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Institute of Mechanics, Materials and Civil Engineering (iMMC)

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Nucleation mechanism of {112}<111> mechanical twins in as-quenched β metastable Ti-12 wt.% Mo alloy

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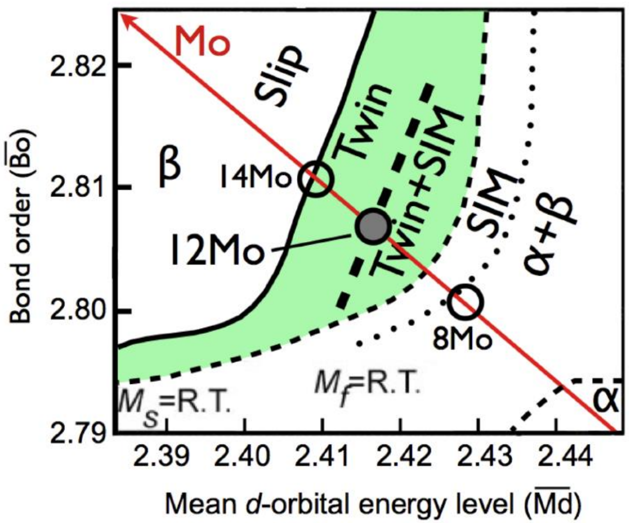
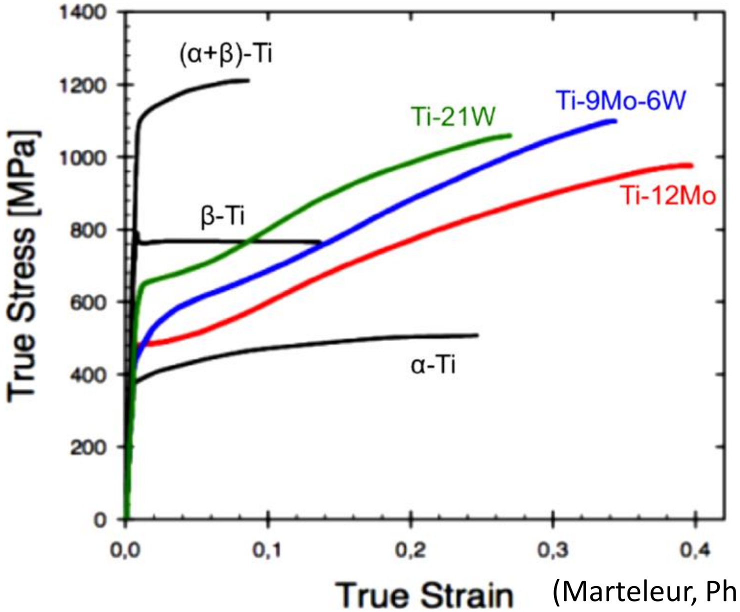
THE 14TH WORLD CONFERENCE ON TITANIUM

12th of June, 2019

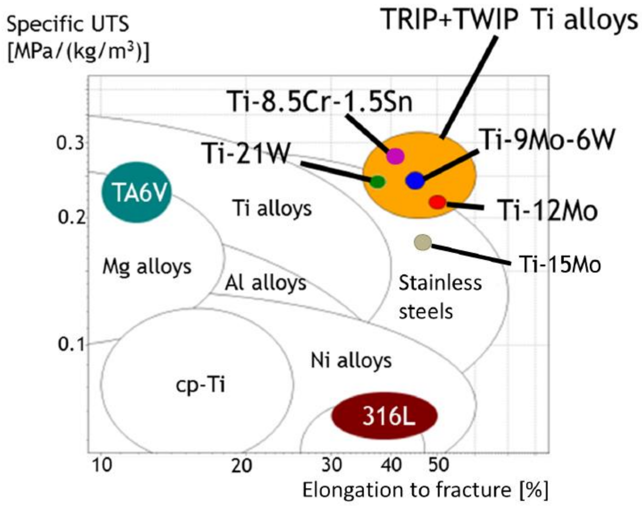
Design of TRIP/TWIP alloys : the seminal work

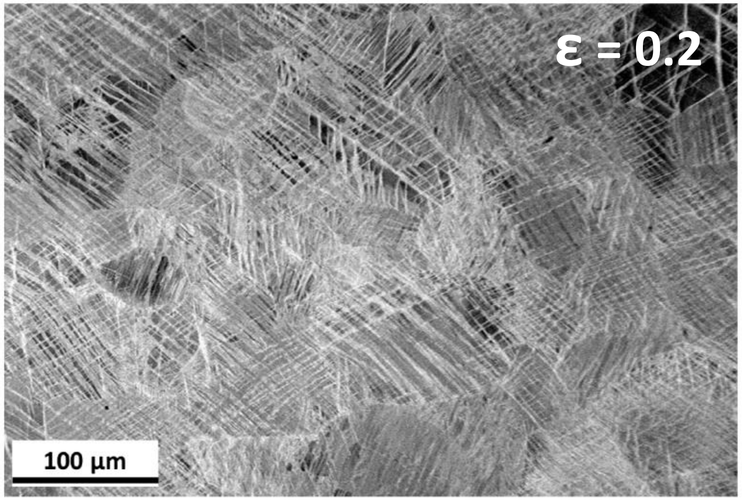


(Marteleur et al., Scripta Mat. 2012)



(Marteleur, PhD thesis 2017)





