

The background of the slide is a high-magnification micrograph of a copper friction stir weld. It shows a complex, granular texture with various shades of orange, brown, and yellow. A prominent, bright, vertical line runs through the center-left of the image, likely representing the weld interface or a region of high oxide concentration. The overall appearance is that of a metal surface with significant oxidation and possibly entrapped particles.

# Entrapped Oxide Particles in Friction Stir Welds of Copper

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# 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

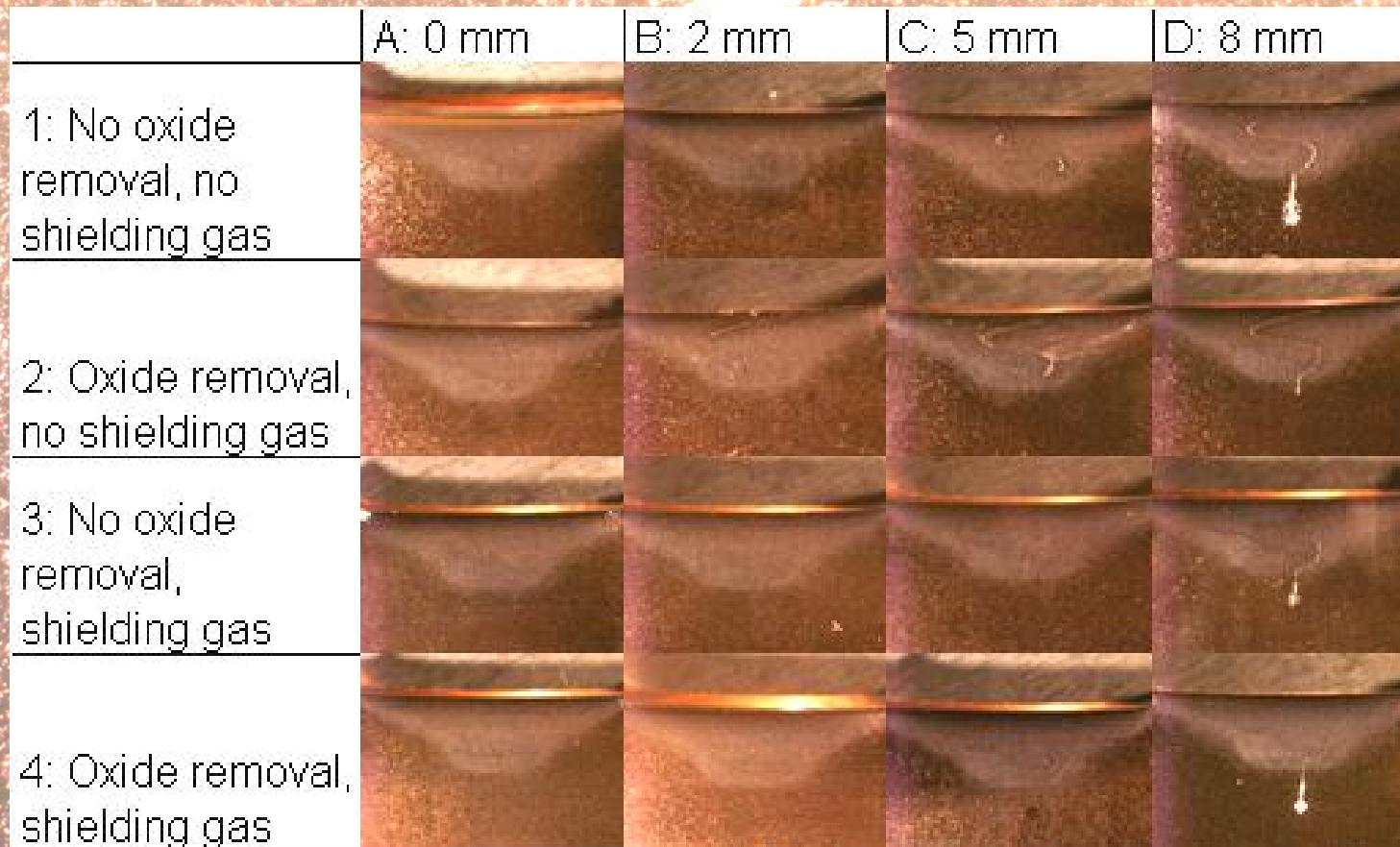
- The combinations:
  - 1: no etching, no shielding gas
  - 2: etching, no shielding gas
  - 3: no etching, shielding gas
  - 4: etching, shielding gas



