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Title: Effects of Grain size and Boundary Structure on the Dynamic Tensile Response of Polycrystalline Copper

Author(s): Juan P. Escobedo-Diaz, Ellen K. Cerreta, Darcie Dennis-Koller, Brian M. Patterson, Curt A. Bronkhorst, Benjamin L. Hansen, Davis Tonks and Ricardo A. Lebensohn.

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TMS abstract

Effects of Grain Size and Boundary Structure on the Dynamic Tensile Response of Polycrystalline Copper.

Juan P. Escobedo-Diaz, Ellen K. Cerreta, Darcie Dennis-Koller, Brian M. Patterson, Curt A. Bronkhorst, Benjamin L. Hansen, Davis Tonks and Ricardo A. Lebensohn

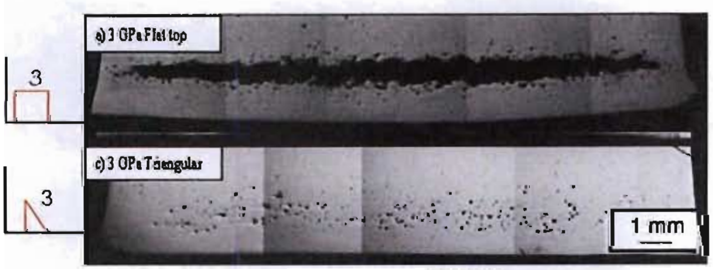
Plate-impact experiments were conducted to examine the effect of grain size (30, 60 and 200 μm) on the dynamic tensile response of high purity copper samples. The preceding compressive stress was ~1.5 GPa for all tests, low enough to cause early stage incipient spall. The free-surface velocity histories show no significant effect of the grain size on the initial pull-back signal. The quantitative metallography of the recovered samples shows the volume fraction of voids to be 0.4 % for all cases. Nevertheless, the void size distribution is different, with the void size increasing with increasing grain size. In the 200 μm samples, void coalescence was observed along the grain boundaries, whereas in smaller grained specimens individual voids dominated the deformation. EBSD observations show that voids preferentially nucleate/grow at grain boundaries with high angle misorientation, while the boundaries corresponding to low angle (<5°) or Σ3 type were more resistant to damage.

Effects of Grain Size and Boundary Structure on the Dynamic Tensile Response of Polycrystalline Copper

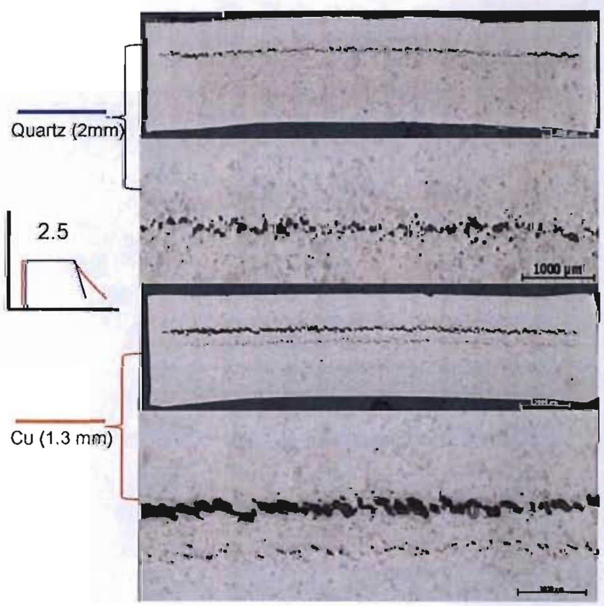
J.P. Escobedo, E.K. Cerreta, D. Dennis-Koller,
B.M. Patterson, C.A. Bronkhorst, B. L. Hansen, D. Tonks
and R.A. Lebensohn

TMS Annual Meeting
San Diego
March 2nd 2011

Background



Koller et. al. , *J. Appl. Phys 98(10)*, (2005)



Escobedo, Trujillo and Cerreta, unpublished (2011)

Damage evolution depends on the microstructure **and** characteristics of the shock wave shape.

Objective

Isolate kinetic and spatial effects on dynamic damage: Study the effect of spatial distribution of defects (grain boundaries) while kinetics were held constant.

