Toughness of duplex steel produced by PM-HIP

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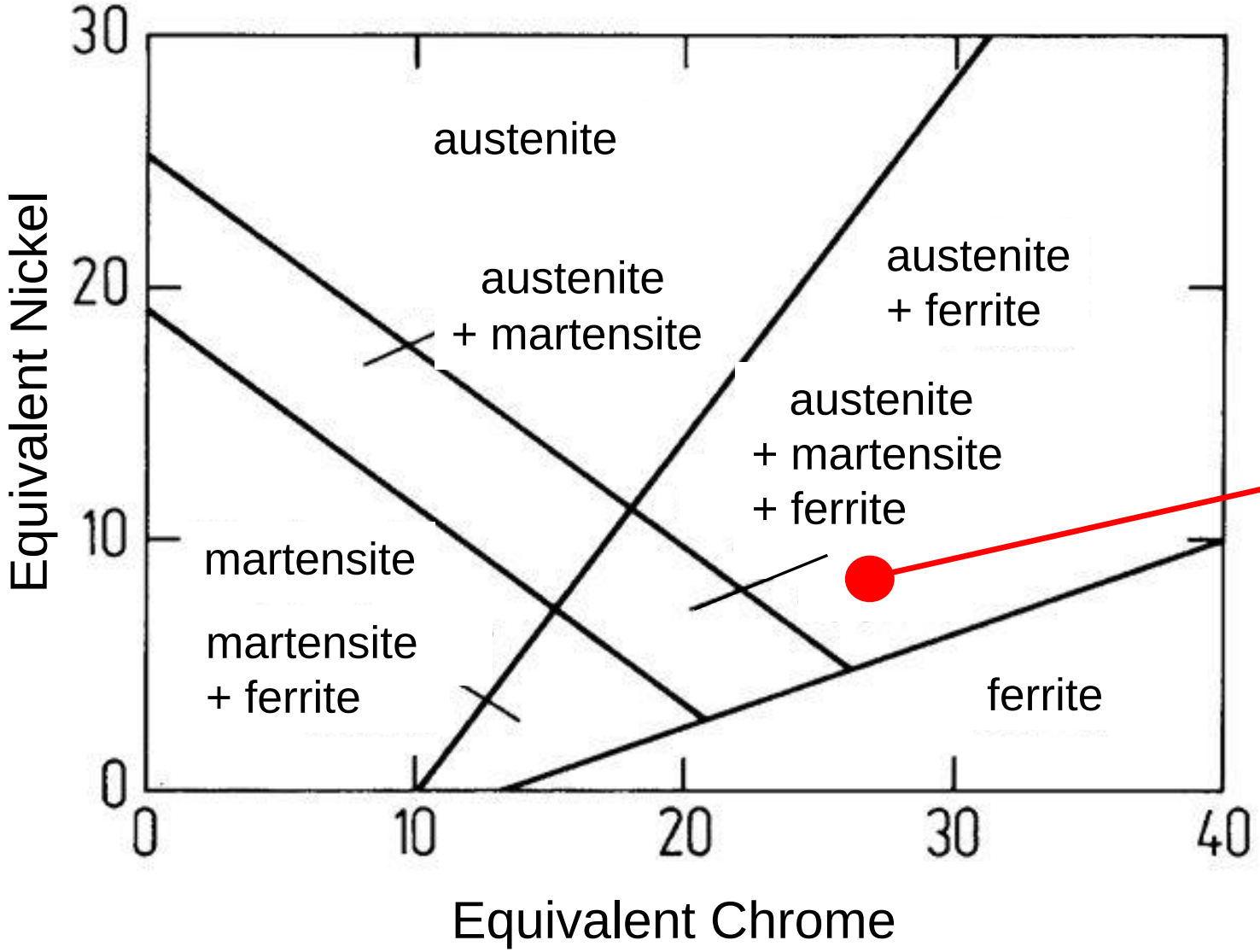
HIP17 – 12th International conference on Hot Isostatic Pressing
5-8 December 2017, Sydney, Australia

Outline

1. Introduction
2. Duplex steel produced by Powder-HIP
3. Influences on impact toughness by
   - production method (as cast, as forged, PM-HIP)
   - local stress triaxiality (notches)
   - sigma phase
   - argon content
4. Summary

Schaeffler-Diagram



Duplex steel:

2205

ASTM F51

AISI 318LN

DIN 1.4462

X2CrNiMoN22-5-3

Distributor piece for sub sea applications

steel: AISI 318LN

produced by: powder HIP

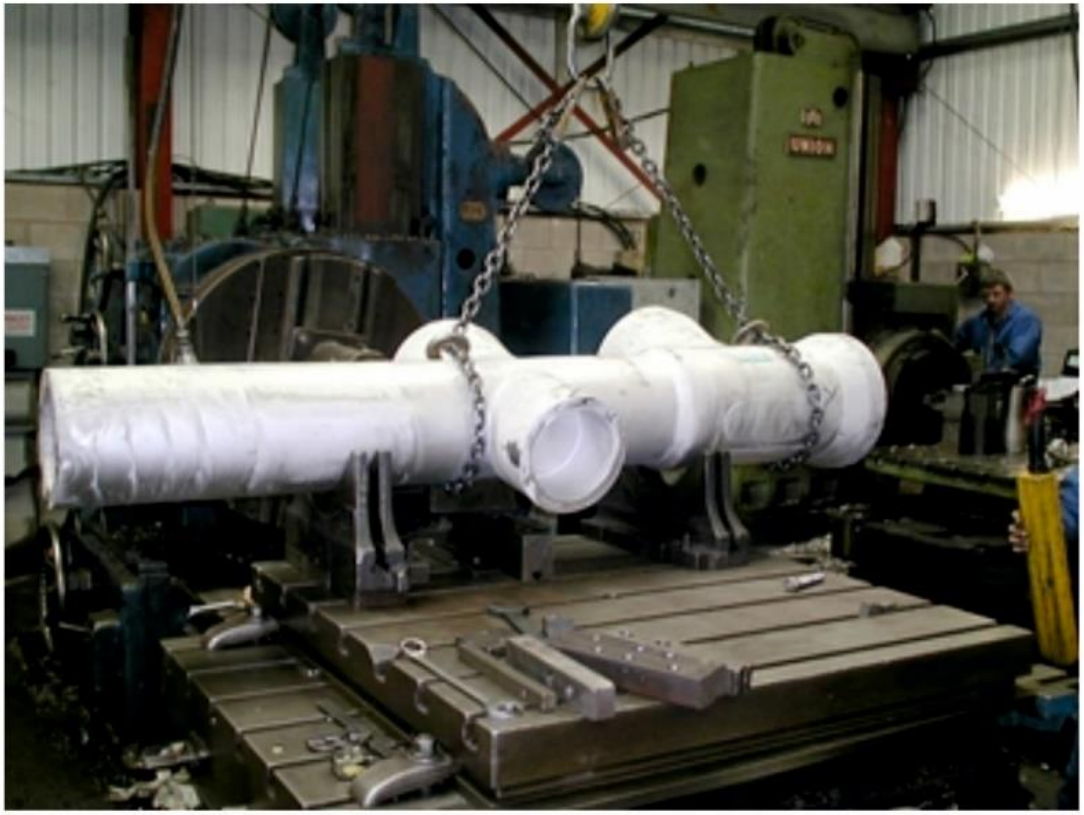
weight: 500 kg

Charpy-V-notch-toughness:

T = -46°C : a_K = 75 - 110 J

courtesy by: Sandvik Powdermet AB

Collecting pipe for offshore platform “Heidrun”



steel grade: AISI 318LN

production: powder HIP

Charpy-V-notch toughness:

T = 20°C : a_K > 150 J
T = - 46°C : a_K > 70 J

courtesy by: Metso AB

Factors influencing toughness

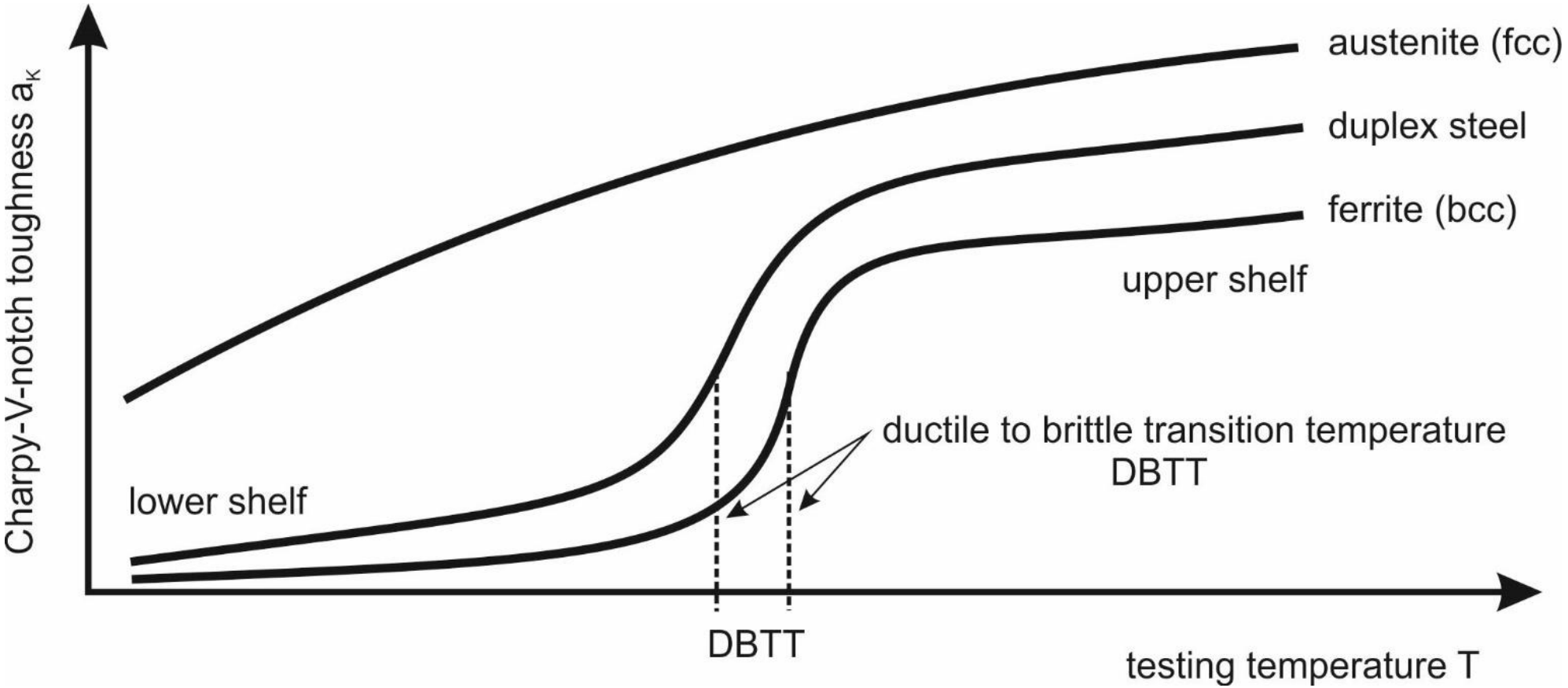
loading conditions:

- thermal activation of deformation mechanisms
  - temperature
  - deformation rate
- stress triaxiality
  - notches

