Karlsruhe Institute of Technology

CuCrZr alloys reinforced by Tungsten

A candidate material for structural Divertor applications for DEMO

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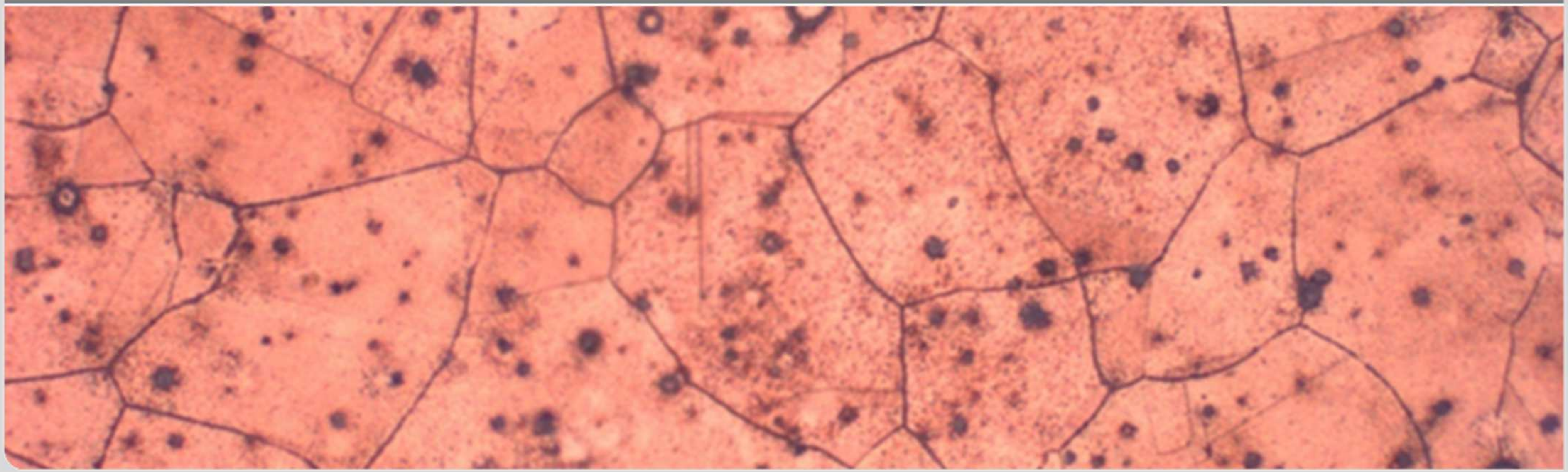
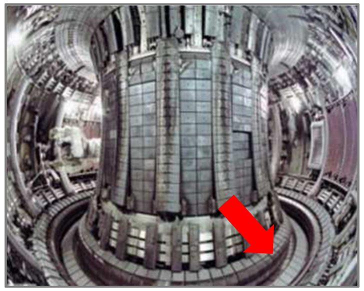
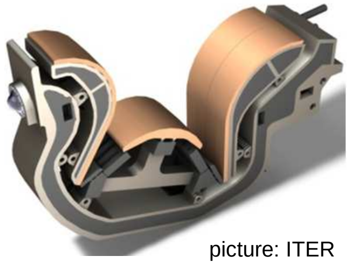
KARLSRUHE INSTITUE OF TECHNOLOGY – Campus Nord, INSTITUTE FOR APPLIED MATERIALS



Motivation / Operating conditions / Design

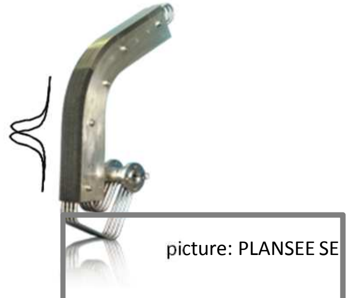


Tokamak fusion reactor



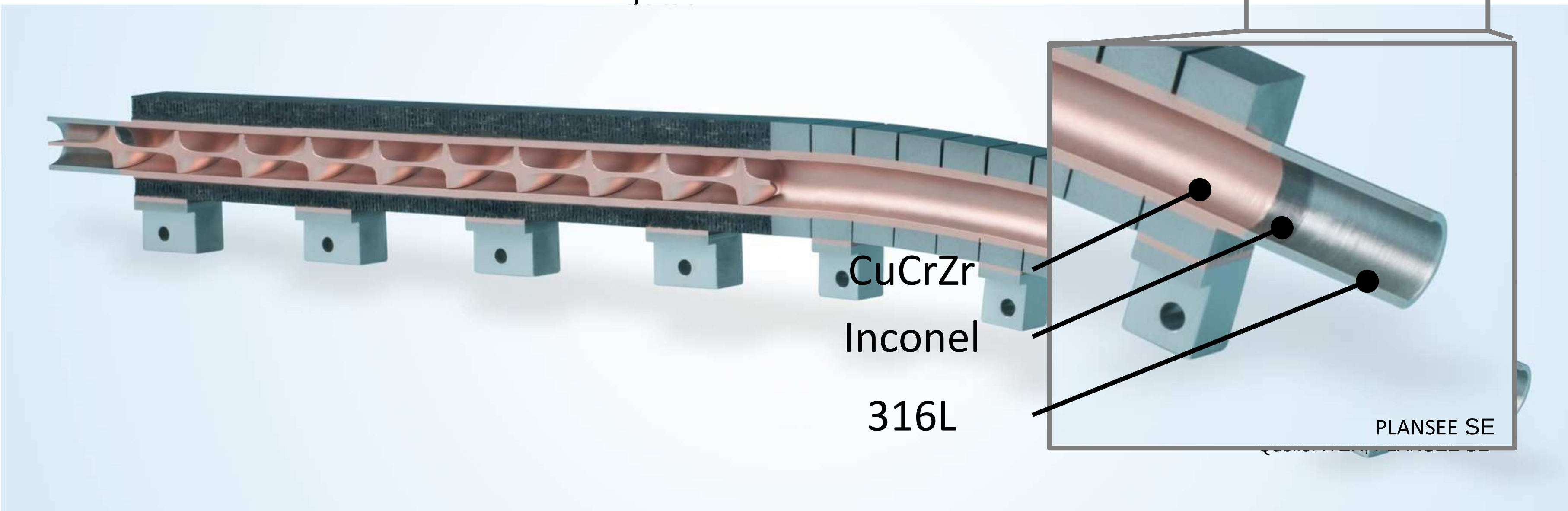
picture: ITER

Divertor cassette:
inner/outer vertical target,



picture: PLANSEE SE

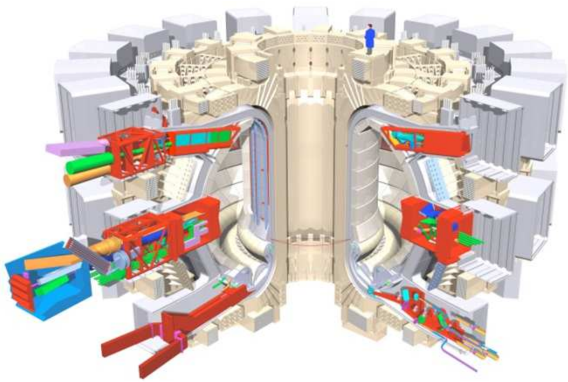
inner/outer vertical
target



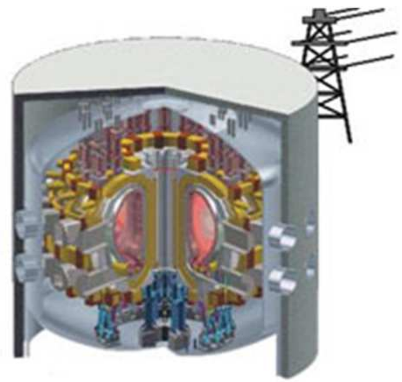
Motivation / Operating conditions / Design

ITER Divertor conditions

Water, 100 bar pressure, 40°C temperature



picture: ITER



picture: ITER

DEMO conditions

- Massive increase in neutron load
- Necessary increase of cooling temperature: e.g. 200°C, 160 bar
- CuCrZr has to be strengthened
- Secondary stresses in the monoblock have to be decreased

Adjustment of the different CTEs!

Copper and Tungsten in Fusion

CuCrZr

www.normalien.de

- ✓ Excellent thermal conductivity!
- ✓ Good ductility
- ✓ Improved mechanical properties (compared to Copper)

- – Still too weak mechanical properties (low strength)
- – Application temperature is limited!

Tungsten

www.tungstenmoly.com

- ✓ Good thermal conductivity!
- ✓ Very high temperature material
- ✓ Good strength

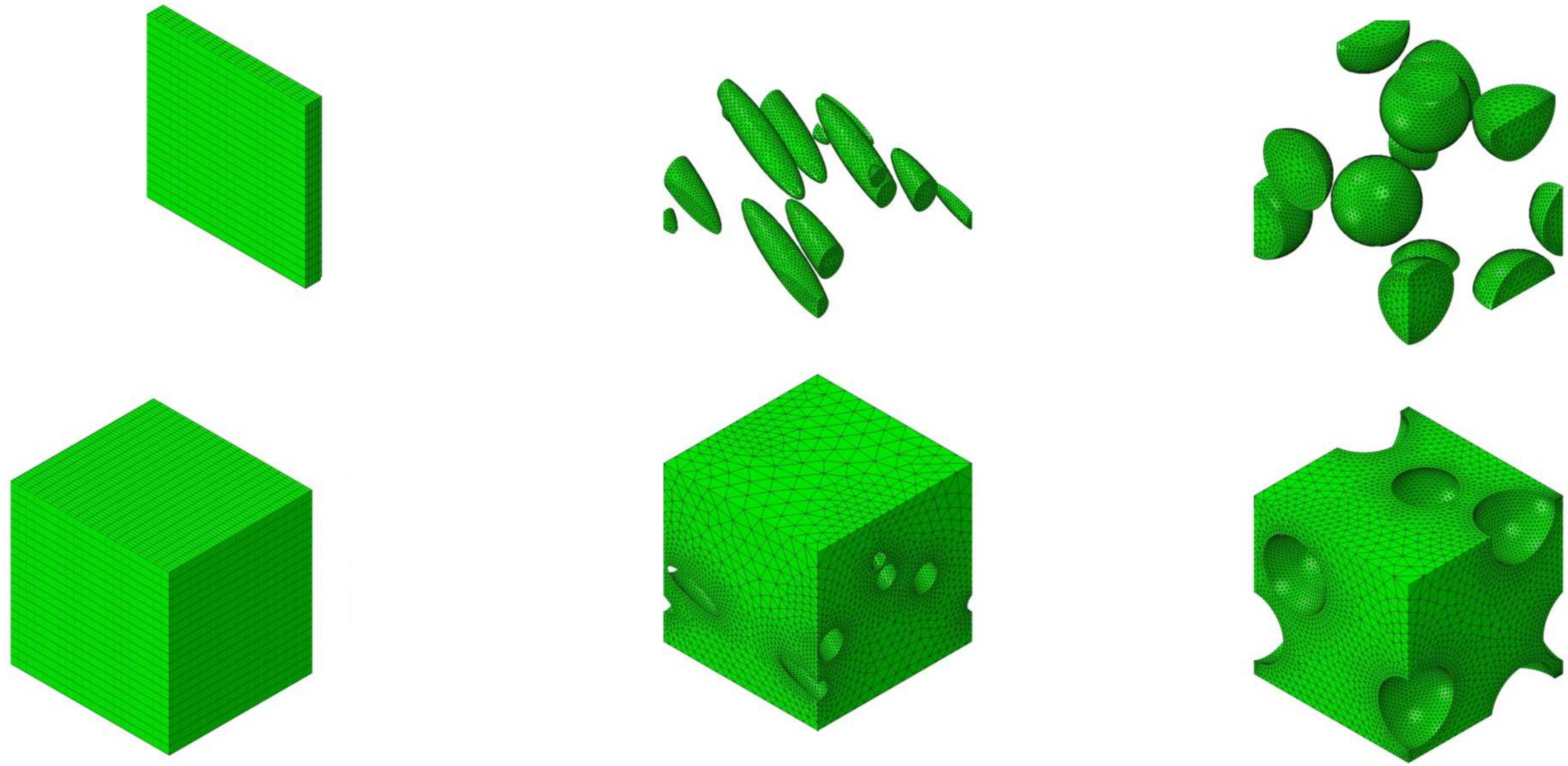
- – Poor ductility
- – Not applicable as structural material

