High electric conductivity and optimum strength in cold-drawn CuCrZr alloys at 295K and 77K

Rongmei Niu, Ke Han, and Vince Toplosky

National High Magnetic Field Laboratory/Florida State University

1800 E Paul Dirac Dr. Tallahassee, FL 32310, USA

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Outline

- Background
- Material preparation method
- Mechanical properties and conductivity comparison
- Hardness and conductivity with deformation
- Chemical and microstructure characterization
- Summary

Conductors in magnets

- Cu-Al2O3(Al60): ~560MPa UTS, ~83%IACS.
- CuNb: >1 GPa UTS, ~63%IACS. High Field magnets.
- CuAg: ~900MPa UTS, ~76%IACS

A promising material:

- CuCrZr: dispersion strengthening by nm-scale precipitates
  easy drawing without intermediate heat-treatment needed
  similar strength and conductivity to AL60.

CuCrZr: a backup material for AL60

Manufacture routes:

Casted ingot → Solid-solution treatment →
- Aging treatment → Cold-drawing (1)
- Cold-drawing → Aging treatment (2)

Cu-0.54Cr-0.046Zr, wt%

(1) Aged Dia. 14mm —cold-drawing→ 6.7 x 11mm^2

(2) 1. Solution-treated dia. 8mm —cold-drawing→ 1.2 x 0.8mm^2 → aging

For properties comparison

2. dia. 9.8mm —cold-drawing→ dia. 2.3mm → aging

Drawing true strain, η= 2.90

For microstructure investigation

Strength and conductivity comparison

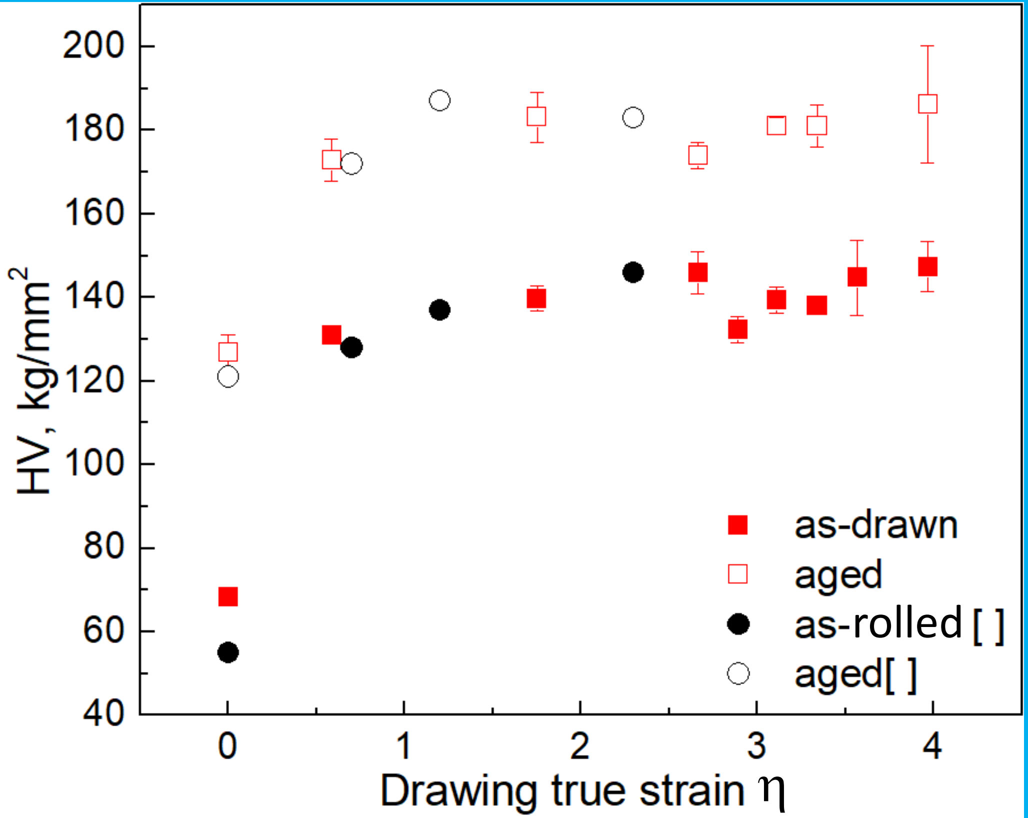
	Sample, mm²	Temp. (K)	Modulus (GPa)	Tensile Strength (MPa)
	CuCrZr			
1	6.7x11	295	123±0	614±0
1	6.7x11	77	131±2	744±8
	Dia. 2.3	295	124±2	604±5
2	0.8x1.2	295	129±2	614±17
2	0.8x1.2	77	140±2	750±12
	Al60			
	6.7x11	295	114±2	564±5
	6.7x11	77	127±5	728±6

