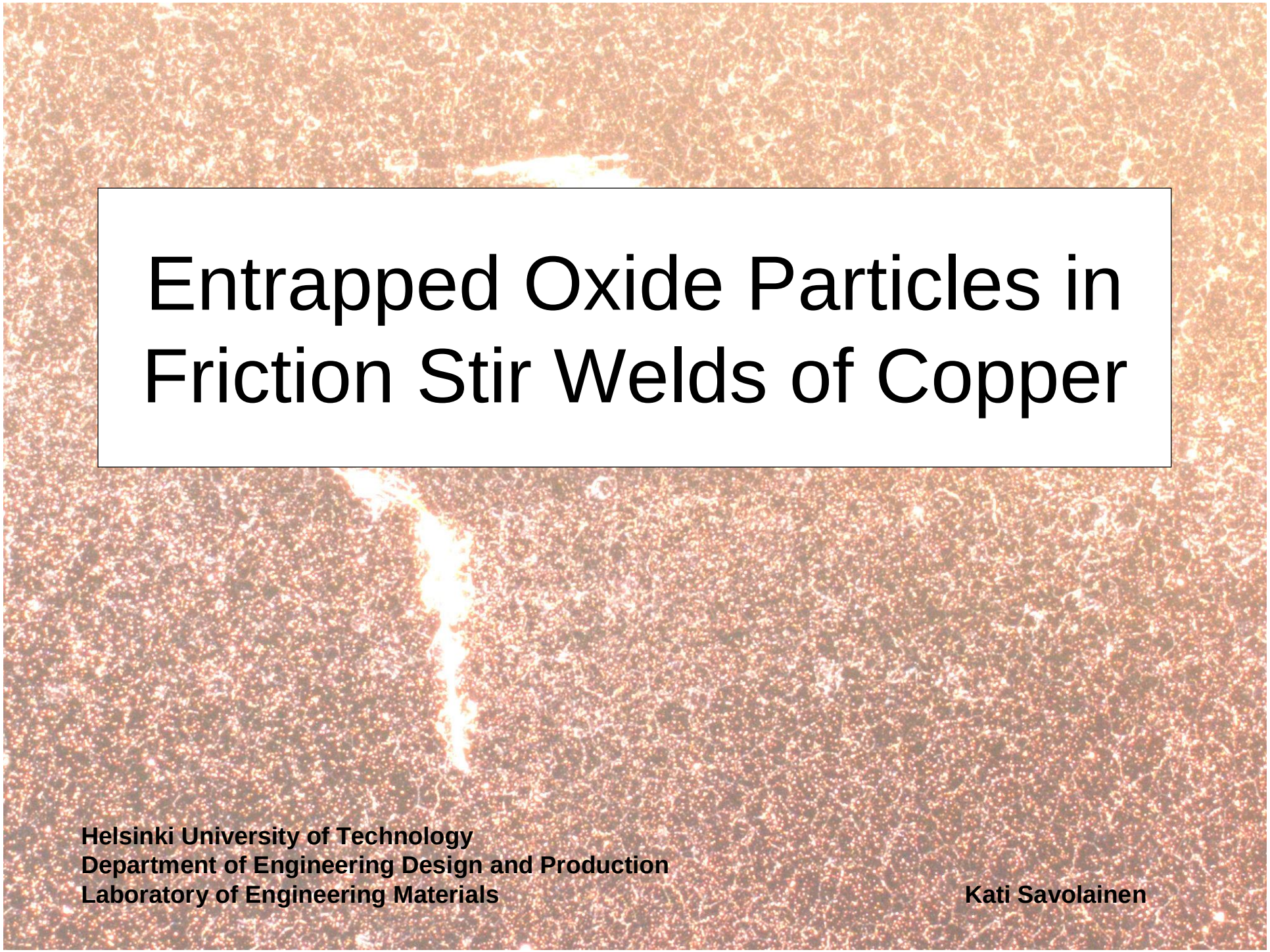


Entrapped Oxide Particles in Friction Stir Welds of Copper

Helsinki University of Technology
Department of Engineering Design and Production
Laboratory of Engineering Materials

Kati Savolainen

Experimental

- Base material Cu-OFEP
- Rotation speed 750 rpm, traverse speed 70 mm/min, plunge depth 5.7 mm
- 0, 2, 5, and 8 mm grooves
- Combinations of oxide removal and shielding gas
- Tri-flat tool, tool material IN738LC