Solution?

Combining the best of both sides in a composite material…

Copper and Tungsten composites

Strategies:



Laminate structures

-> see talk by S. Bonk Thursday Session i5, 11 am

Fiber reinforced

<u>Particle reinforced</u>

Pre Study of CuCrZr (ITER grade)

CuCr0.8Zr0.1 plate material

Alloy	Alloying Element (wt.%)			
	Cu	Cr	Zr	Impurities
CuCrZr-IG	Balance	0.6-0.9	0.07-0.15	total < 0.01

ITER specifications for CuCrZr [1]

www.normalien.de

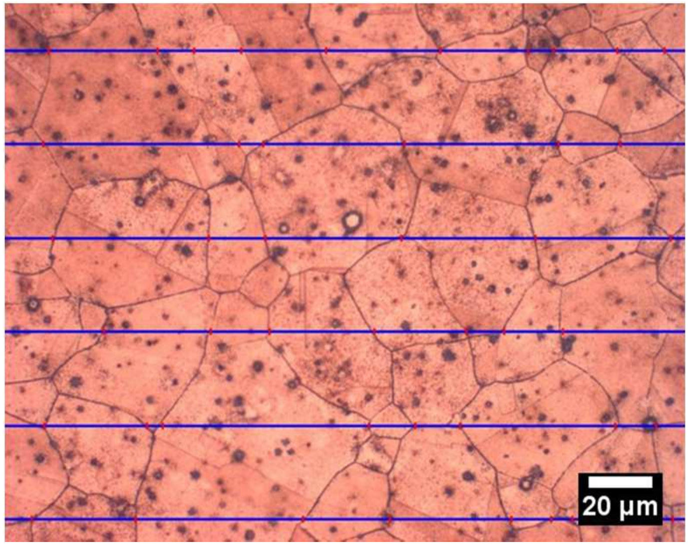
Characterization of Microstructure and hardness

1. Solution annealing @ 1000 °C for 1 hour
2. Water quenching

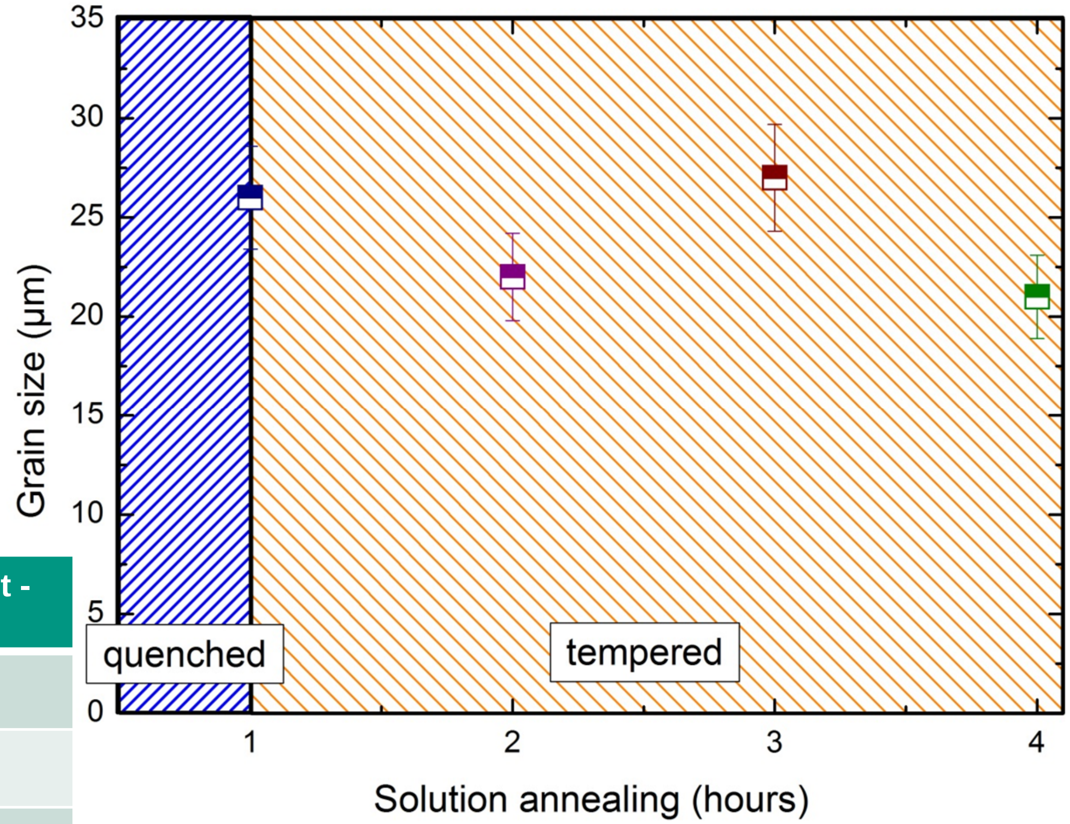
3. Variation of Ageing @ 450 °C for **2 / 3 / 4 hours**

[1] V. Barabash et al., J. Nucl. Mater., 417 (2011) 904-907.

Pre Study of CuCrZr (ITER grade)

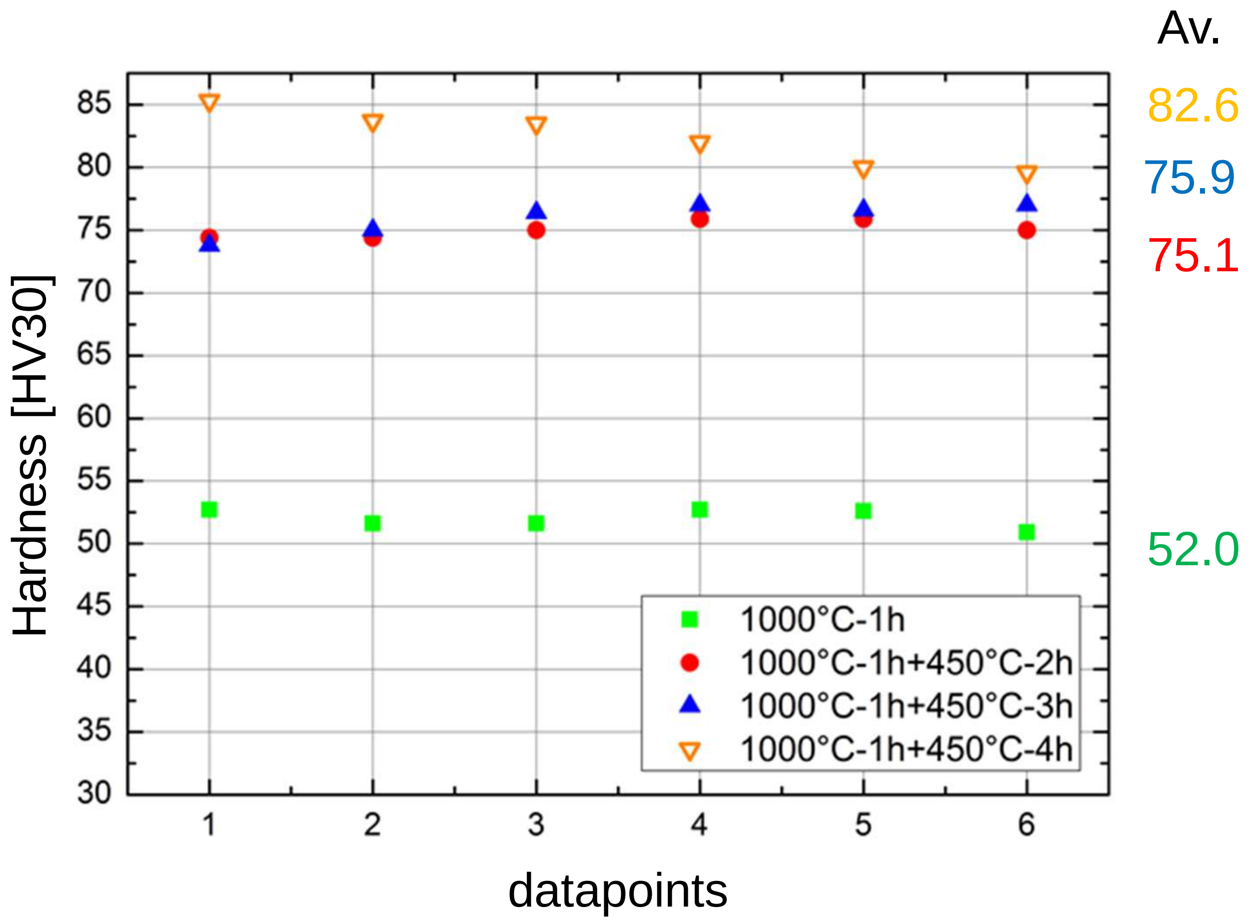


Grain-Size (Line intercepts)



