Energetic TWIP

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The Problem?

High density, high velocity penetrators defeat armour by;

"Shear Plugging" - locally imparting so much energy that the material comes close to melting, and burrowing through, or

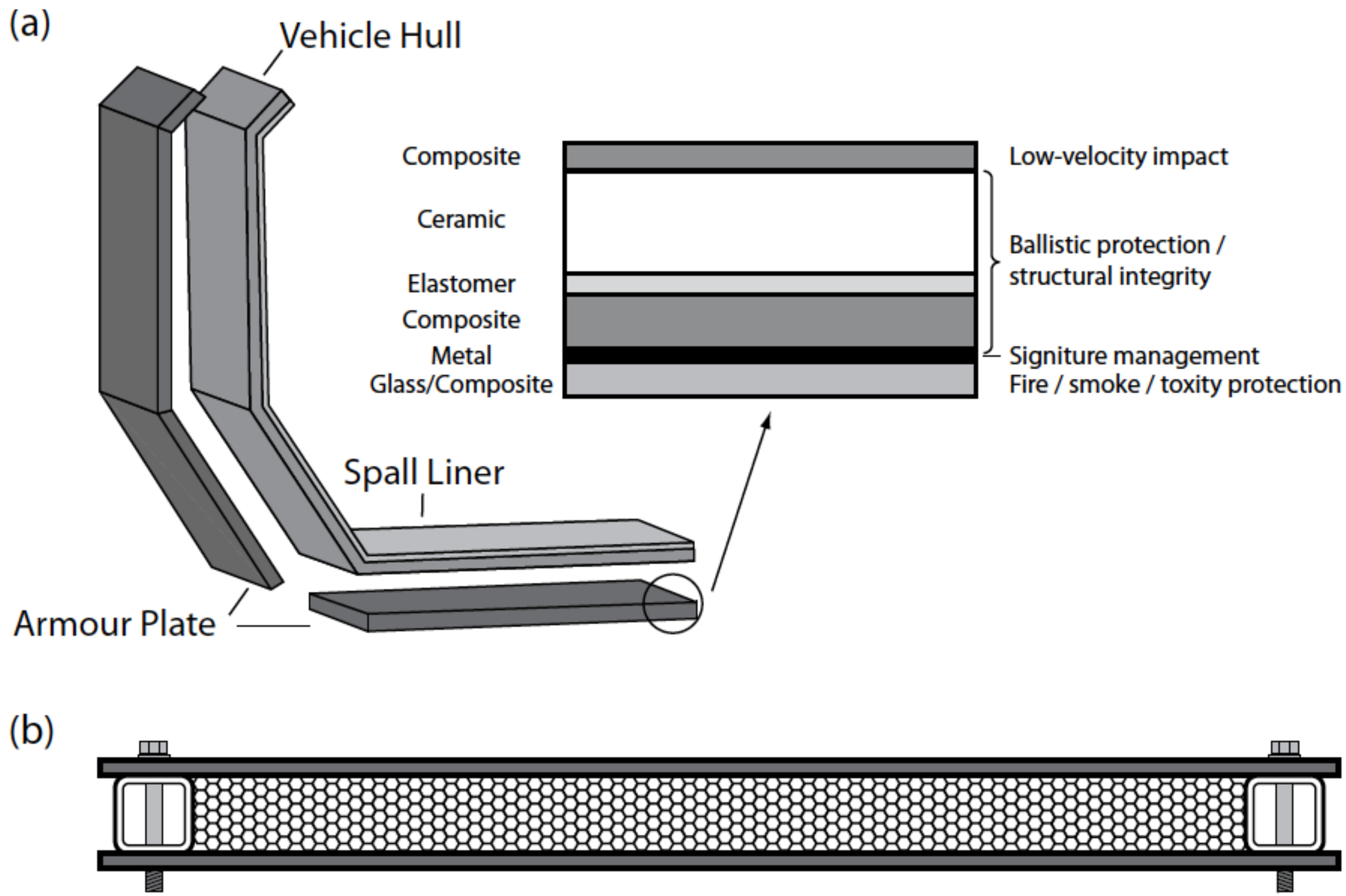
Behind armour effects such as spall fragments caused by shock waves on the back side

Armour systems

<u>Disturber</u> - acts to rotate / break and spread out the projectile, maximising its area

<u>Absorber</u> - absorbs all of the energy imparted

<u>Spall liner</u> - catches spalled fragments

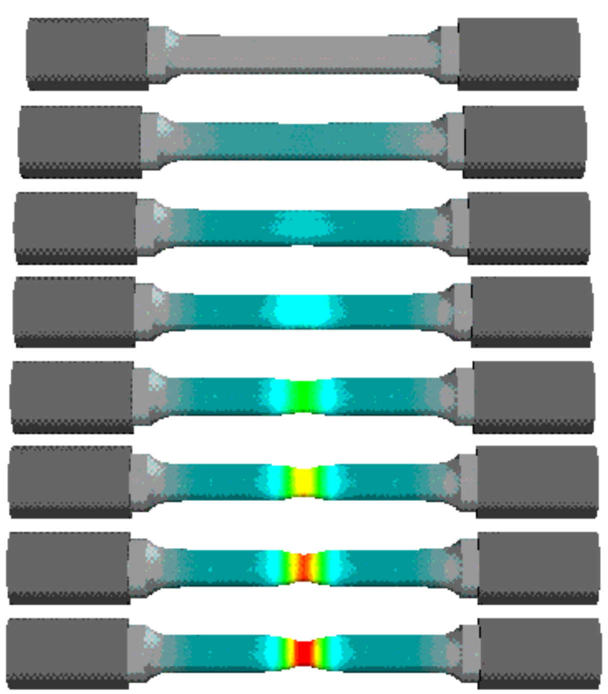


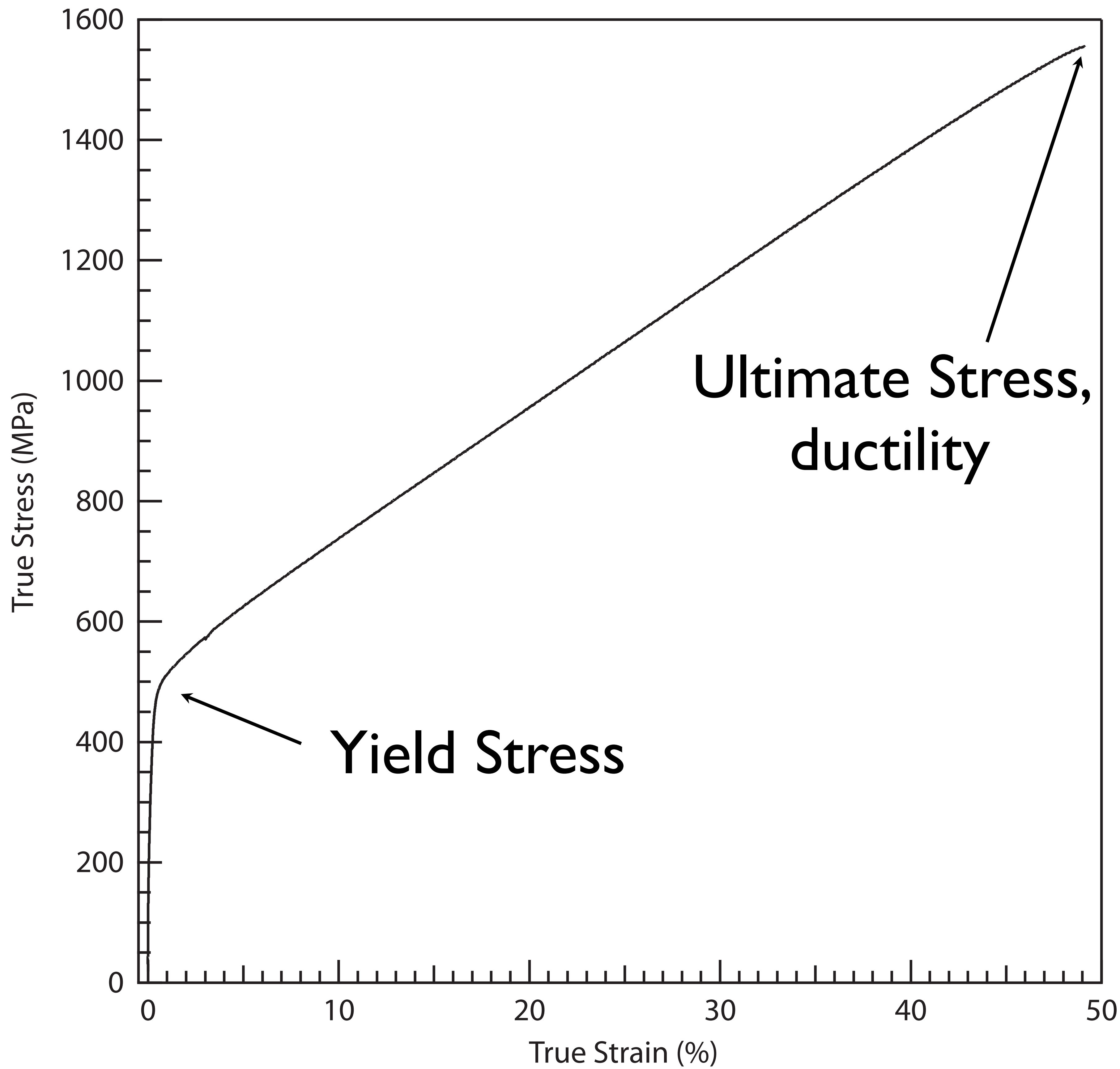
Adapted from Thomas EL, Opportunities in protection materials science and technology for future army applications. The National Academies Press, 2012.