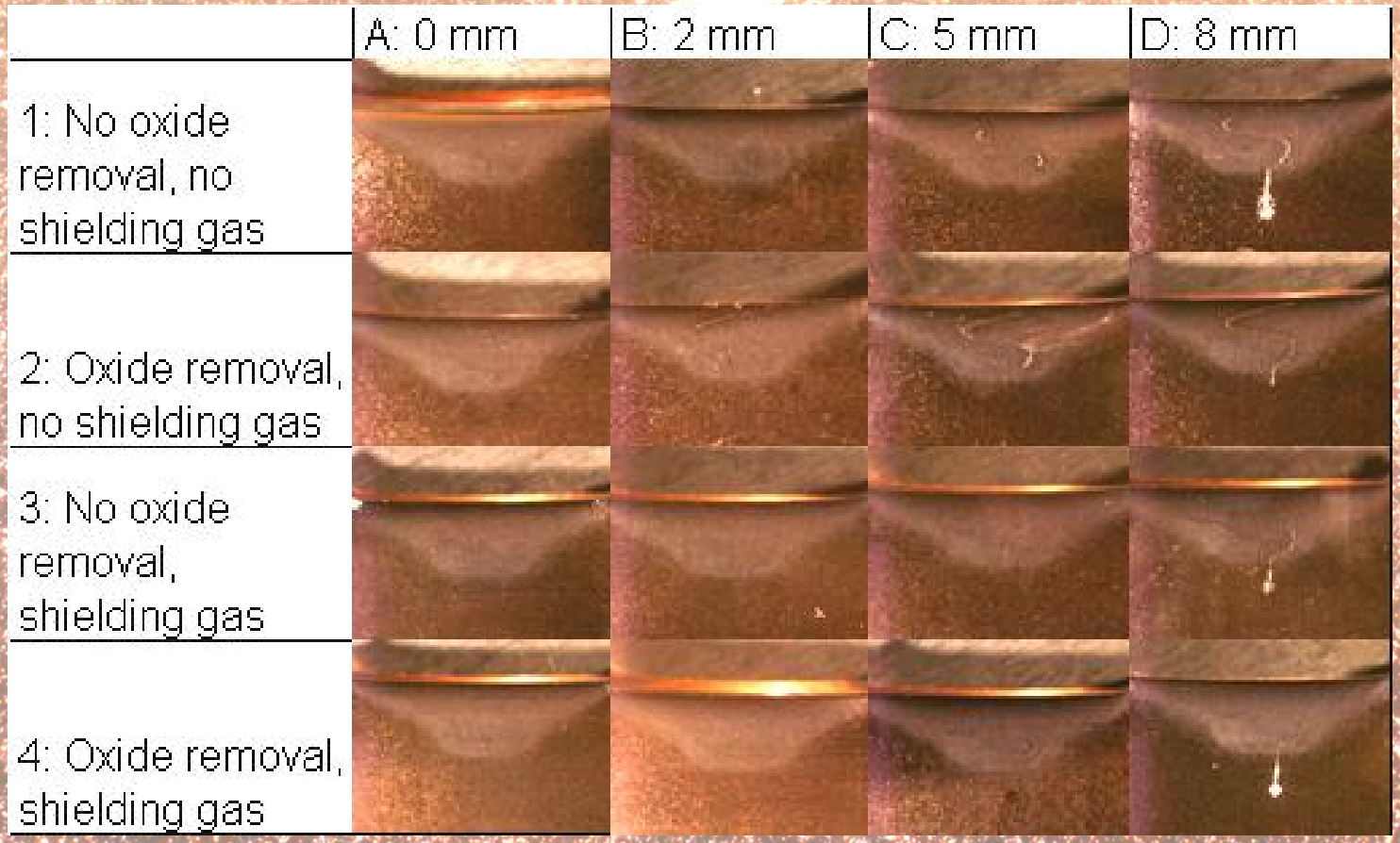
Experimental

- The combinations:
  1: no etching, no shielding gas
  2: etching, no shielding gas
  3: no etching, shielding gas
  4: etching, shielding gas

Experimental and Results

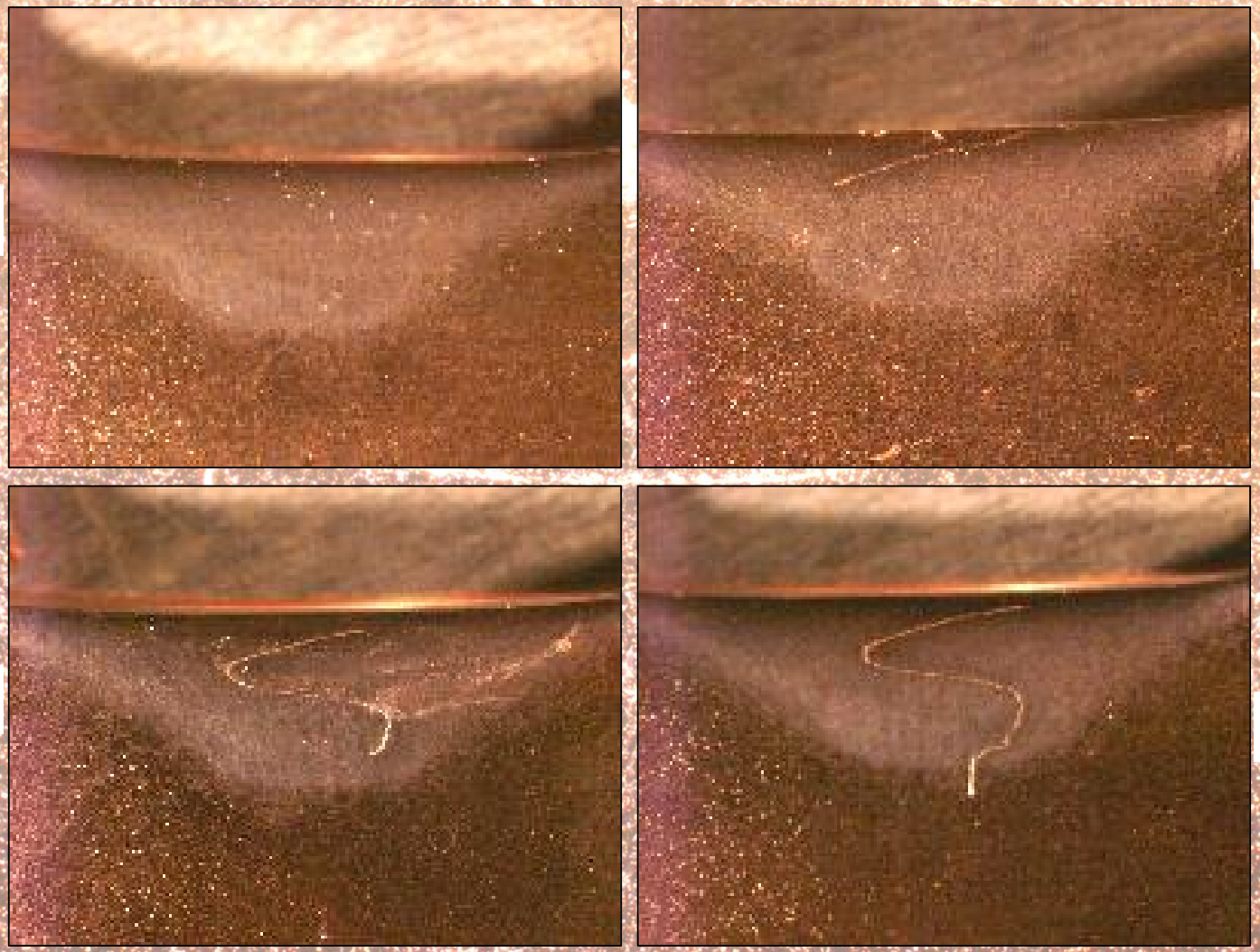
- Macroscopy
- Microscopy
- SEM and EBSD
- Hydrogen annealing
- Temperature measurement

Macroscopy



Helsinki University of Technology
Department of Engineering Design and Production
Laboratory of Engineering Materials