	CuCrZr mm²	% IACS		RRR
		295 K	77 K	
1	6.7x11	84.2±0.9	322.8±4.8	3.84±0.09
	Dia. 2.3	83.4±1.1	351.7±17.2	4.21±0.15
2	0.8x1.2	85.6±0.2	306.0±0.7	3.57±0.01
	AL60			
	6.7x11	83.4±0.3	359.8±5.2	4.31±0.06

- The order between aging and cold drawing has no influence on strength and conductivity.

- CuCrZr and Al60 have similar properties at room temperature and below.

Hardness and conductivity with cold-drawing followed by aging



HV increases rapidly during early deformation (η<1, ~60%RA)

then varies slightly after true strain, η >1

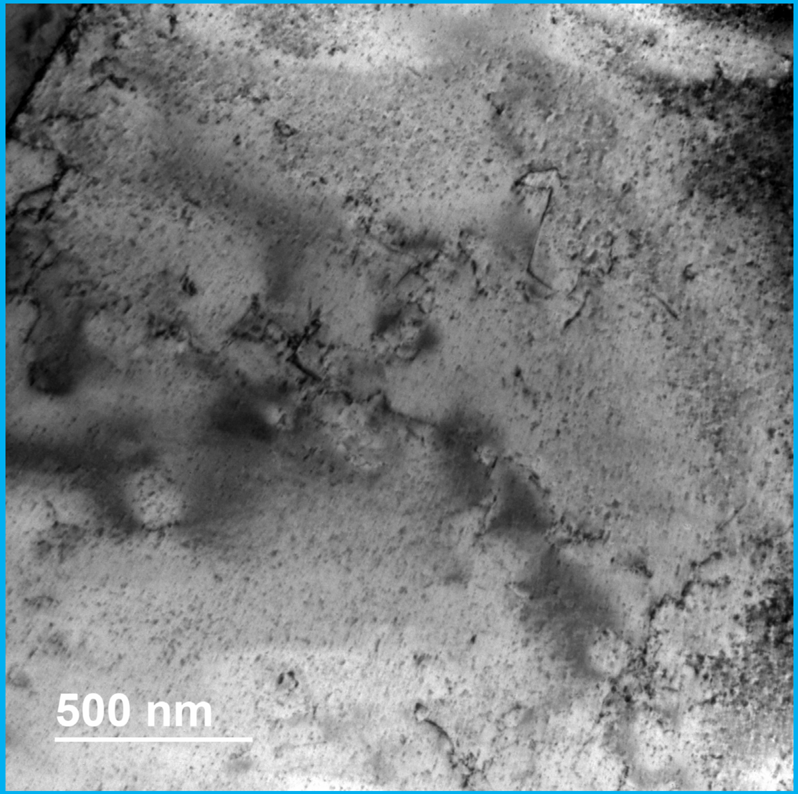
The extent of HV increase (~50 kg/mm^2) caused by aging is independent of the previous deformation strain.