Experimental configuration and loading path

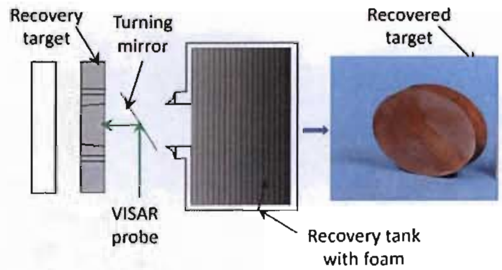
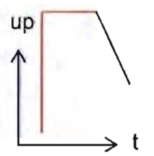
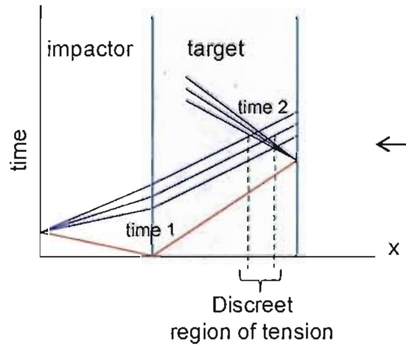
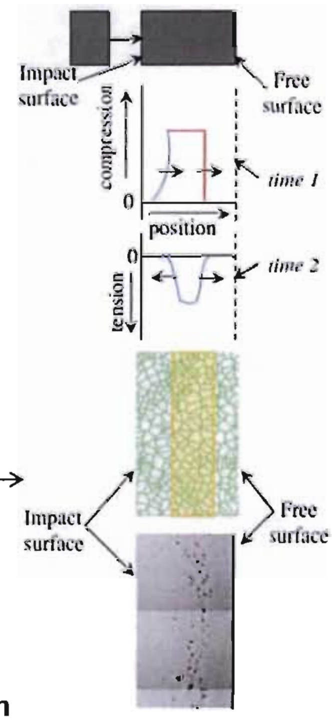


Plate impact technique



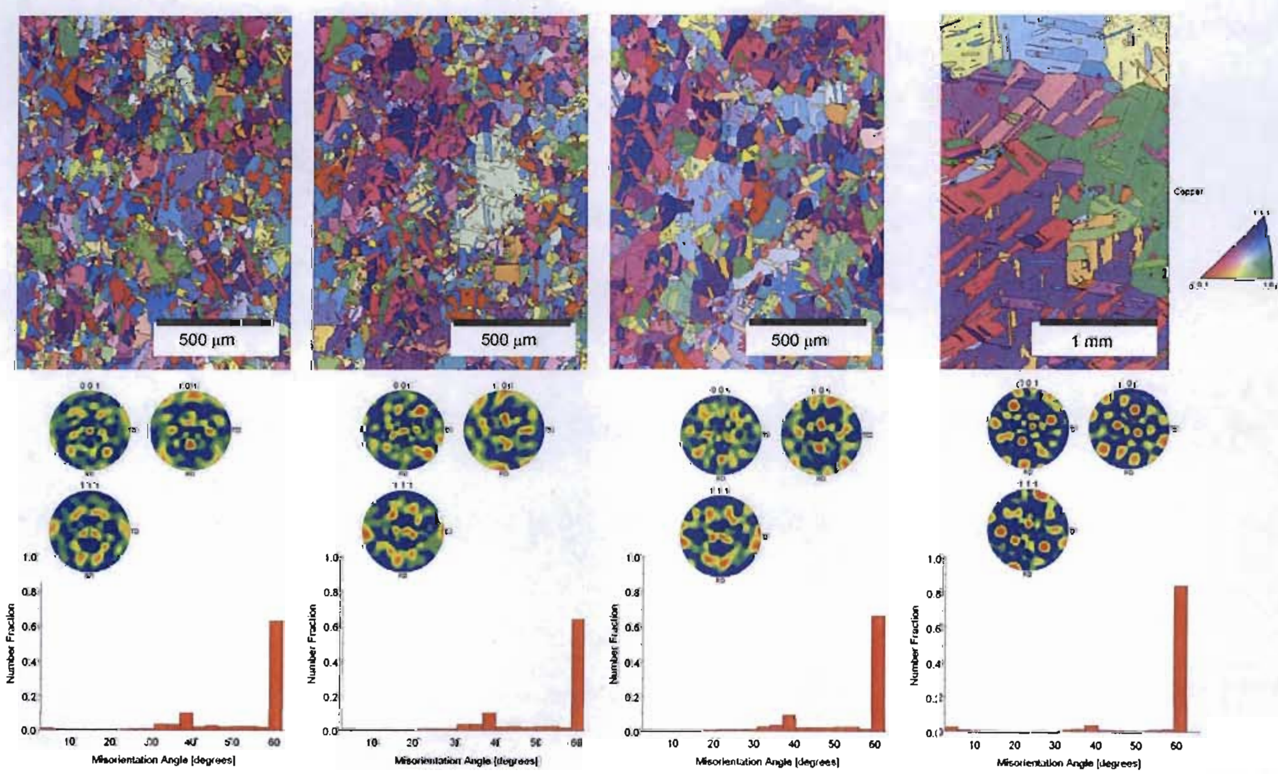
Flat top loading





Loading path

Initial characterization: OFHC Copper



450 °C – 30 min (~30 μm),

600 °C – 1 hr (~60 μm)