Overview of mechanisms of {112}<111> twin formation

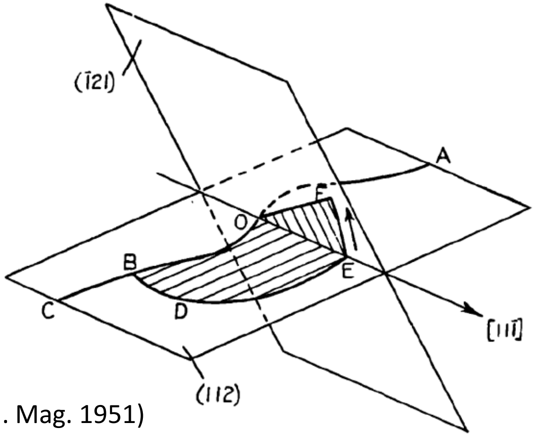
1 : Dissociation on 112 planes

- Pole mechanism of Cottrell and Bilby

$$\frac{a}{2}[111] \longrightarrow \frac{a}{6}[11\bar{1}] + \frac{a}{3}[112]$$

Twinning partial (glissile) — Pole (sessile)

Monolayer nucleus :



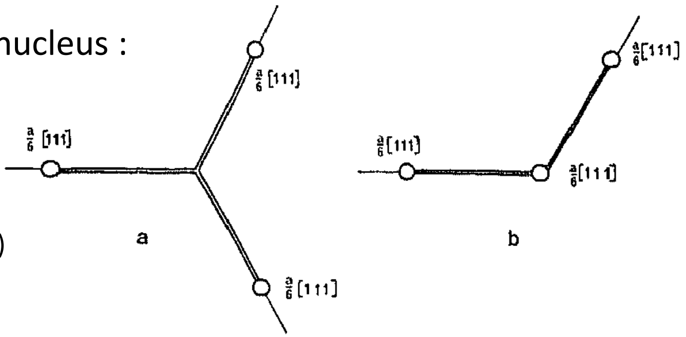
(Cottrell et al., Lond. Edinb. Dubl. Phil. Mag. 1951)

- Sleeswyk adaptation :

$$\frac{a}{2}\langle 111\rangle \longrightarrow \frac{a}{6}\langle 111\rangle + \frac{a}{6}\langle 111\rangle + \frac{a}{6}\langle 111\rangle$$

3 twinning partials

3-layers nucleus :



(Sleeswyk , Phil. Mag. 1963)

unstable —Cross-slip→ stable

(Vitek, Cryst. Lattice Defects 1974)

2 : Dissociation on 110 planes

3 : Dissociation due to pile-up on sessile jogs

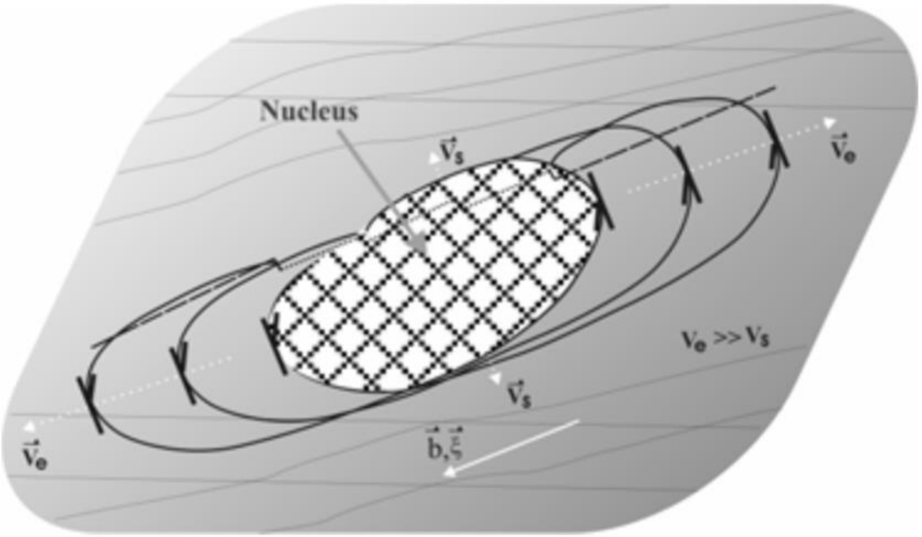
4 : Shuffle mechanism

Overview of mechanisms of {112}<111> twin formation

1 : Dissociation on 112 planes

- Hsiung and Lassila extension of Cottrell-Bilby-Sleeswyk model

$$\frac{a}{2}\langle 111\rangle \rightarrow zonal\ dislocation \begin{cases} \frac{-a}{6}\langle 111\rangle \\ \frac{a}{3}\langle 111\rangle \\ \frac{-a}{6}\langle 111\rangle \end{cases} + twinning\ dislocations \begin{cases} \frac{a}{6}\langle 111\rangle \\ \frac{a}{6}\langle 111\rangle \\ \frac{a}{6}\langle 111\rangle \end{cases}$$



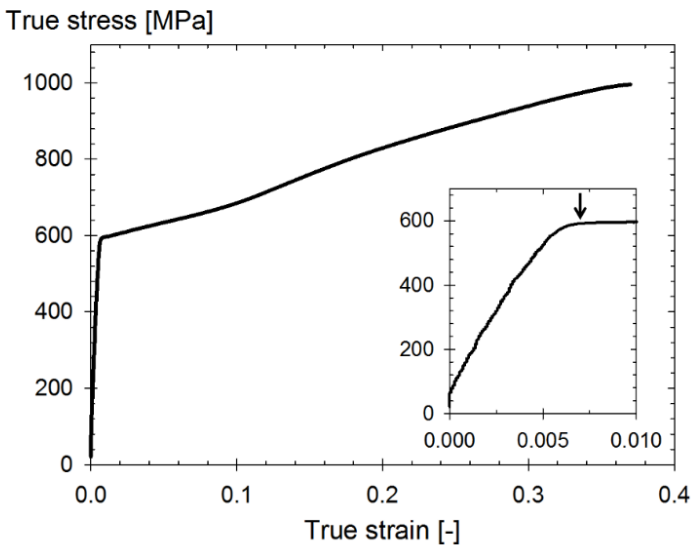
- For shock-induced twins in Ta and Ta alloys