Conductivity, IACS%	Solution-treated	Deformed with η=2.90	aged
295K	37%	46%	83%

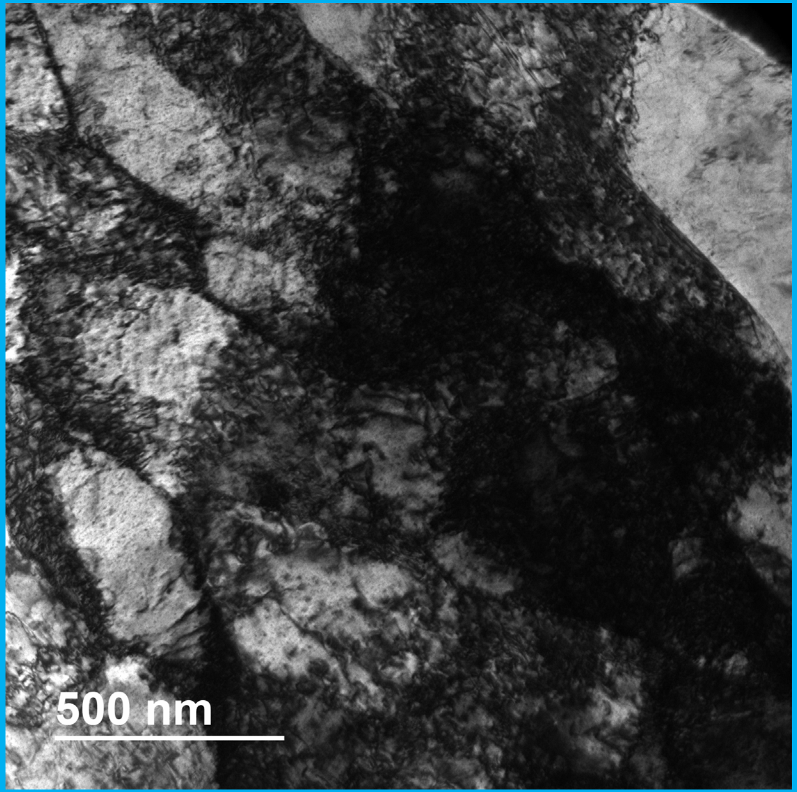
Influence of drawing deformation and aging(425Cx4hrs) on hardness, [ ] adapted from Chbihi et al.

Chbihi, A., X. Sauvage, and D. Blavette, *Influence of plastic deformation on the precipitation of Cr in copper.* Journal of Materials Science, 2014. **49**(18): p. 6240-6247.

Grain refinement during deformation



Solution-treated, HV 68
Average grain size, ~80µm



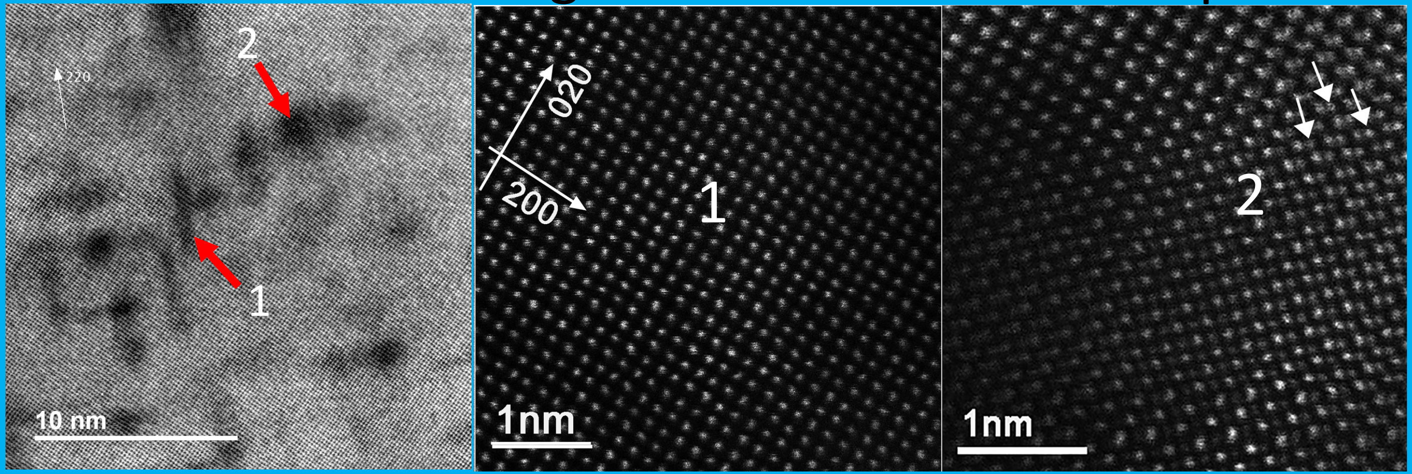
Sample with drawing true strain of 2.90, HV 132