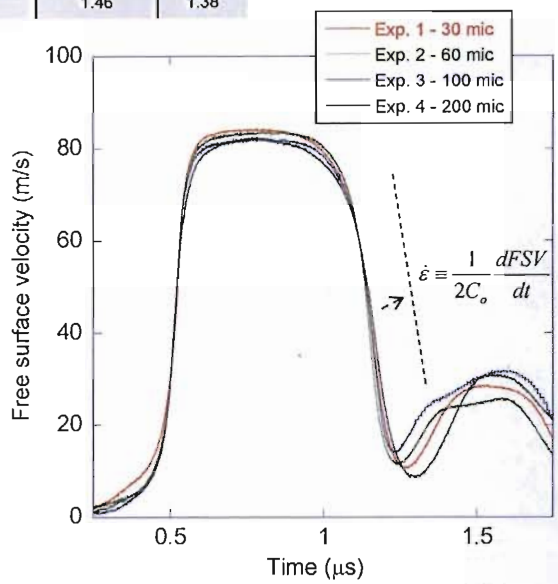
850 °C – 1 hr (~100 μm)

900 °C - 35 min (~200 μm)

Experimental parameters

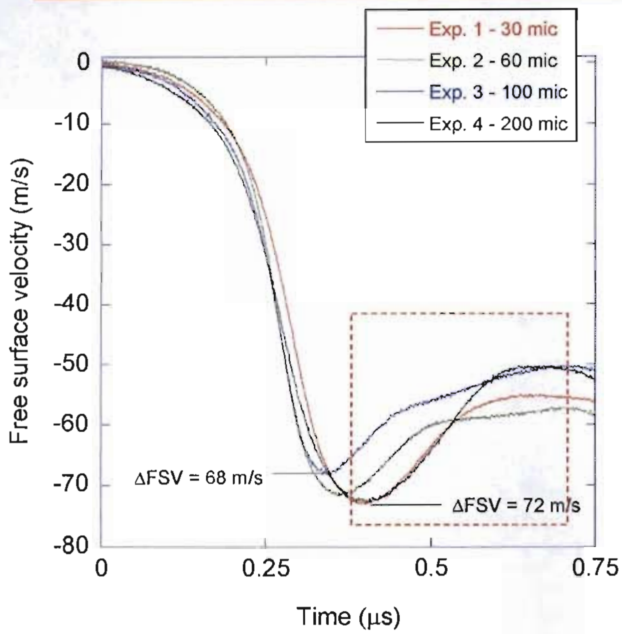
Exp. No.	Grain size (μm)	Impactor			Sample thickness (mm)	Compressive stress (GPa)	Onset stress σ_{onset} (GPa)
		Material	Thickness (mm)	Velocity (m/s)			
1	30	z-cut quartz	2.0	134	4.0	1.50	1.38
2	60	z-cut quartz	2.0	133	4.0	1.50	1.36
3	100	z-cut quartz	2.0	131	4.0	1.46	1.31
4	200	z-cut quartz	2.0	131	4.0	1.46	1.38

Samples were subjected to same loading conditions: peak stress, pulse duration and release rate.