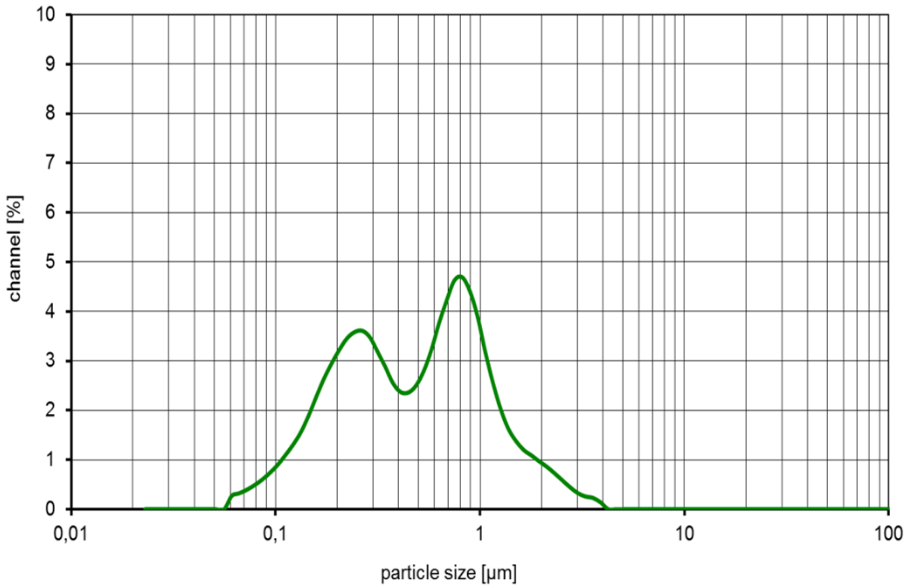
Heat treatment	Grain size (ASTM)	Intercept - length
1000°C-1h	7,3	26µm
1000°C-1h + 450°C-2h	7,7	22µm
1000°C-1h + 450°C-3h	7,2	27µm
1000°C-1h + 450°C-4h	7,9	21µm

Pre Study of CuCrZr (ITER grade)
- Solution annealing and ageing



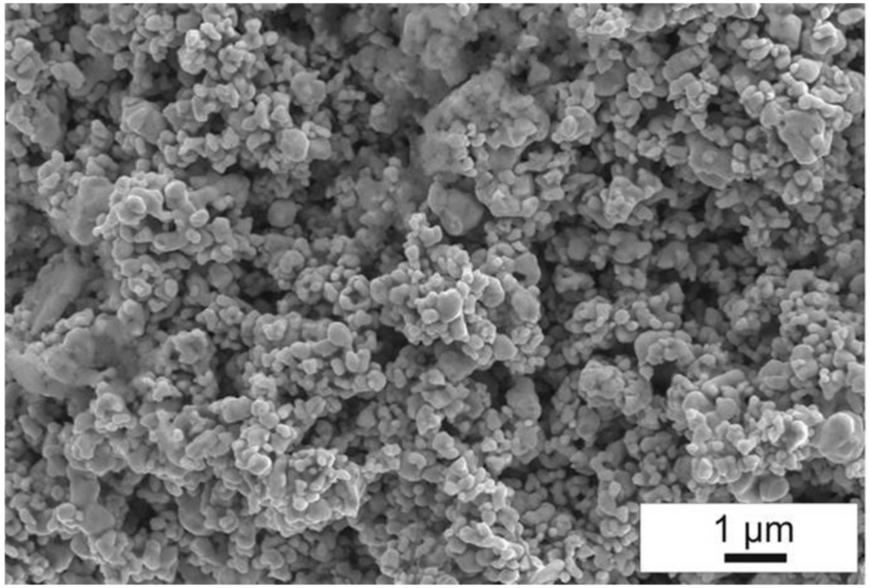
Pre Study of CuCrZr (ITER grade)

CuCr0.8Zr0.1 powder and W powder (as received)



W powder particle size distribution

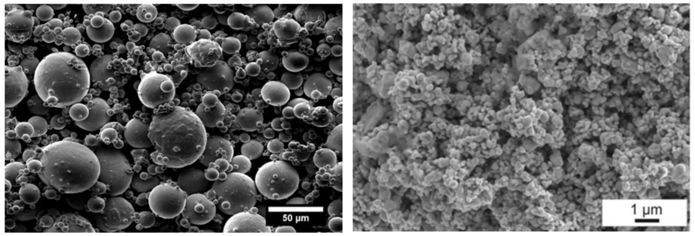
CuCrZr powder particle size ~ 50 µm

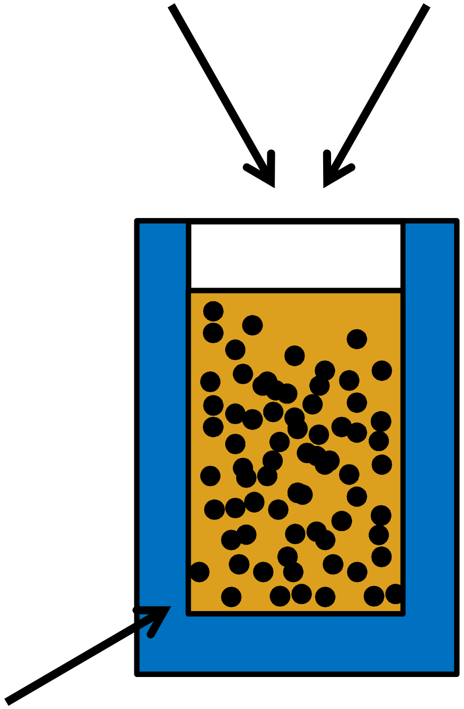


W powder particle size ~ 0.7 µm

Gas-atomized from CuCrZr plates

Pre Study of CuCrZr (ITER grade)





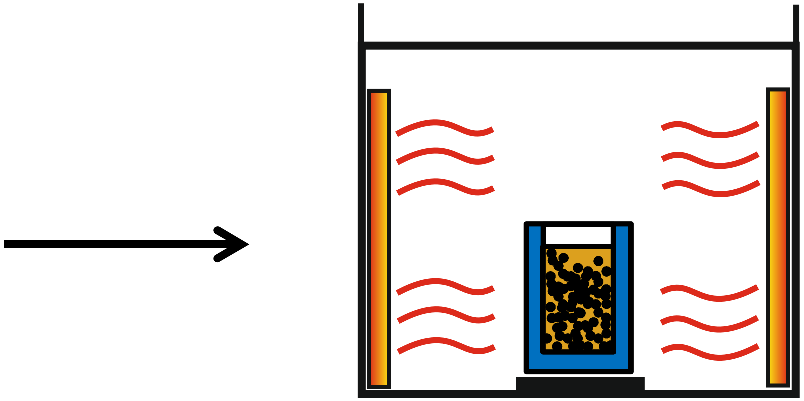
Stainless steel container

Fabrication process:

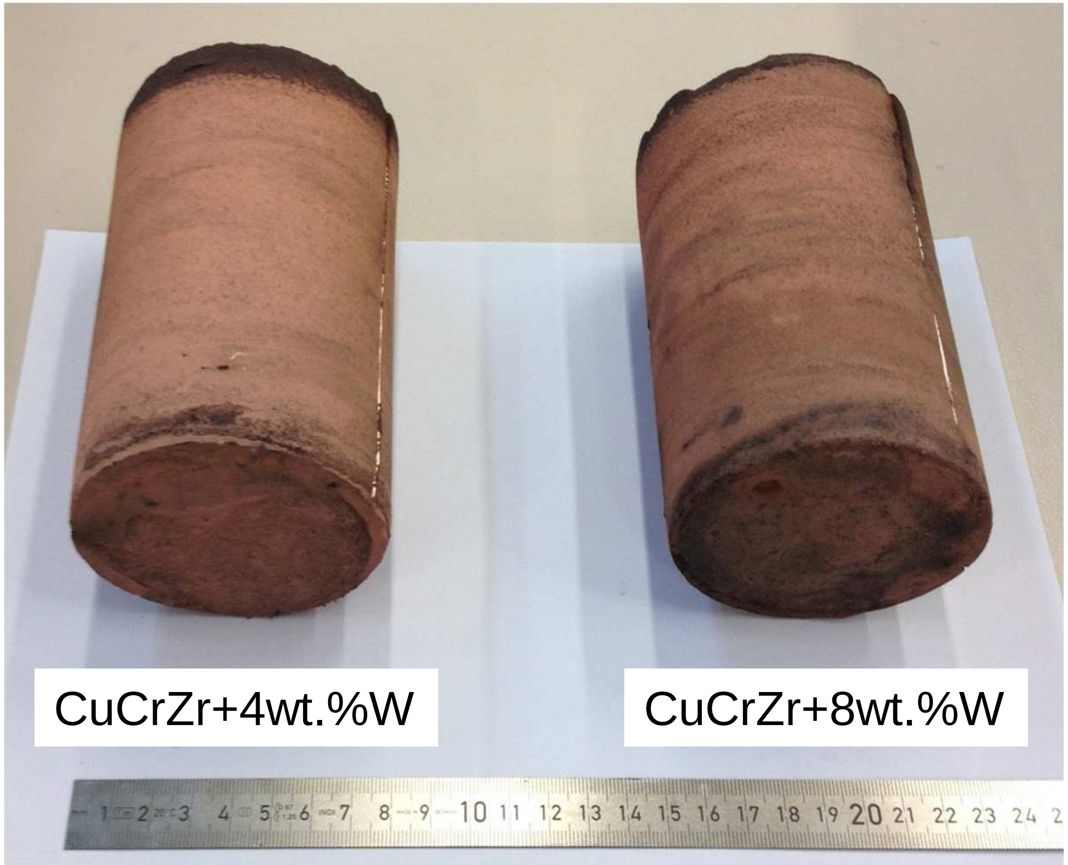
1. Manual mixing of the two powders

   I. CuCrZr-4%W
   II. CuCrZr-8%W

2. Sintering in a furnace at 1000°C for 2 hours

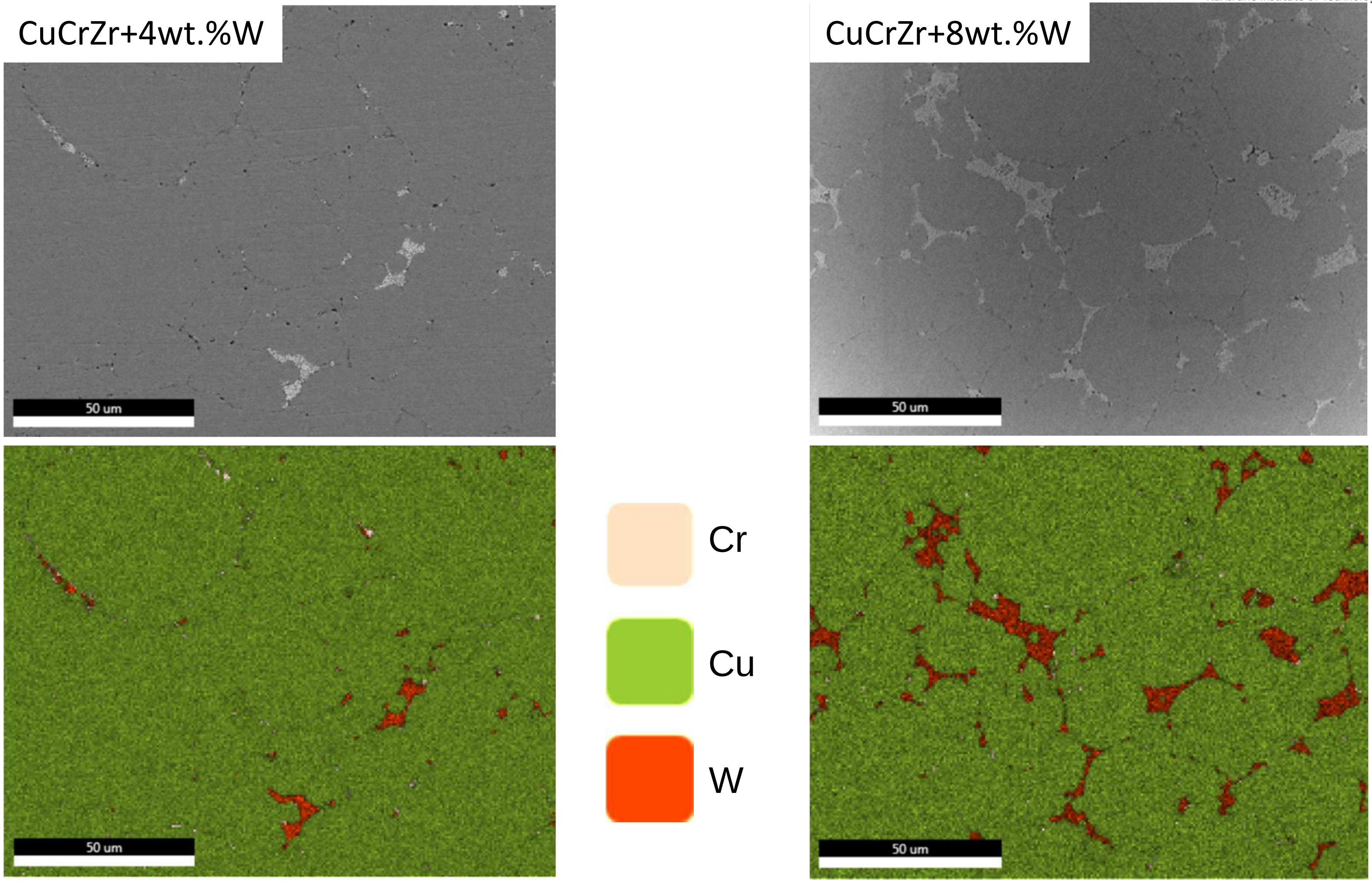


Results: pre-study of W particle reinforcement CuCrZr rods

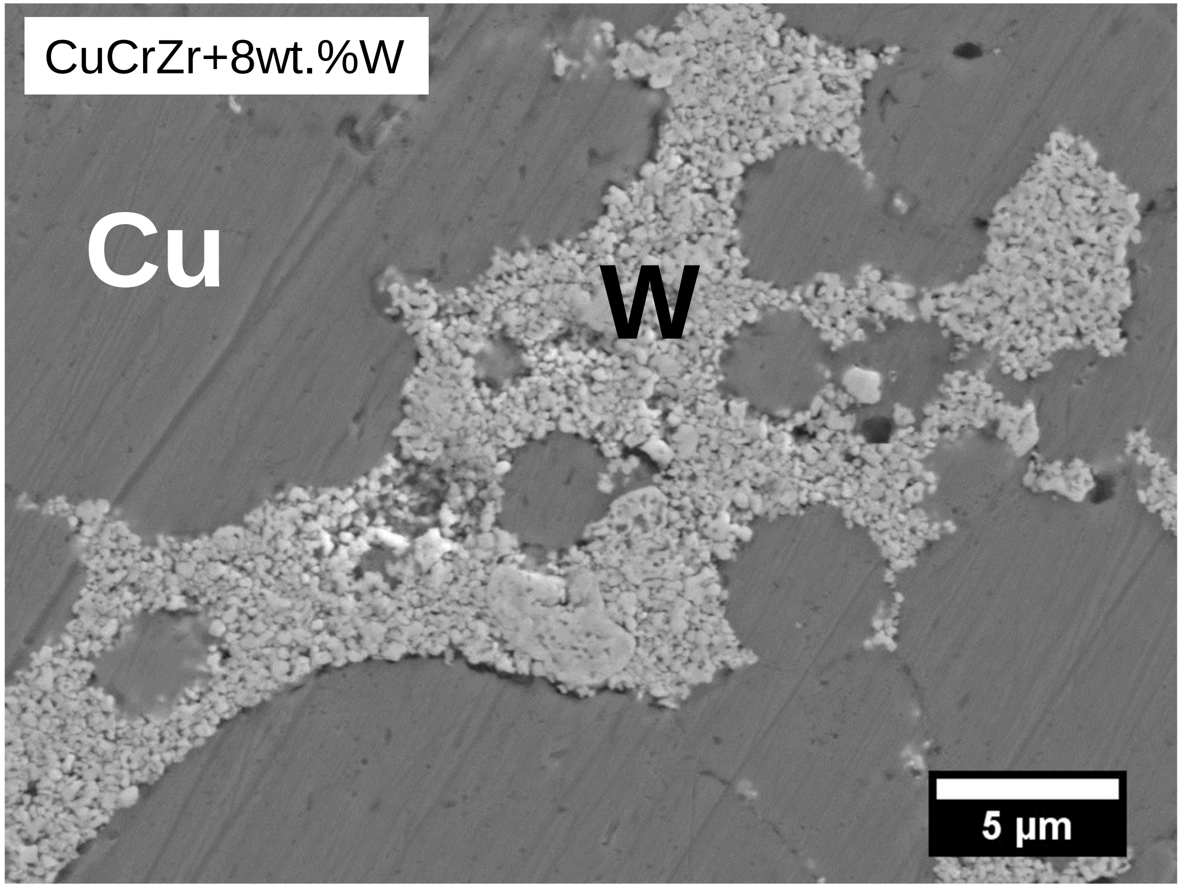


After sintering @ 1000 °C each block: 3800 grams, Ø 80 mm, length 140 mm

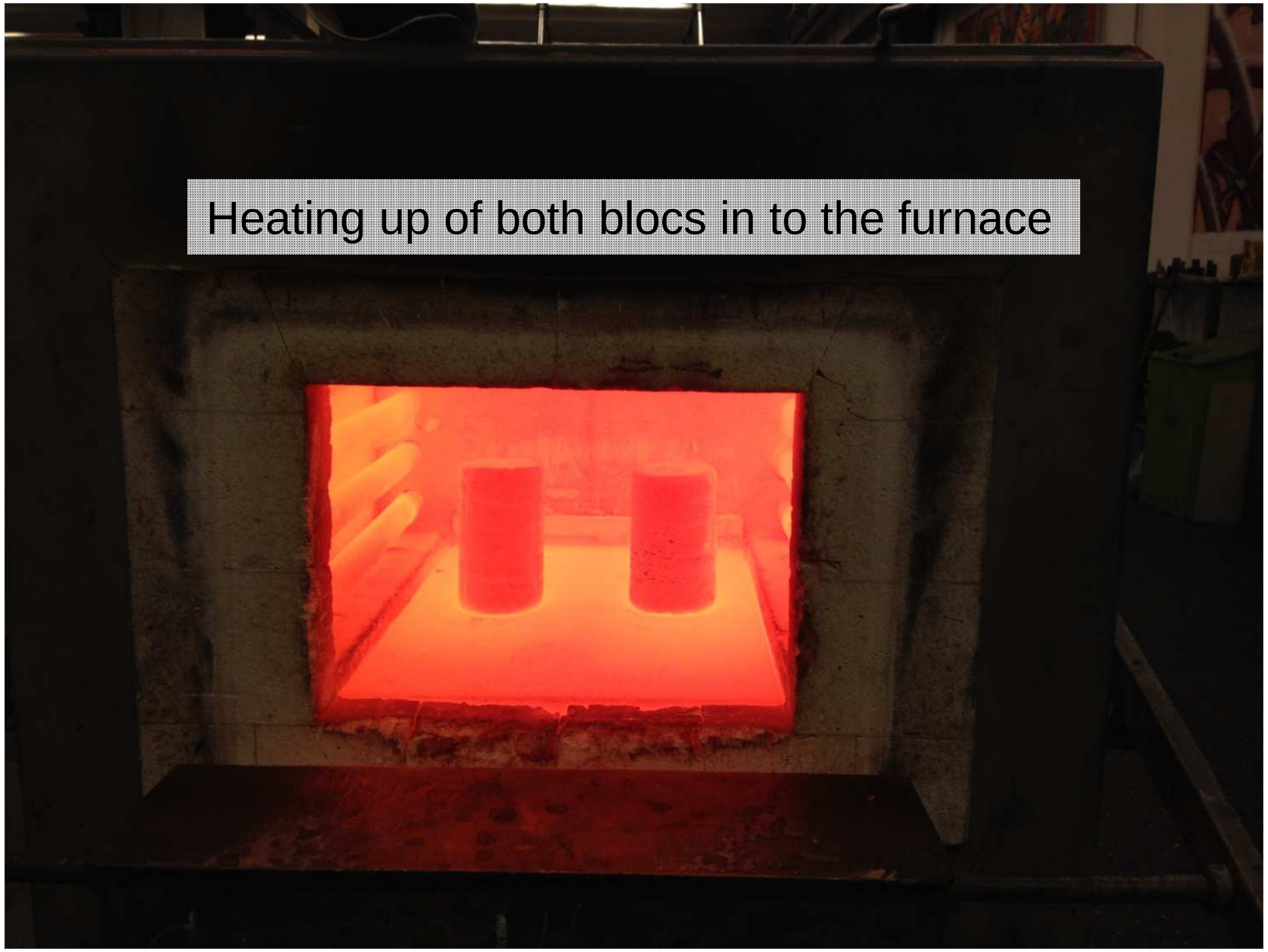
Results: pre-study of W particle reinforcement CuCrZr rods