Average grain size, ~280nm + high density of dislocations

Recovery occurred partially accompanying the deformation explain why HV curve became plateau after drawing strain of 0.76 (=53% RA)

Precipitation during cold-drawing- layered structure

Fine clustering in solution-treated samples



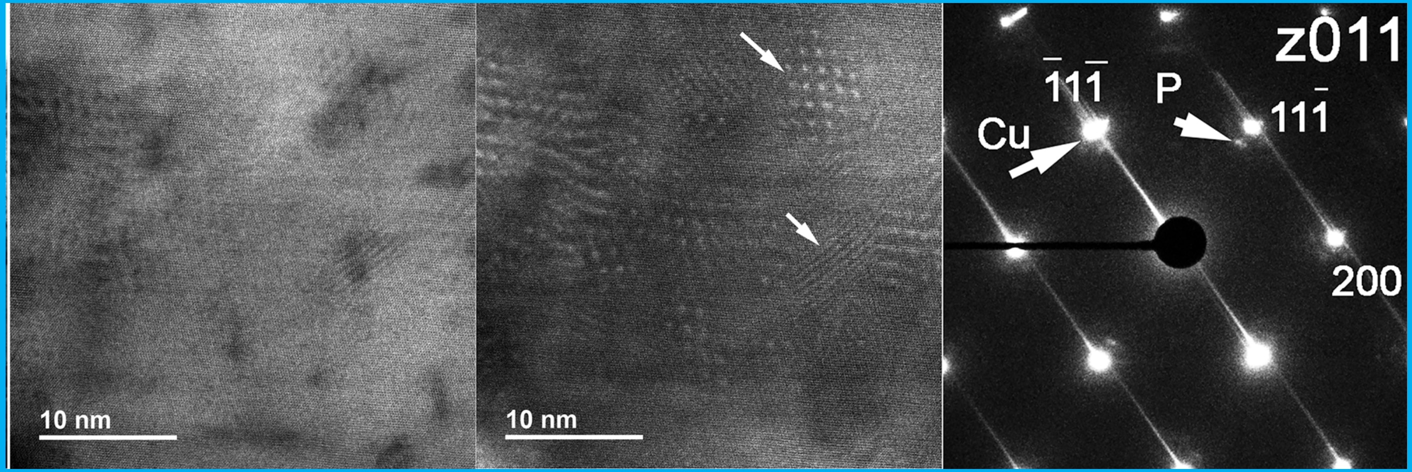
STEM-BF STEM-HAADF STEM-HAADF

High density of fine clusters exist

Fully coherent structure at “1”

Fine precipitates exist at “2”

Fine clustering in deformed (η=2.90) samples



STEM-BF STEM-HAADF SADP

Moire fringes (MF) forms with drawing.