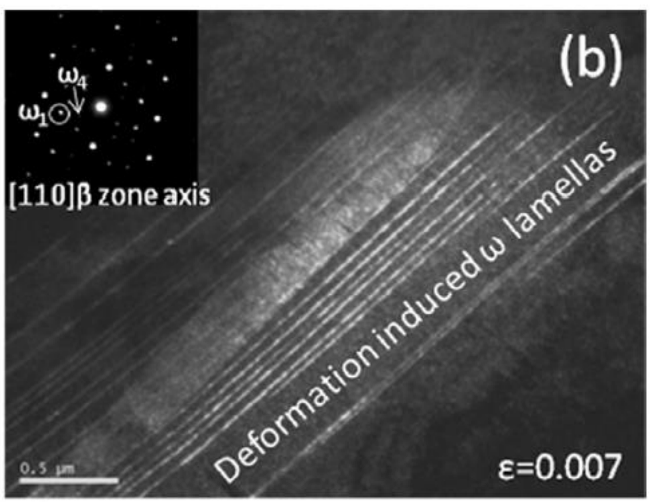
  (Hsiung et al., Acta Mater. 2000)

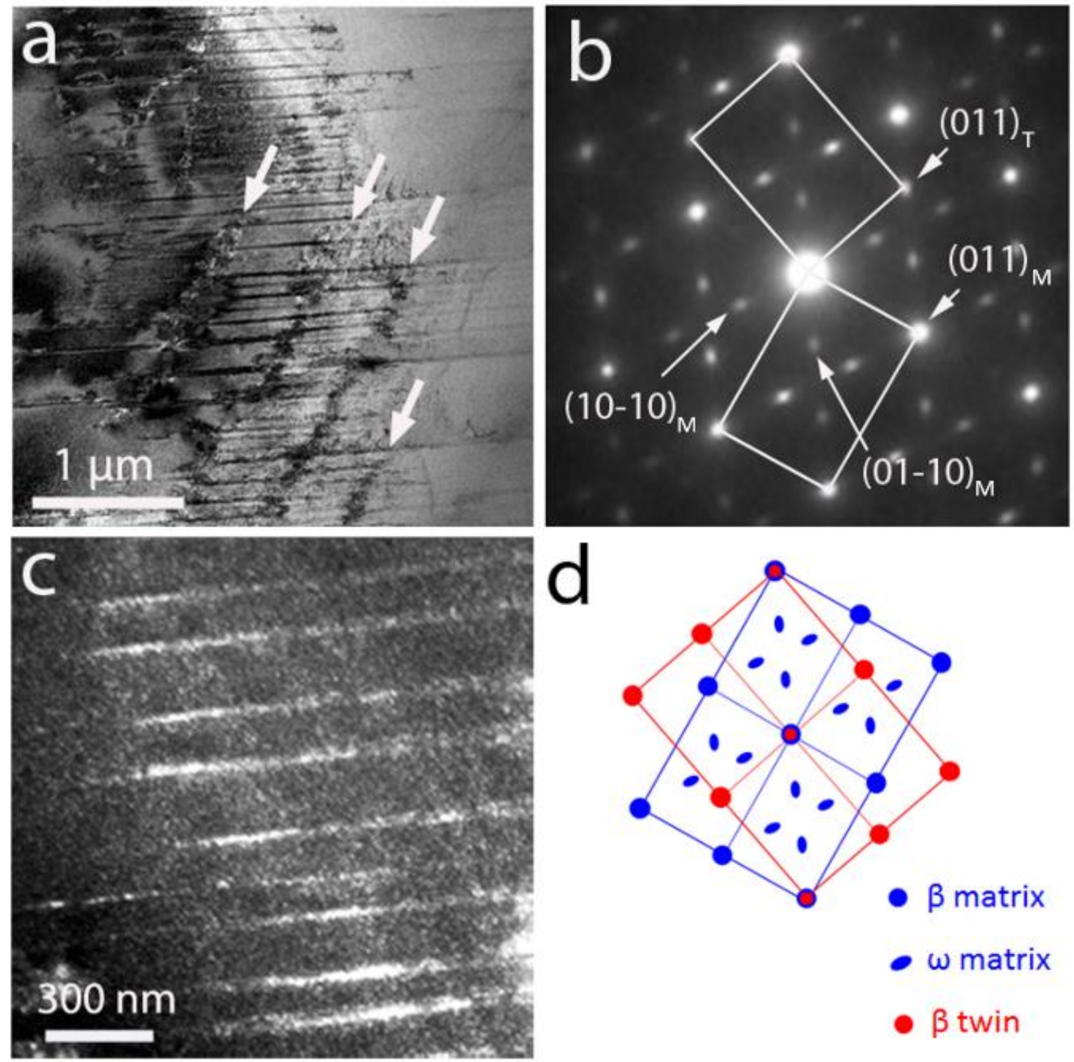
- On Gum metal deformed in compression

  (Xing et al., APL 2008)