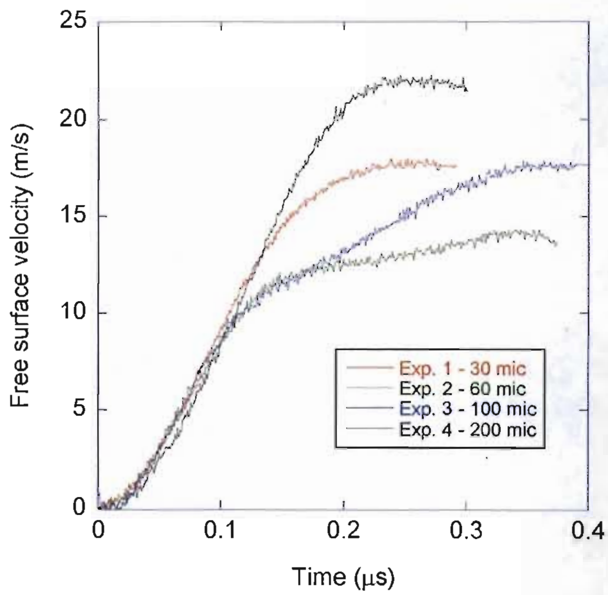


Free surface velocity histories

Free surface velocity traces



Pull-back wave

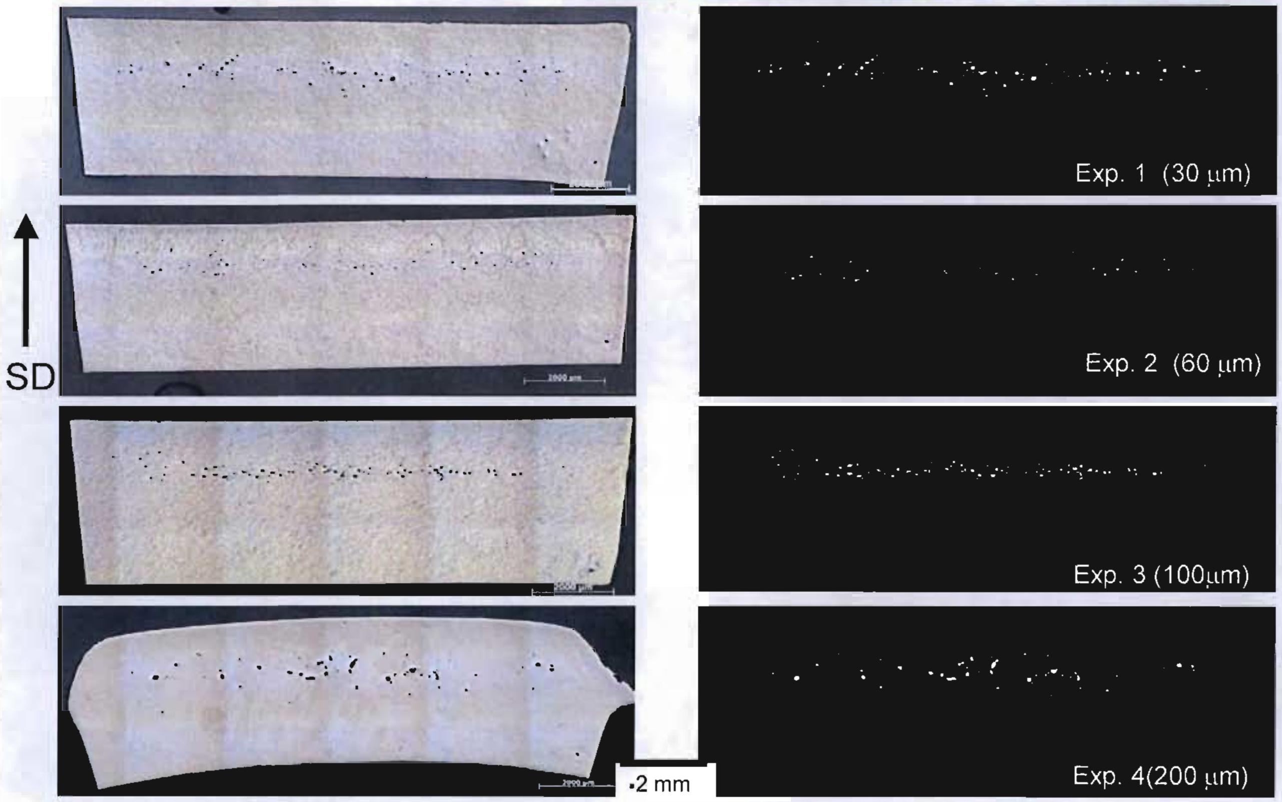


Free surface velocity after the minima.

S. Cochran and D. Banner, J Appl. Phys **48** (7), (1977)

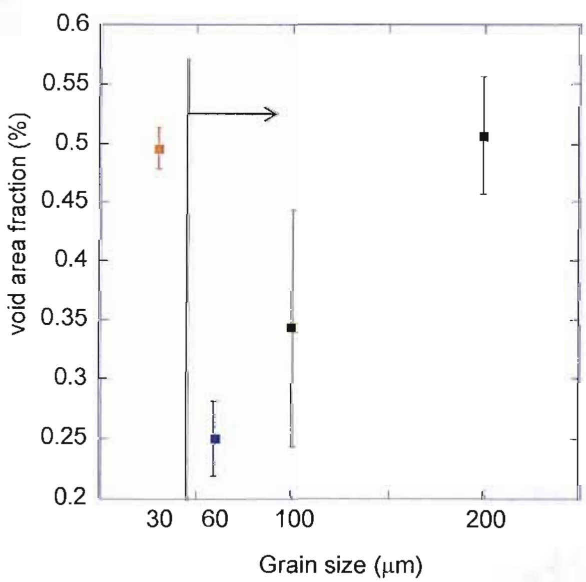
- Similar pull-back signal for all grain size.
- Different spall peak magnitude and re-acceleration rate → damage dynamics.