Absorbing energy

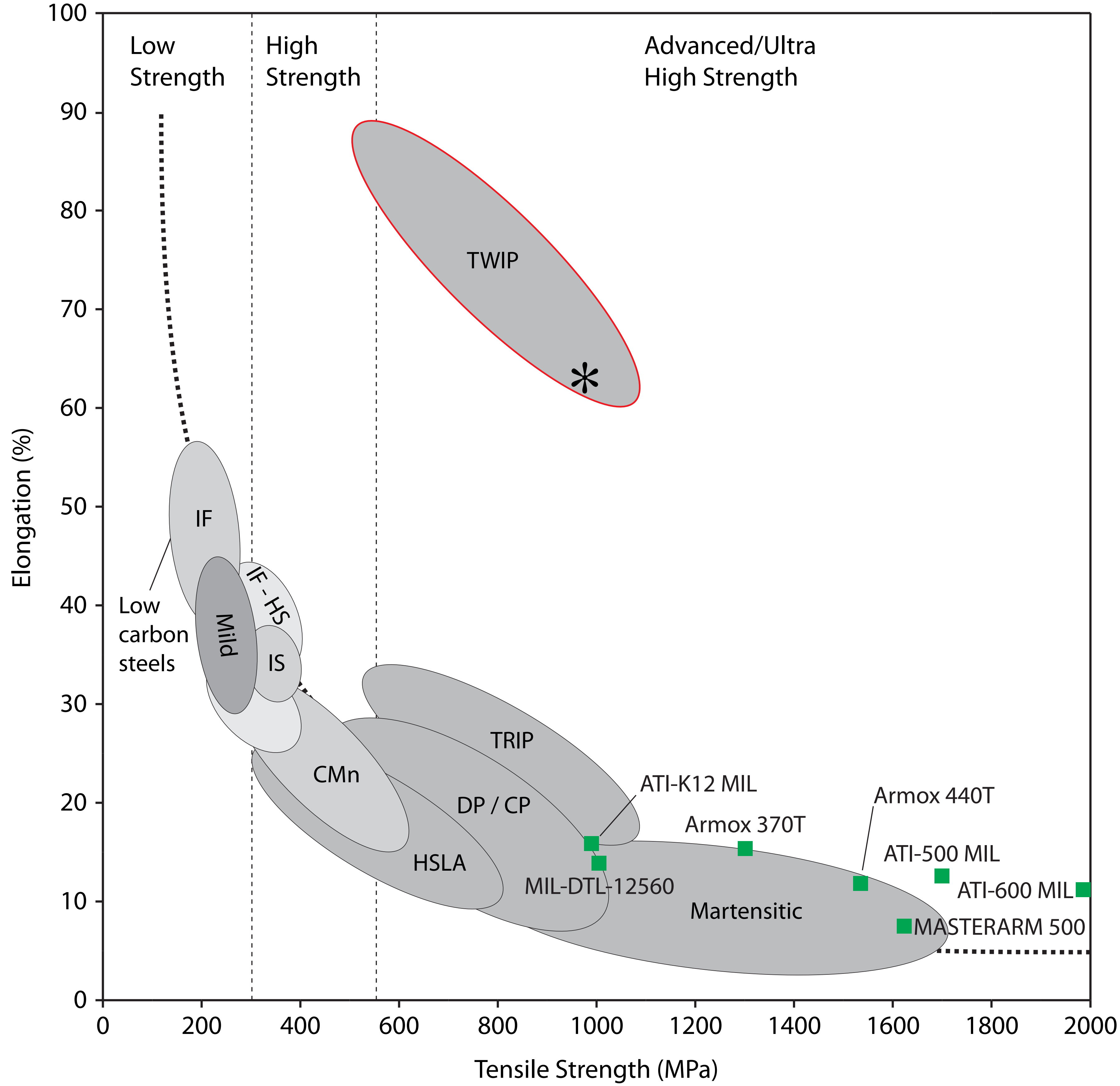
Failure occurs on necking, when the material runs out of hardening.

Then, any instability and stress localises, resulting in failure.