Post-mortem TEM analysis

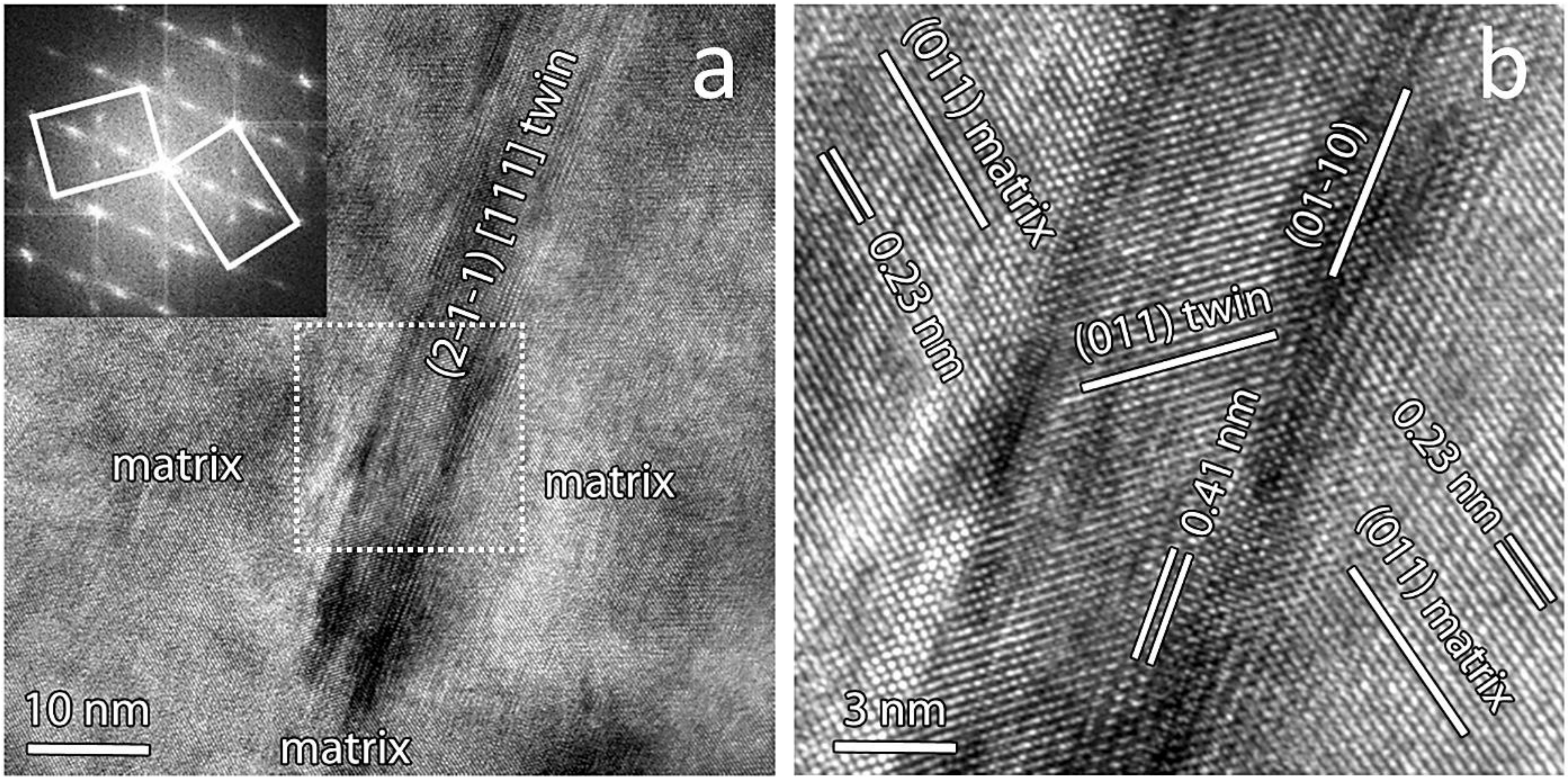






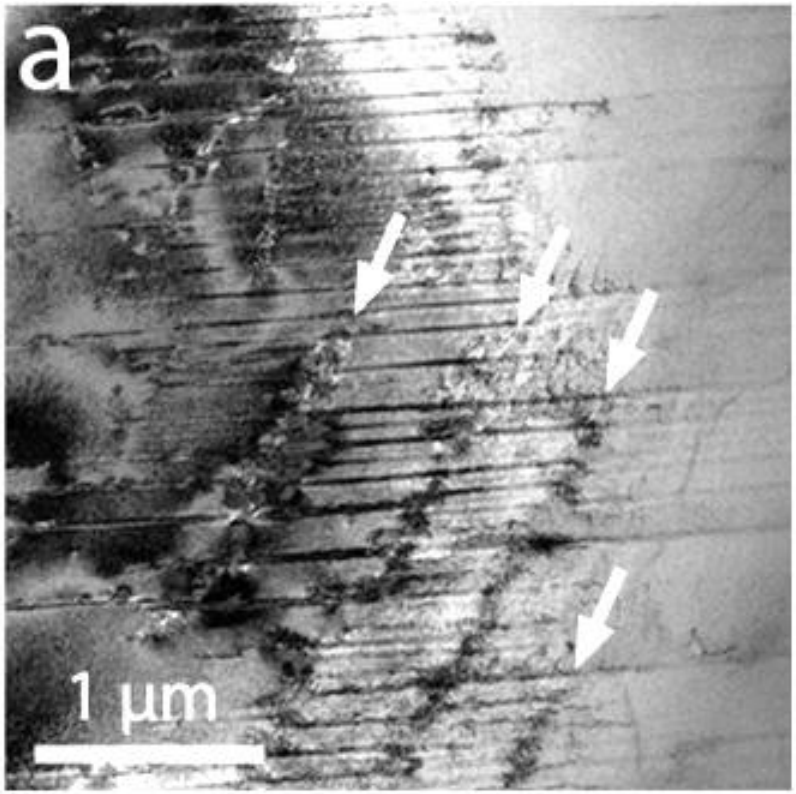
(Sun et al., Acta Mater. 2013)