Optical analysis

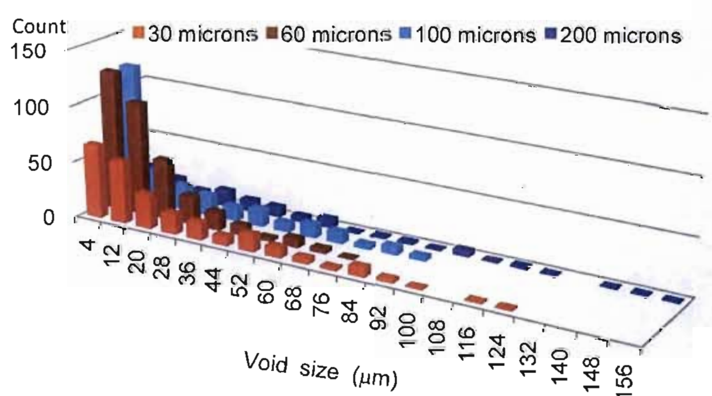


Damage fields depend on the grain size with no linear trend.

Damage quantification



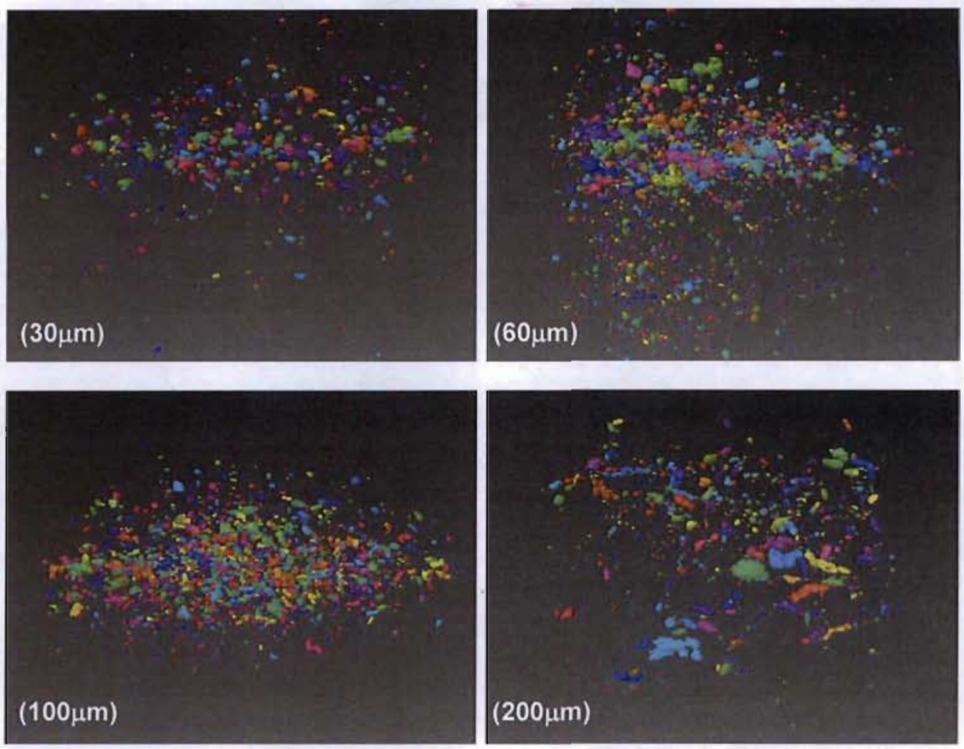
Void area fraction as function of the grain size



Void size distribution.