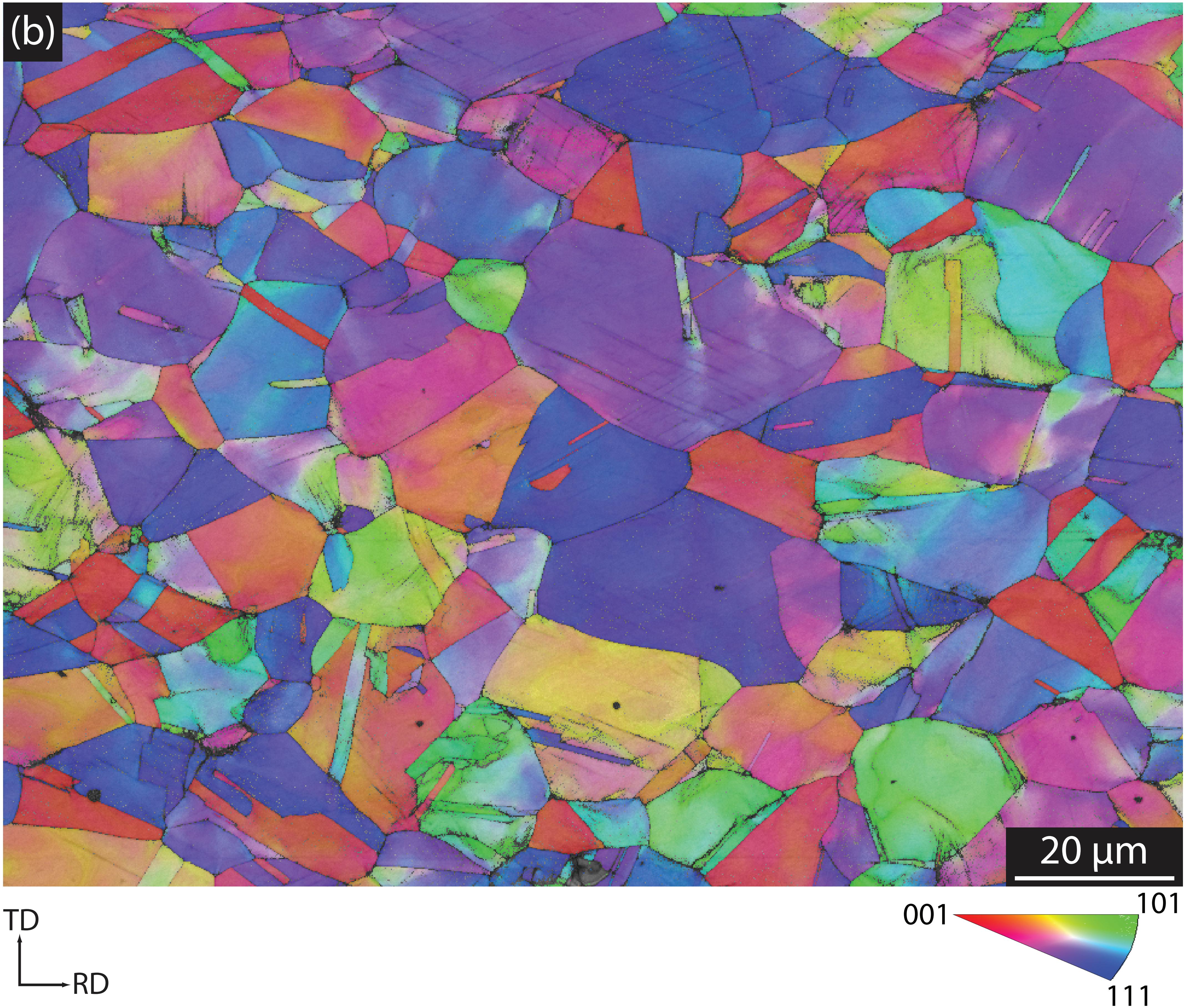




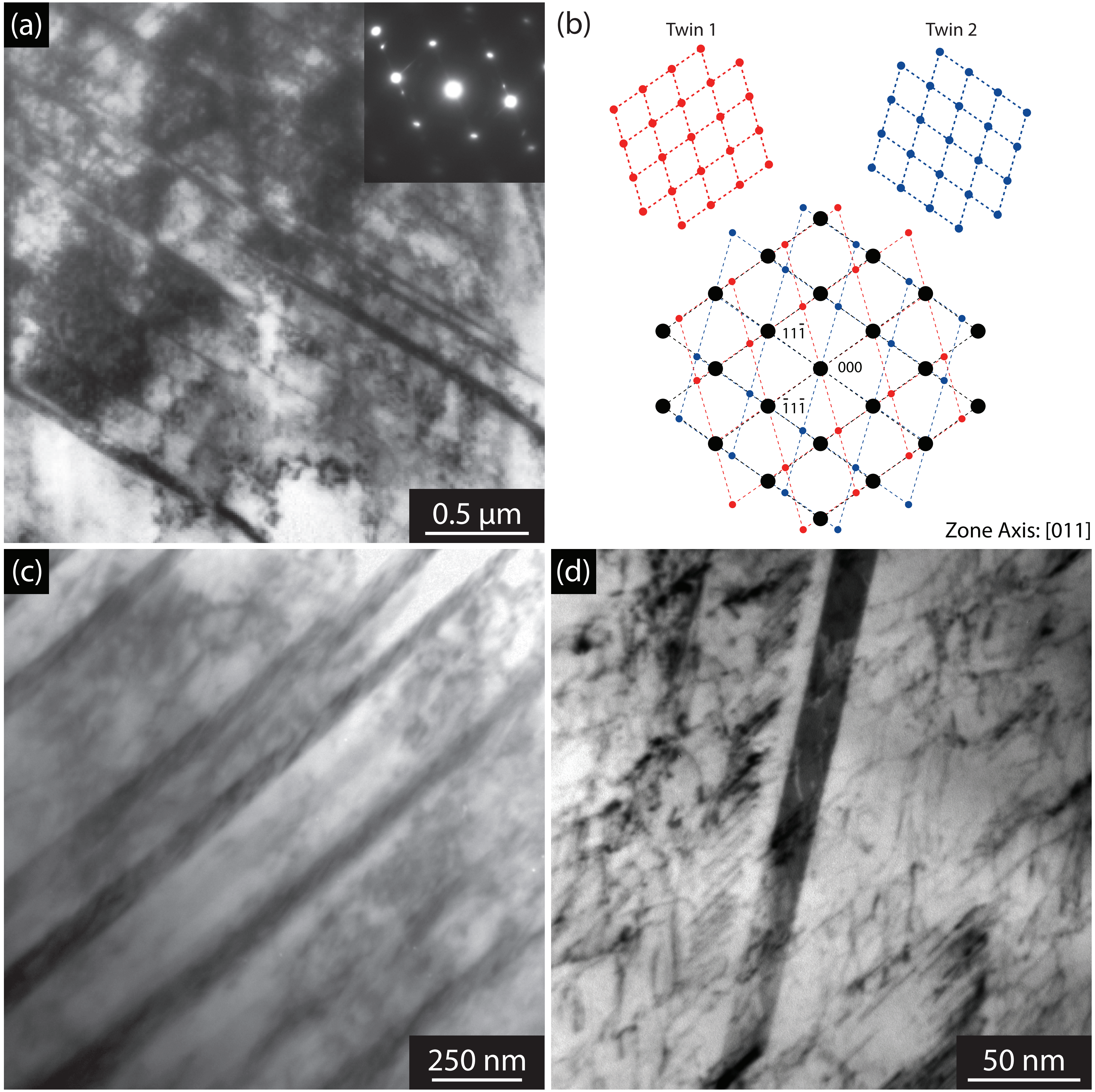
Performance diagram for steels



How do TWIP steels work?

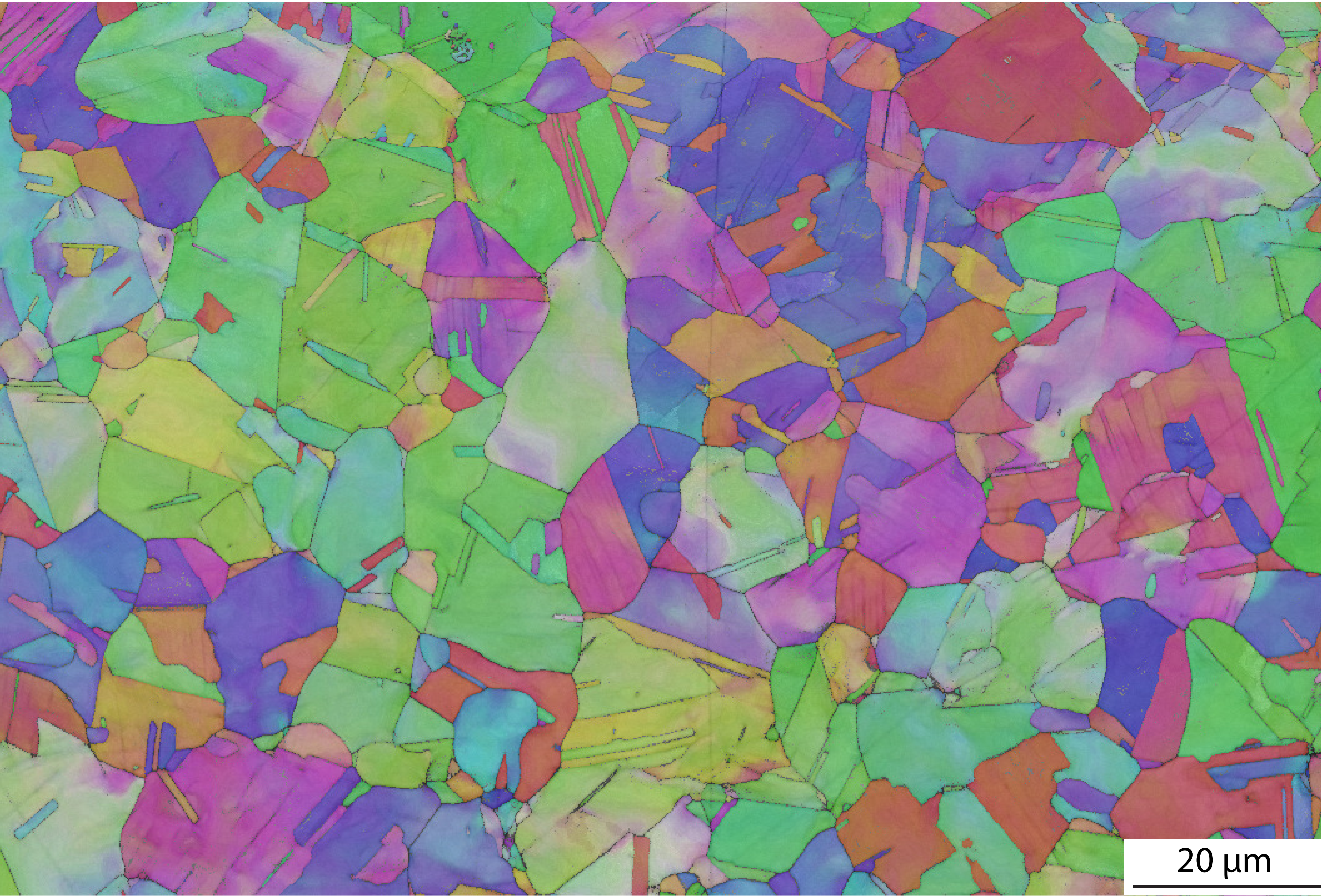


Repeated twinning= dynamic Hall-Petch (AR, ε=22%)