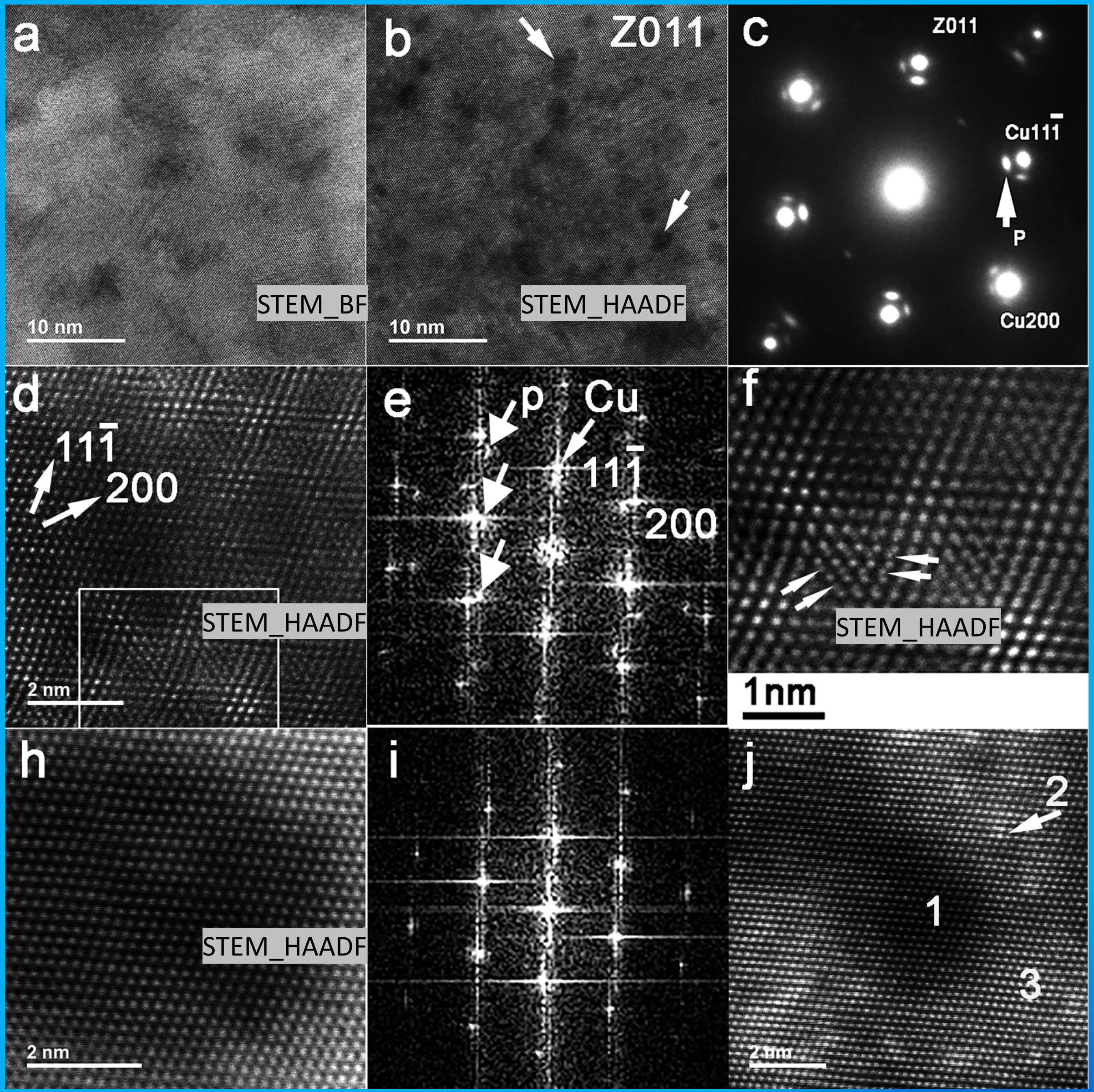
MF raises from the superposition of the two mismatched lattices.

fine clusters act as precipitates nucleation sites.

Wherever MF exists, where has a multiple layered structure of {110}Cu/Cr planes.

“p” means precipitates, SADP shows the forming of precipitates.

Aging induced precipitation ----3-D structure



Dark-contrast precipitates form. (Cr, Z=24, Cu, Z=29)

Size: ~1-3nm

Cr%, 1~8%, at% from TEM-EDS

Cube-on-cube OR with matrix

Precipitates near MF

TEM-EDS	1	2	3
Element	At %	At%	At%
Cu	91.5	99.6	99.7
Cr	8.4	0.4	0.3
Zr	0.1	0	0

Summary

- We achieved both high conductivity and optimum strength and in CuCrCr wires, which is comparable to those of Al60 both at 295K and 77K. The ultimate tensile strength is above 610MPa at 295K. The room temperature conductivity is 84 % IACS with a residual-resistivity ratio (RRR at 77 K) of 3.57.
- During deformation, these clustering acted as heterogenous nucleation sites for precipitates growing in 2-D layer structure. Precipitates formed a multilayer structure with the matrix.
- Differently, aging treatment induced precipitates growing in 3-D, forming in particle shape. The forming of former precipitated had no obvious beneficial impact on conductivity, while the latter contributed to the conductivity significantly.

Thanks for your attention!