Kati Savolainen

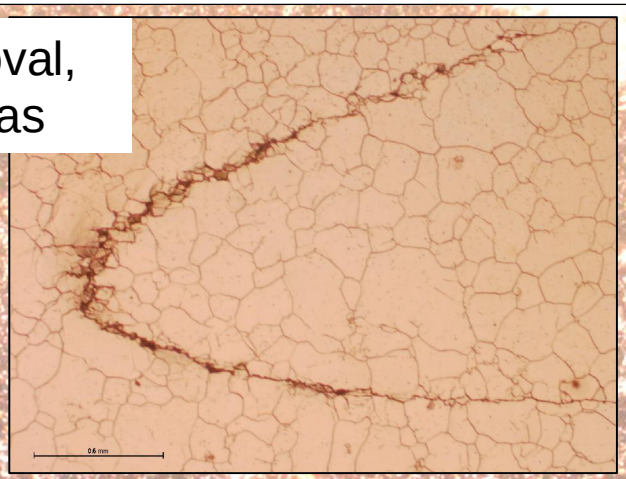


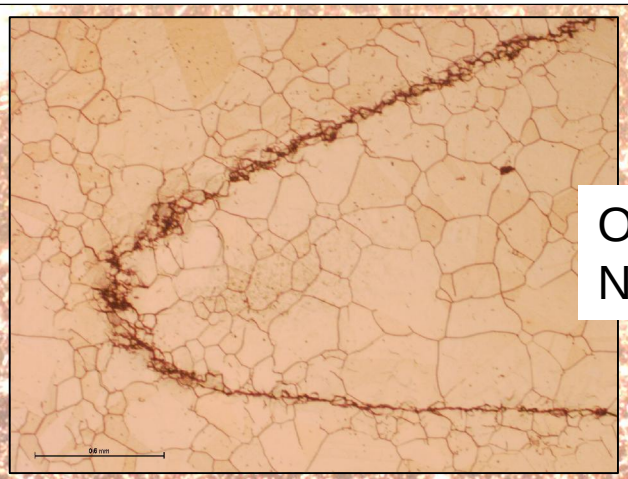
Helsinki University of Technology
Department of Engineering Design and Production
Laboratory of Engineering Materials

Kati Savolainen

Microscopy

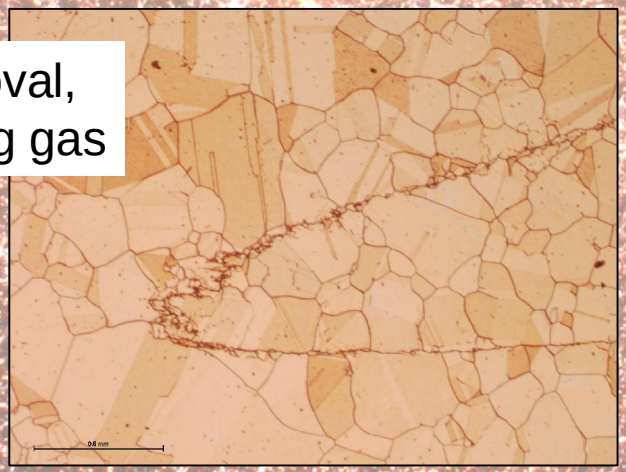
No oxide removal,
No shielding gas

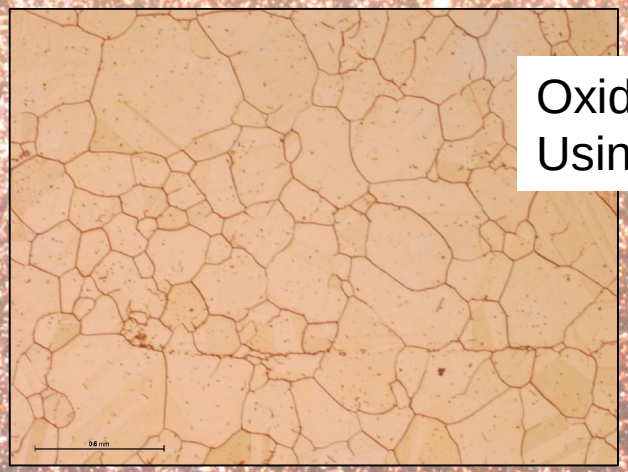




Oxide removal,
No shielding gas

No oxide removal,
Using shielding gas





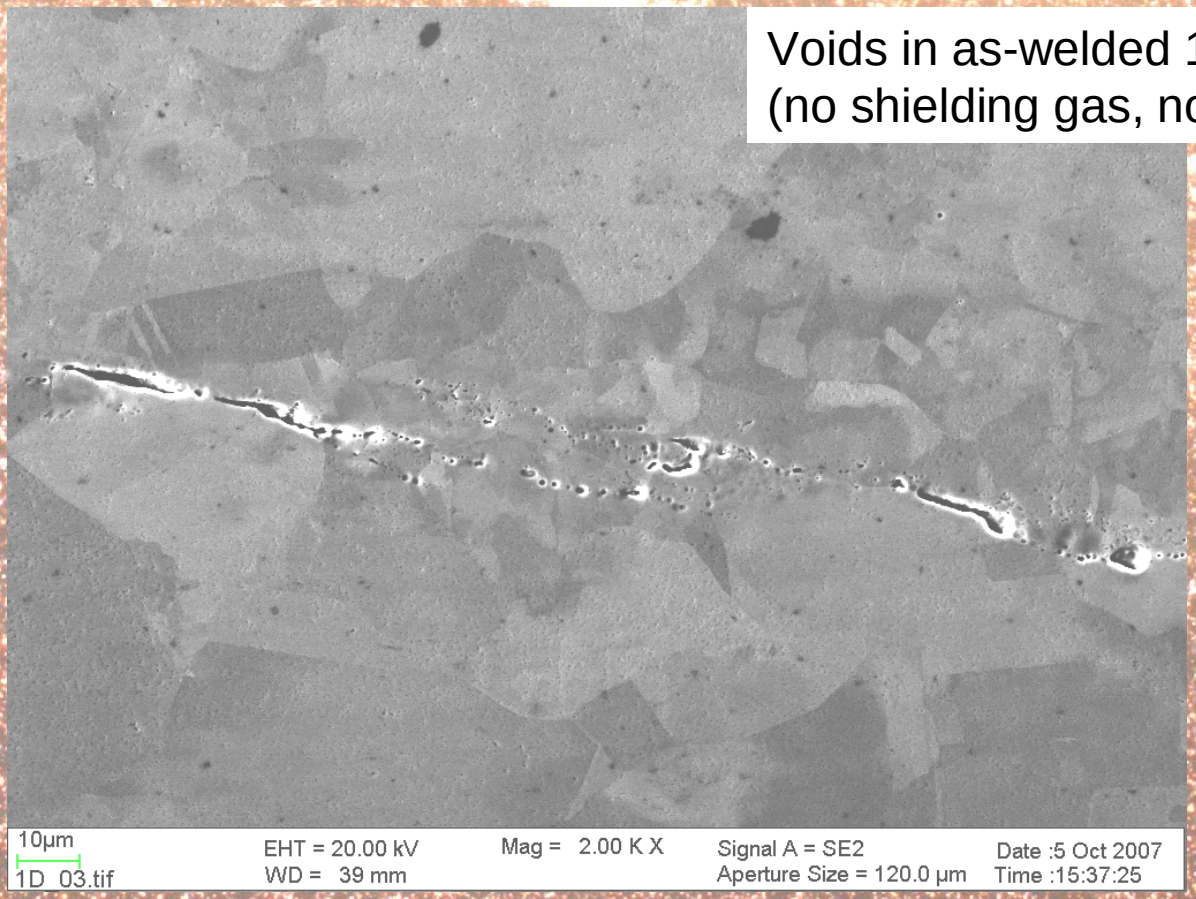
Oxide removal,
Using shielding gas

Helsinki University of Technology
Department of Engineering Design and Production
Laboratory of Engineering Materials