Void area fraction and void size similar in the 30 and 200 µm

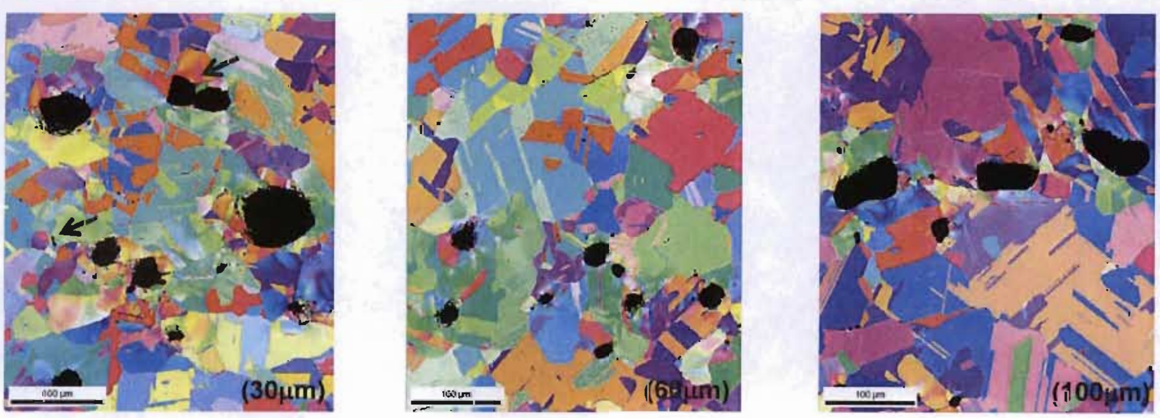
Micro x-ray tomography

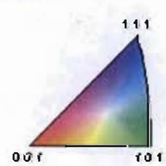


Tomography results (3D) qualitatively agree with optical (2D)

B.P. Patterson et al, Submitted to Microscopy and Microanalysis (2010).

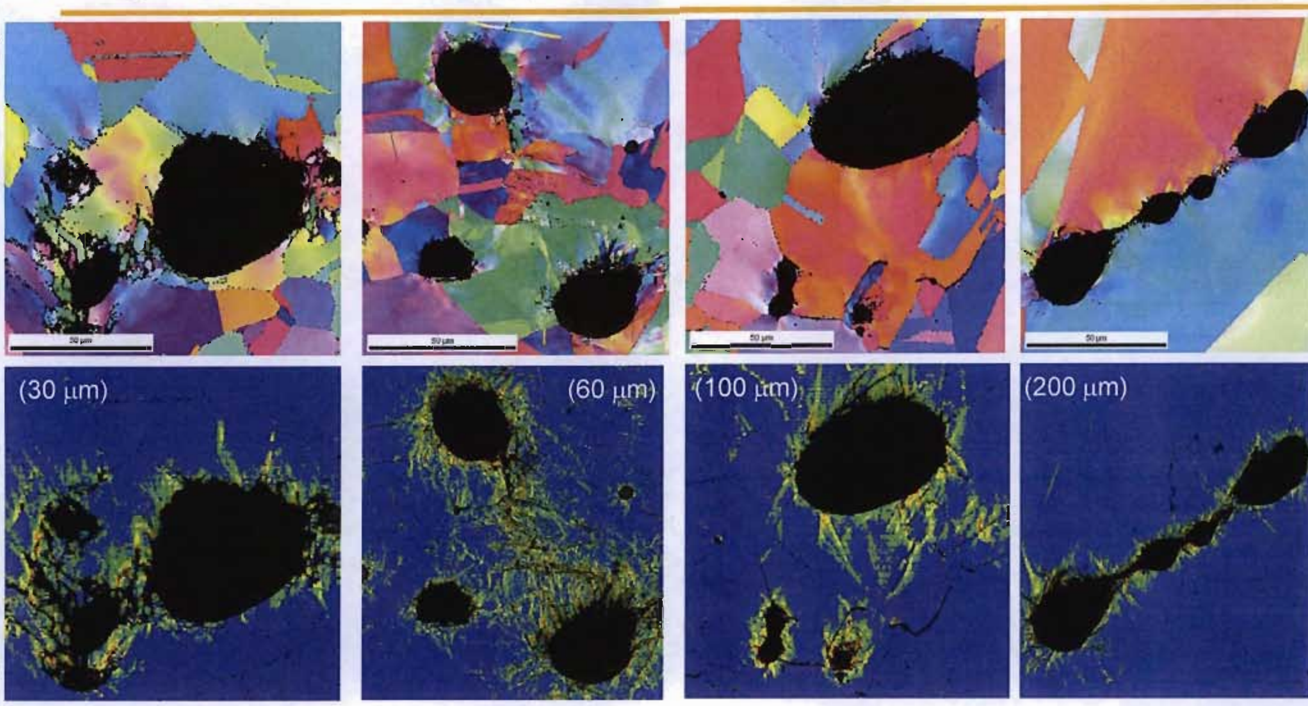
EBSD Orientation Maps



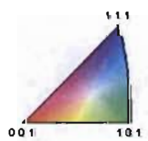


- Voids remain isolated in the 60 and 100 μm samples
- Coalescence is promoted in the 30 and 200 μm sample