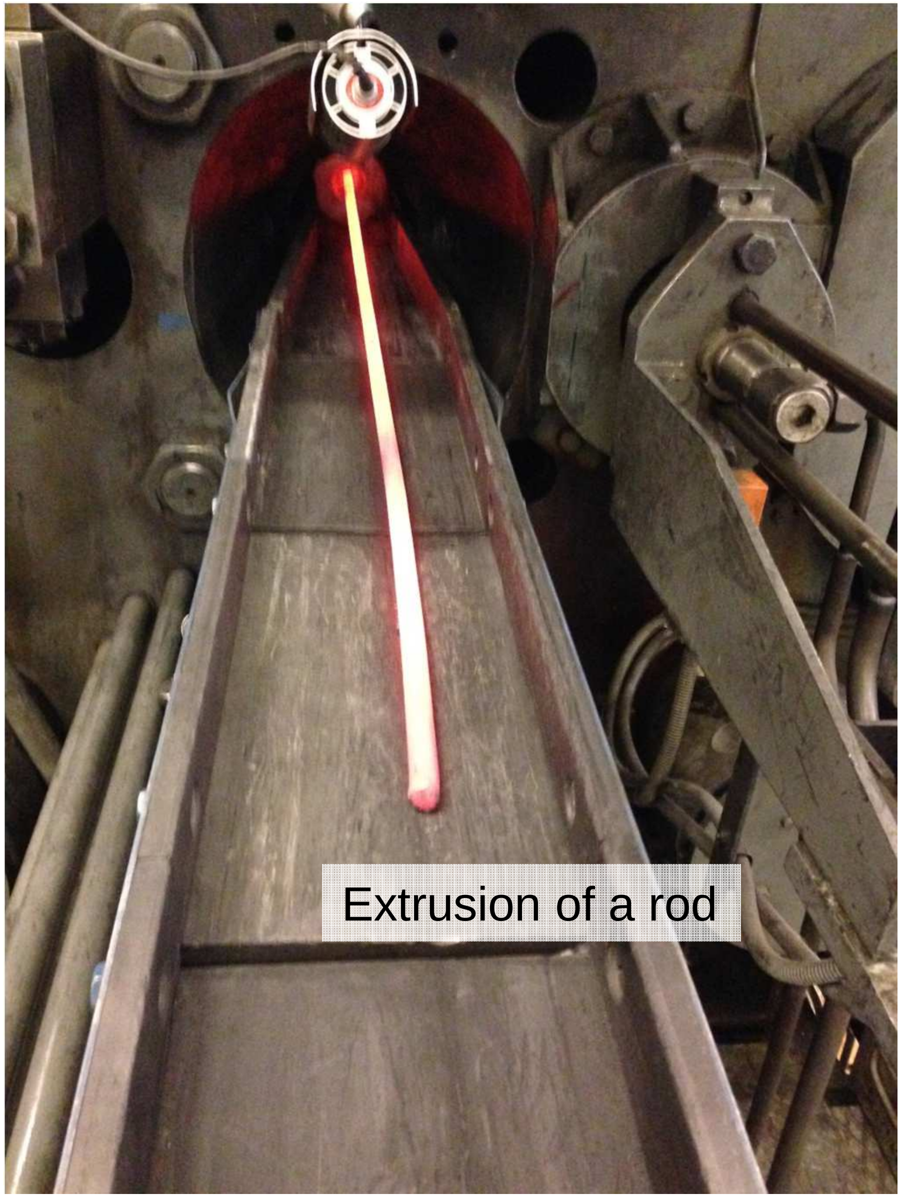
Results: pre-study of W particle reinforcement CuCrZr rods



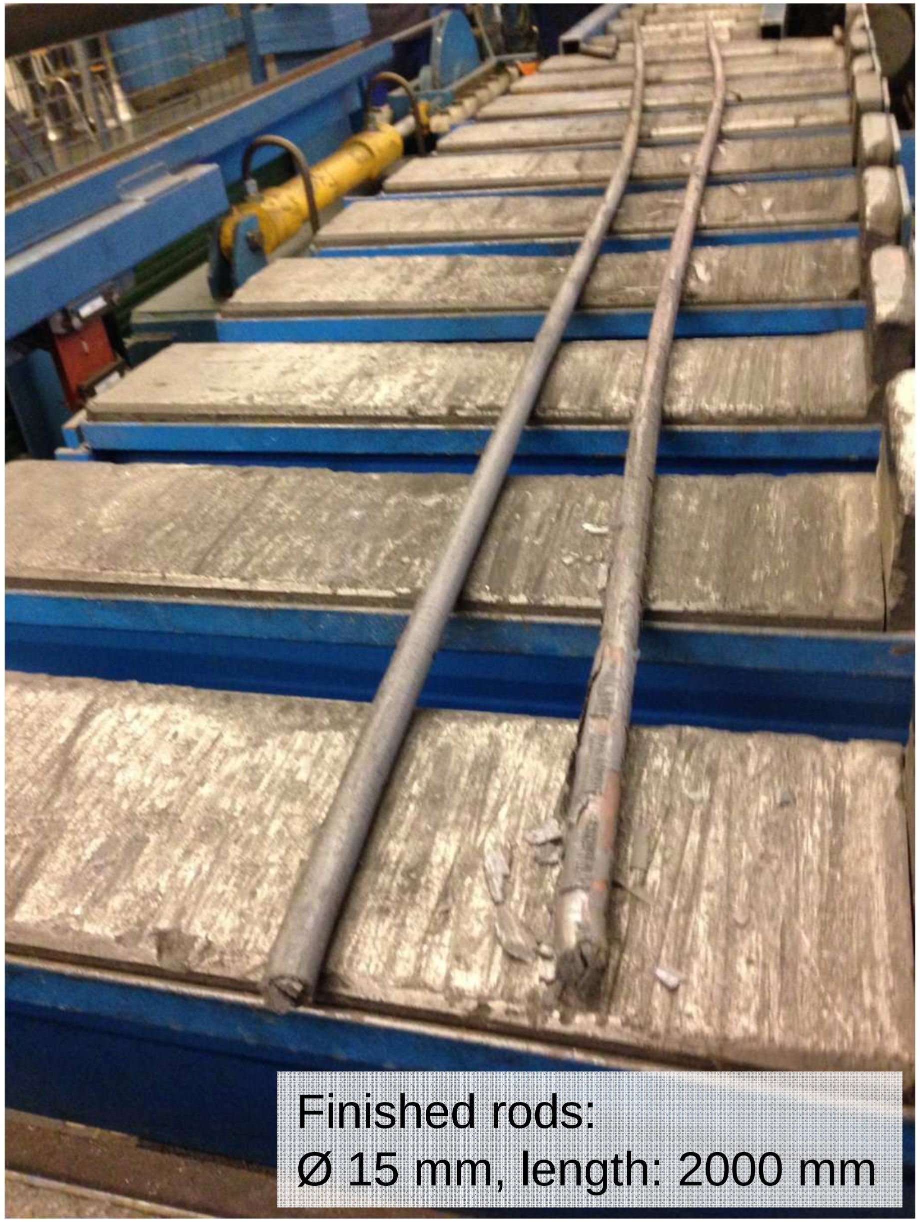
Results: pre-study of W particle reinforcement CuCrZr rods



Results: pre-study of W particle reinforcement CuCrZr rods

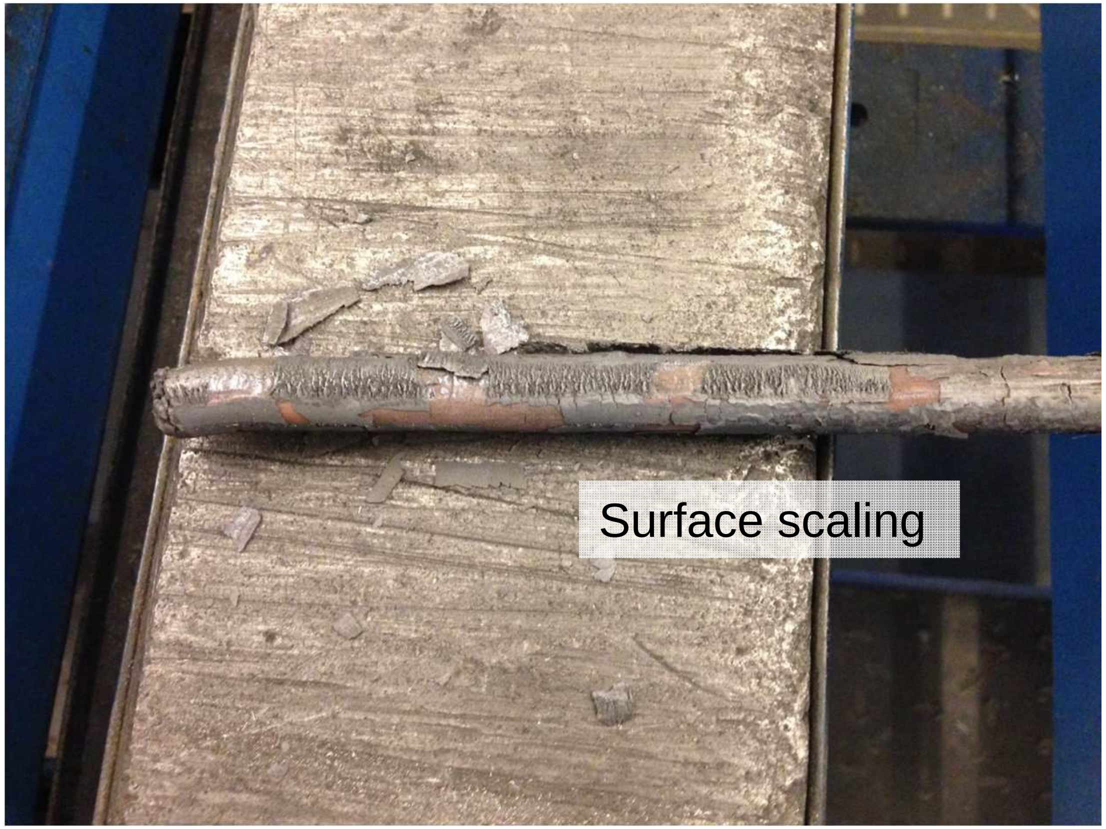


Results: pre-study of W particle reinforcement CuCrZr rods



Finished rods:
Ø 15 mm, length: 2000 mm

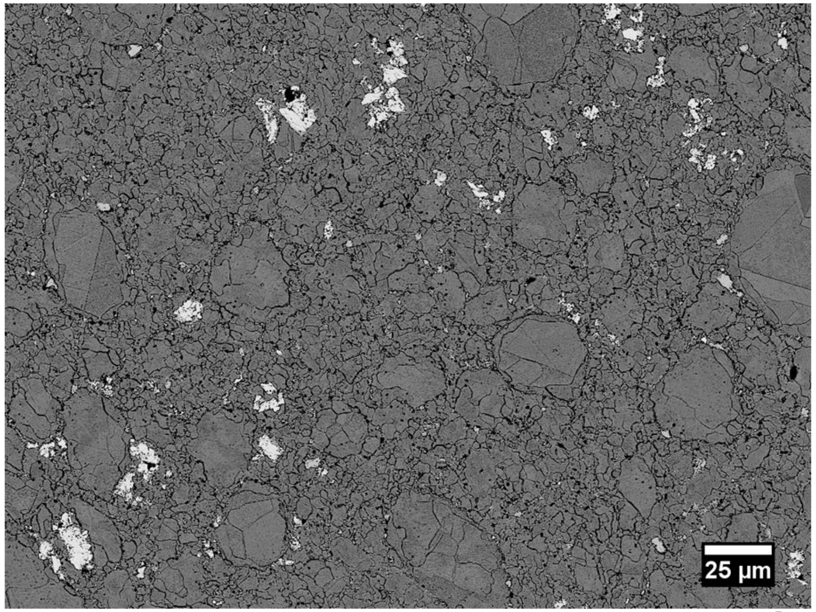
Results: pre-study of W particle reinforcement CuCrZr rods