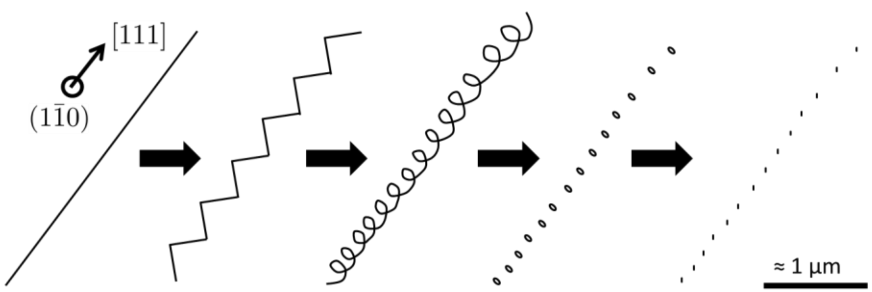
High resolution observations



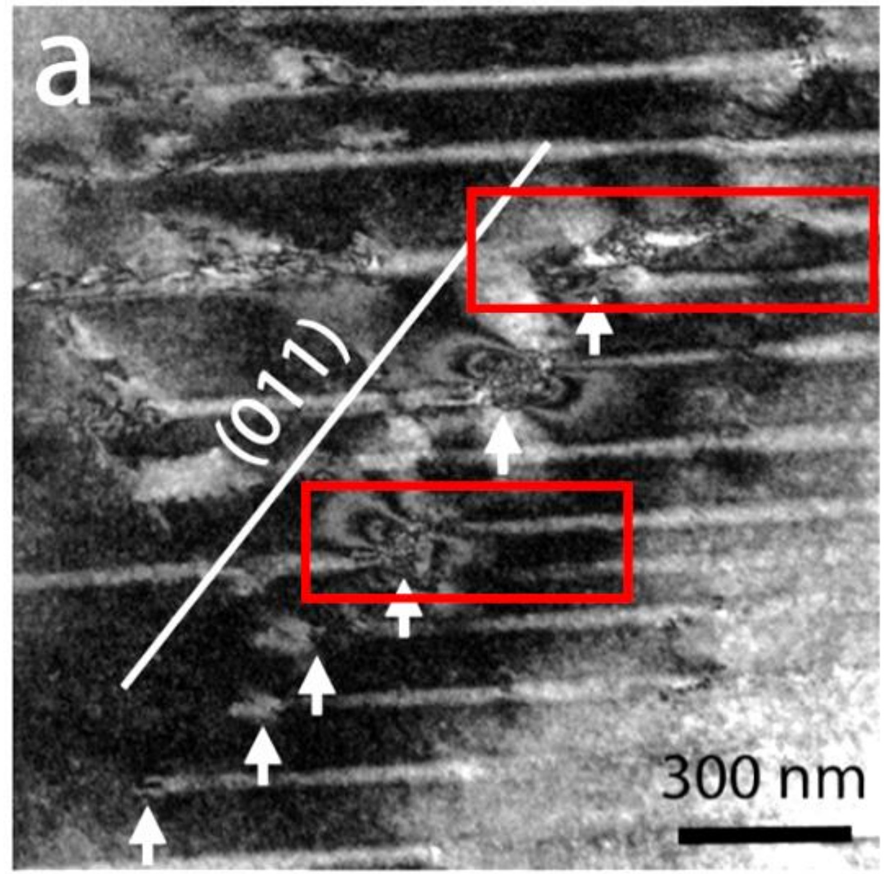
- HRTEM highlights the BCC periodicity within the bands
- Precipitation of ω phase at the TB for strain accommodation