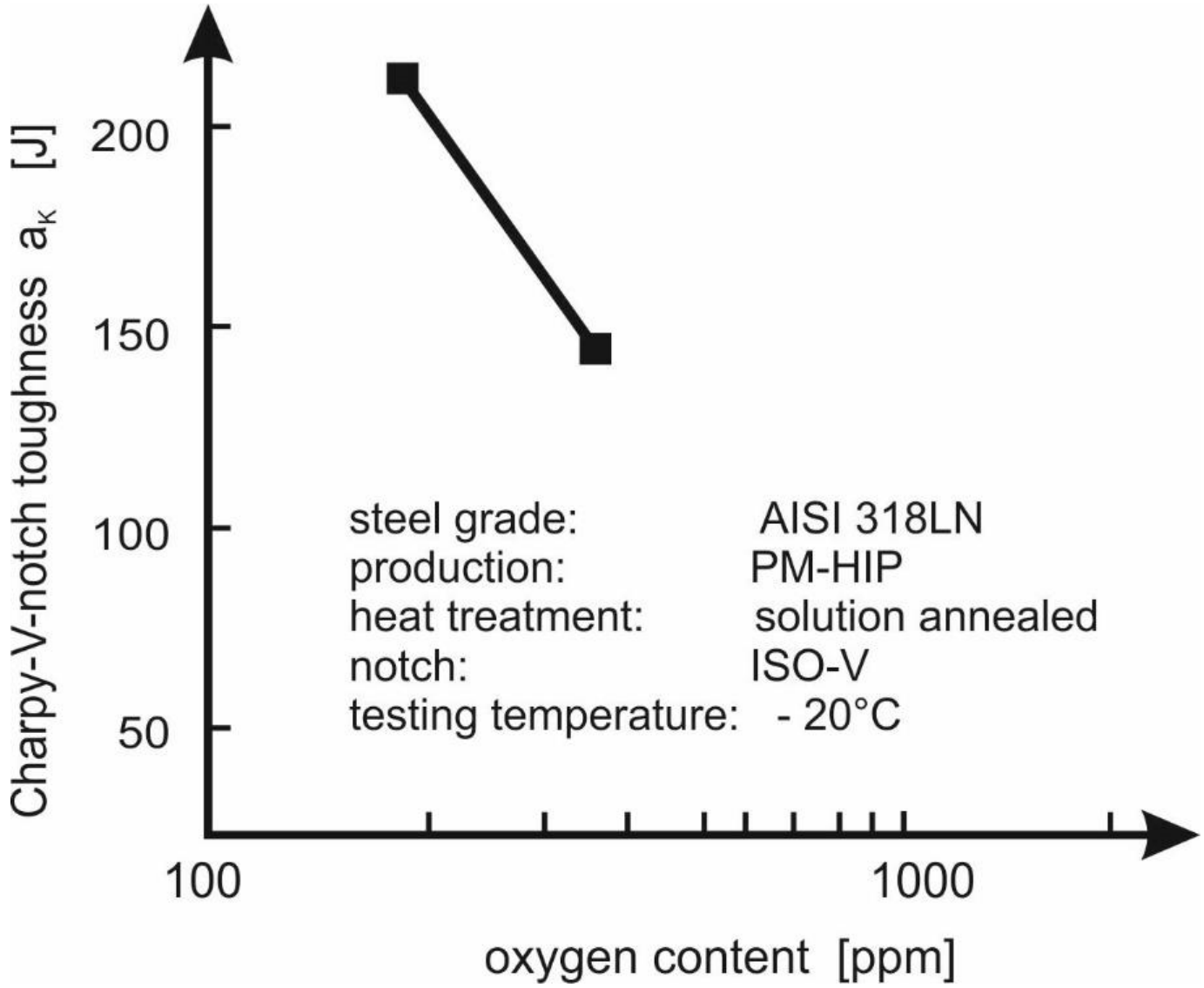
microstructure of the material:

- crystal lattice
- grain size
- non metallic inclusions
- in case of duplex steels: intermetallic phases
  - σ-phase
  - α‘-Phase
- in PM-HIP materials
  - oxides at the prior particle boundaries (PPB‘s)
  - Ar-voids

Toughness – temperature diagram (schematic)



Influence of the oxygen content on the Charpy-V-notch toughness



[Hämöläinen e.a. 1997]

Chemical composition of the investigated steel grades

production route	chemical composition [weight- %]						
	C	Si	Mn	Cr	Mo	Ni	N
PM HIP (powder)	0,015	0,68	1,02	22,20	3,09	5,19	0,189
continuous cast + hot forged	0,020	0,50	1,71	22,46	3,36	5,40	0,184
sand cast	0,029	0,72	1,35	23,07	2,78	6,50	0,181
EN 10088	≤ 0,03	≤ 1,0	≤ 2,0	21,0 - 23,0	2,5 -3,5	4,5 - 6,5	0,10 - 0,22

Production of samples by PM-HIP

gas atomized powder:

particle size distribution:

particle size [µm]	500	250	125	106	63	45
fraction < [%]	100	84	47	37	18	10

oxygen content of the powder: 85 ppm

apparent density: 4,69 g/cm^3

tap density: 5,30 g/cm^3

capsule size: D = 110 / 200 mm, H = 235 mm

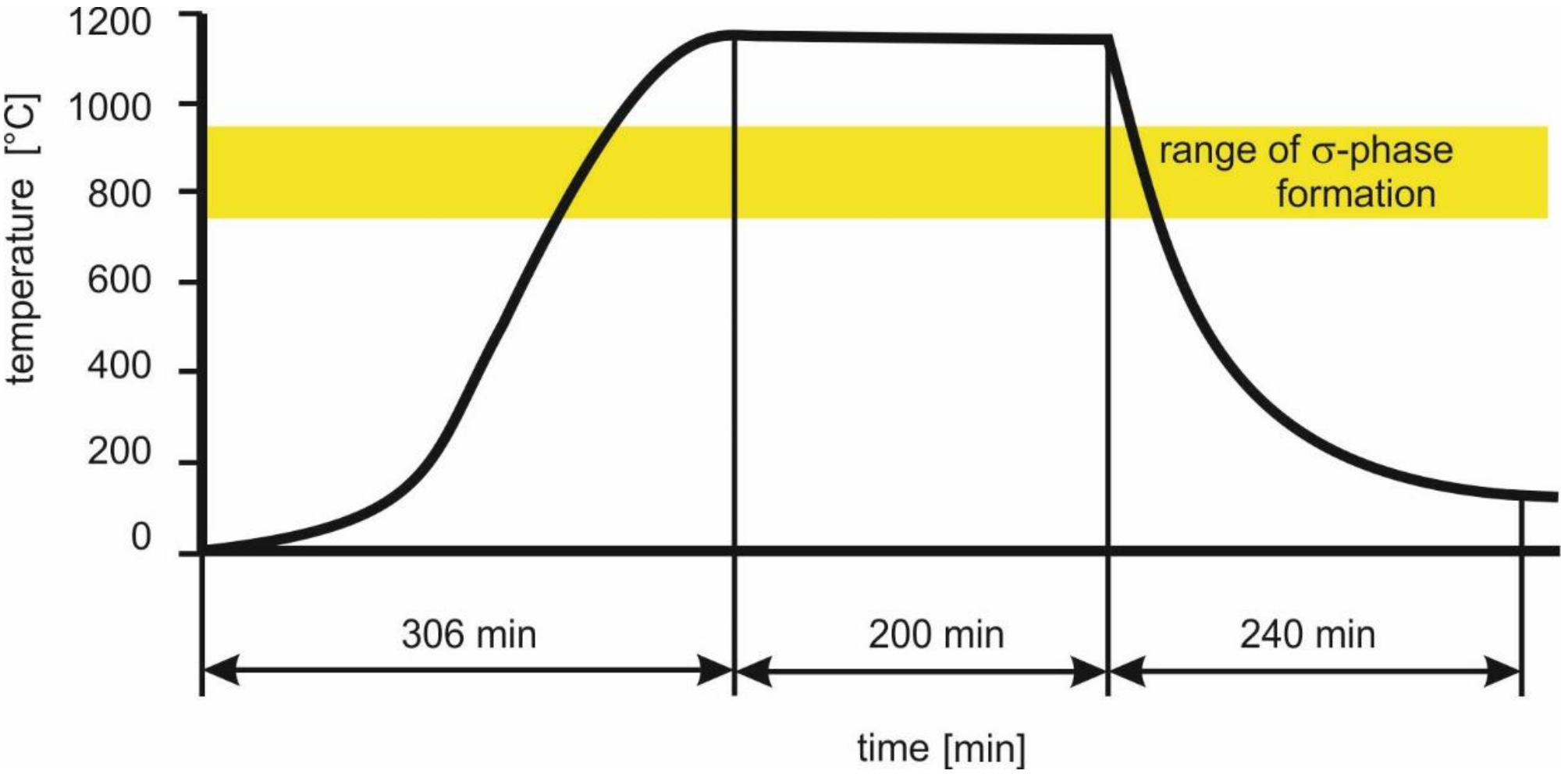
HIP-cycle:

holding temperature: 1140 °C

holding time: 200 min

pressure: 1010 bar

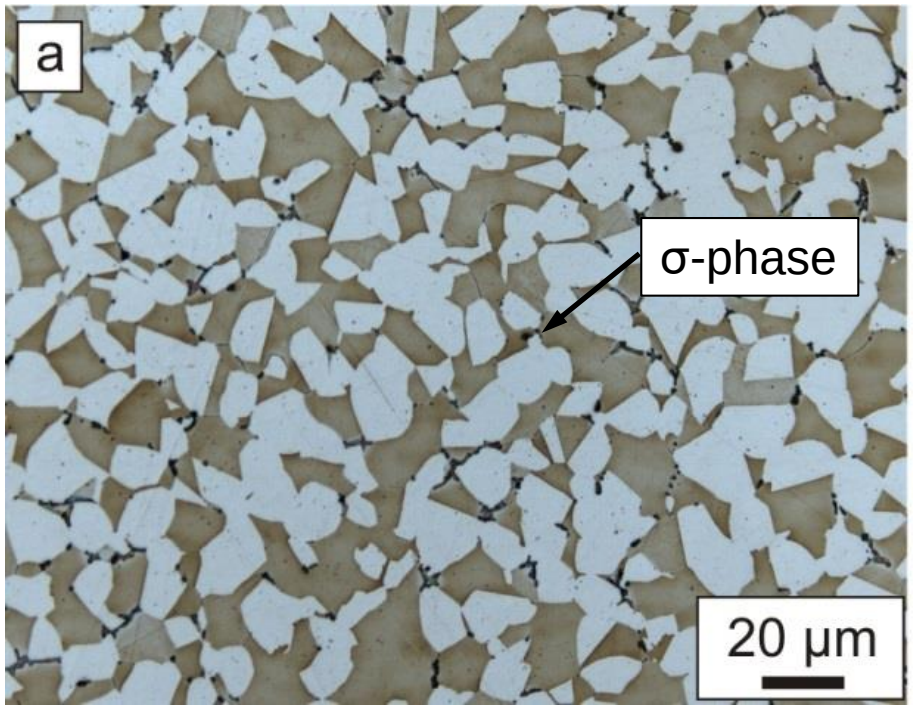
HIP cycle



time between 940°C and 750°C: 45 min

Microstructure in the as HIP state and heat treatment parameters

microstructure as HIP

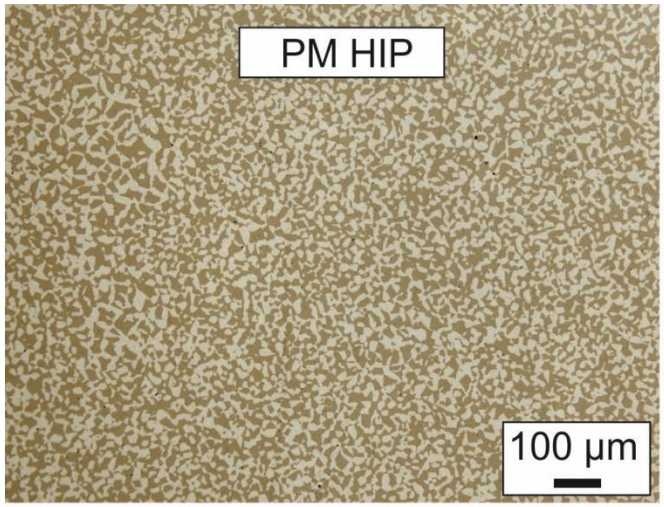


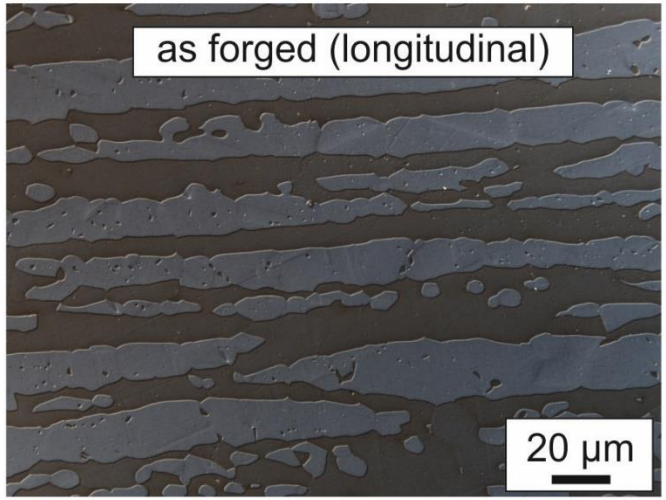
heat treatment of the PM-HIP-grade:

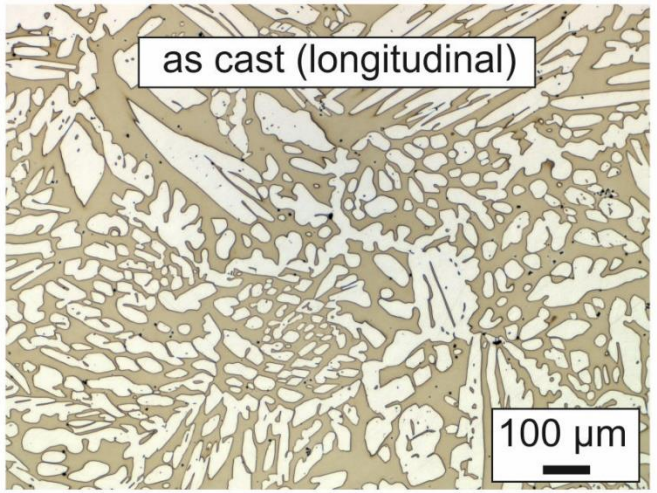
- solution annealing at 1060 °C for 3 h
- quenching in water

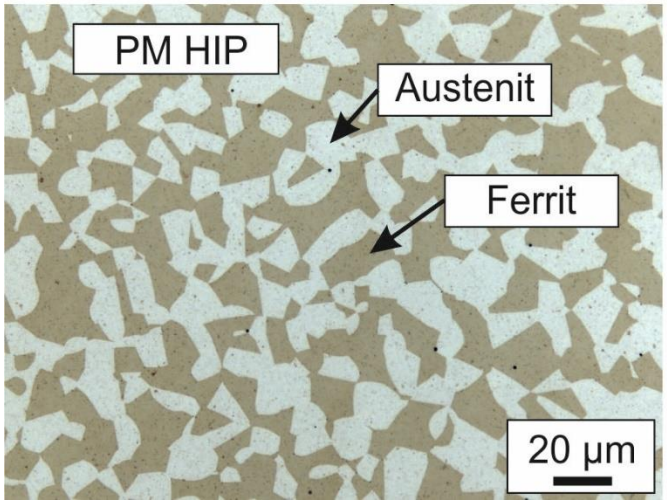
State	phase fraction [vol.- %]		
	austenite	ferrite	σ-phase
as HIP	50,9 ± 1,3	46,8 ± 2,2	1,3 ± 0,2
HIP + solution annealed	50,5 ± 1,4	49,4 ± 1,4	0

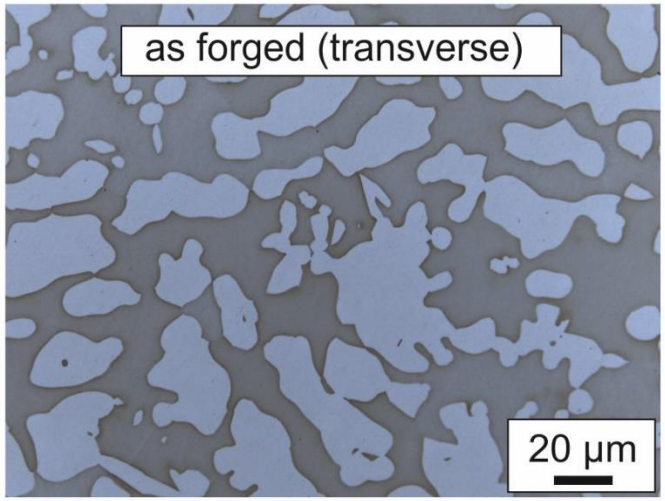
Microstructure of duplex steel after solution annealing