Kati Savolainen

SEM Studies

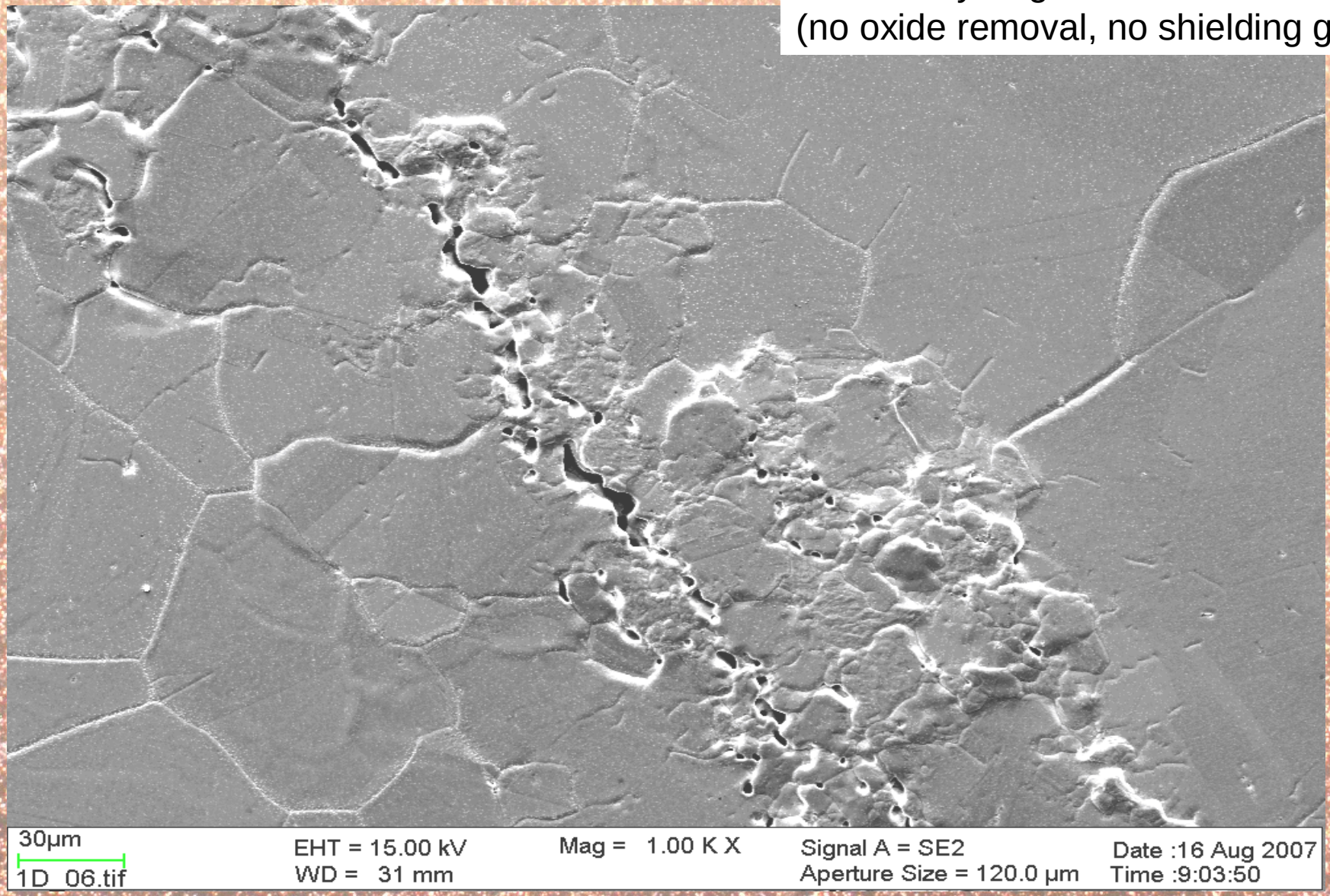
Voids in as-welded 1D
(no shielding gas, no oxide removal)



Helsinki University of Technology
Department of Engineering Design and Production
Laboratory of Engineering Materials

Kati Savolainen

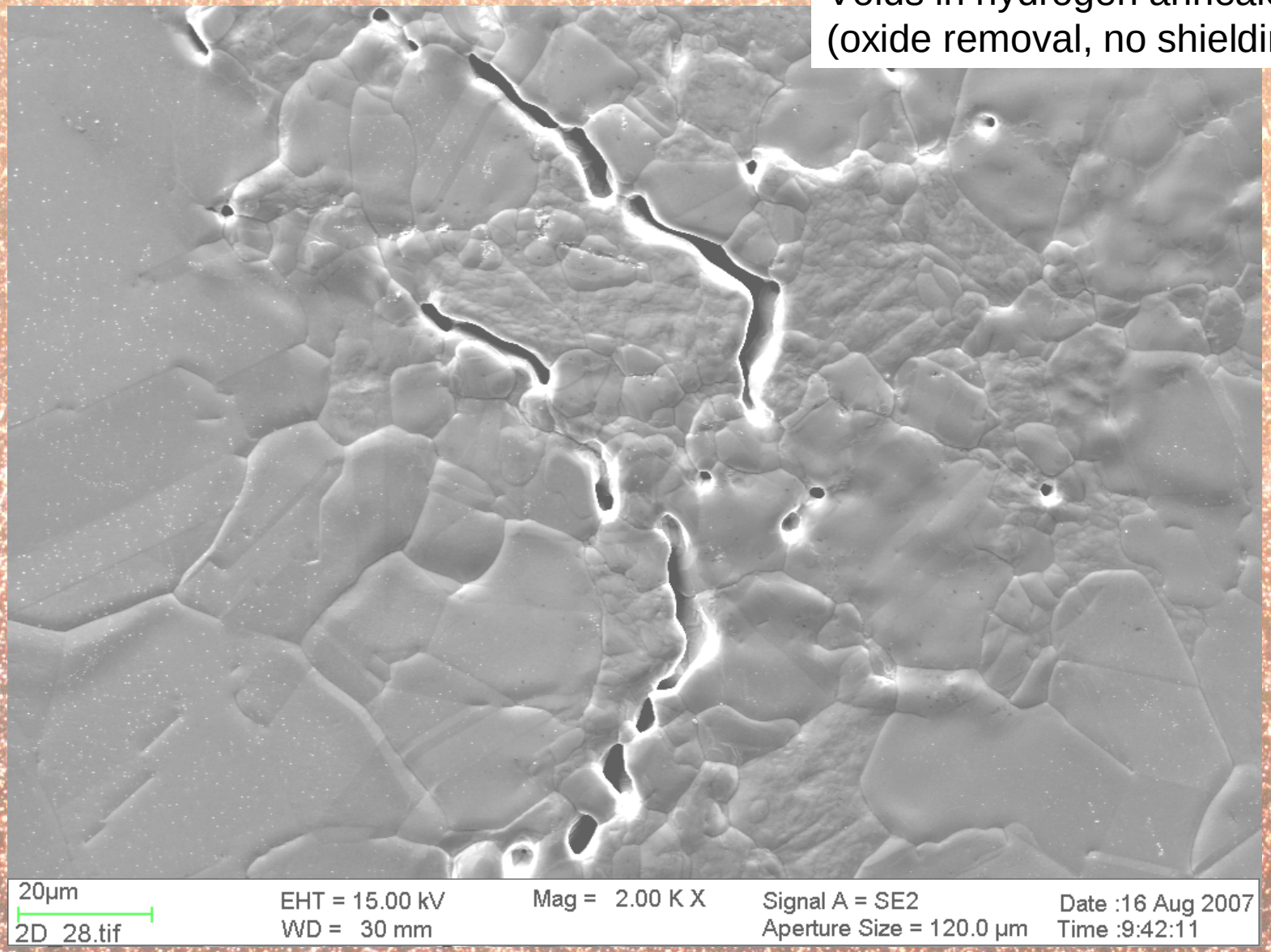
Voids in hydrogen annealed 1D
(no oxide removal, no shielding gas)



