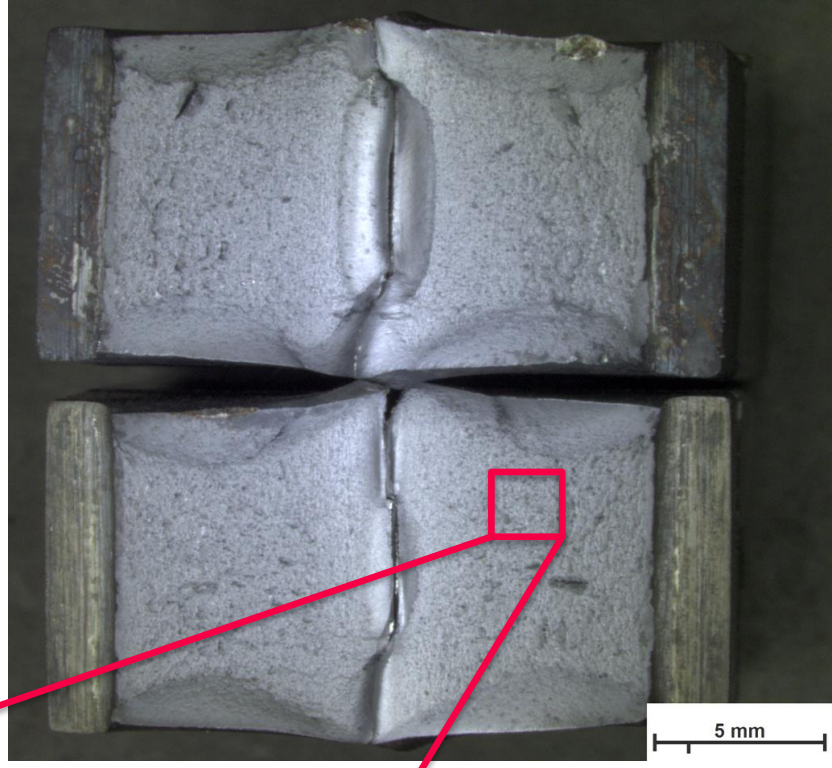
charged

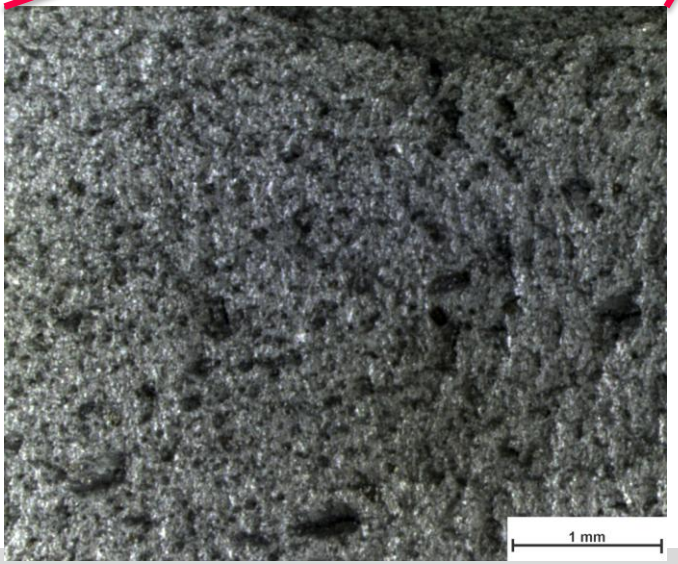
Charged
+heat treated

Fractography



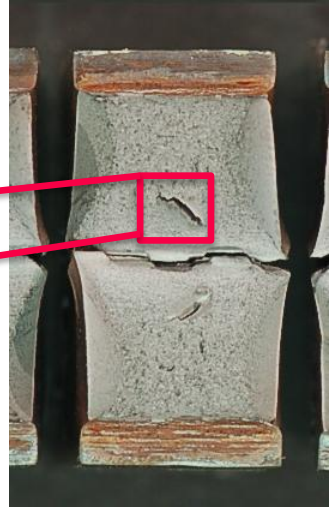
Uncharged B_1

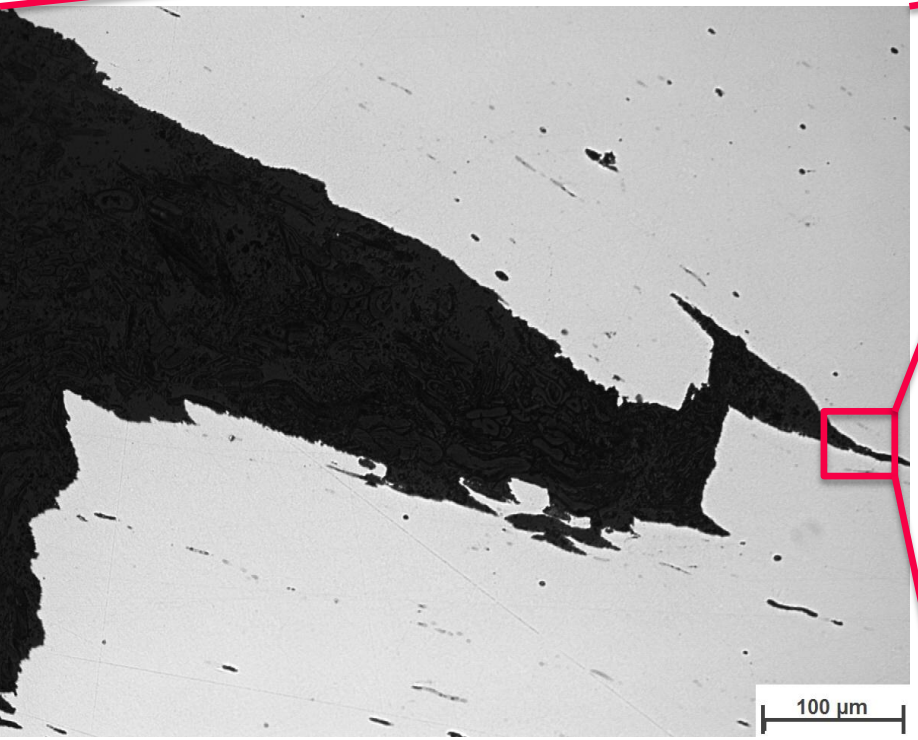


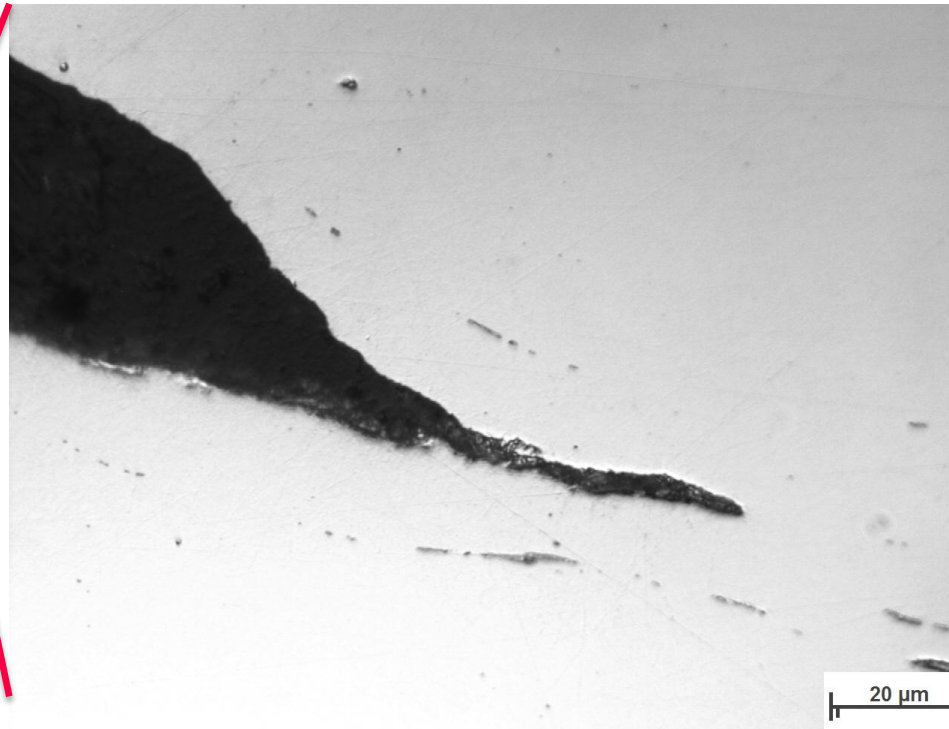


Charged B-P2_2
20mA/cm²; 1h

Fractography

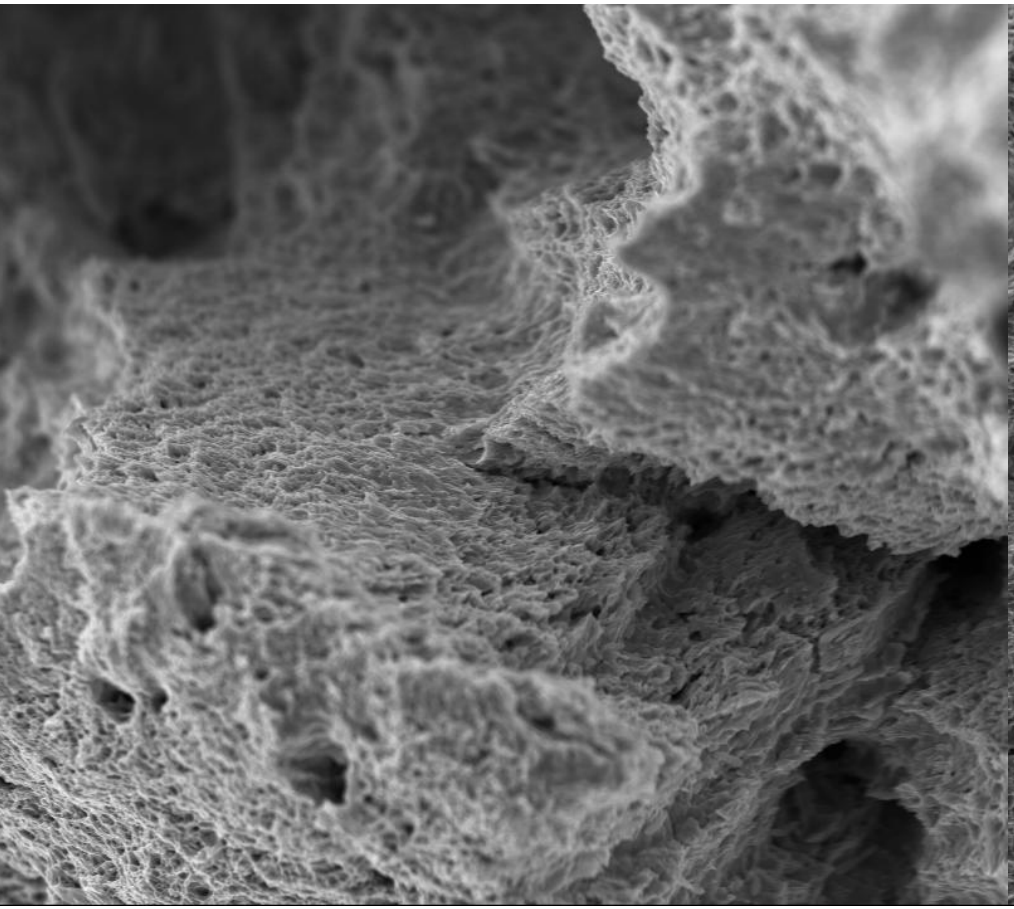