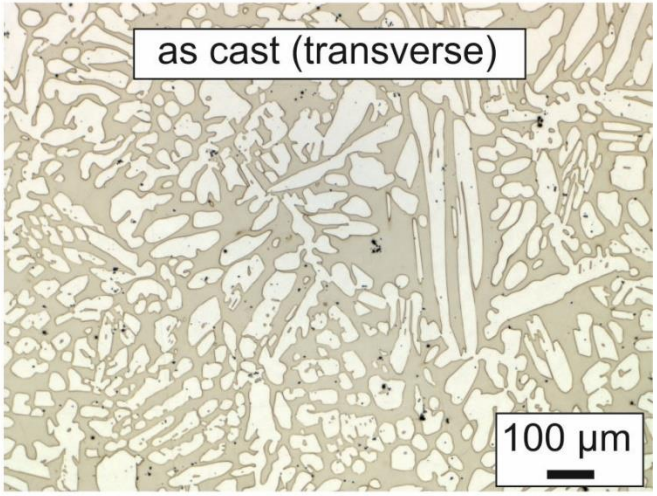










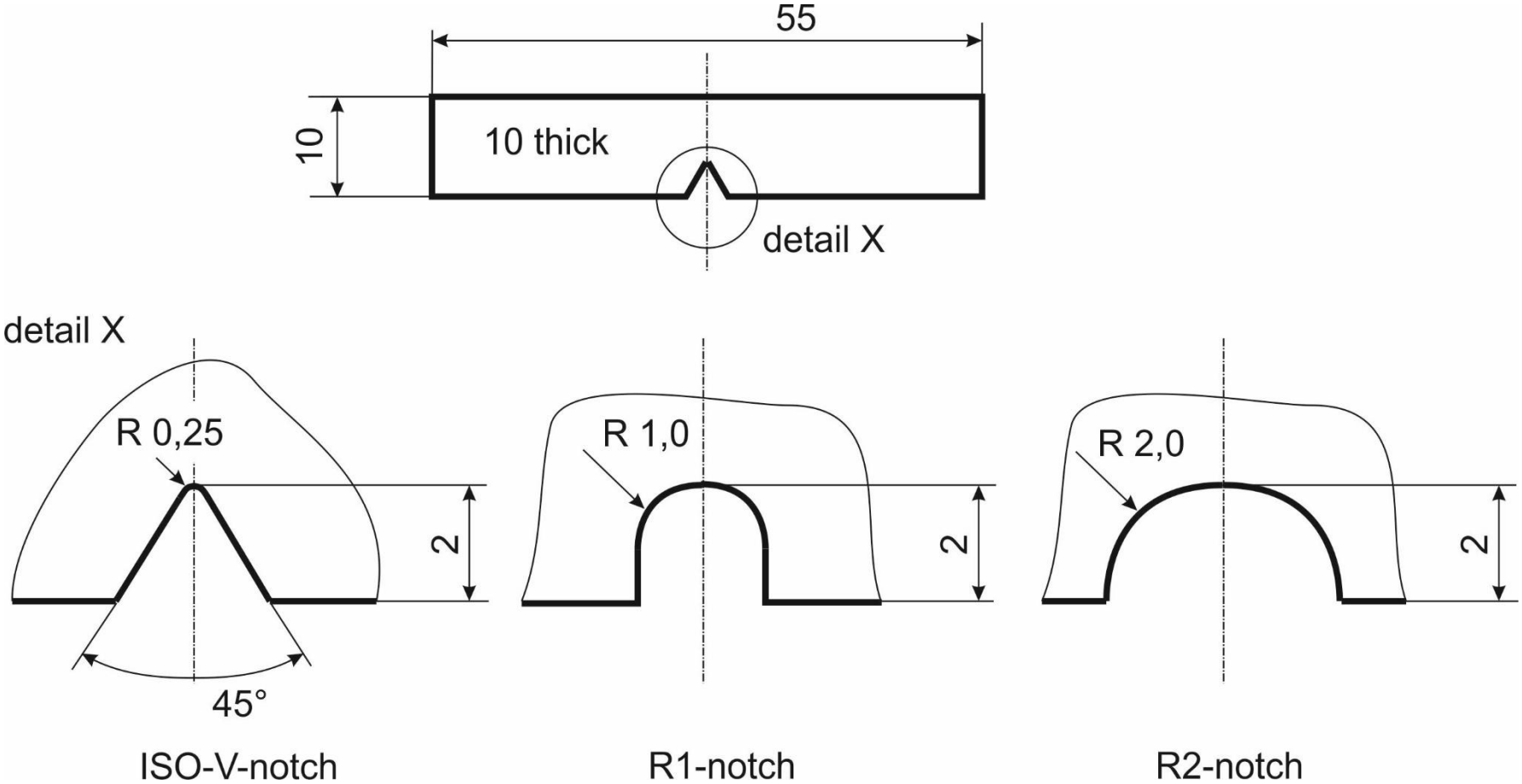


Testing of Charpy notch-toughness

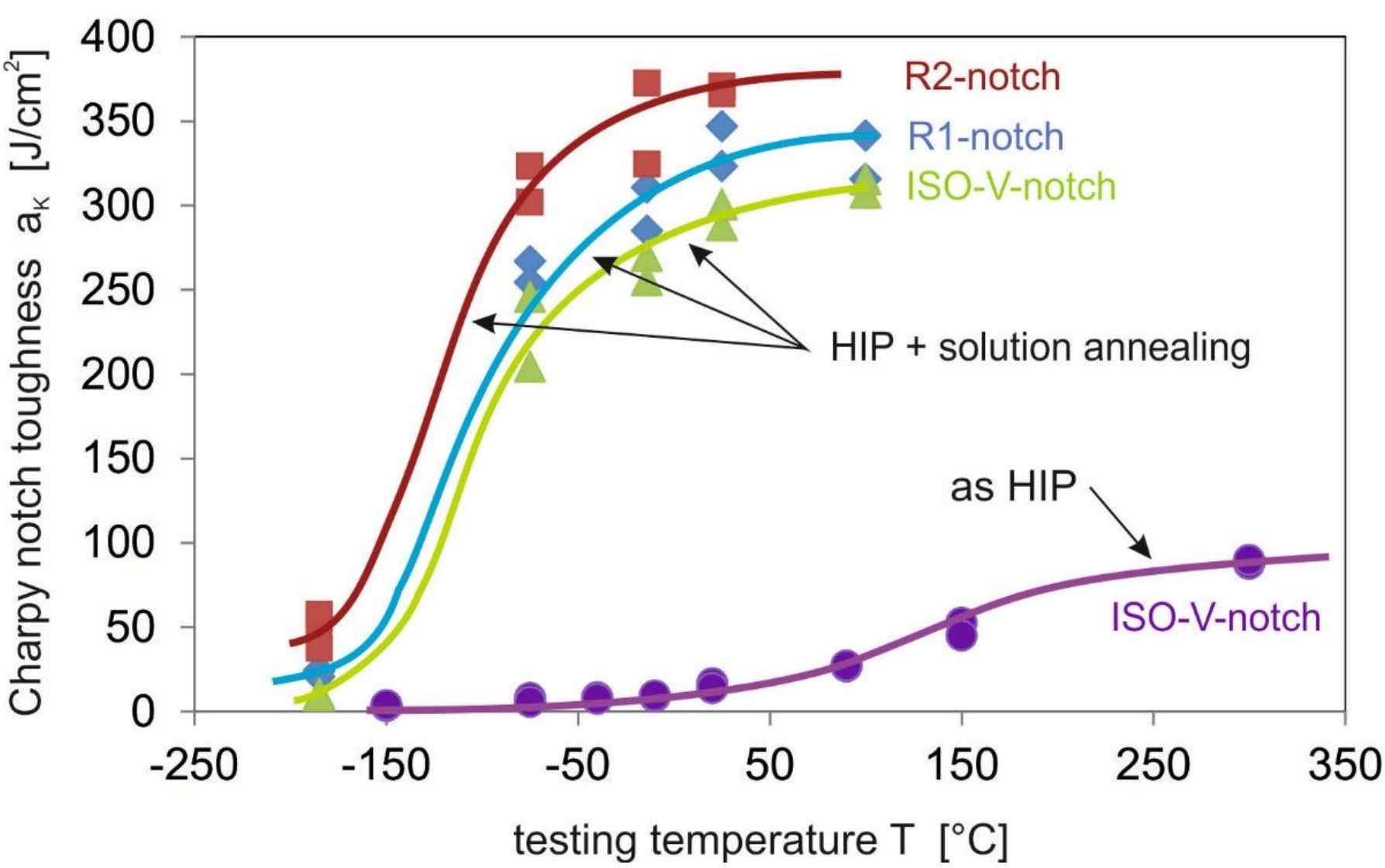
max. energy of the hammer: 300 J

variation of testing temperature: -196°C bis +400°C

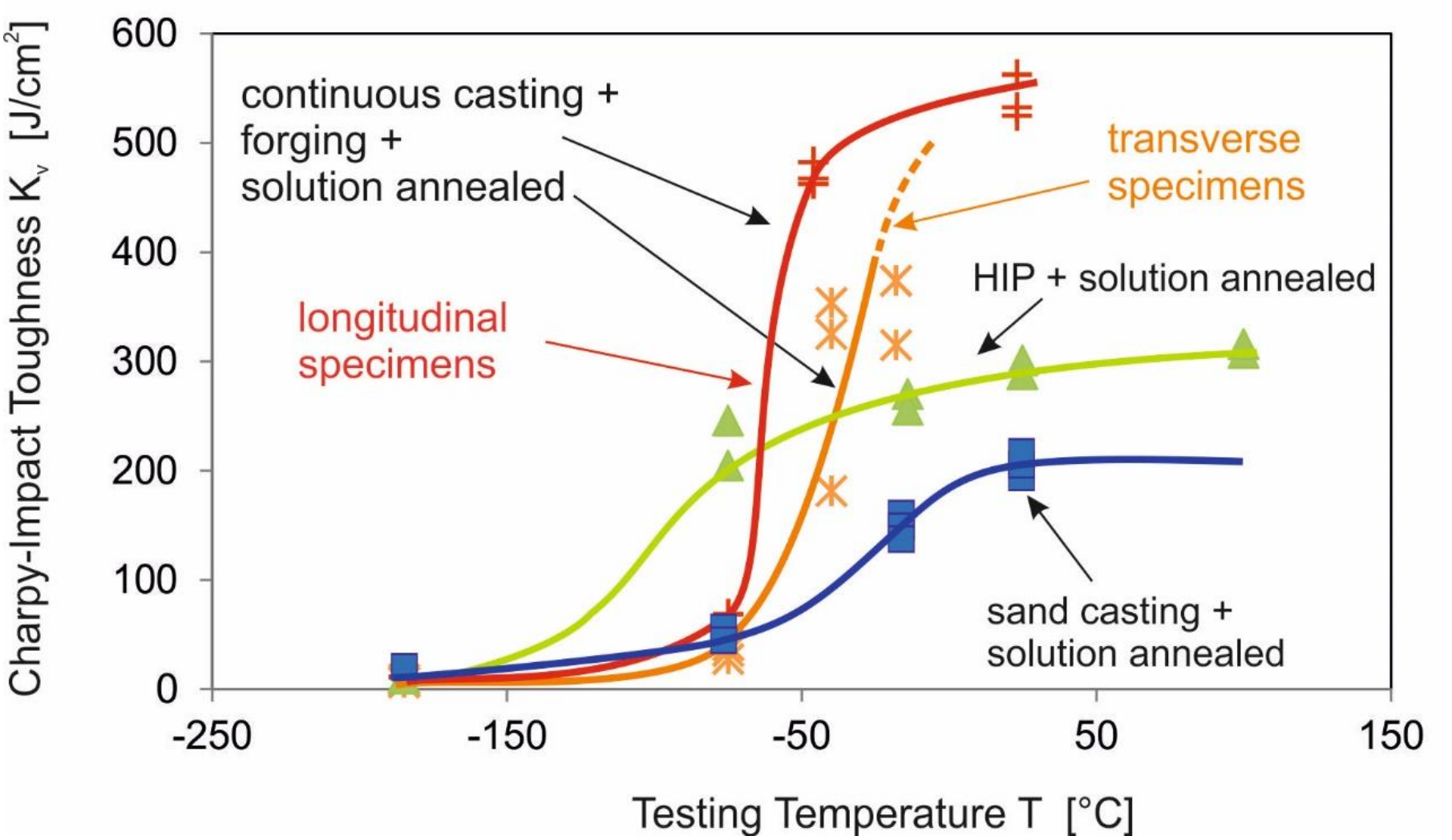
specimen geometry and variation of notch geometry:



Charpy toughness of PM-HIP duplex steel - influence of heat treatment and notch geometry



Chemical composition of the investigated steel grades



Production of samples with defined Ar-content

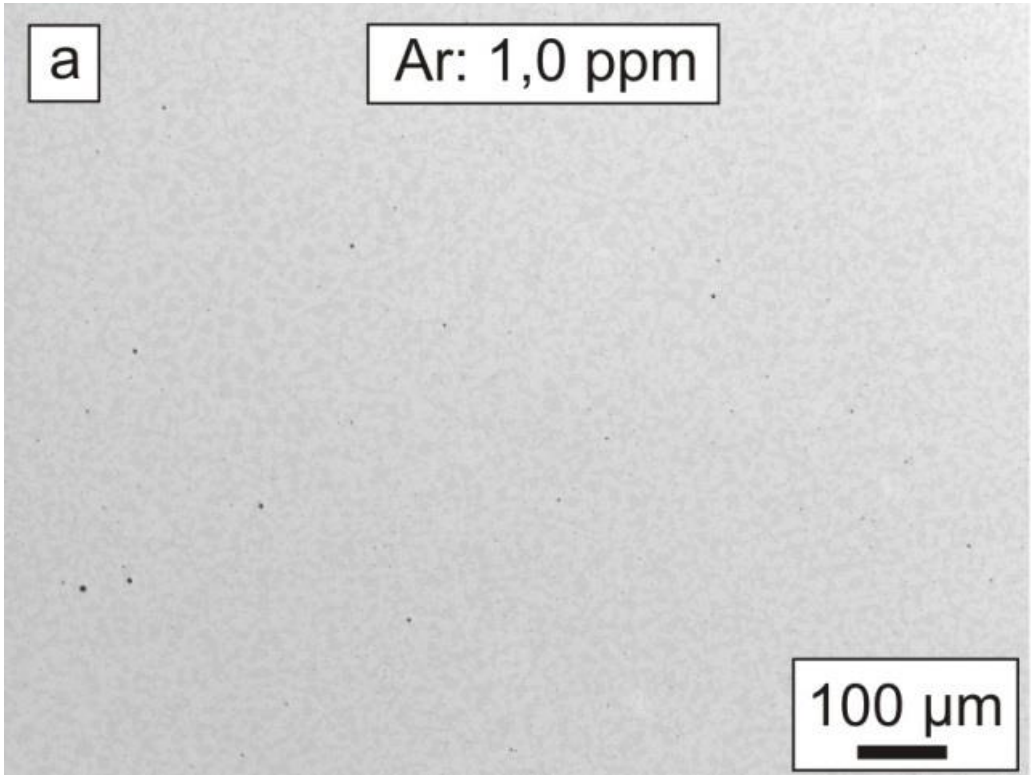
- capsule size: D 110 mm x H 230 mm:
- capsule material: AISI 304
- relative filling density: 66 – 69 %

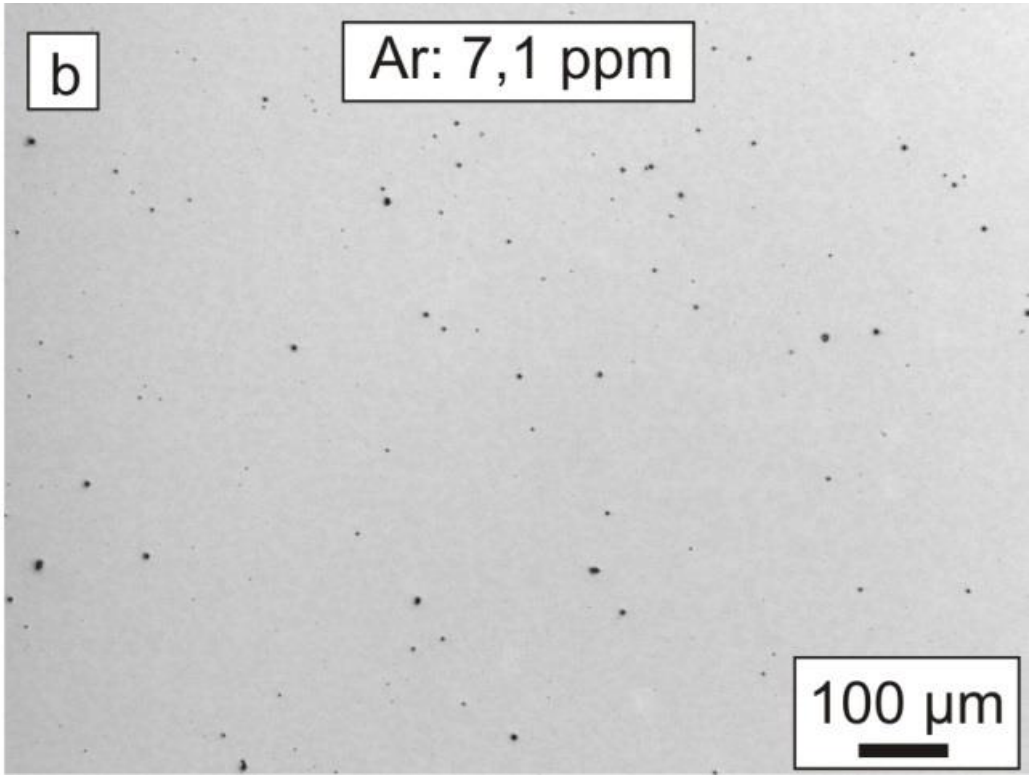
- evacuation-process:
  - flushing with He for leak test
  - 5 x evacuation down to 10-3 mbar and flushing with Ar (1.5 bar)
  - adjusting the final Ar pressure according to the desired Ar-content

- HIP-cycle:
  - holding temperature: 1140 °C
  - holding time: 200 min
  - pressure: 1010 bar