# Experimental and Results

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

# Macroscopy





0 mm



2 mm



5 mm



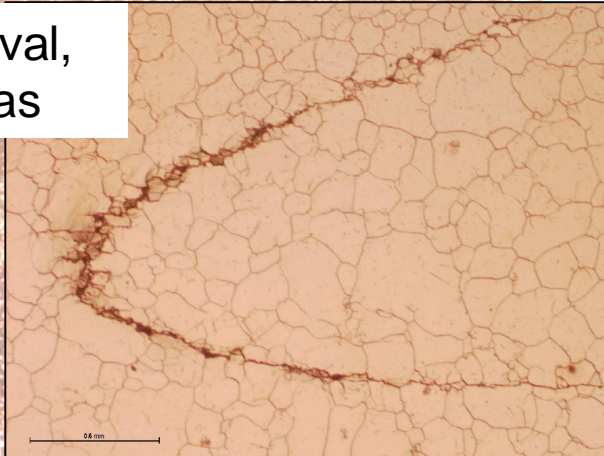
8 mm



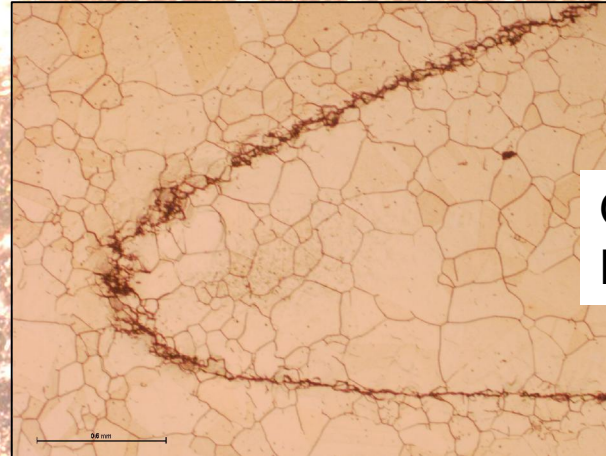


# Microscopy

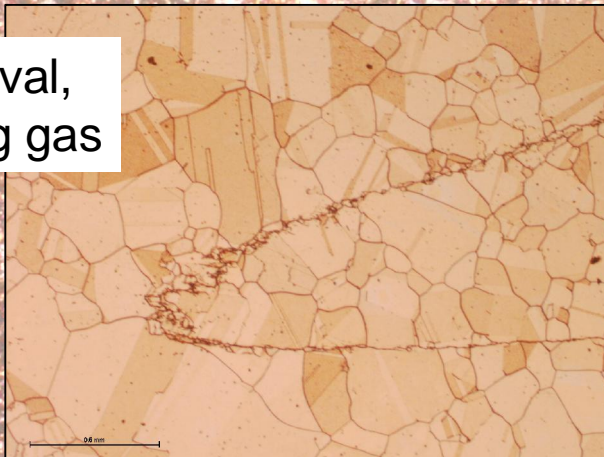
No oxide removal,  
No shielding gas



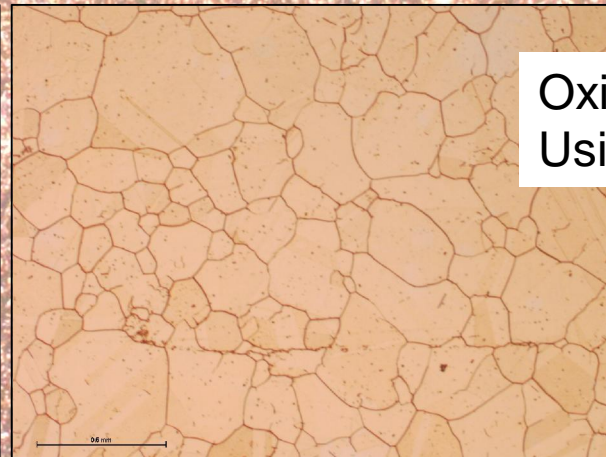
Oxide removal,  