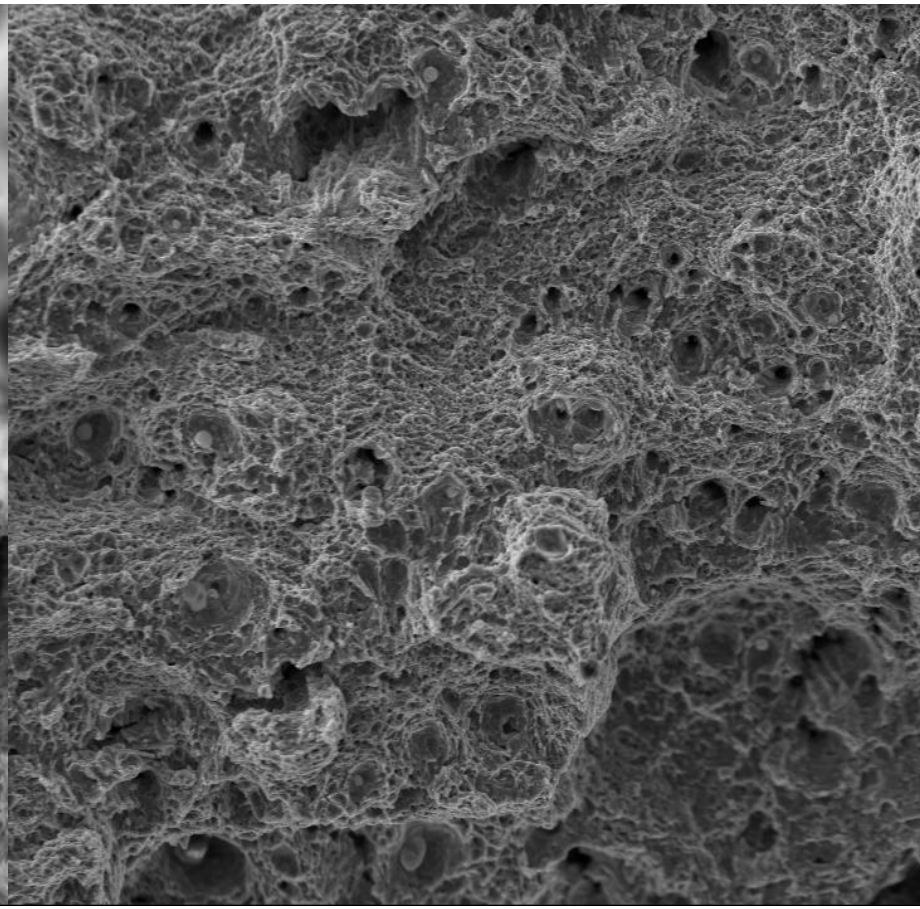


Charged B-P4_3
20mA/cm²; 1h + HT

Fractography



Charged B-P2_2
20mA/cm²; 1h



Charged B-P4_3
20mA/cm²; 1h + HT

Summary

- Charpy-V:
  - Reproducible results
  - Faster plastic deformation at reduced toughness
  - Dynamic yield strength and max. force remain the same
  - Crosscheck: Effusion at elevated temperature
  - Difference between Hydrogenation parameters is insignificant
- Fractography:
  - 100% ductile fracture
  - No difference in fracture behavior → no fractographic signs of Hydrogen embrittlement

→ With given parameters reduced impact toughness only

Outlook

- Steel: S960QL (1.8933) – high strength steel
- Planned investigations/considerations
  - Comparison of charged and uncharged basematerial– same for HAZ samples
  - Change of DBT temperature
  - Instrumented Charpy-V: Change of crack initiation and arrest of (partially) brittle samples
  - Quasistatic tensile test
  - Quantification via Hot Gas Extraction (also for optimization of charging parameters → specimen saturation with H)

Questions?