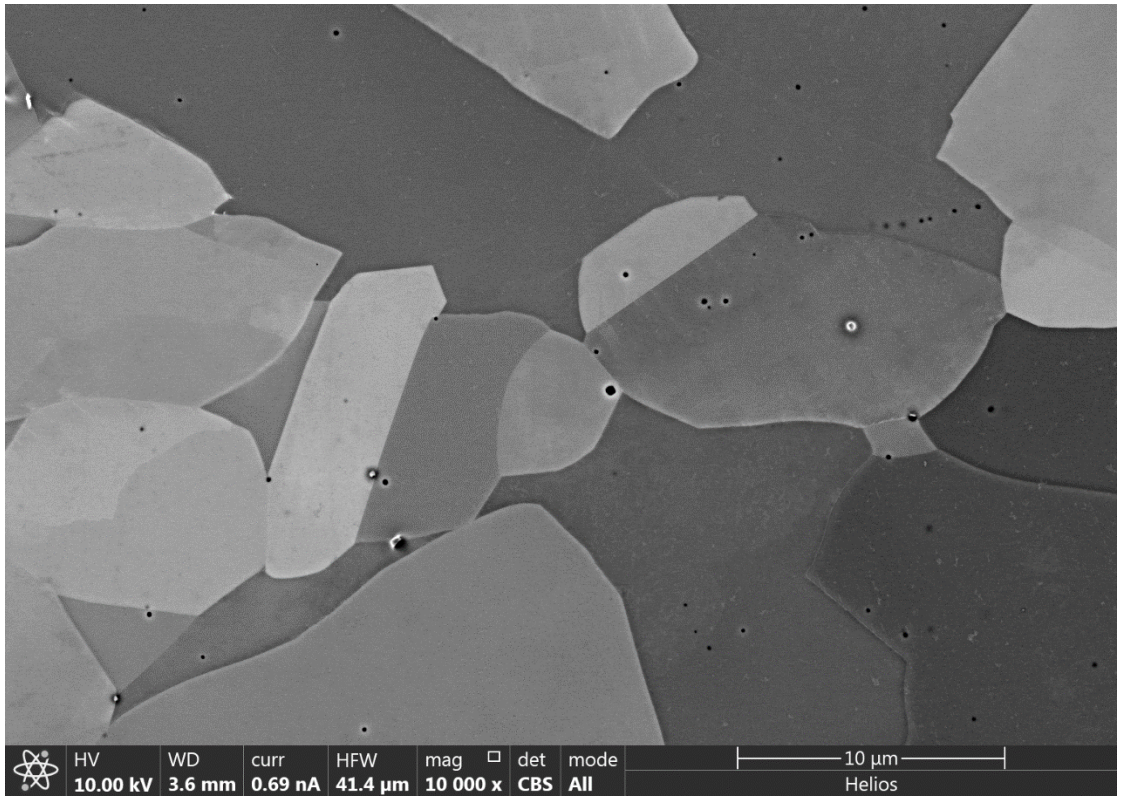
- determination of Ar-content: analyser type Eltra-Werf

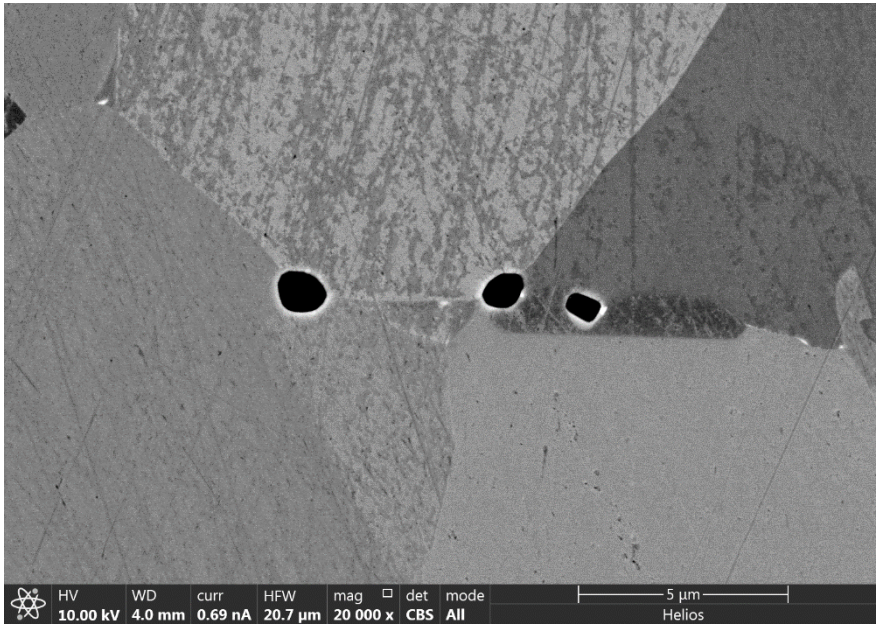
Ar-pores

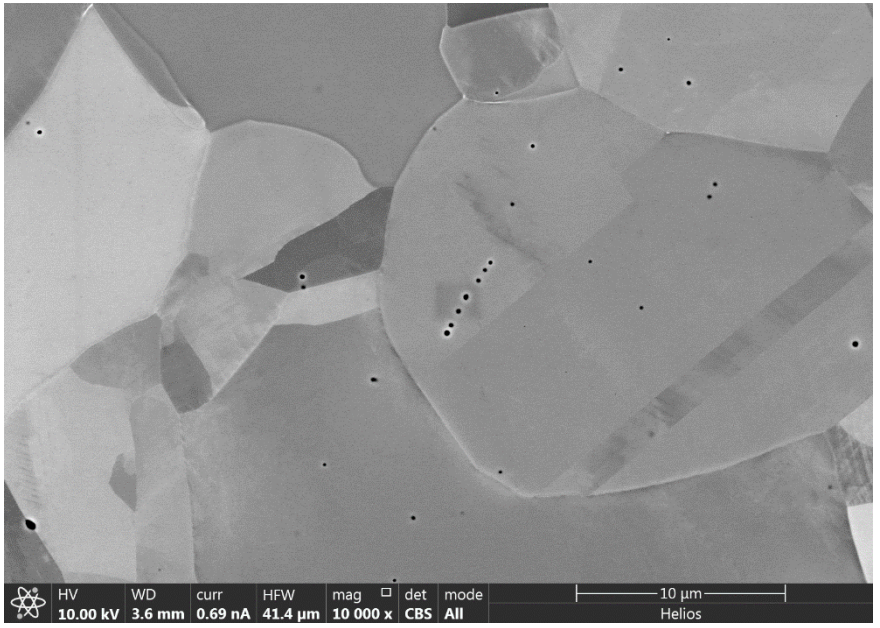




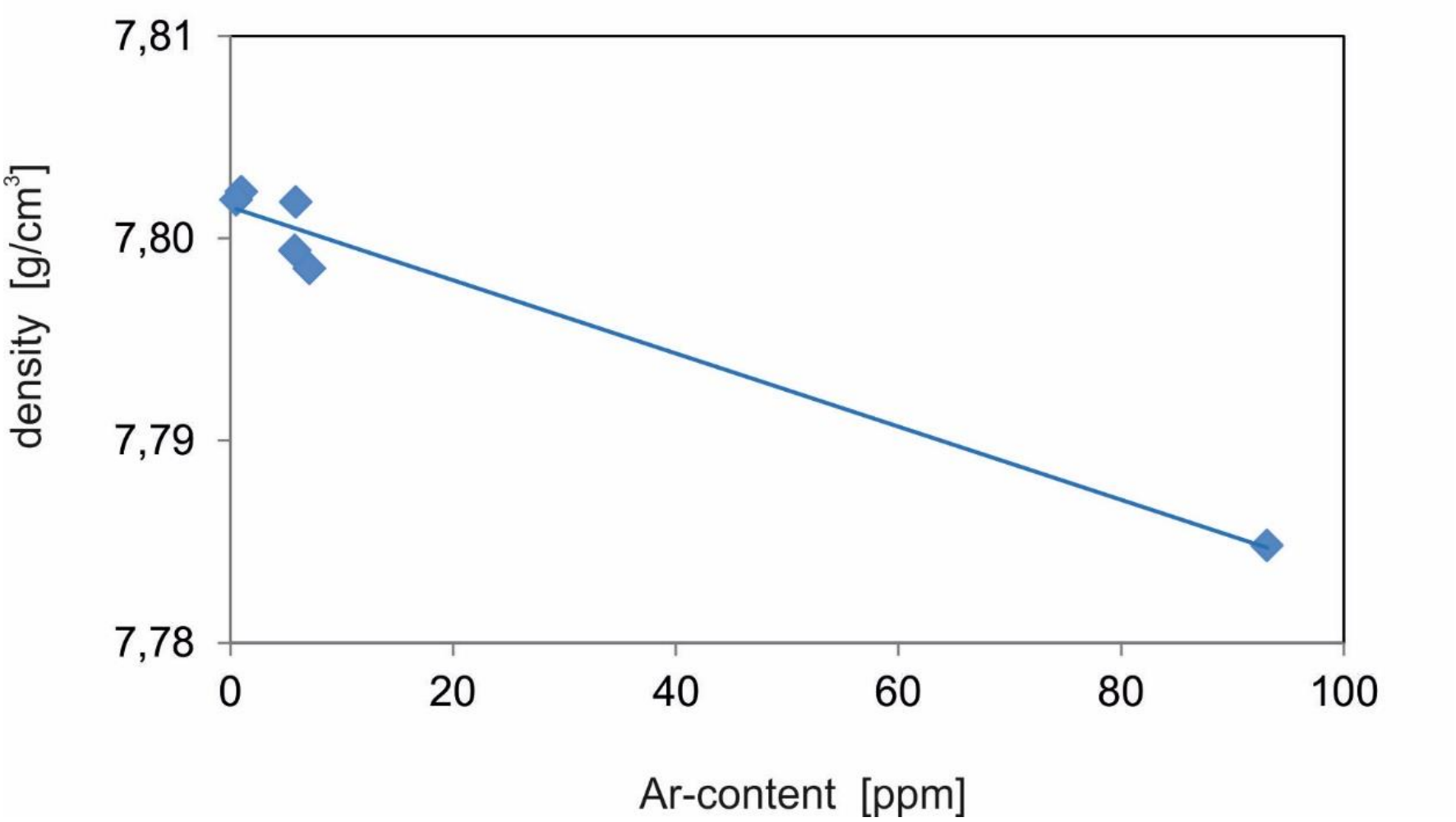
Microstructure with Argon pores in a sample with 1.0 ppm Ar