No shielding gas



No oxide removal,  
Using shielding gas



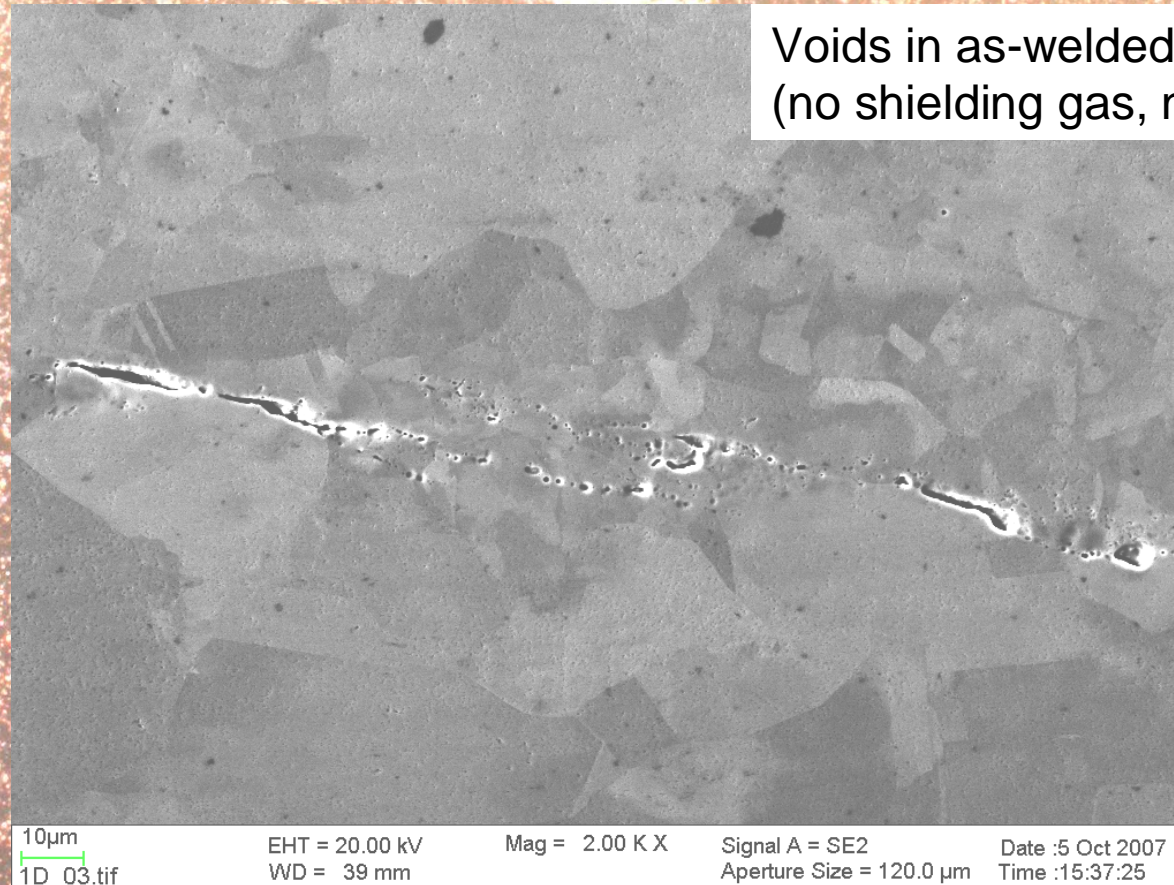
Oxide removal,  
Using shielding gas





# SEM Studies

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

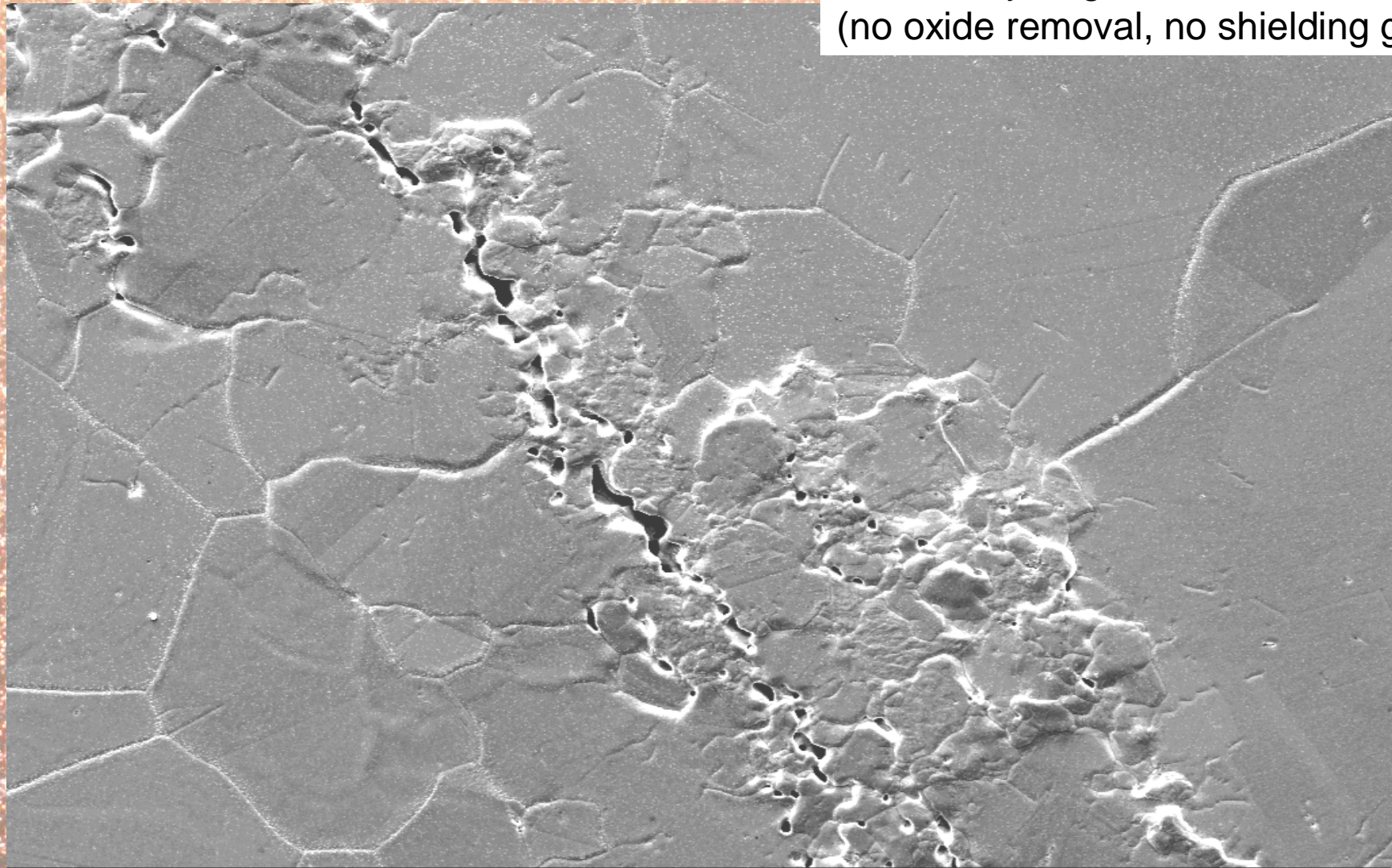


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Voids in hydrogen annealed 1D  
(no oxide removal, no shielding gas)