Initial defect configuration





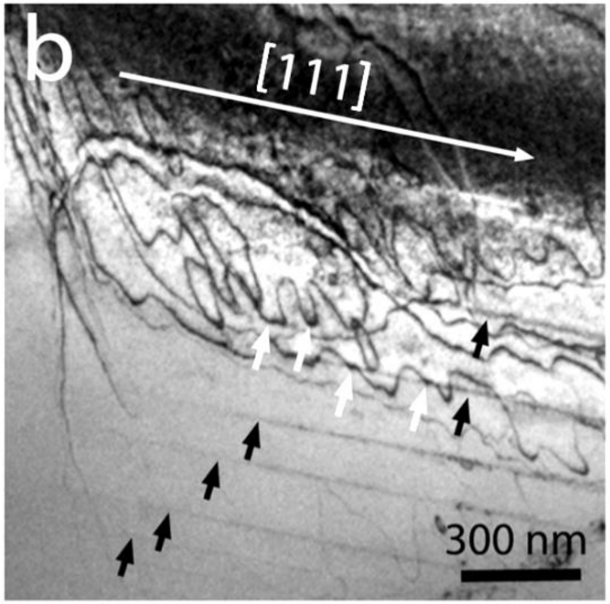
Evolution during annealing

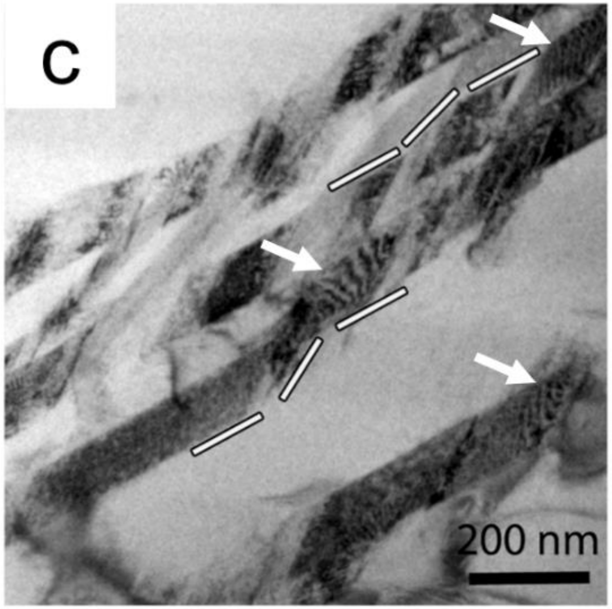


Nucleation on aligned jogs

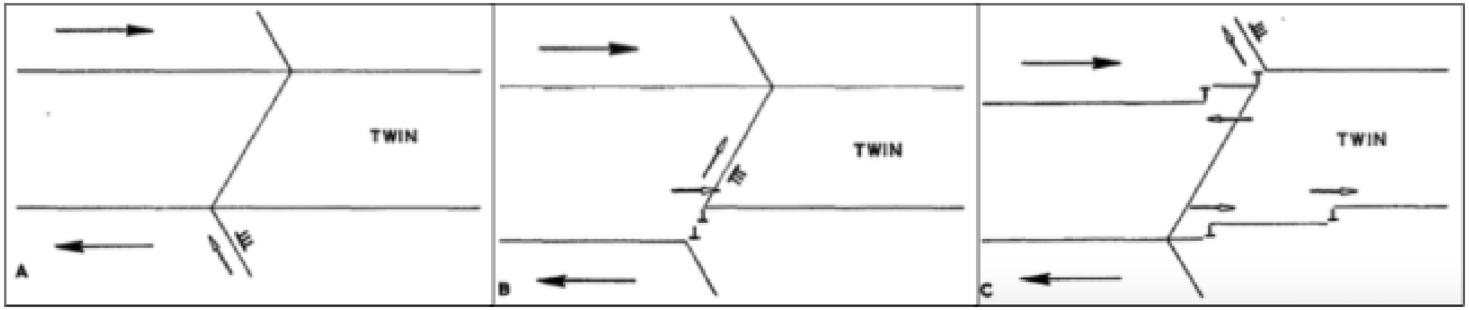
Jogs initially present in the material

Twins growth mechanism



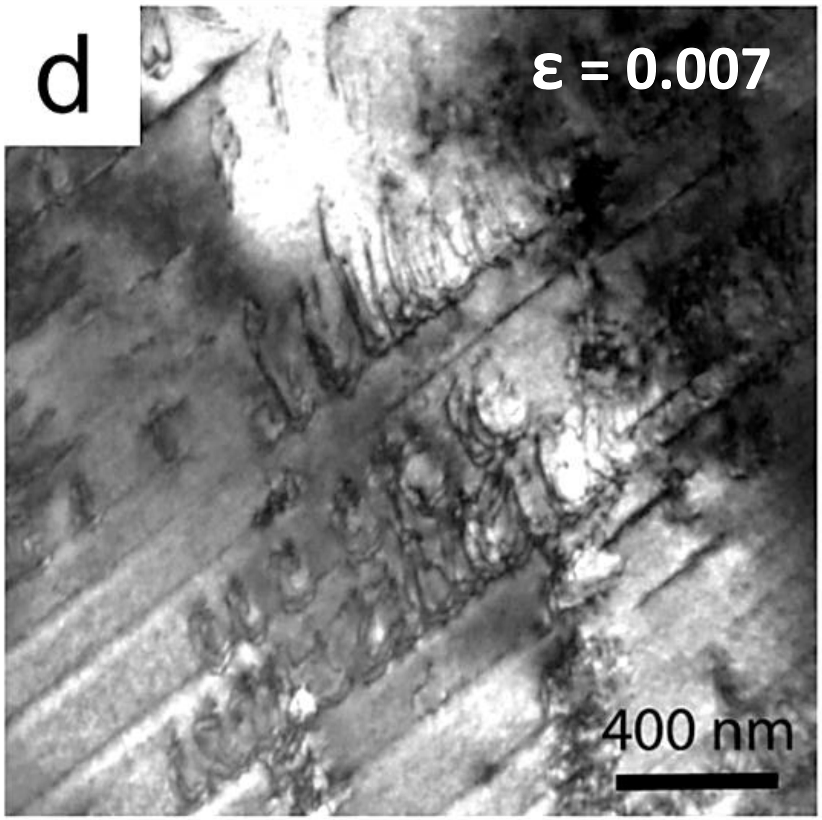


- Numerous cross-slip events due to dislocation-twin boundary interactions
- Growth of twins by incorporation mechanism proposed by Sleeswyk and Verbraak
- Formation of super-jogs



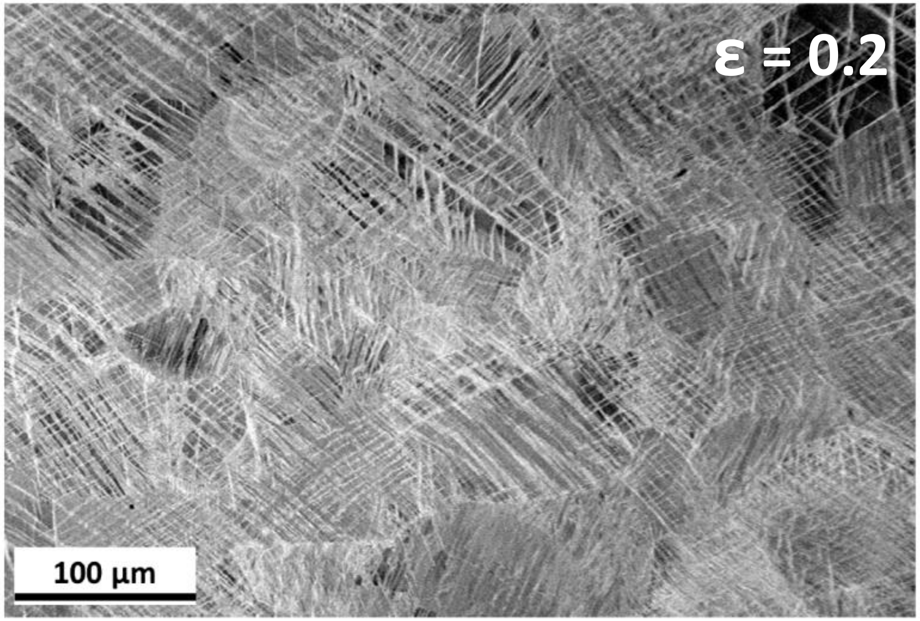
(Sleeswyk and Verbraak, 1961)