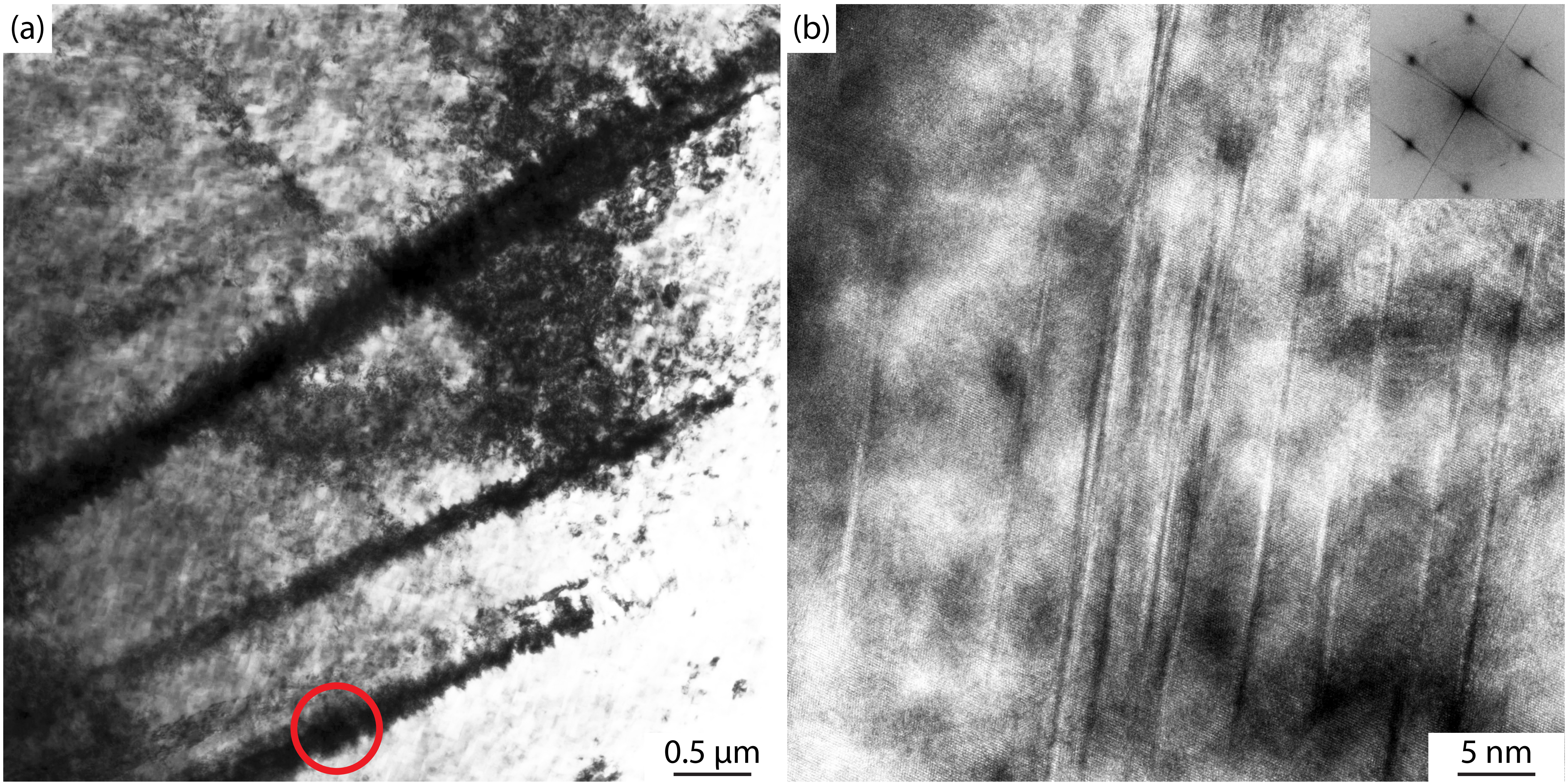


Do they perform in high rate / blast?