30µm  
1D\_06.tif

EHT = 15.00 kV  
WD = 31 mm

Mag = 1.00 K X

Signal A = SE2  
Aperture Size = 120.0 µm

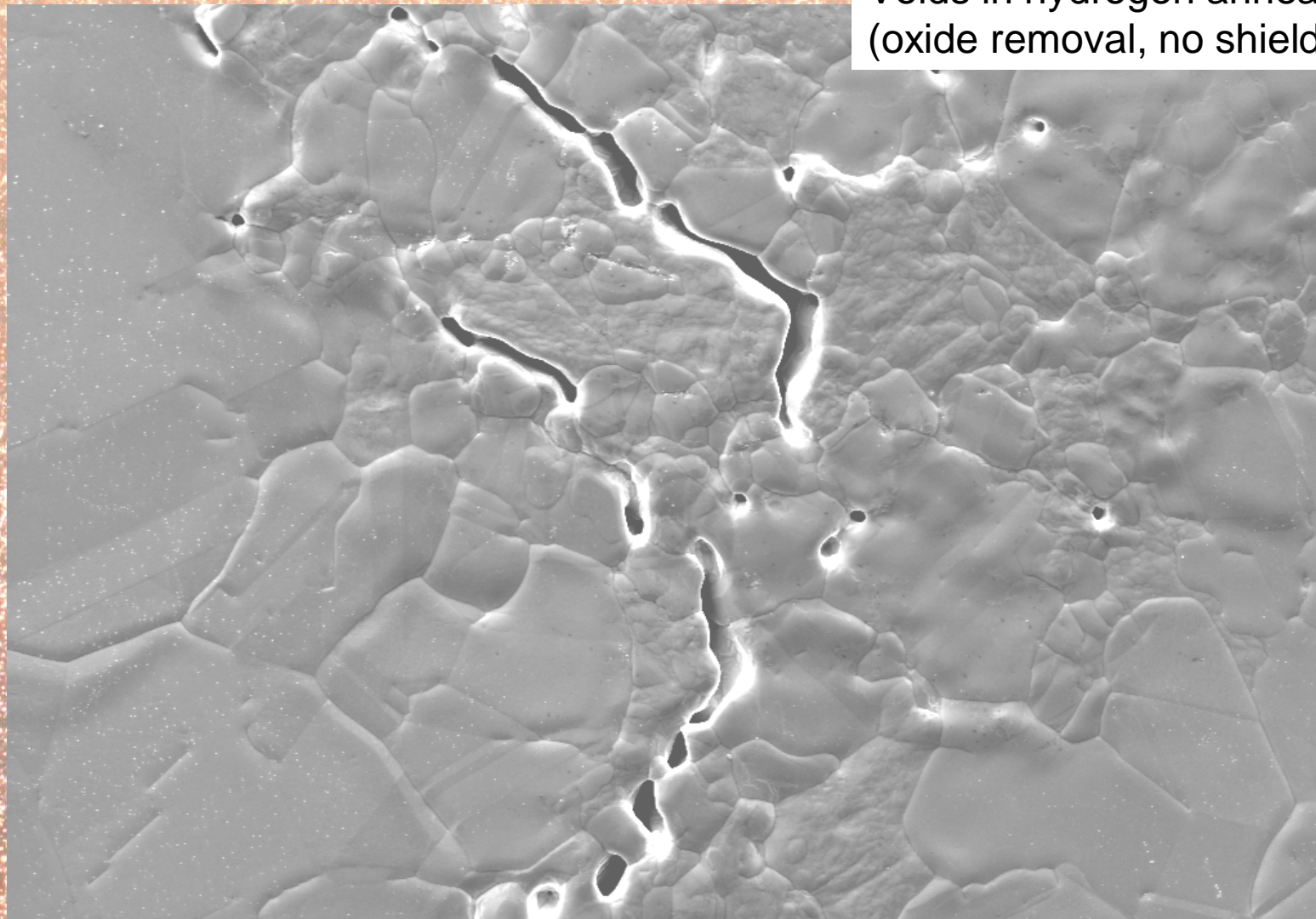
Date :16 Aug 2007  
Time :9:03:50

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



20µm  
2D 28.tif

EHT = 15.00 kV  
WD = 30 mm

Mag = 2.00 K X

Signal A = SE2  
Aperture Size = 120.0 µm

Date :16 Aug 2007  
Time :9:42:11

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



100µm  
3DV 67.tif EHT = 10.00 kV Mag = 300 X Signal A = SE2 Date :5 Oct 2007  
WD = 13 mm Aperture Size = 120.0 µm Time :18:28:51