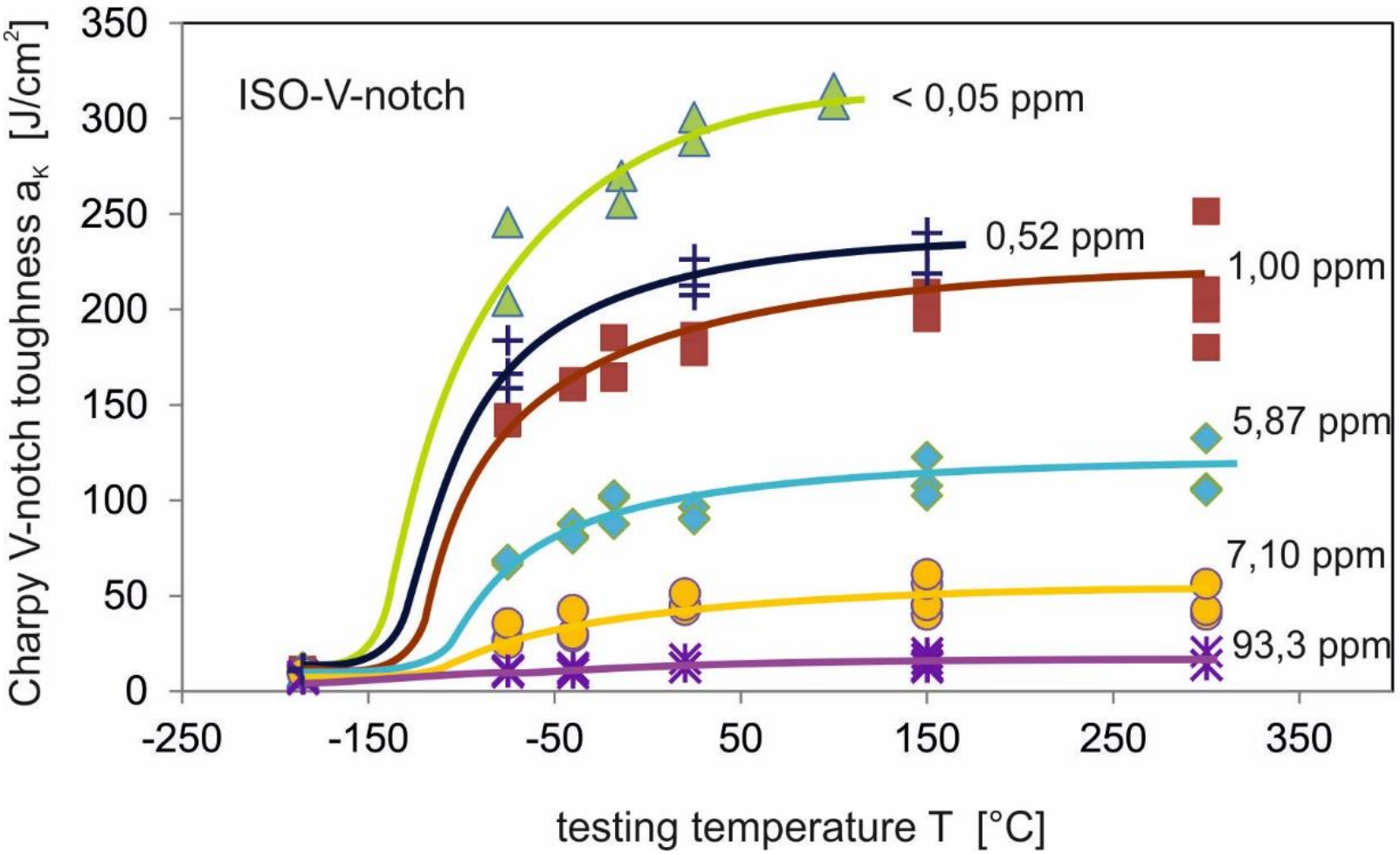




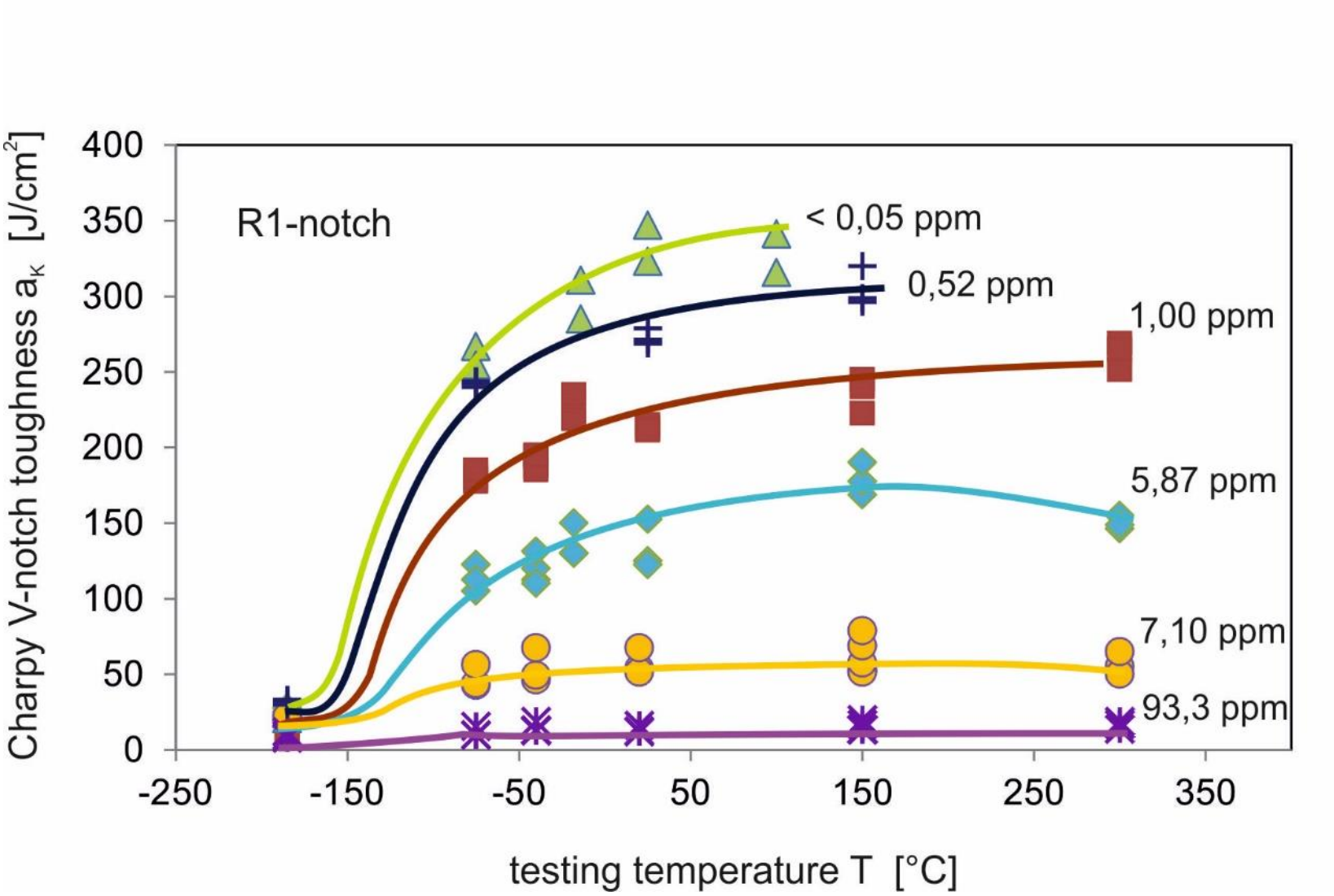
Influence of Ar-content on the density



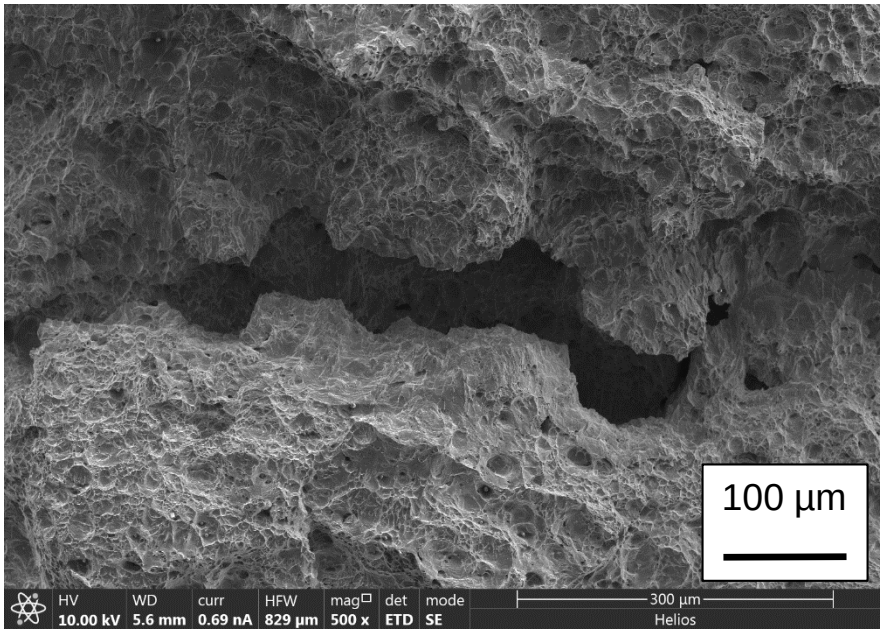
Influence of Argon content on notch toughness – V-notch

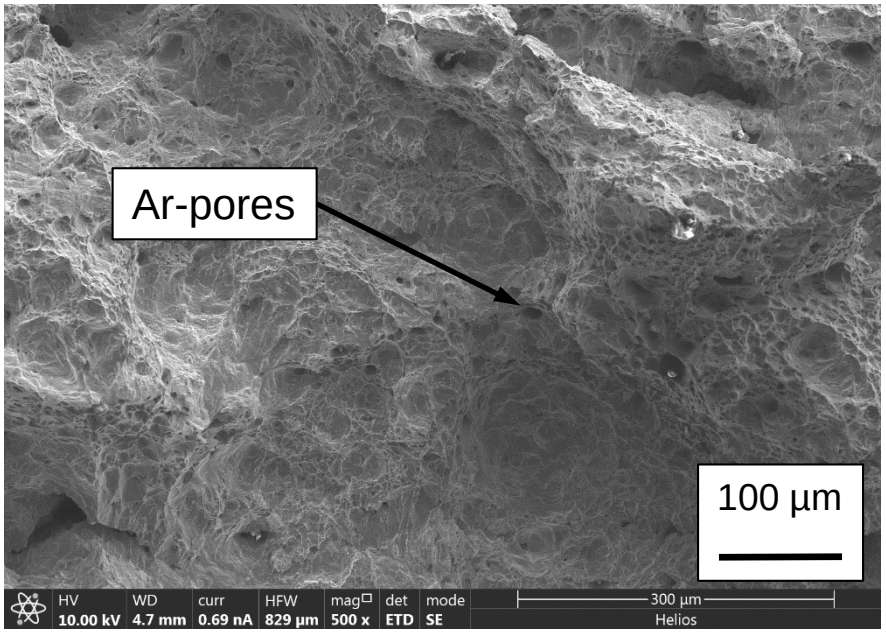


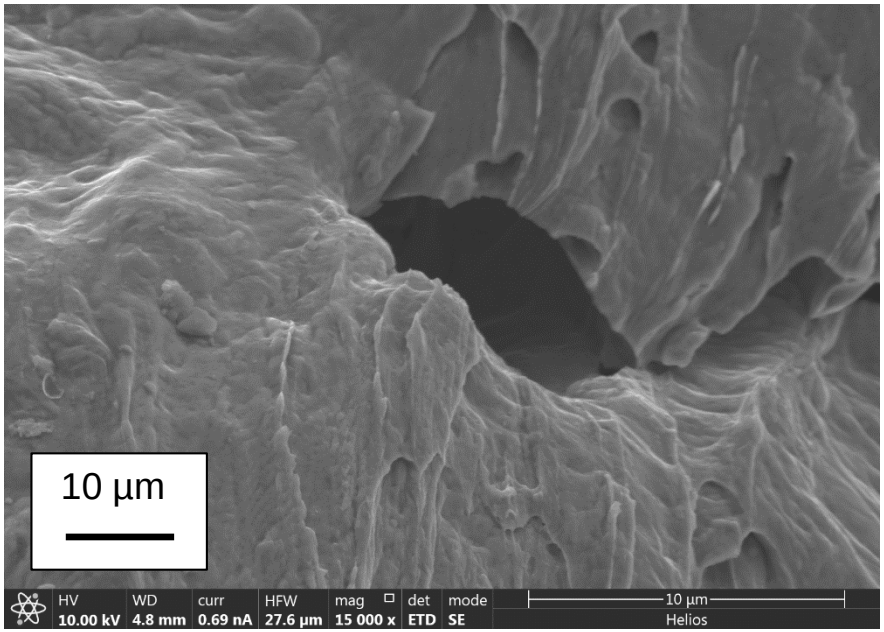
Influence of Argon content on notch toughness – U-notch