The blast centre

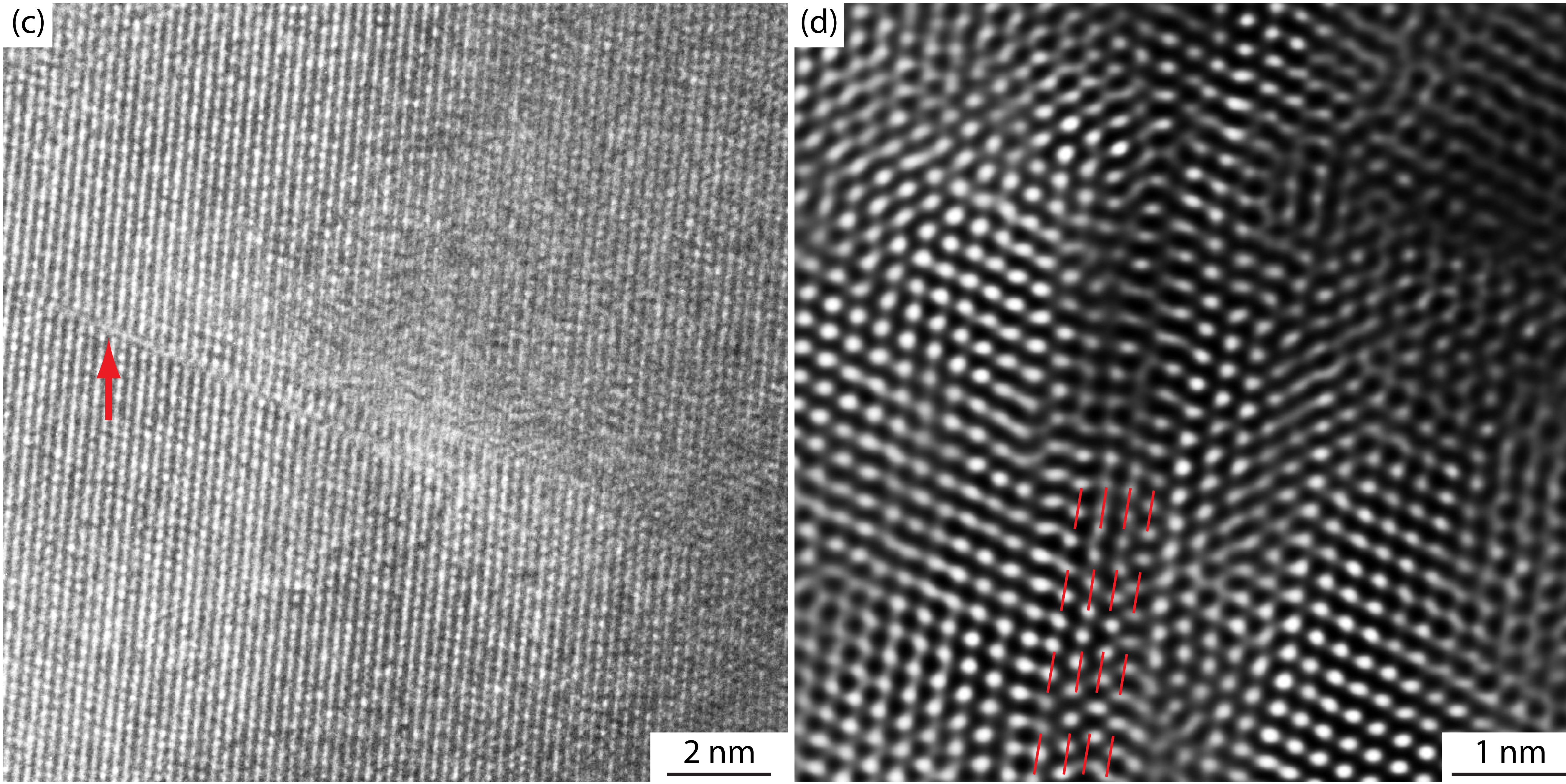


Centre of the bulge



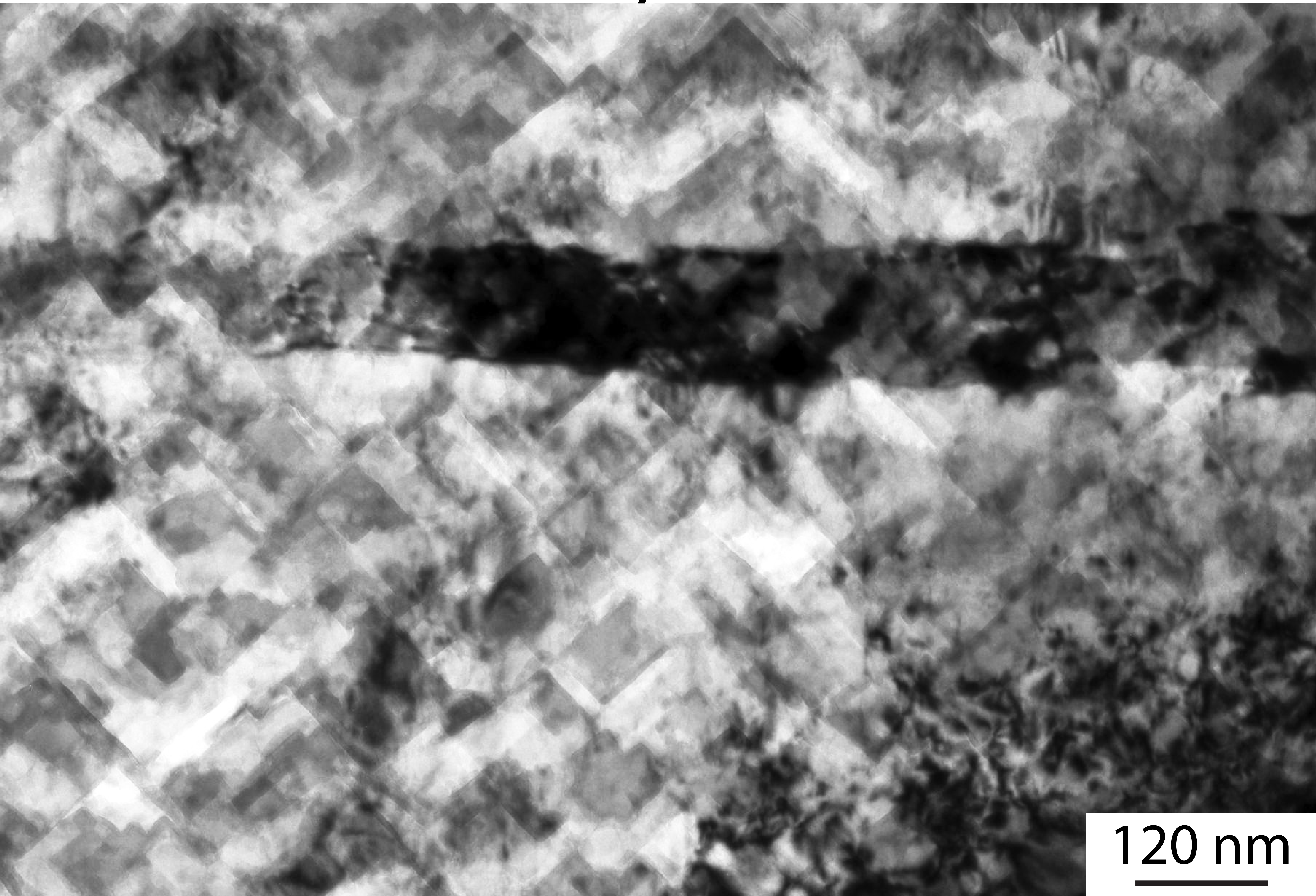
Material from centre of blast crater - (a) BF TEM overview, (b) examination of internal structure of a selected twin

... into the twin

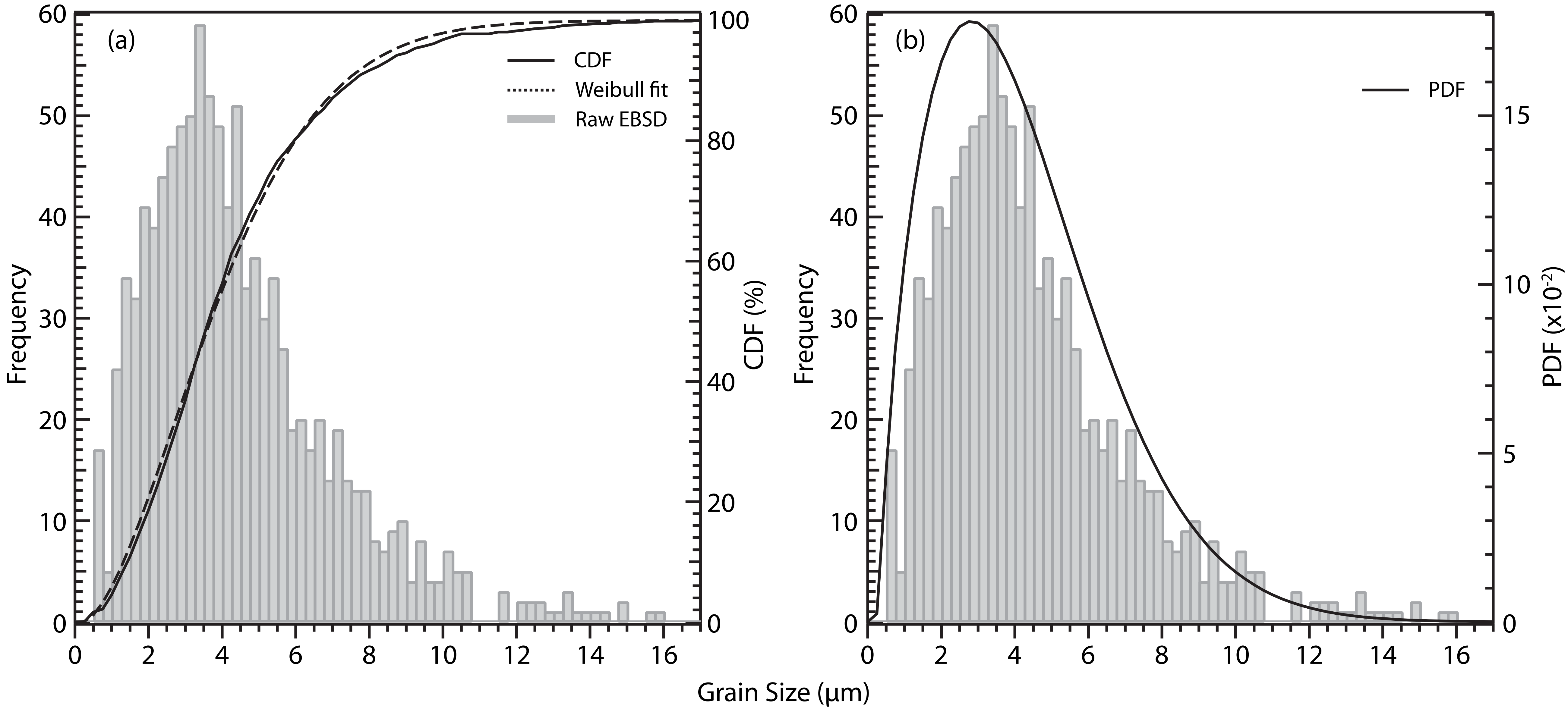


Material from centre of blast crater - HREM of the twin imaged (down [110]) in (b), showing numerous intrinsic SFs