New dislocation sources

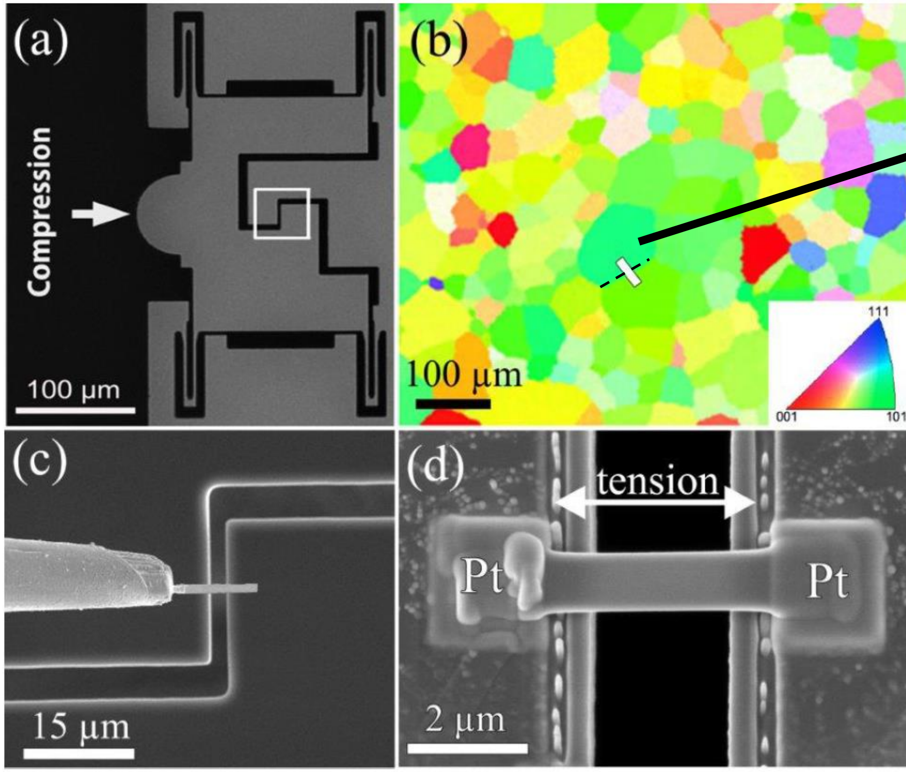


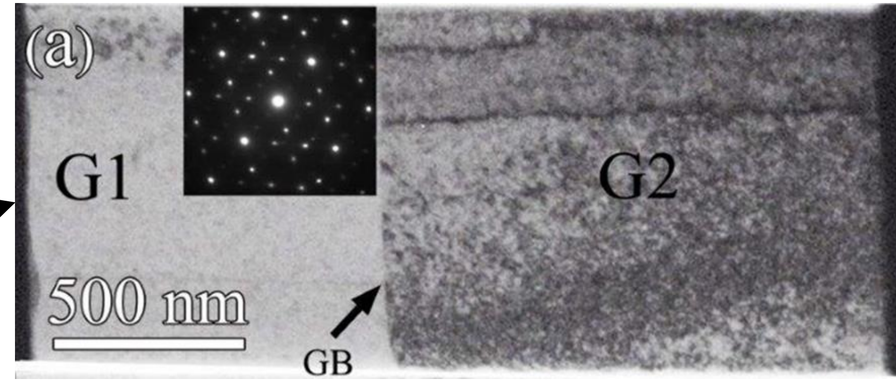
- Twin boundaries act as effective dislocation sources
- Emission of dislocations from the jogged interfaces
- Brings the components for subsequent plasticity mechanisms : β→α'' SIM transformation