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



20µm  
4D\_14.tif

EHT = 15.00 kV  
WD = 17 mm

Mag = 2.02 K X

Signal A = SE2  
Aperture Size = 120.0 µm

Date :16 Aug 2007  
Time :9:17:55

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# SEM and EBSD Studies

	Grain size ( $\mu\text{m}$ )	
	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

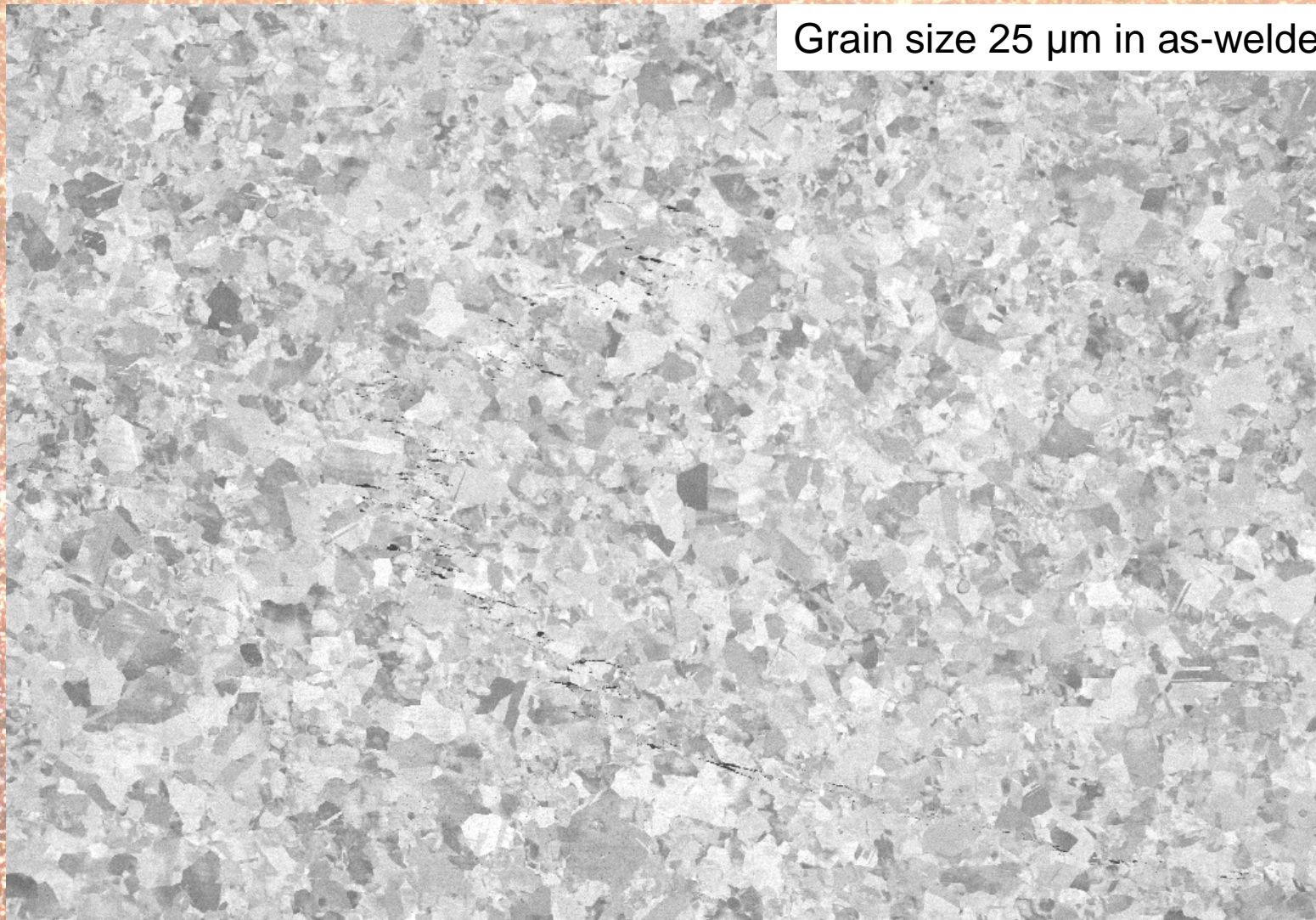


# Pinning Effect of Oxide Particles

- 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  $\mu\text{m}$  in as-welded 1D