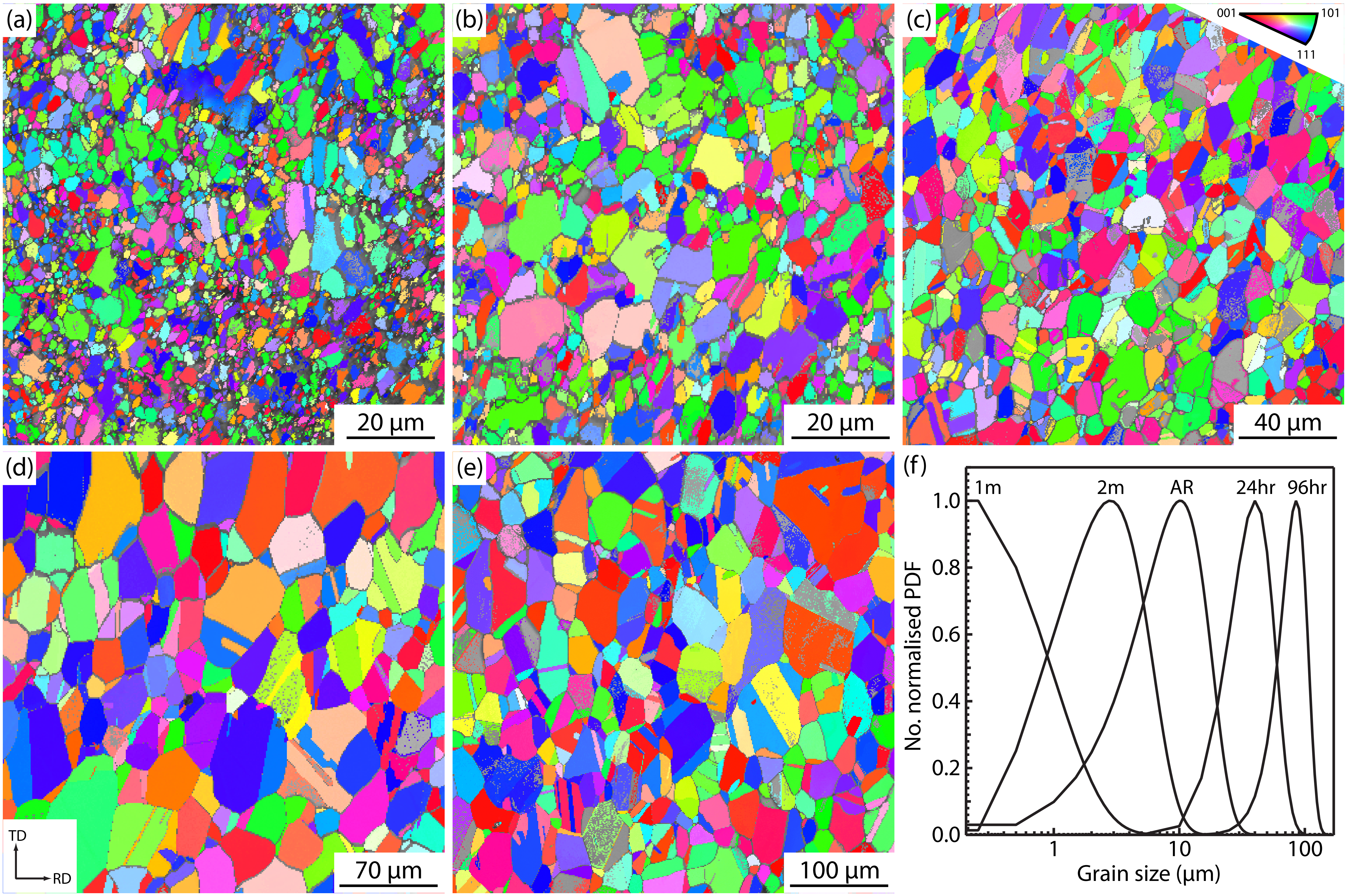
Fault density near a twin



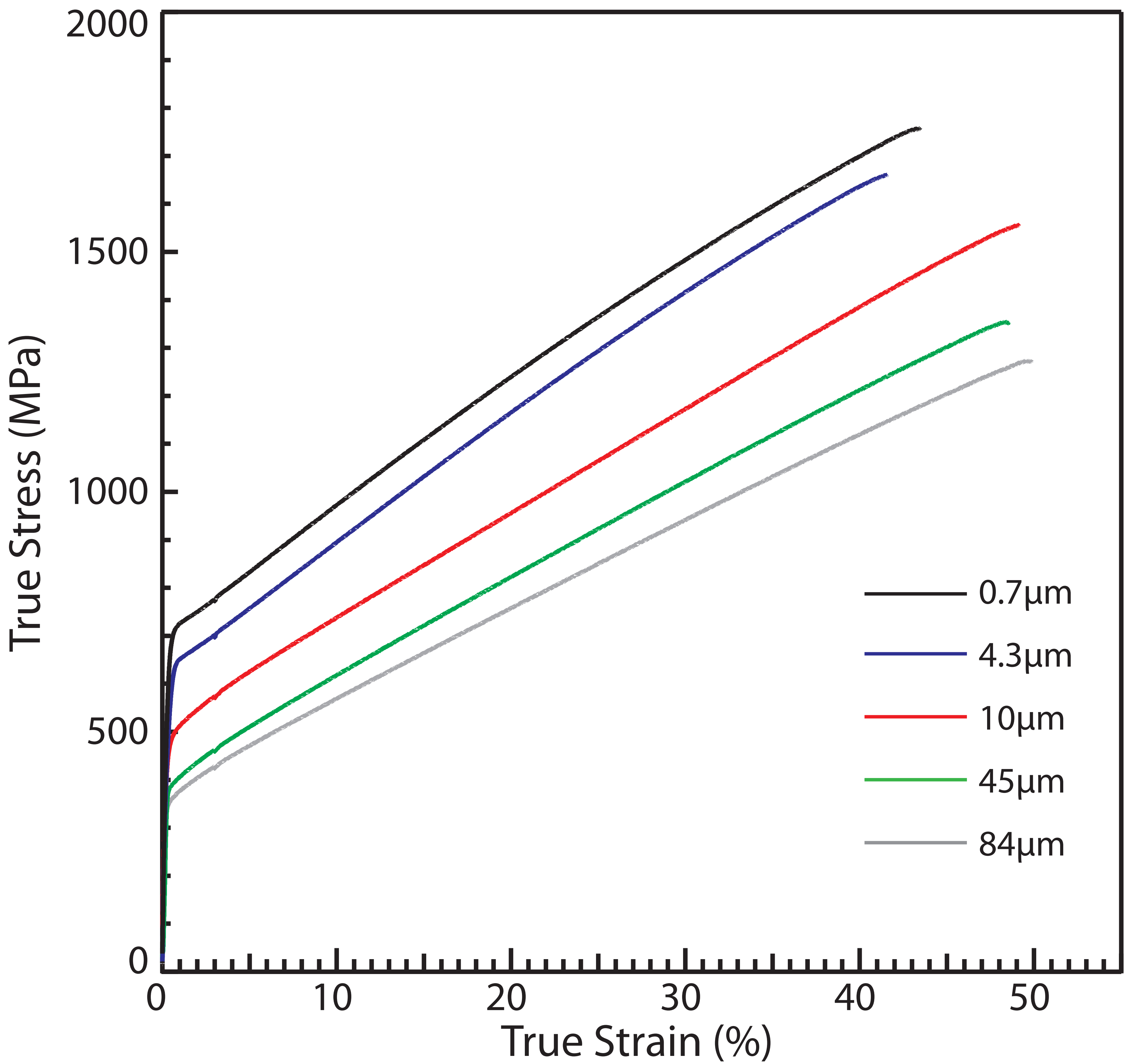
Measuring grain sizes



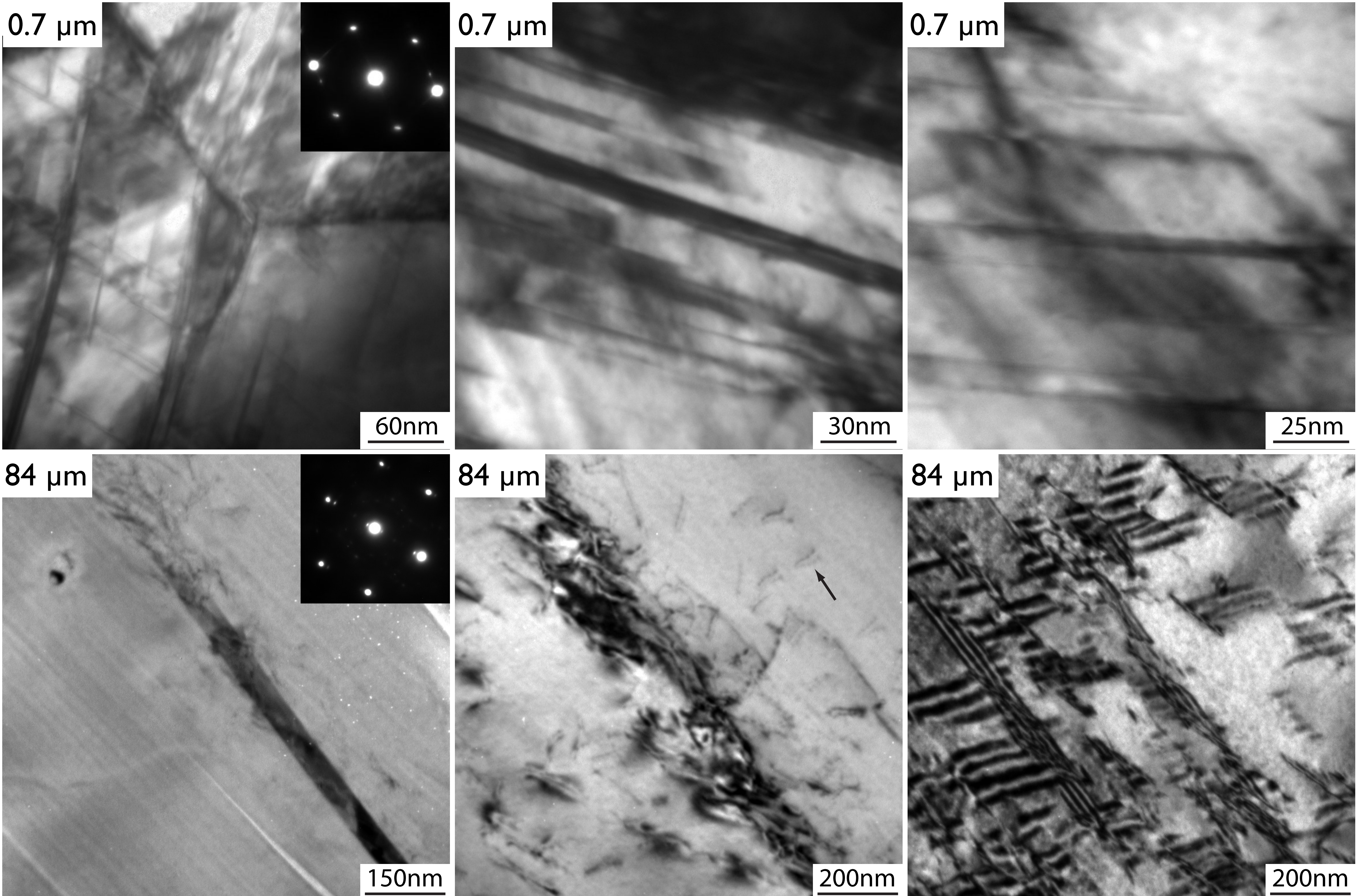
CR + anneal


(a)
20 µm
(b)
20 µm
(c)
001
101
111
40 µm
(d)
TD
RD
70 µm
(e)
100 µm
(f)
1m
2m
AR
24hr
96hr
No. normalised PDF