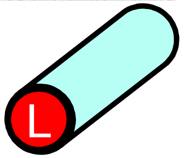


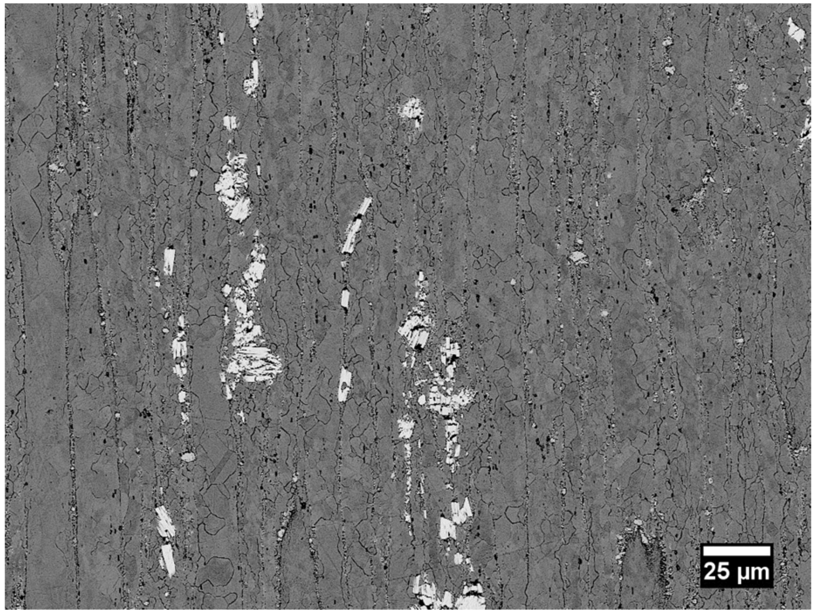
Results: pre-study of W particle reinforcement CuCrZr rods

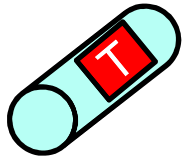
The extruded rods after sandblasting

Microstructure of CuCrZr-W-Rods (SEM)





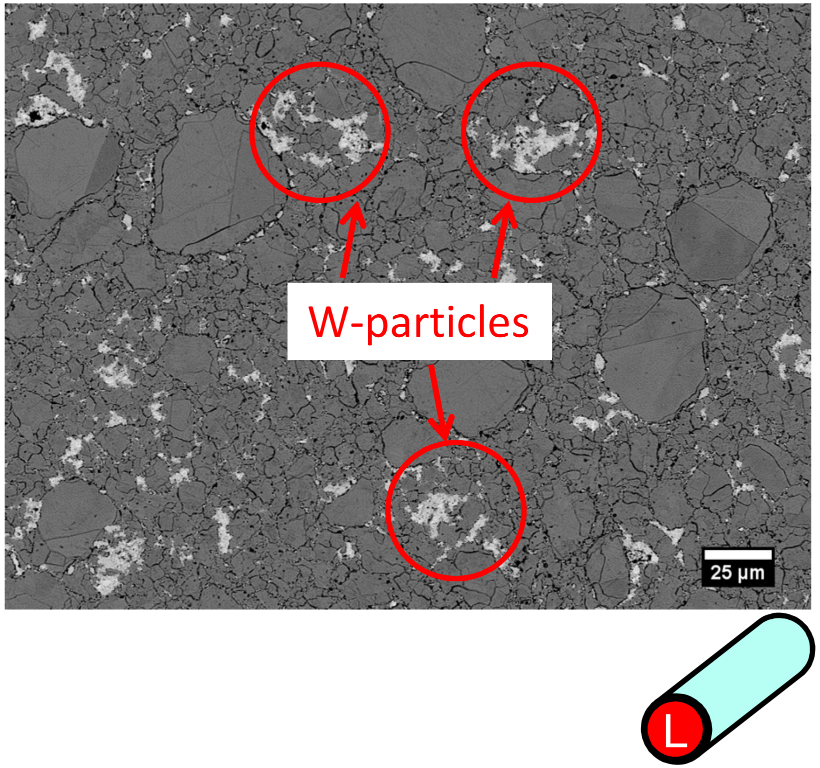


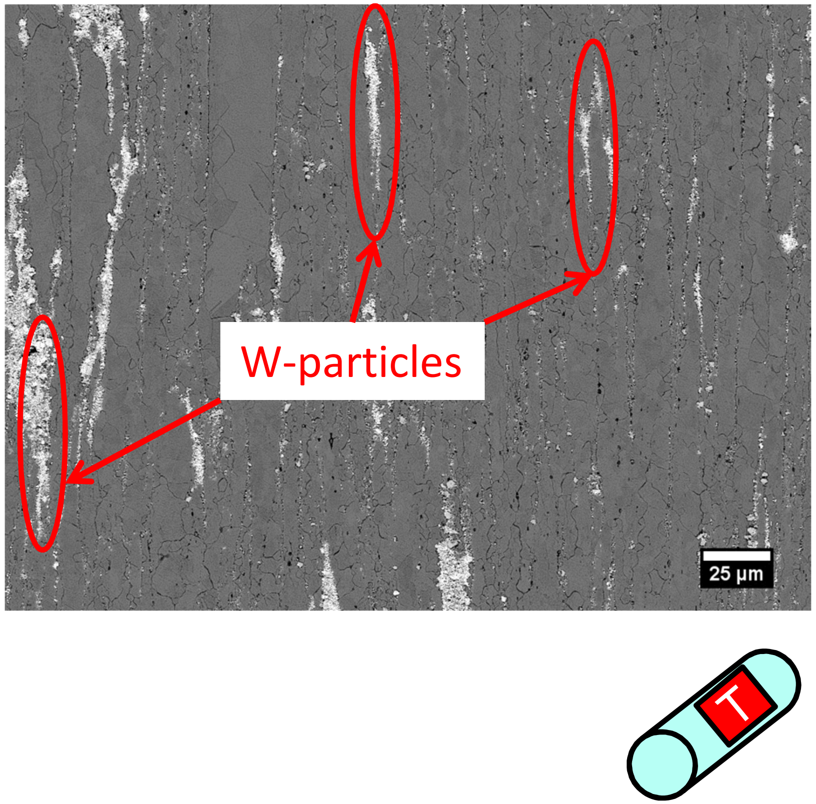


CuCrZr+**4wt.**%W

BSE-SEM images

Microstructure of CuCrZr-W-Rods (SEM)

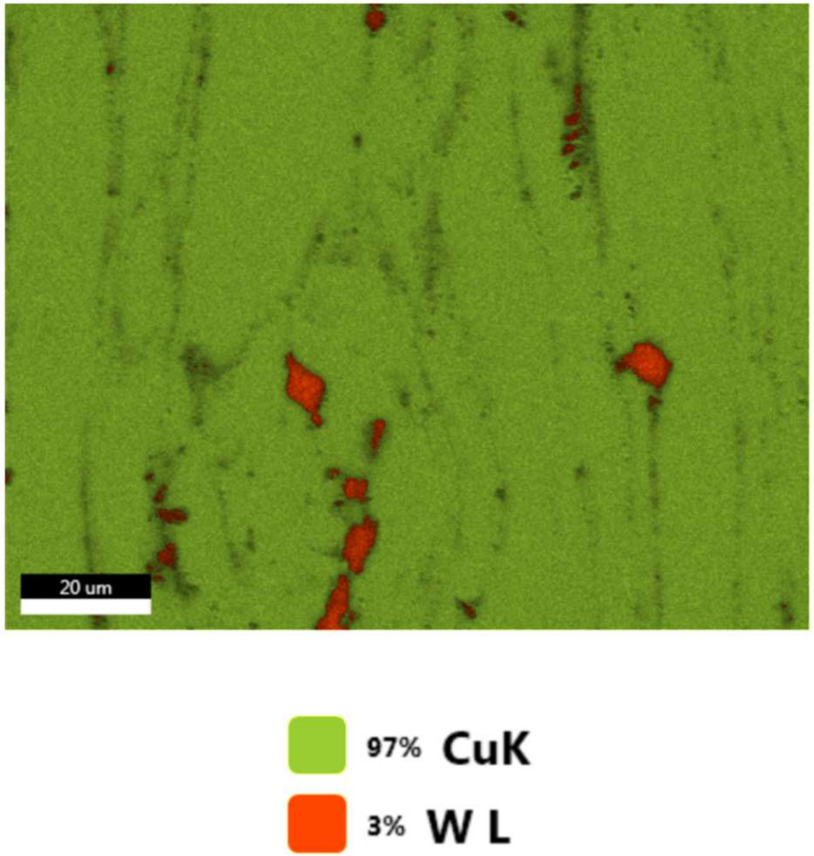


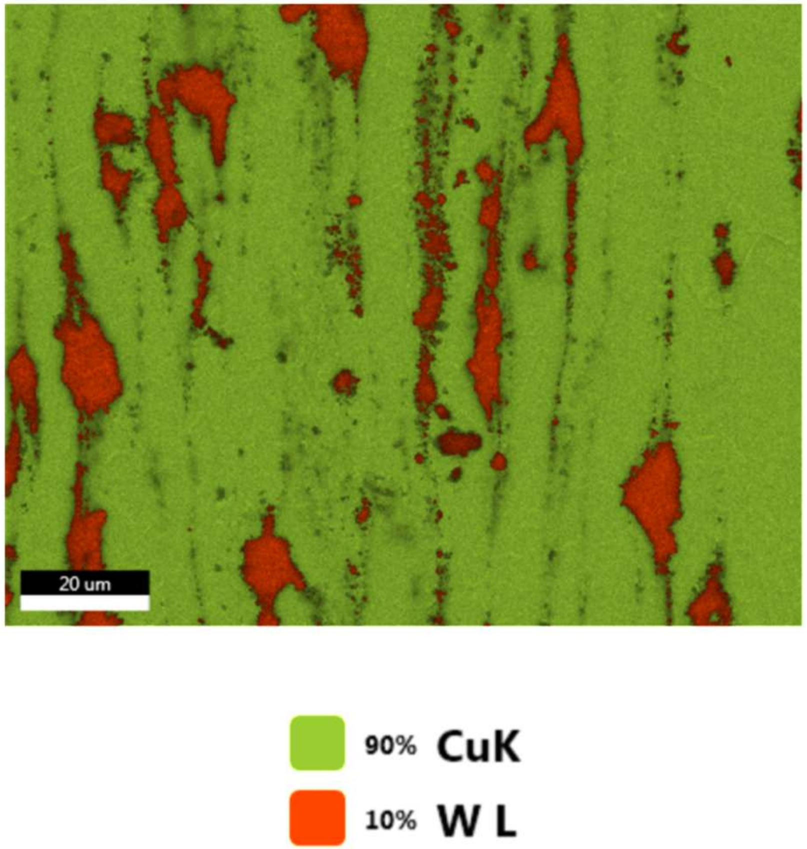


CuCrZr+**8wt.**%W

BSE-SEM images

Microstructure of CuCrZr-W-Rods (EDS)