Helsinki University of Technology
Department of Engineering Design and Production
Laboratory of Engineering Materials

Kati Savolainen

Voids in hydrogen annealed 2D
(oxide removal, no shielding gas)



Helsinki University of Technology
Department of Engineering Design and Production
Laboratory of Engineering Materials

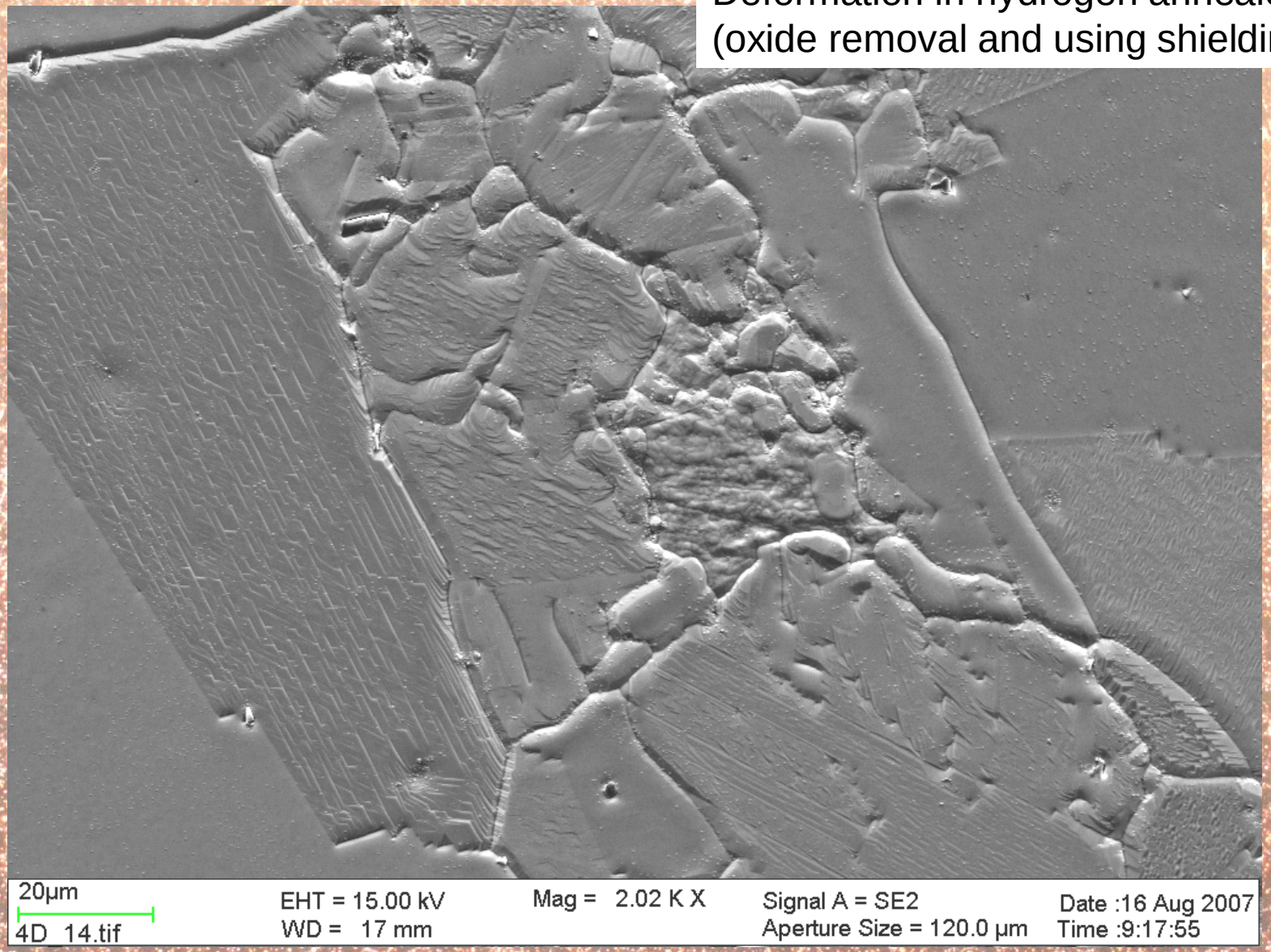
Kati Savolainen

Deformation in hydrogen annealed 3D
(no oxide removal, using shielding gas)

Helsinki University of Technology
Department of Engineering Design and Production
Laboratory of Engineering Materials

Kati Savolainen

Deformation in hydrogen annealed 4D
(oxide removal and using shielding gas)



Helsinki University of Technology
Department of Engineering Design and Production
Laboratory of Engineering Materials