1.0
0.8
0.6
0.4
0.2
0.0
1
10
100
Grain size (µm)

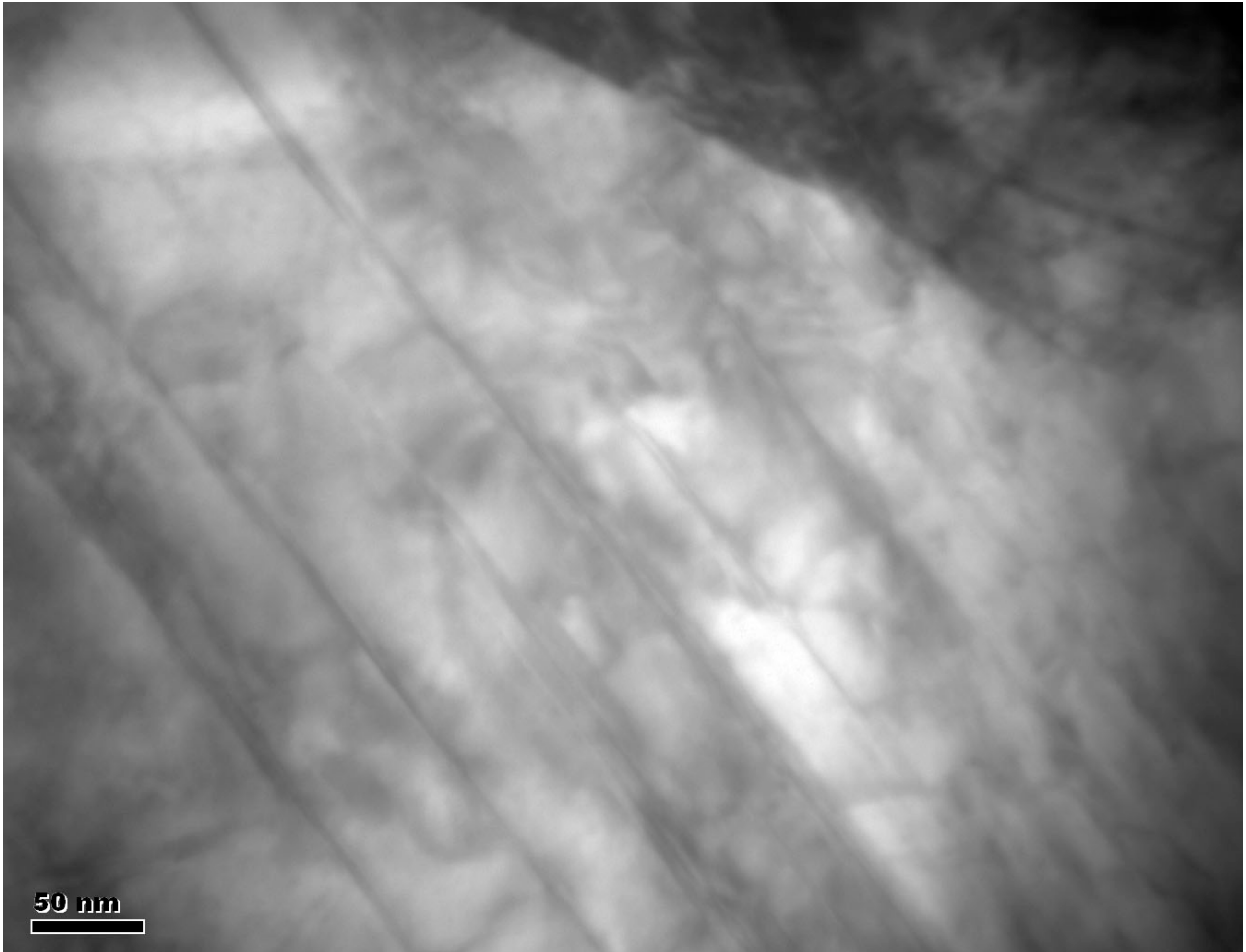
Effect of grain size



Finer grains = thinner twins (ε=5%)



Twins in the fine grain…



Thinking about the problem…

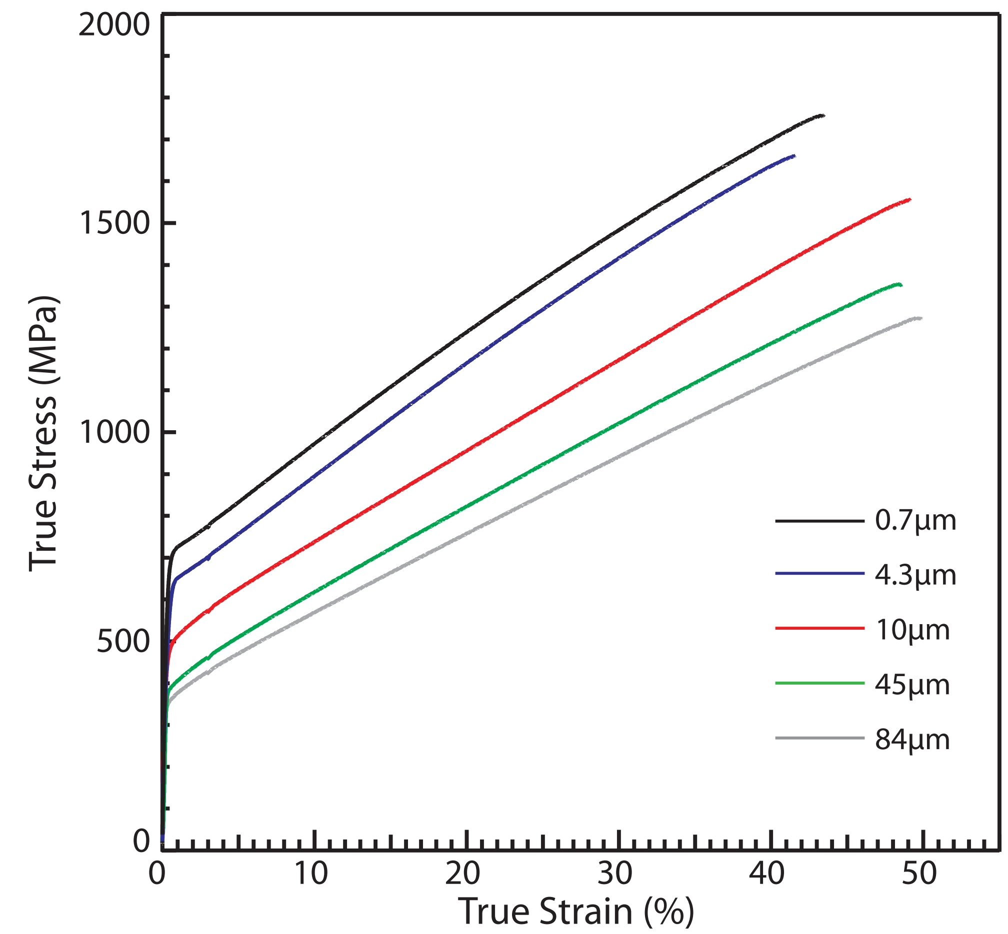
Flow Curve: $\sigma = \sigma_y + m\varepsilon$