EDS elemental mapping

- Columnar alignment of W-particles along the ED
- Quantification not accurate (no standard was used)
- Quenched state (no Cr-rich precipitates visible)

Microstructure of CuCrZr-W-Rods (EBSD)

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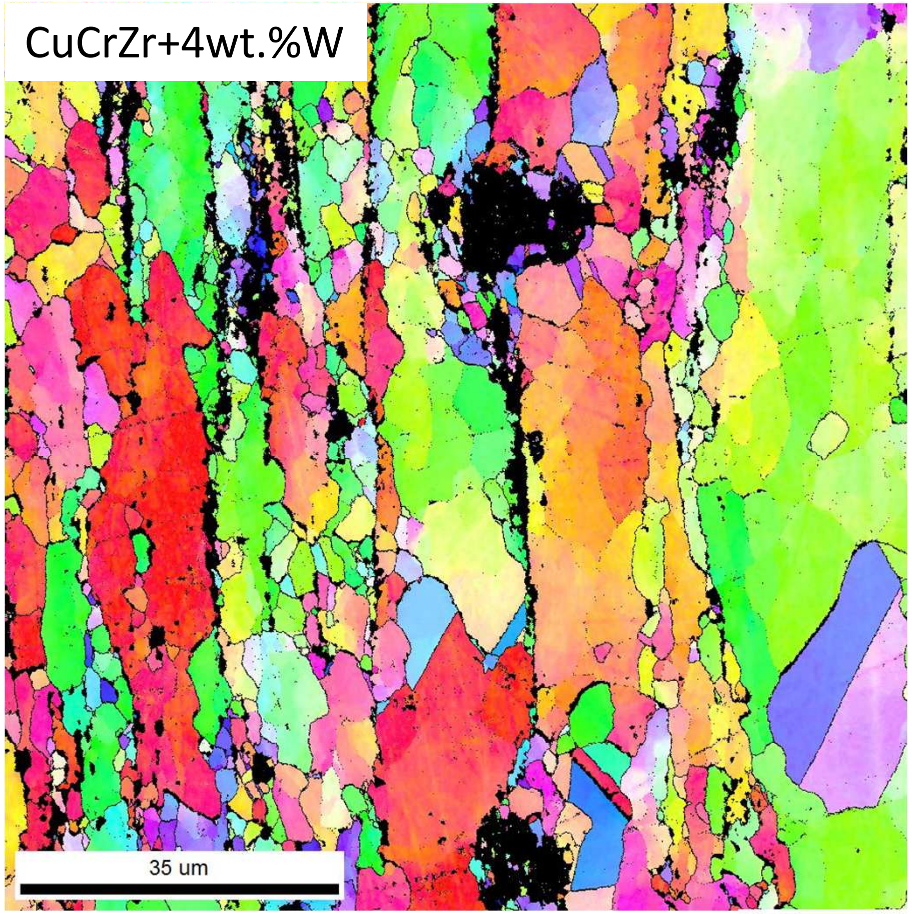
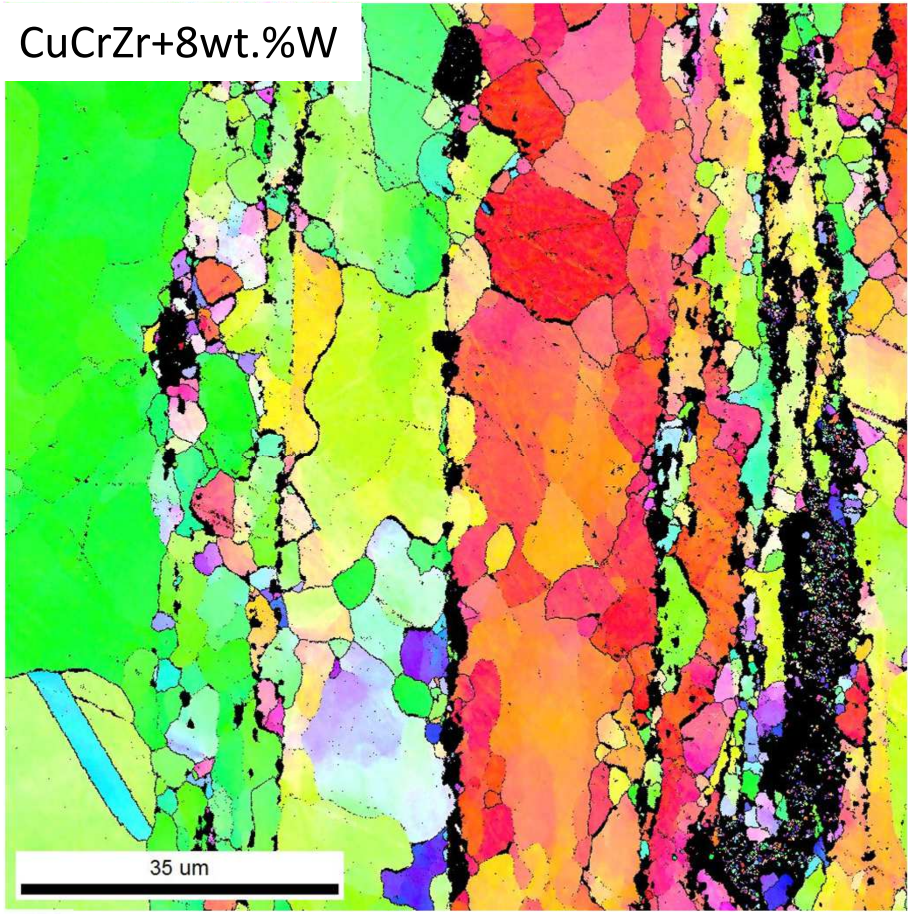
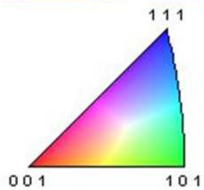
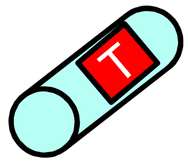


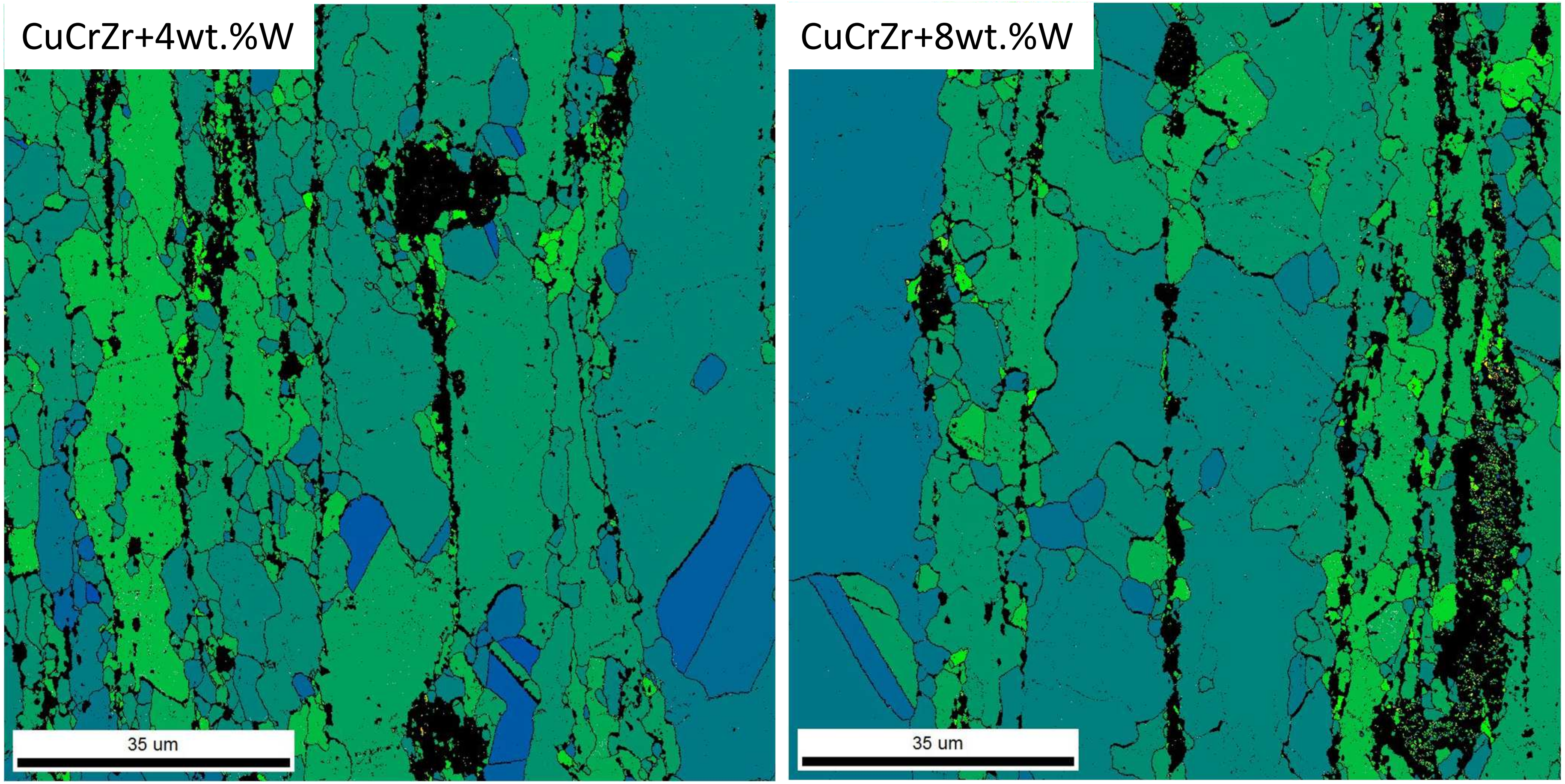


IPF Maps (along ND)