100 $\mu\text{m}$   
1D\_07.tif

EHT = 10.00 kV  
WD = 11 mm

Mag = 200 X

Signal A = QBSD  
Aperture Size = 120.0  $\mu\text{m}$

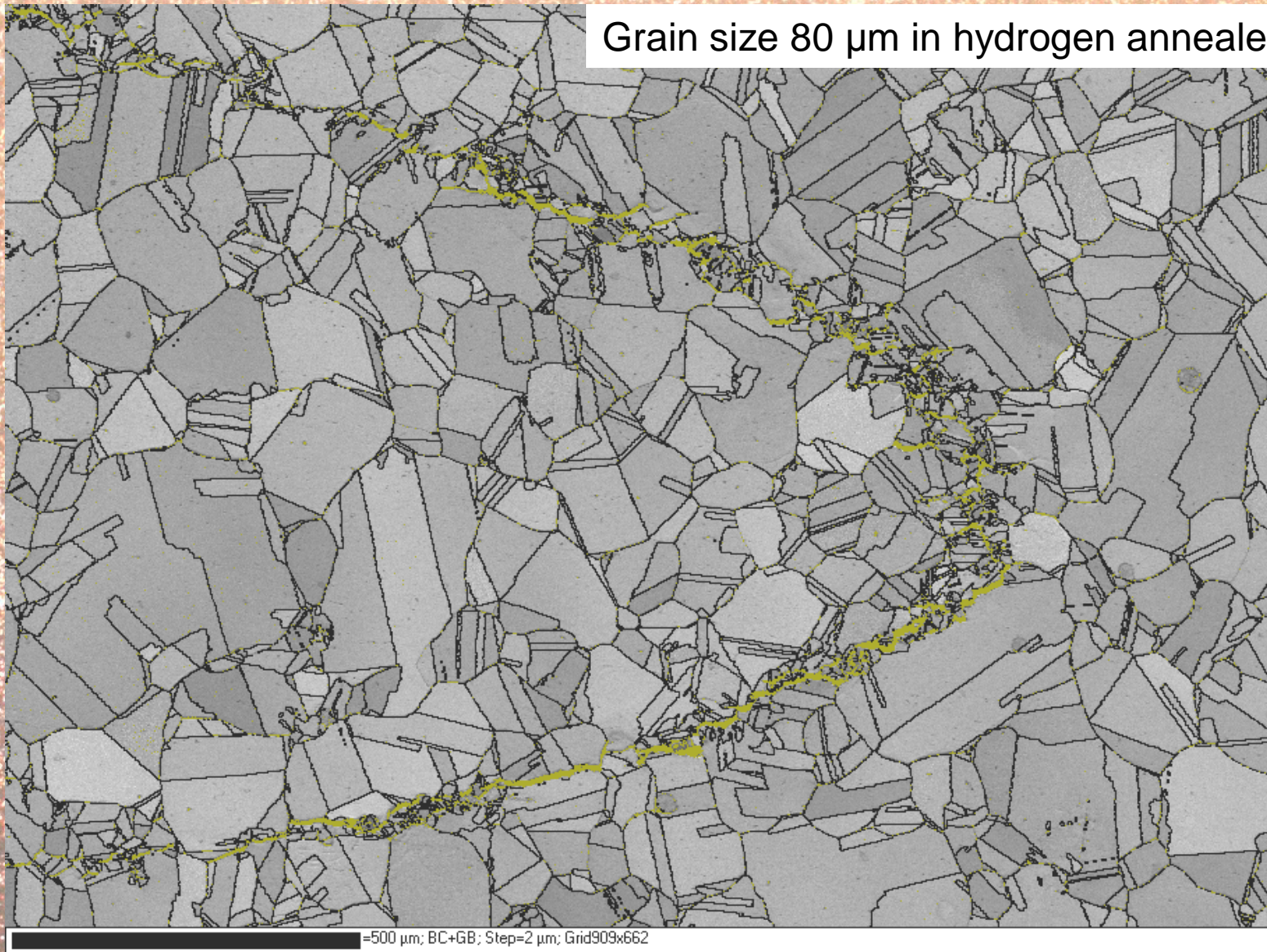
Date :5 Oct 2007  
Time :15:47:26

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Grain size 80  $\mu\text{m}$  in hydrogen annealed 1DV