Kati Savolainen

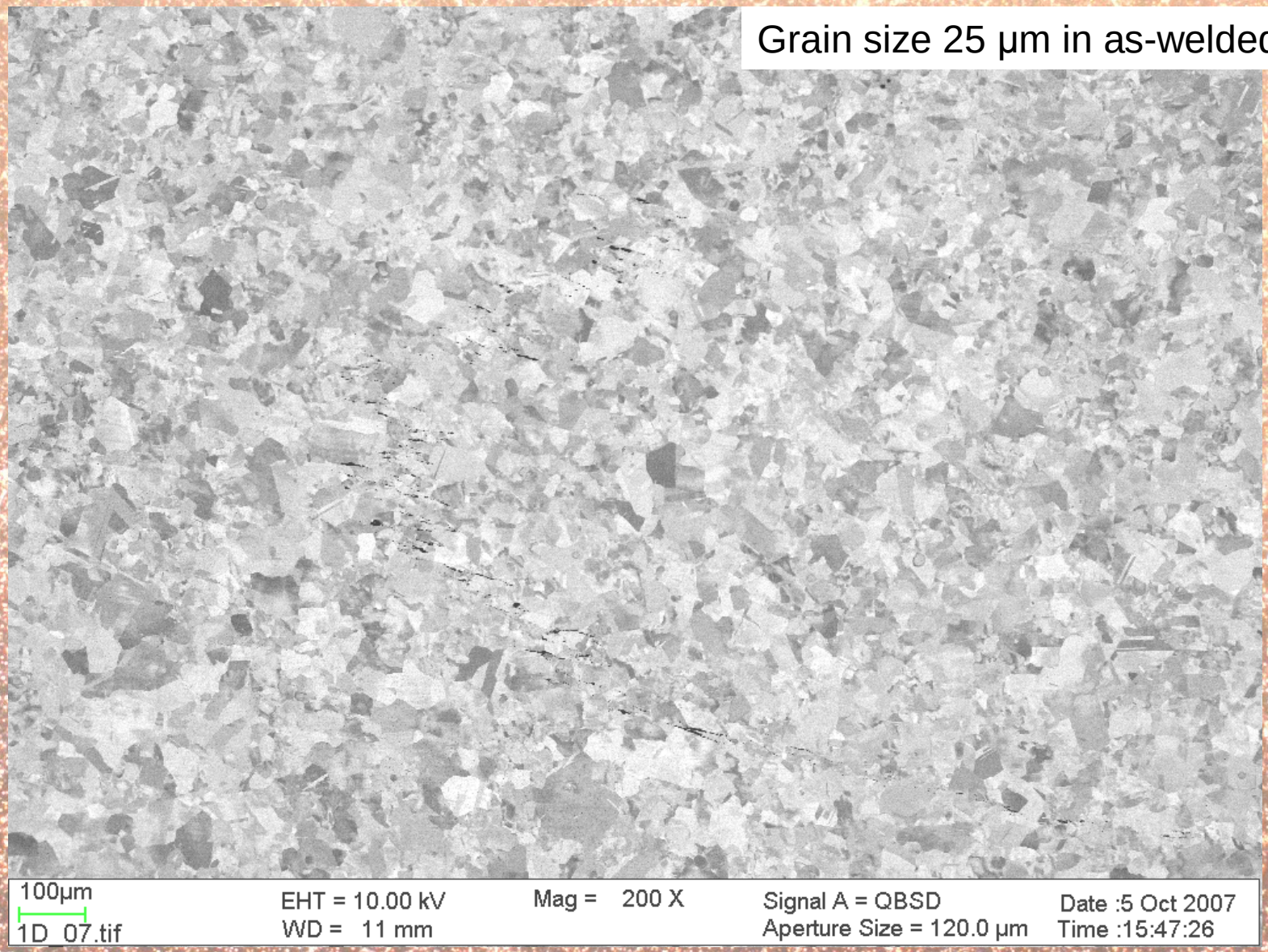
SEM and EBSD Studies

	Grain size (µm)	
	Horizontal	Vertical
Base material	182	183
1D, 8 mm groove, no oxide removal, no shielding gas, no hydrogen annealing	26	22
1DV, 8 mm groove, no oxide removal, no shielding gas, with hydrogen annealing	80	74
4D, 8 mm groove, oxide removal, using shielding gas, no hydrogen annealing	25	23
4DV, 8 mm groove, oxide removal, using shielding gas, with hydrogen annealing	141	122

Pinning Effect of Oxide Particles

- Small copper oxide particles hinder grain boundary movement and, thus, grain growth (Zener pinning)
- Samples with larger amount of entrapped oxide particles exhibit smaller grain size, in particular at the region of entrapped oxide particles

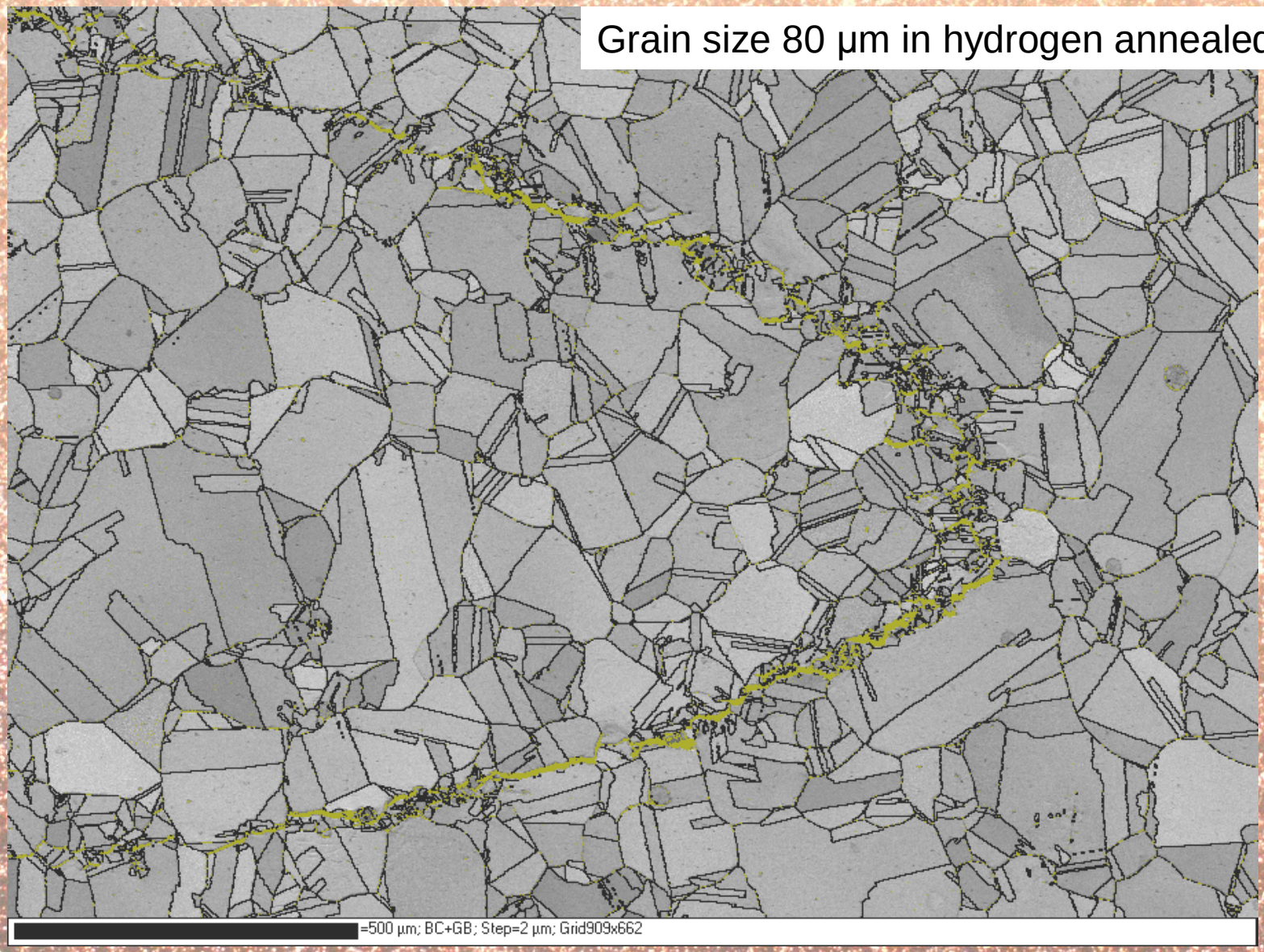
Grain size 25 µm in as-welded 1D



Helsinki University of Technology
Department of Engineering Design and Production
Laboratory of Engineering Materials