Void growth/coalescence vs. grain size



Copper

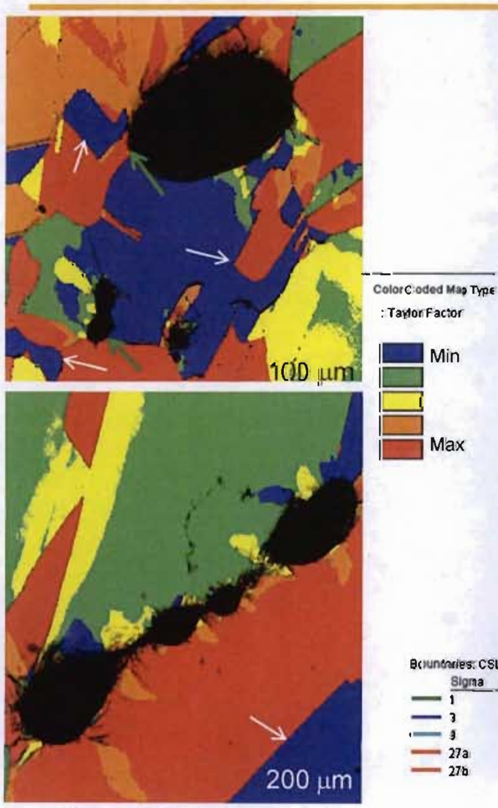


Color Coded Map Type: Kernel Average Misorientation

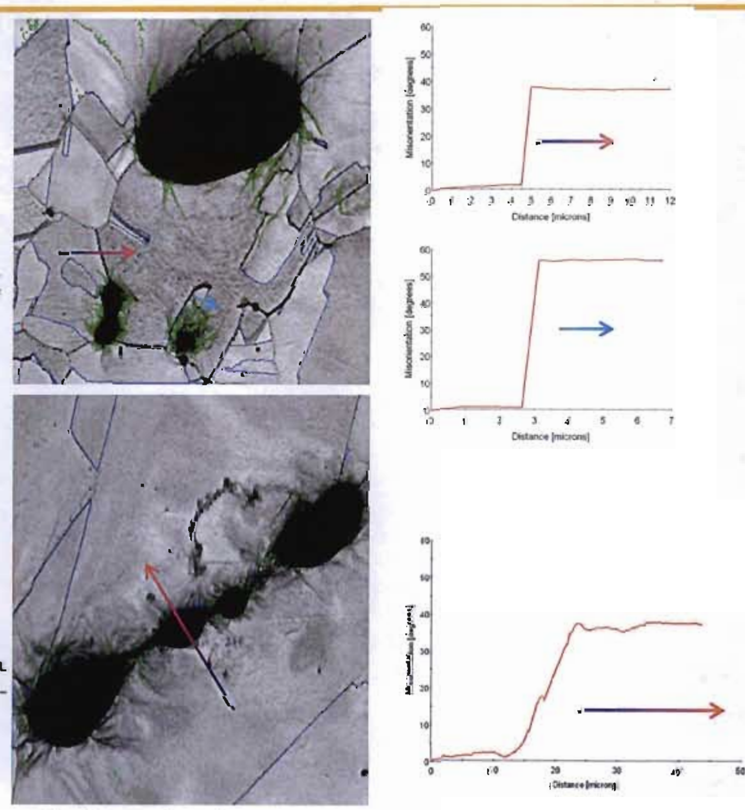
Min	Max	Total Fraction	Partition Fraction
0	1	0.661	0.772
1	2	0.143	0.166
2	3	0.035	0.041
3	4	0.009	0.011
4	5	0.009	0.010

Higher misorientation (~plastic work) is observed in the 60 µm sample.