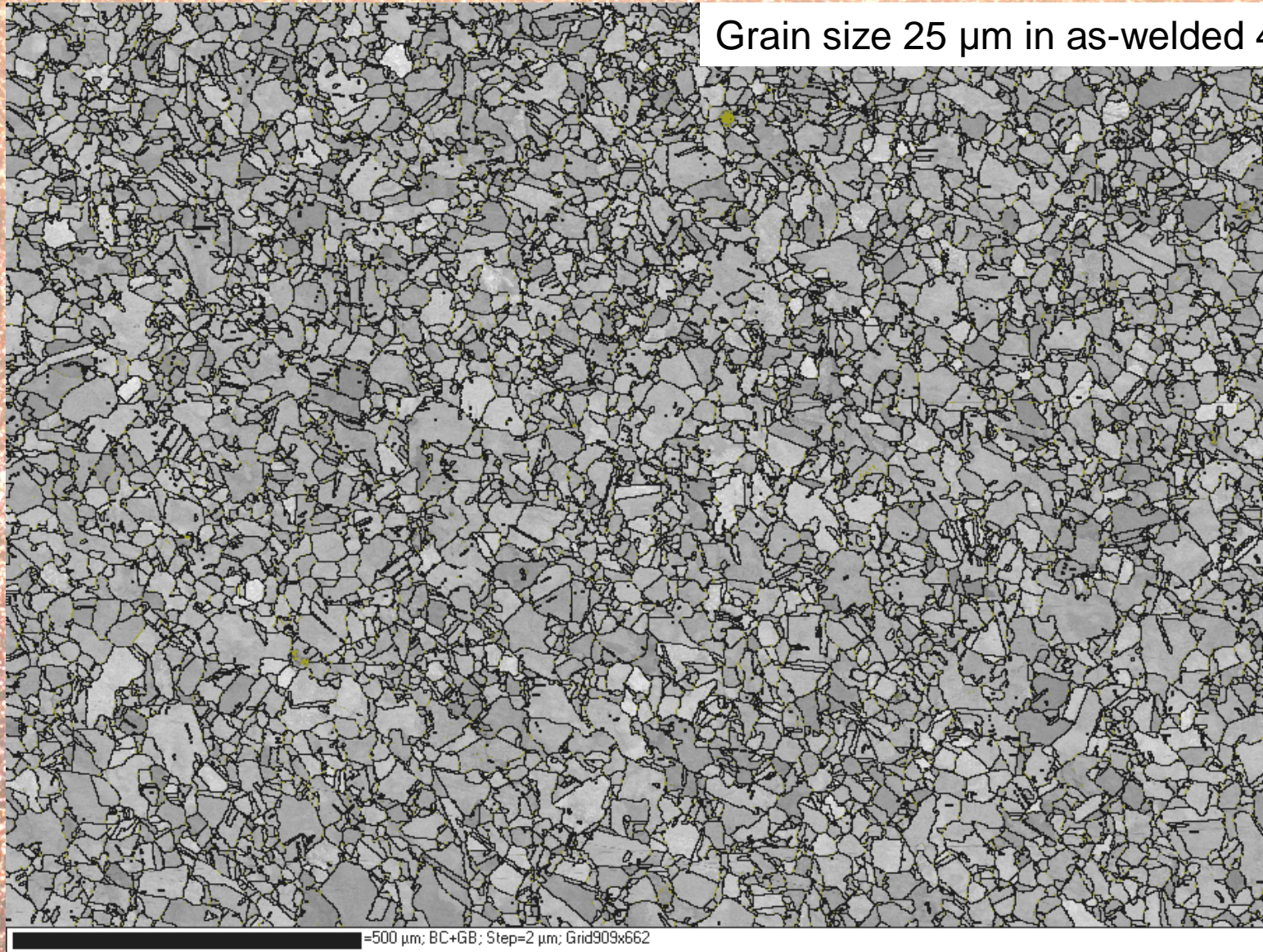


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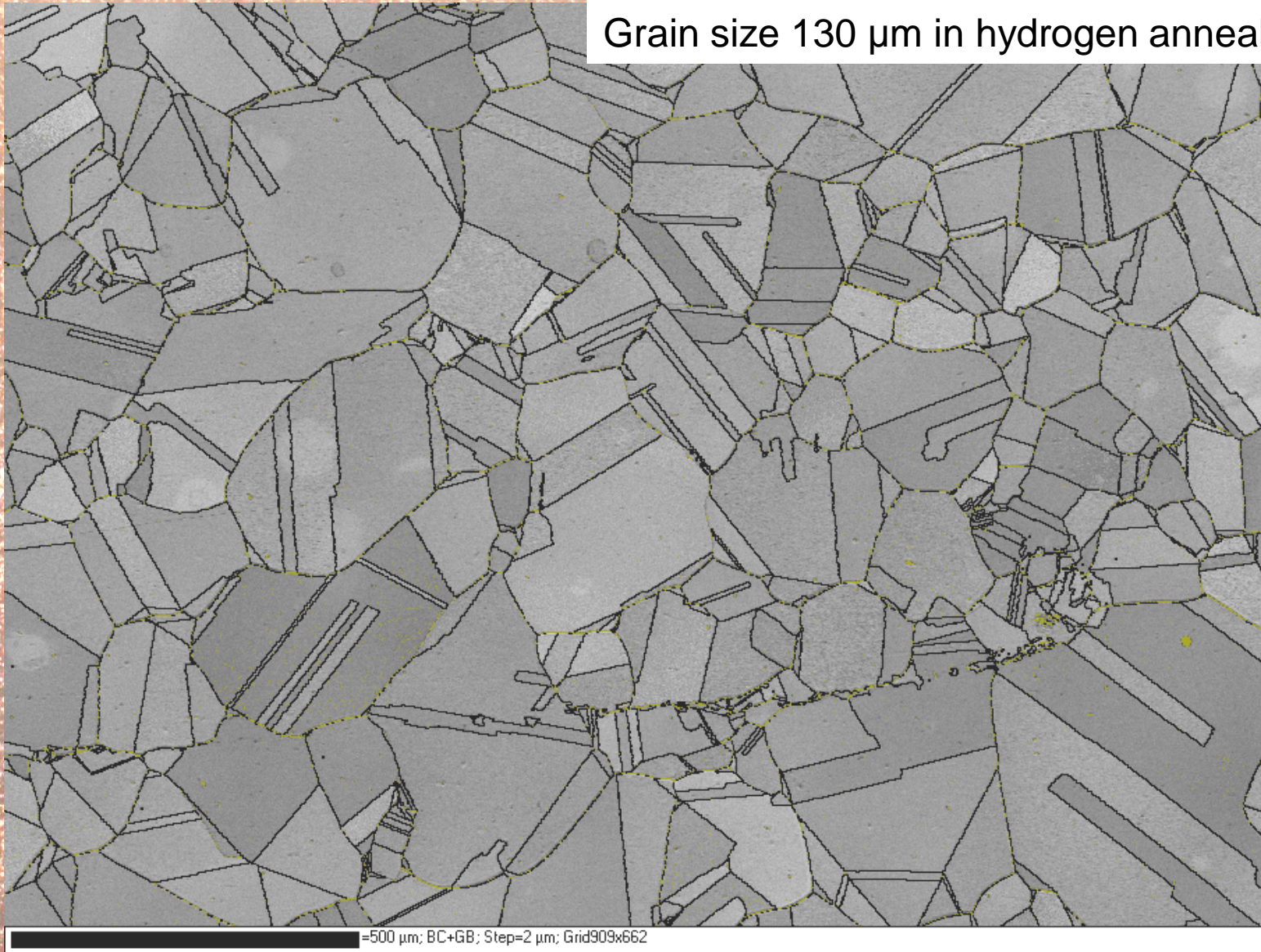