Kati Savolainen

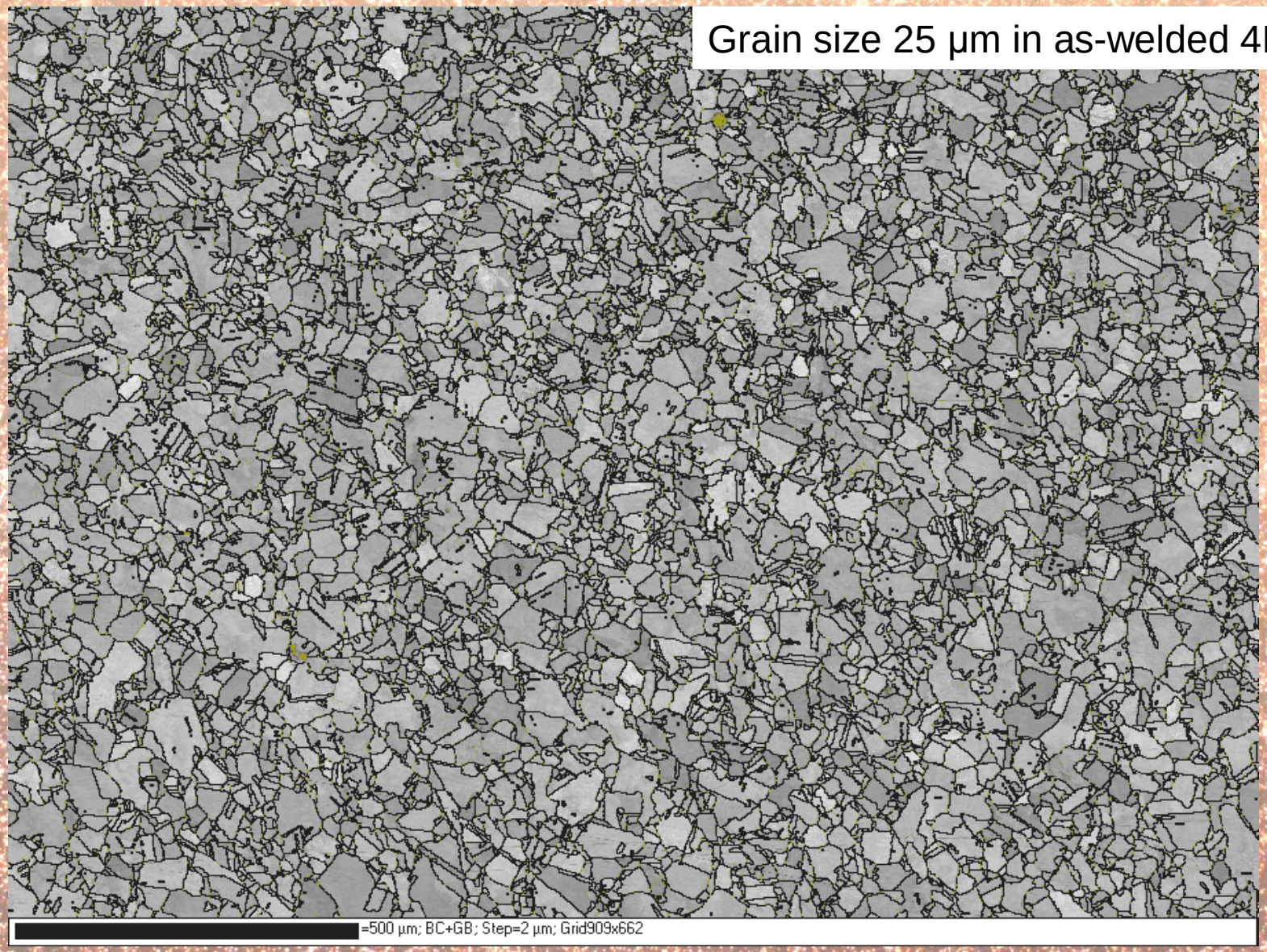
Grain size 80 µm in hydrogen annealed 1DV



Helsinki University of Technology
Department of Engineering Design and Production
Laboratory of Engineering Materials