Properties from EBSD data: Taylor Factor and boundary type



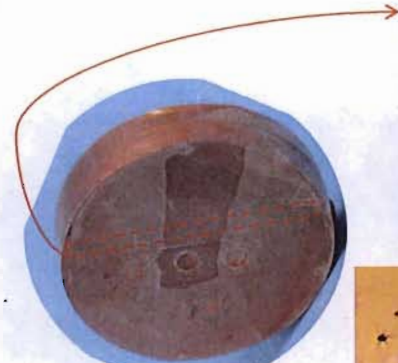
Taylor Factor

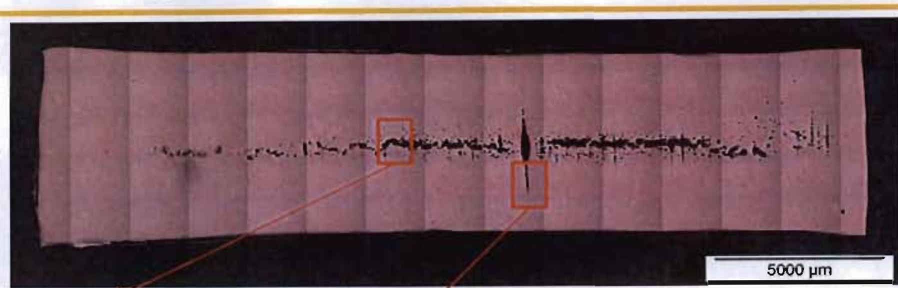


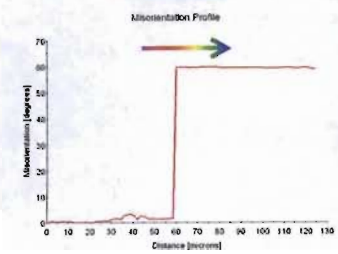
G. Boundary type

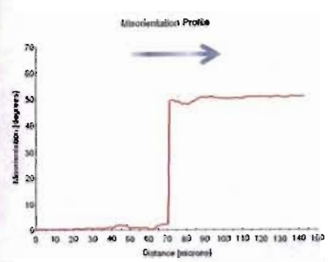
Grain boundary structure as the determining factor for preferred void nucleation location.

Effect of GB structure: columnar grained case









Σ3 boundary (60^0 <111>)

High angle boundary (~50^0)

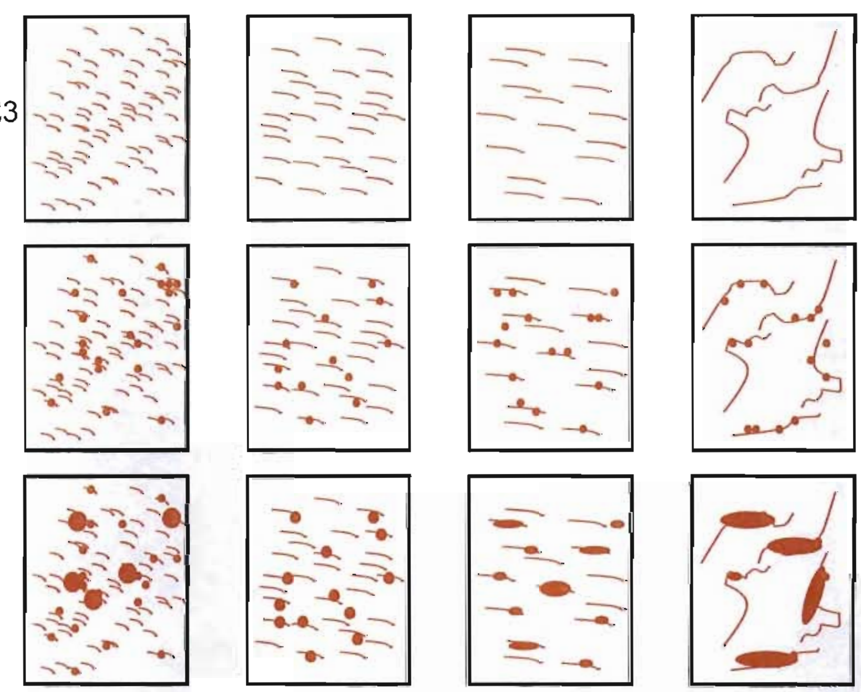
A. Perez-Bergquist et. al., TMS 2011.

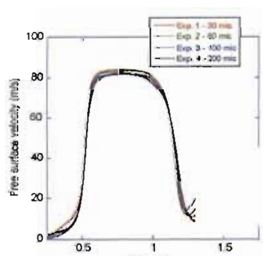
Confirmation of previous observations:

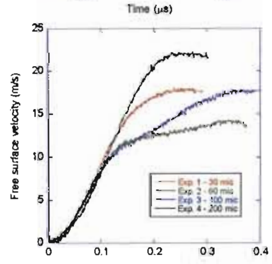
Mechanisms for damage evolution

Potential nucleation sites:
Grain boundaries ≠ Σ1 and Σ3

30 µm | 60 µm | 100 µm | 200 µm







Distance between voids determine individual growth or coalescence.

Main findings

- No clear effect of the grain size on the shock rise, compression, release and calculated spall strength. However, the magnitude of the spall peak and the rate at which the free surface velocity rises to achieve it, were clearly dependent upon the grain size.

- Higher spall peaks correlated with a larger amount of damage observed in the respective recovered sample. Similarly, the re-acceleration rates correlated adequately with the void shape/size observed in the damage field of the recovered samples.

- A grain boundary other than the special $\Sigma 1$ or $\Sigma 3$ boundary was found to be a necessary, but not a sufficient, condition for void nucleation.

- Void growth and coalescence behavior are clearly dependent on the spatial distribution and size of the defects (i.e. grain size), with coalescence being more dominant in the 30 and 200 μm samples.