Grain size 25  $\mu\text{m}$  in as-welded 4D





Grain size 130  $\mu\text{m}$  in hydrogen annealed 4DV

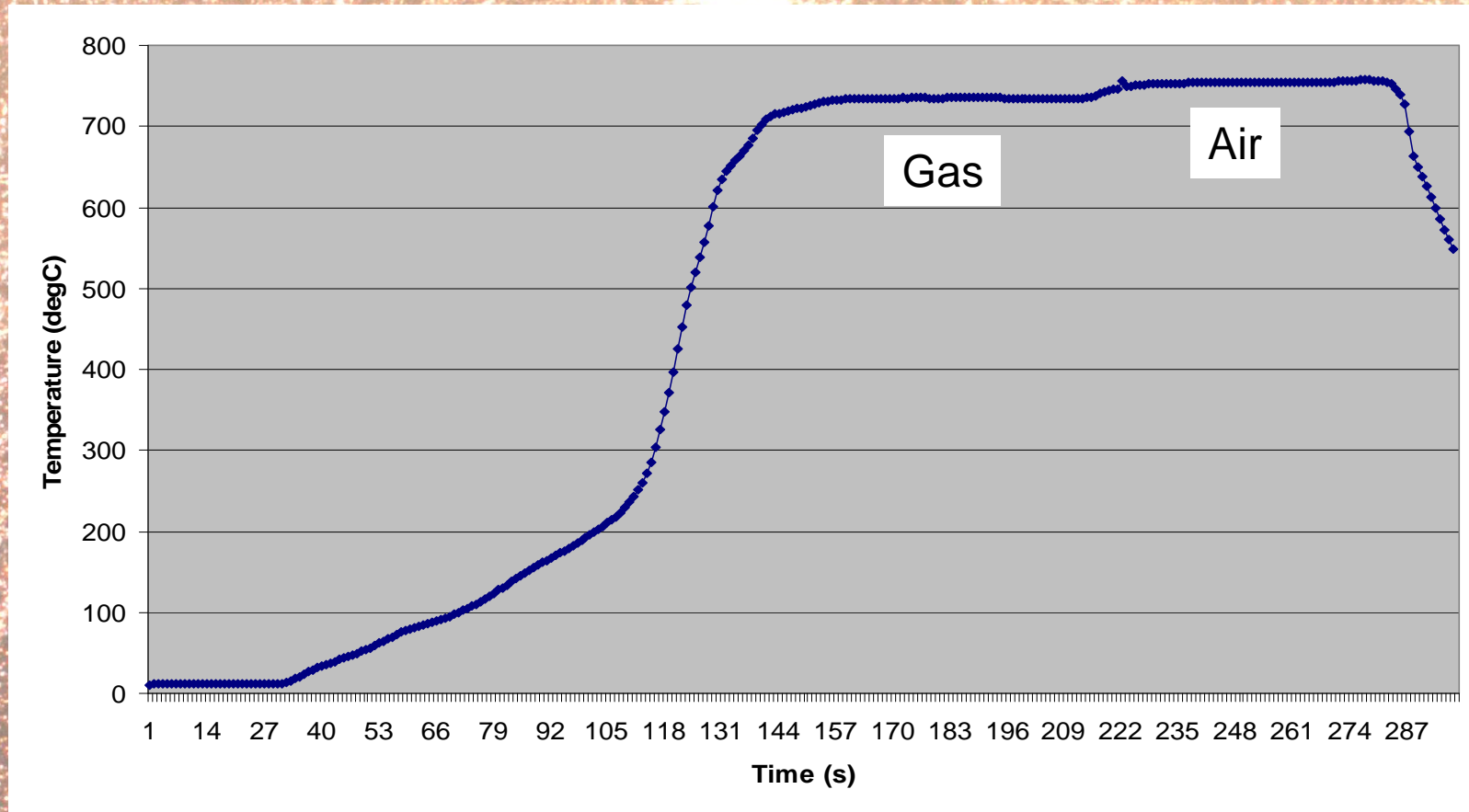


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# Temperature Measurements





# 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)