Kati Savolainen

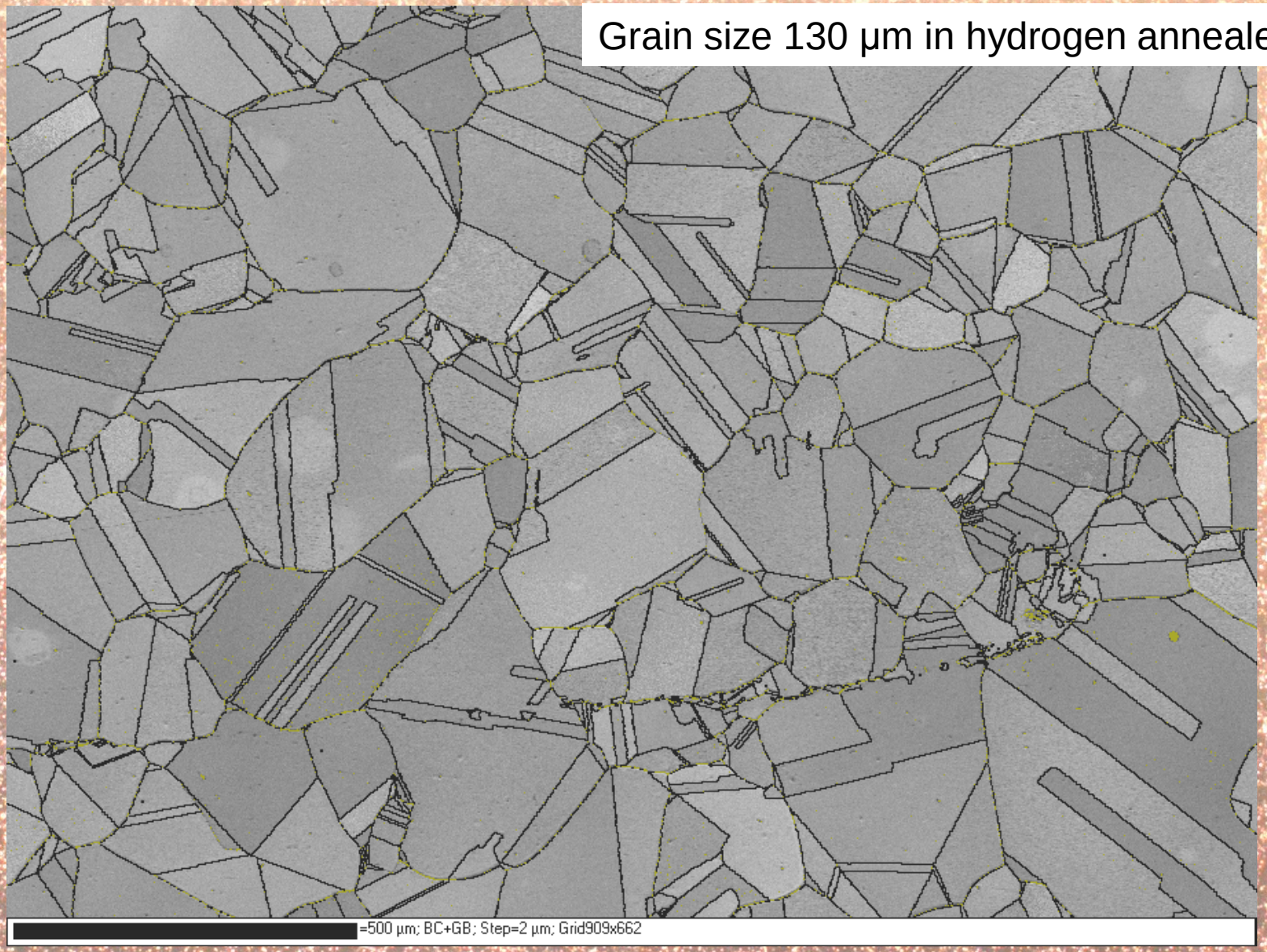
Grain size 25 µm in as-welded 4D



Helsinki University of Technology
Department of Engineering Design and Production
Laboratory of Engineering Materials

Kati Savolainen

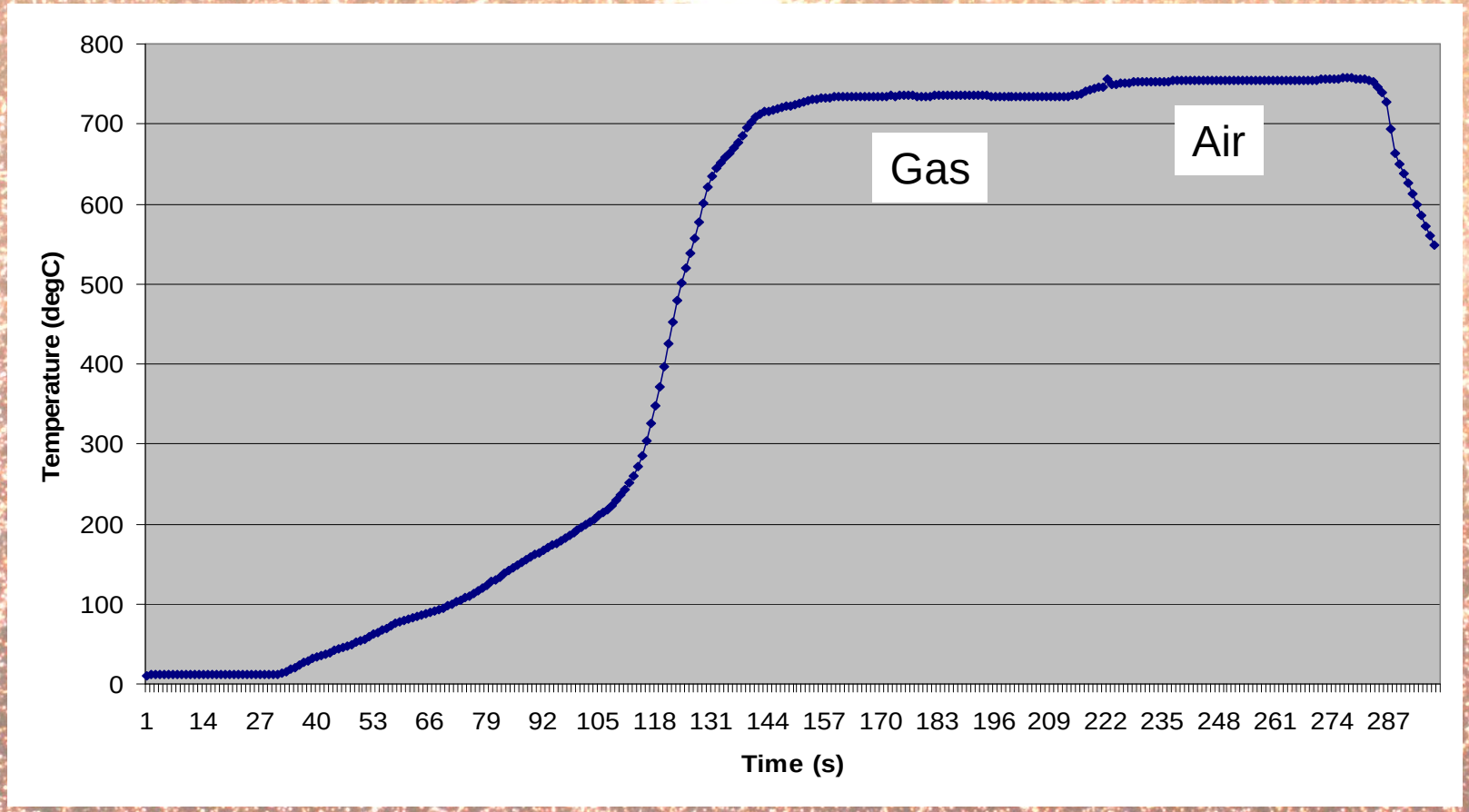
Grain size 130 µm in hydrogen annealed 4DV



Helsinki University of Technology
Department of Engineering Design and Production
Laboratory of Engineering Materials

Kati Savolainen

Temperature Measurements



Helsinki University of Technology
Department of Engineering Design and Production
Laboratory of Engineering Materials

Kati Savolainen

Conclusions

- Combination of oxide removal and shielding gas gives the best results
- Small grain size near the oxide particles even after hydrogen annealing
- Vertical feature of entrapped oxide particles from the butting faces

Conclusions

- Use of shielding gas (argon) reduces the welding temperature
- Higher hardness and smaller grain size in the weld than in the base material (Hall-Petch effect)