Then necking criterion gives

$$\sigma_u = m$$

So: $\varepsilon_f = 1 - \sigma_y/m$

$U_{el} = m^2/2E$ $\quad U_{pl} \simeq \frac{1}{2}\left(m - \frac{\sigma_y^2}{m}\right)$



	σ_y (MPa)	m (GPa)	ε_f (%)	U_{pl} (GPa)
FG	750	2.26	67	0.99
AR	480	1.98	76	0.92
CG	250	1.7	85	0.81

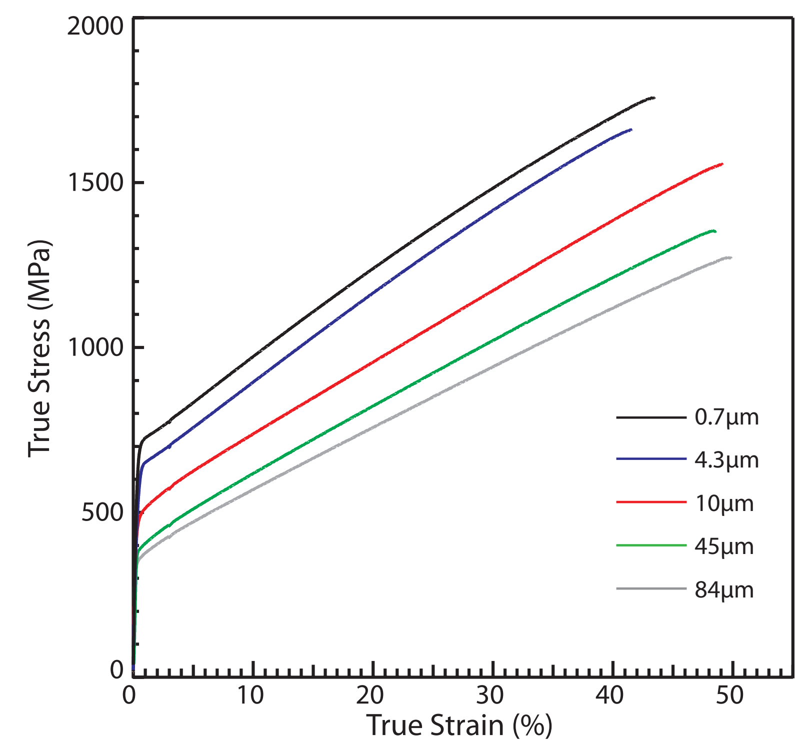
But **Intrusion...**

Flow Curve: $\sigma = \sigma_y + m\varepsilon$

Then impose a max. allowable strain.

If failure strain is greater, then

$$U_{\varepsilon_t} \simeq \sigma_y \varepsilon_t + \frac{1}{2}\varepsilon_t^2 m$$



	σ_y (MPa)	m (GPa)	ε_f (%)	U_{max} (GPa)	U_{30} (GPa)
Target TWIP	1300+	2.2+	41	0.7	**0.47**
FG TWIP	750	2.26	67	0.99	0.32
AR TWIP	480	1.98	76	0.92	0.23
CG TWIP	250	1.7	85	0.81	0.15
Ti-6Al-4V	950	1.0	10	0.13	0.13*
Armox 440	1300	1.54	16	0.21	0.21*

Goal: 3X strength, +10% hardening & 2X usable energy adsorbtion

Adding interstitial N

Pressurised ESR: Additions of up to 1 wt% N increase austenitic stainless steel strengths to ~2GPa.

ESR originally developed in the 1960s in the UK in Sheffield.

But, no onshore PESR capability.

Adding microalloying

Ti, Nb, V additions can increase strength without interfering with the TWIP mechanism.

Both retarding grain growth in hot rolling (μm grains), and providing nm precipitates

Ti additions promote TiN – limit to 0.1wt% - maybe 150 MPa

V additions – limit to 0.4 wt% - up to 300 MPa

See Scott et al, Int J Mat Res 102(5):538-549, 2011.

Initial Process Route Development

Microalloy with 0.5 wt. % Ti

↓

Heat to 1150°C for 15 minutes and quench

↓

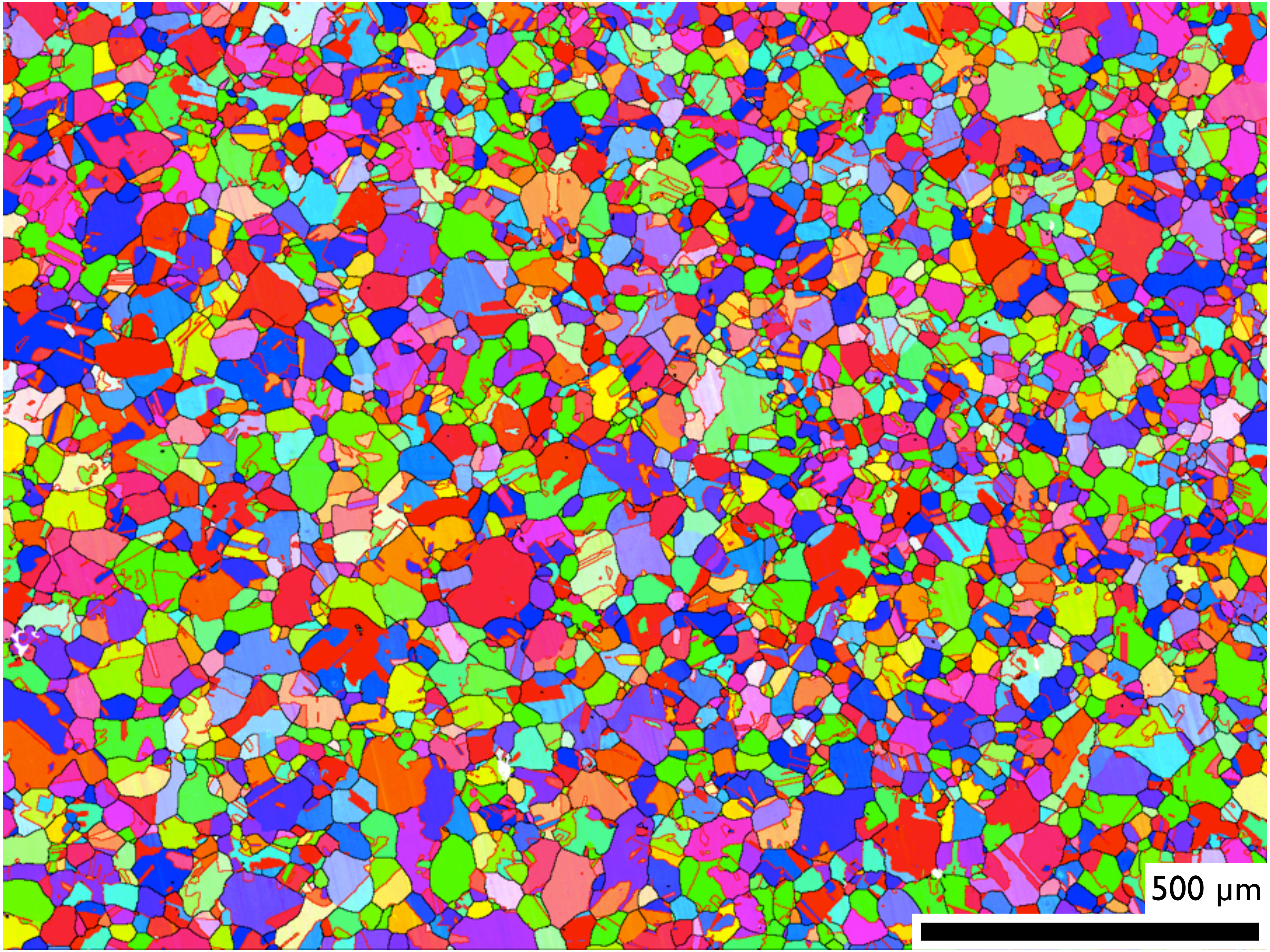
Cold roll to 75% reduction

↓

Heat treat at 850°C for 1, 2 and 5 minutes.

Need a recrystallisation heat treatment (T,t) to generate the correct grain size AND ~nm precipitate size

+Ti TWIP



Melted from master alloys, hot rolled, annealed - 30 µm grain size

Conclusions

The TWIP mechanism does operate in the blast regime.

Not all of the ductility is useful.

Improved, higher strength TWIP alloys that retain the hardening rate associated with the TWIP mechanism would be desirable.

Some thoughts on how to do this have been presented

Backup Slides

Effect on twin thickness (ε=5%)