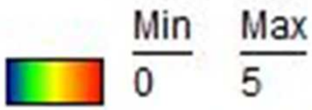


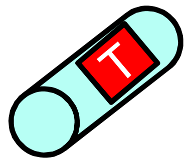


Microstructure of CuCrZr-W-Rods (EBSD)

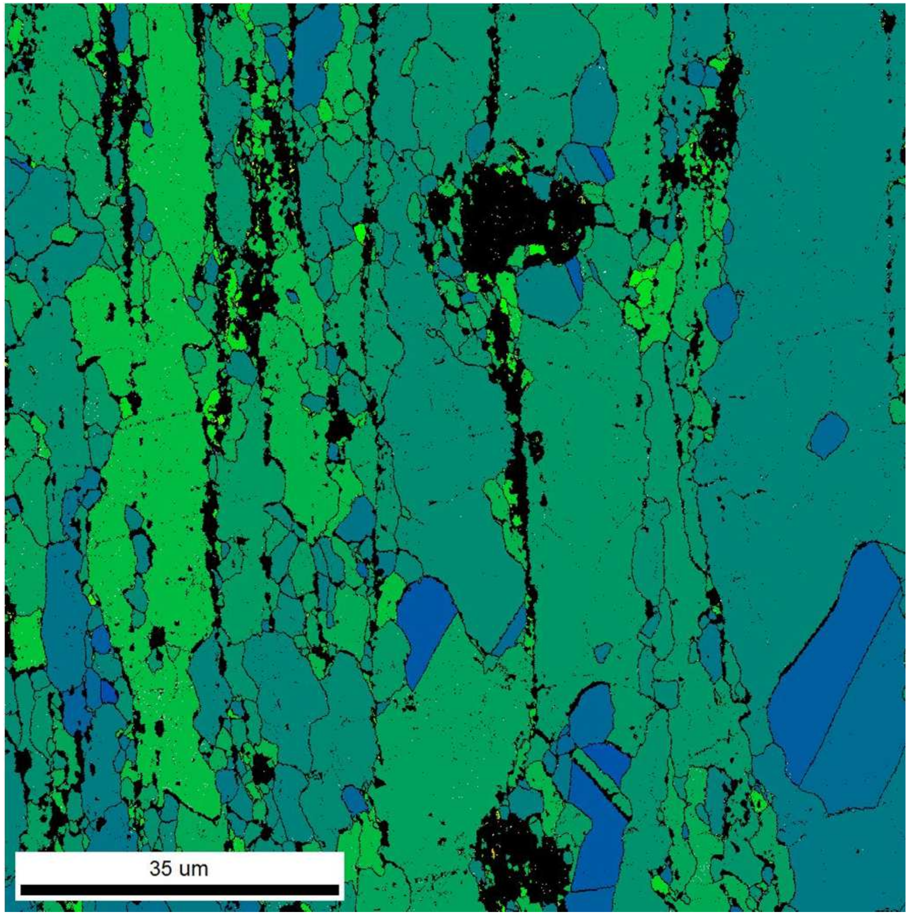


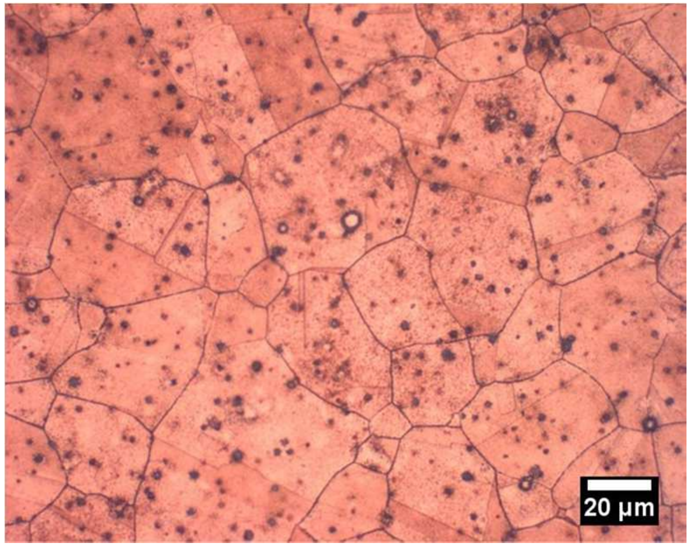
Grain Average Misorientation





Microstructure of CuCrZr-W-Rods





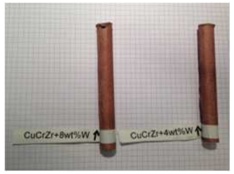
Distribution of W-particles across the microstructure leads to successful suppression of grain growth during sintering!

Dispersion needs to be further optimized to achieve homogeneous grain-size-distributions

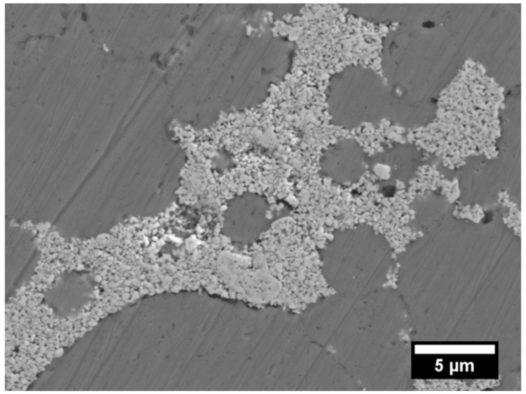
Conlusions

- First CuCrZr-W rods successfully fabricated!

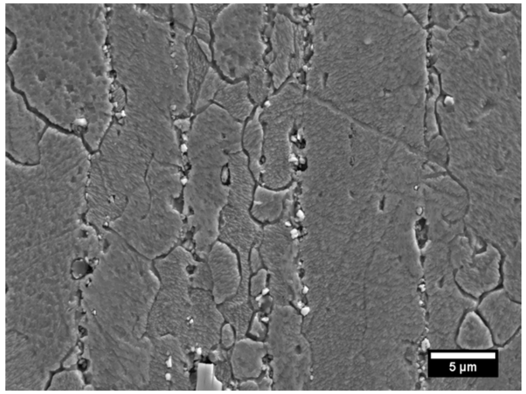
Via hot-extrusion



- Microstructure showed ……



Columnar alignment of W-Particles



- Microstructure is not yet homogeneous

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Thank you for your attention!

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Fraunhofer IWM, Freiburg
and
our colleagues from IAM (KIT).

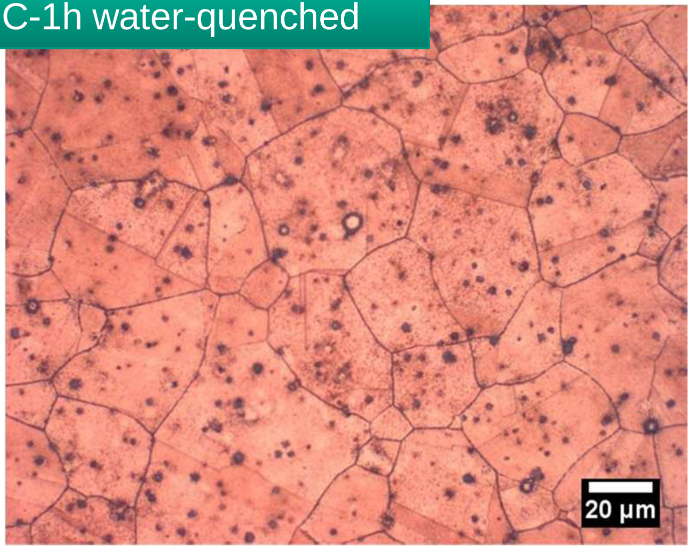
Technische Universität Berlin Forschungszentrum Strangpressen

Fraunhofer IWM

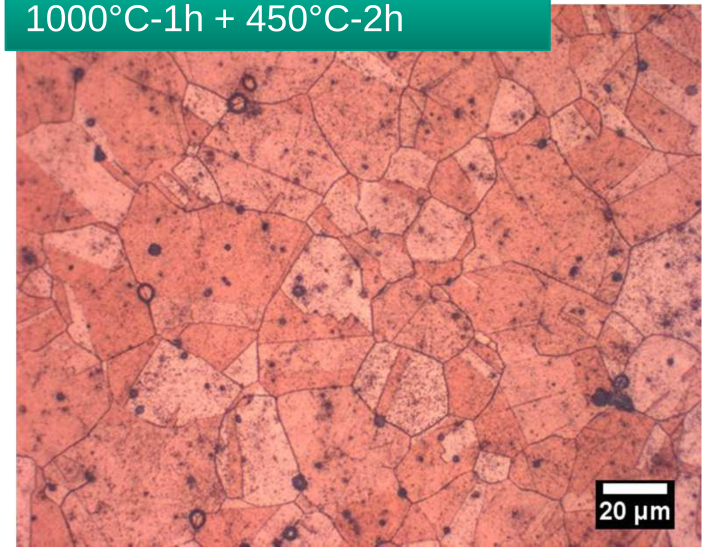
EUROfusion

Pre Study of CuCrZr (ITER grade)

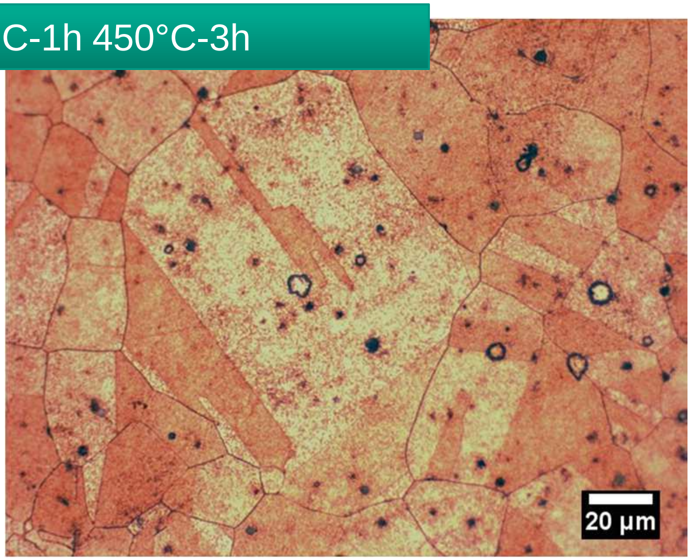
1000°C-1h water-quenched



1000°C-1h + 450°C-2h



1000°C-1h 450°C-3h



1000°C-1h + 450°C-4h