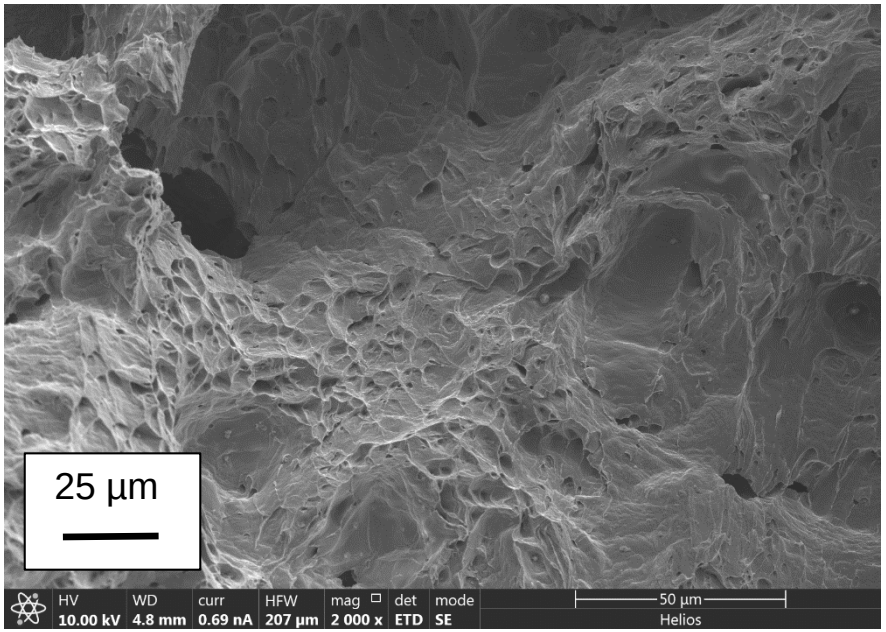


Fracture Surface
PM-HIP - 1 ppm Ar - T=150 °C - a_k = 201 J/cm²

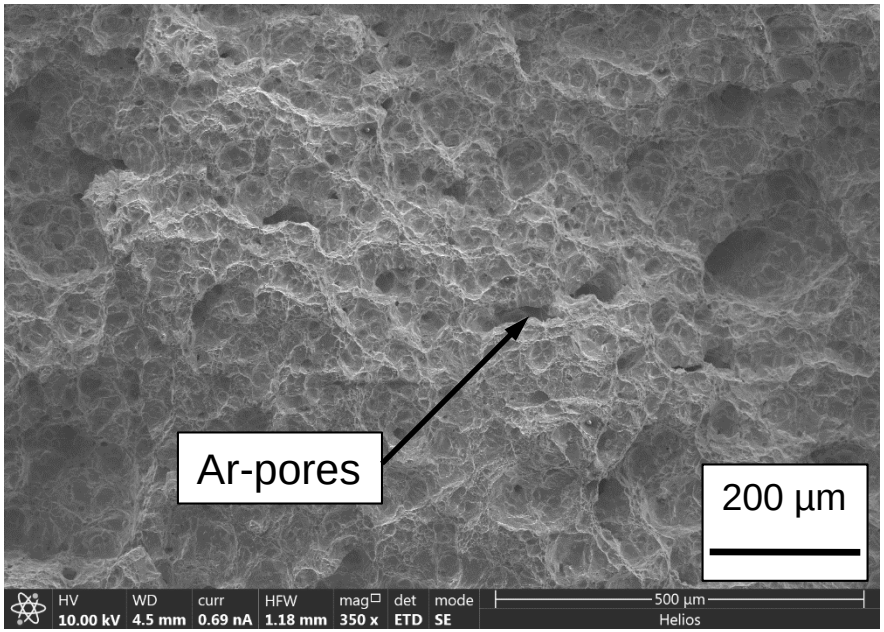


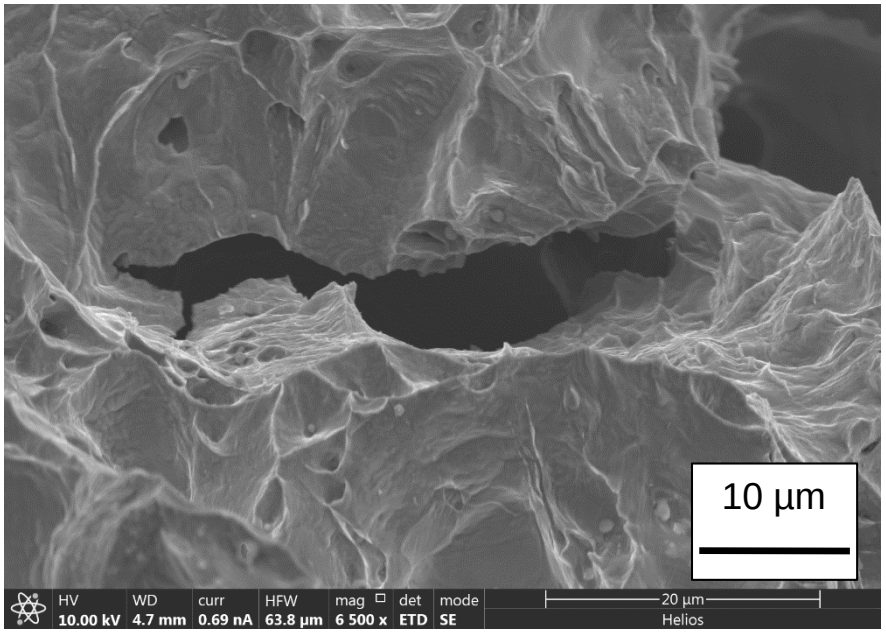


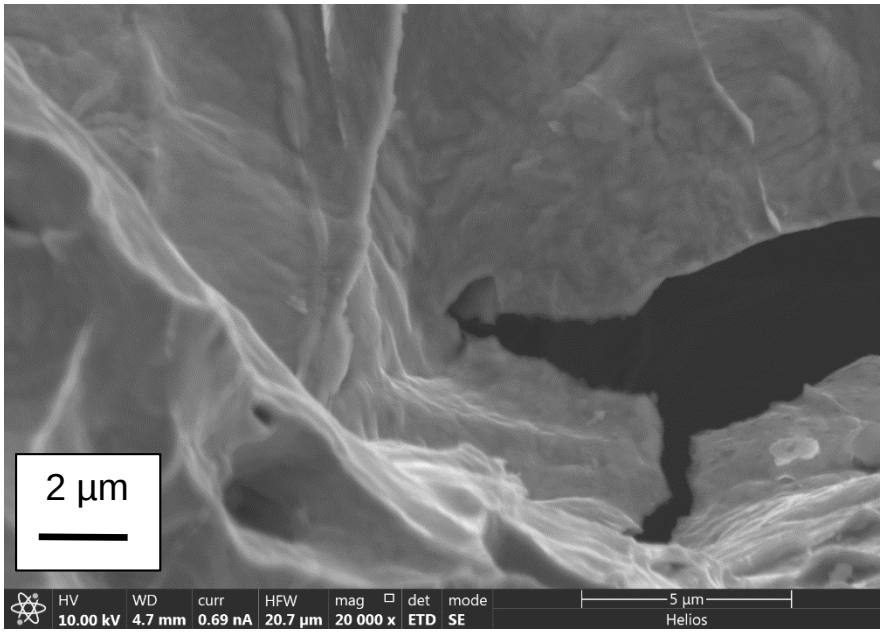


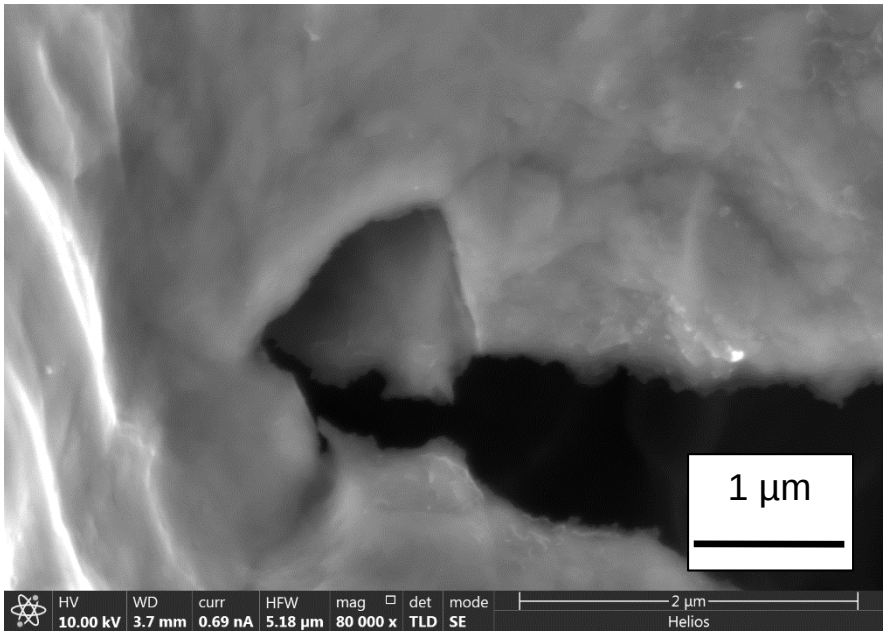


Fracture Surface
PM-HIP – 5.8 ppm Ar - T=150 °C - a_k = 91 J/cm²

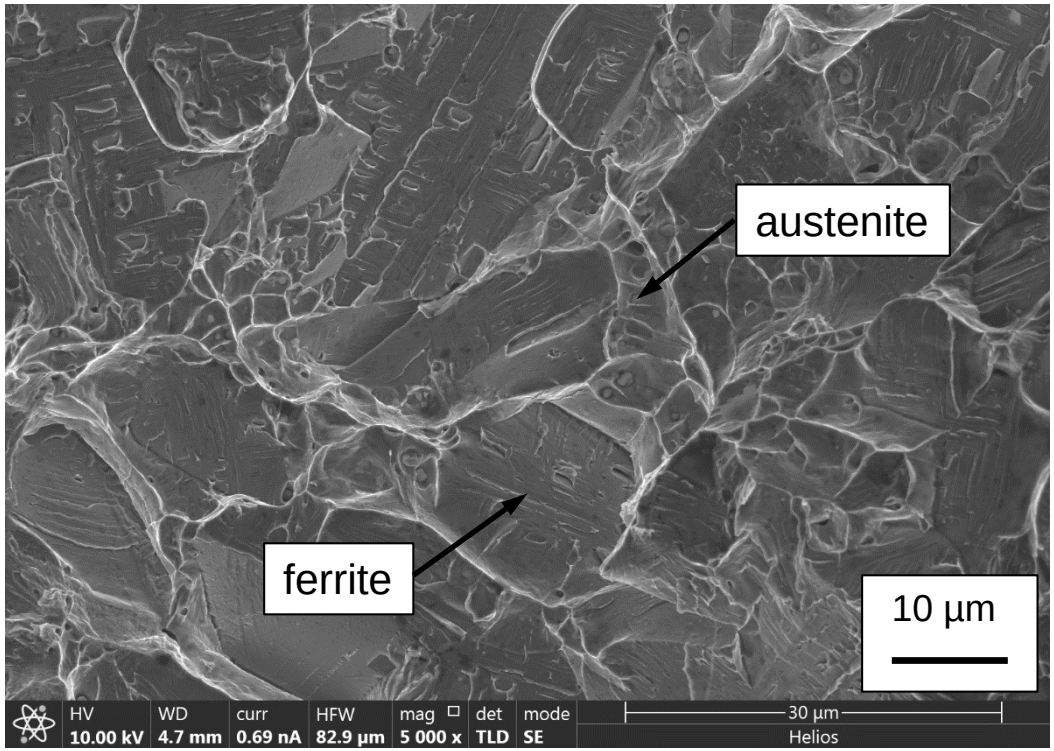


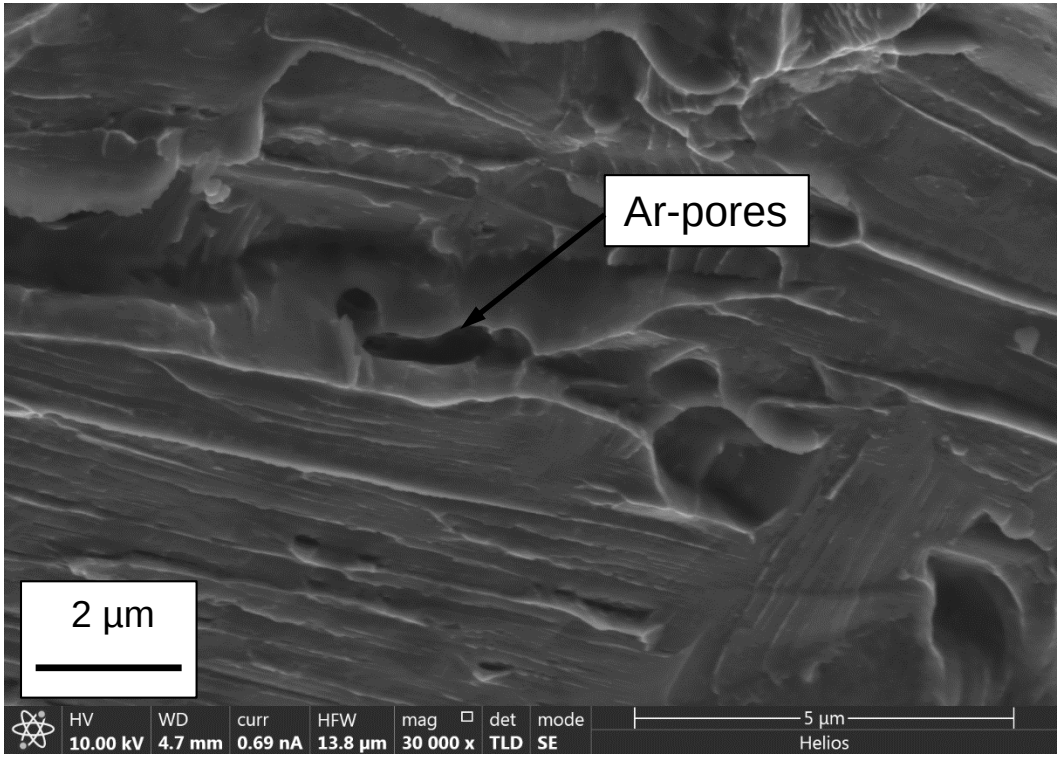




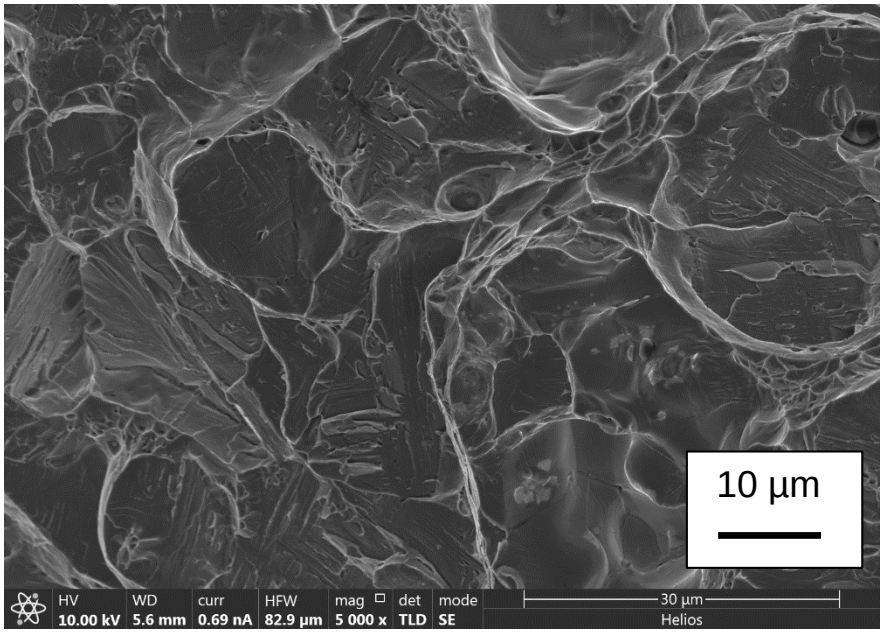


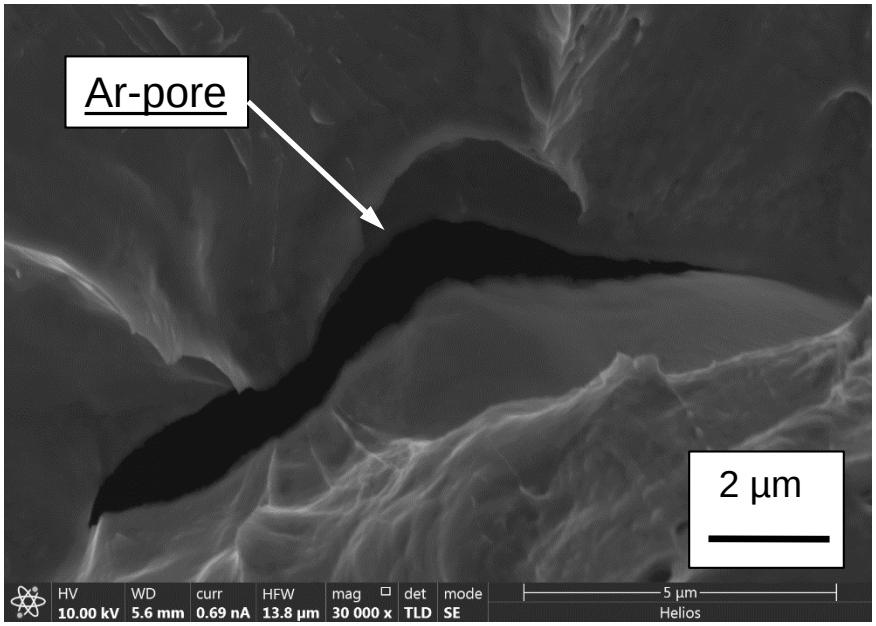
Fracture Surface
PM-HIP - 1 ppm Ar - T=-185 °C - a_k = 11 J/cm²

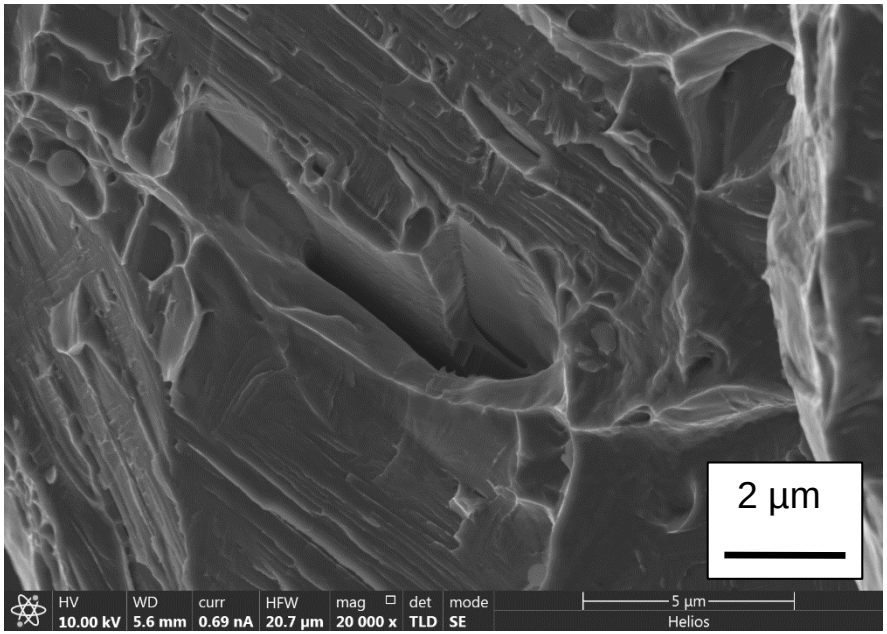


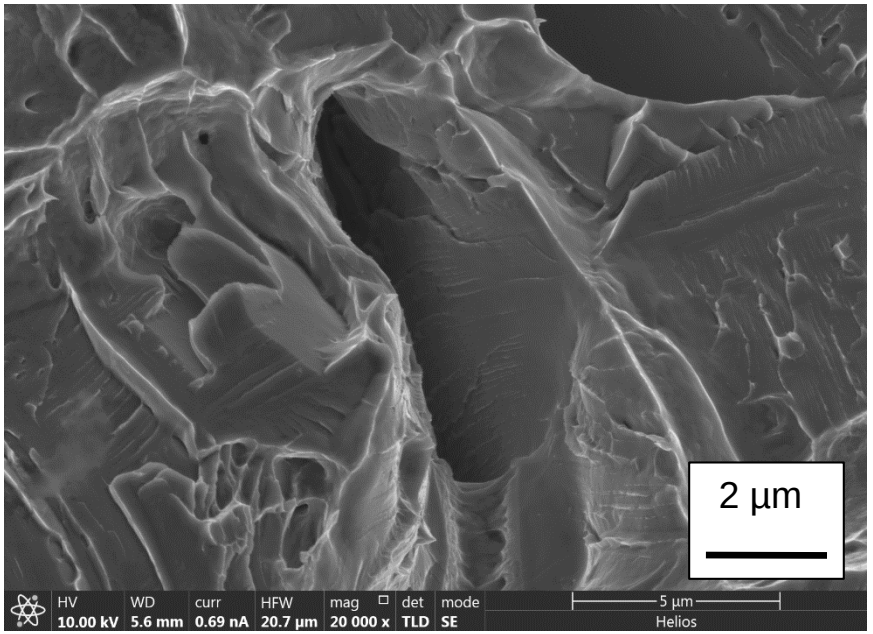


Fracture Surface
PM-HIP – 5.8 ppm Ar - T=-185 °C - a_k = 8 J/cm²









Summary

- The effects of manufacuturing method, heat treatment, notch geometry and Ar-content on the Charpy notch-toughness of AISI 318 duplex steel have been investigated.
- Independent of the testing temperature the toughness of PM-HIP steel is superior to cast material.
- PM-HIP material shows higher toughness compared to forged steel at temperatures lower than -50°C.
- Even a very small amount of σ-phase drastically reduces the toughness.
- A small notch radius leads to an increase of the BDTT and a decrease of the toughness level in the upper shelf.
- Toughness is very sensitive to the Ar content. 90 ppm of Ar lead to brittle fracture even at higher temperatures.

Acknowledgement

The author would like to thank

- Mrs. Vanessa Derichs, Mr. Johannes Kunz, Mr. Thomas Güthoff, Mr. Robert Mager, Mr. Henrik Wünsch for their contribution to the lecture,
- Mr. Bengt Olof Bengtson from Carpenter Powder Products AB for the delivery of the powder,
- The company Deutsche Edelstahlwerke and Schmolz&Bickenbach Guss for delivery of the cast and forged grades and
- Mrs. Kathrin Horrenkamp from Bodycote HIP GmbH in Haag-Winden, Germany, for performing the Ar-Analysis.

Thank you for your Interest!

Prof. Dr.-Ing. Christoph Broeckmann

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