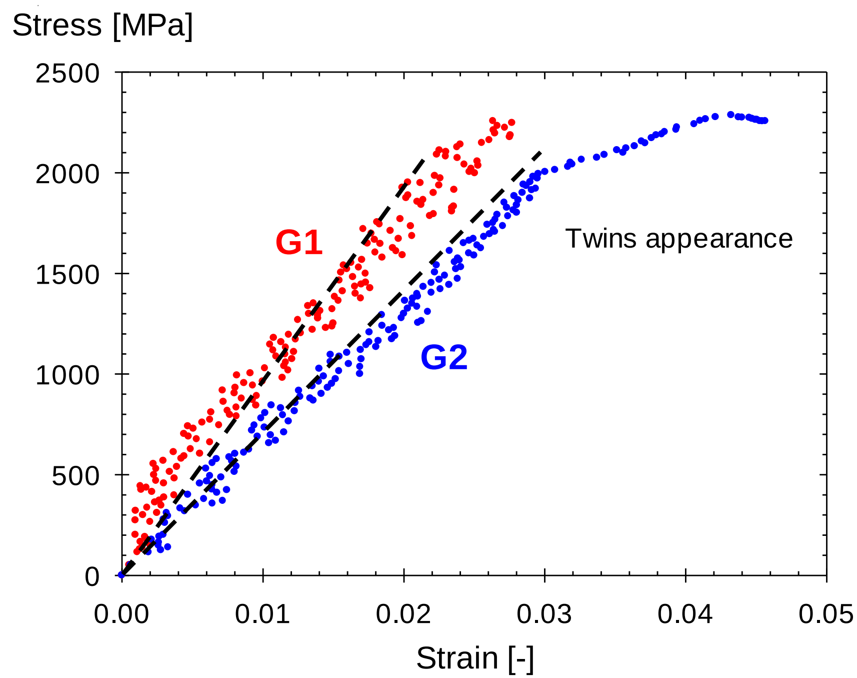
  {332}<113> twinning



In situ TEM tensile test



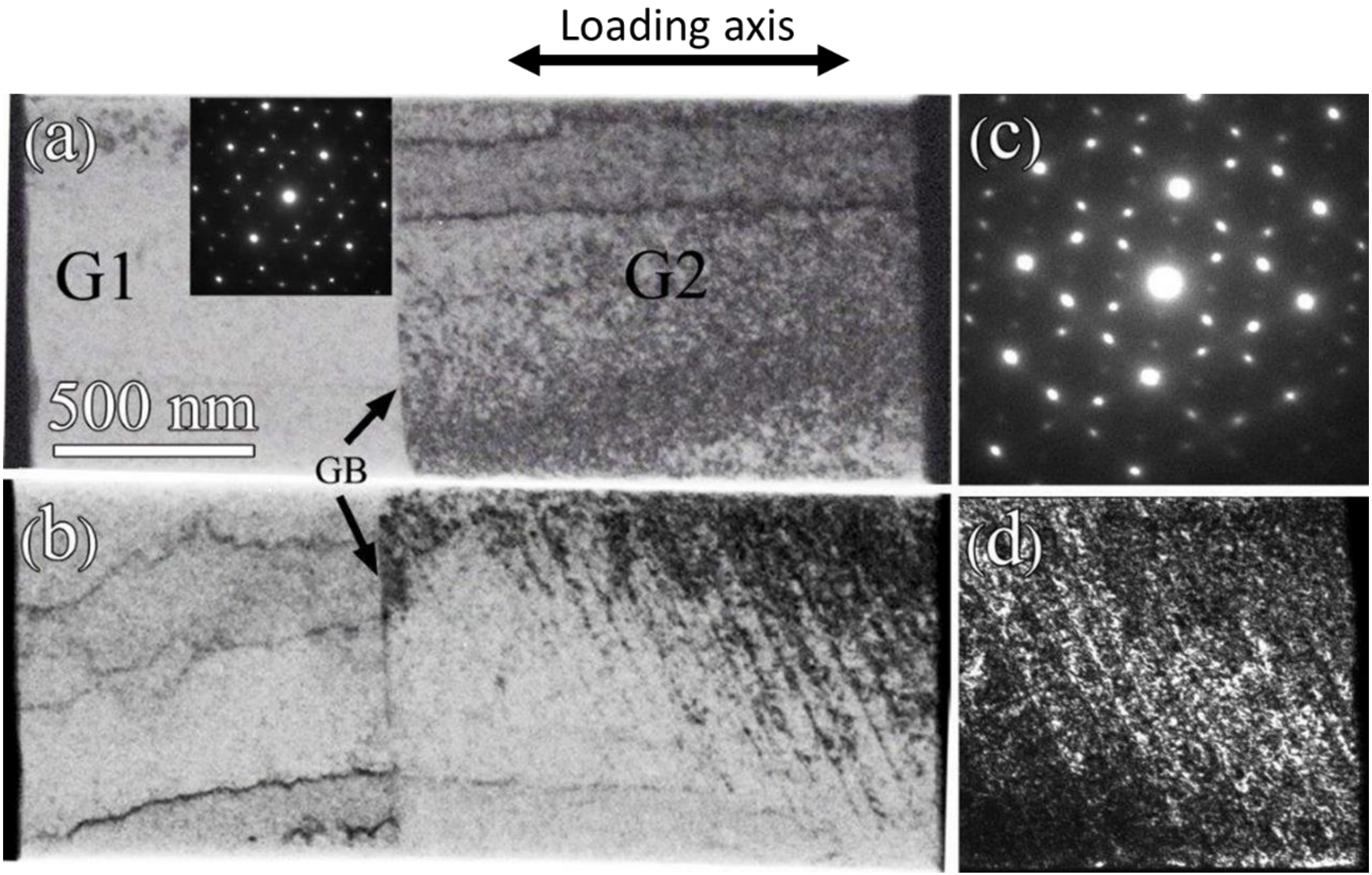




Calculated values of E_{hkl} close to observed ones

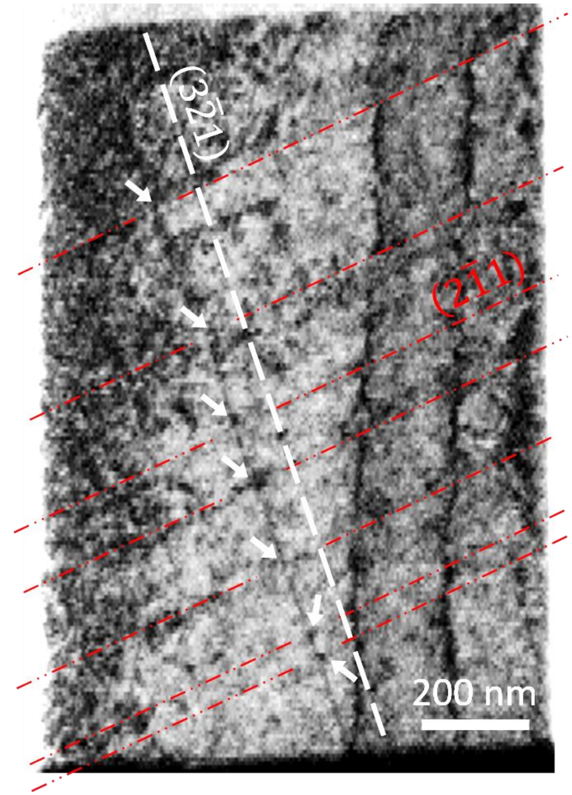
$E_{111} \approx 110$ Gpa $E_{112} \approx 72$ GPa

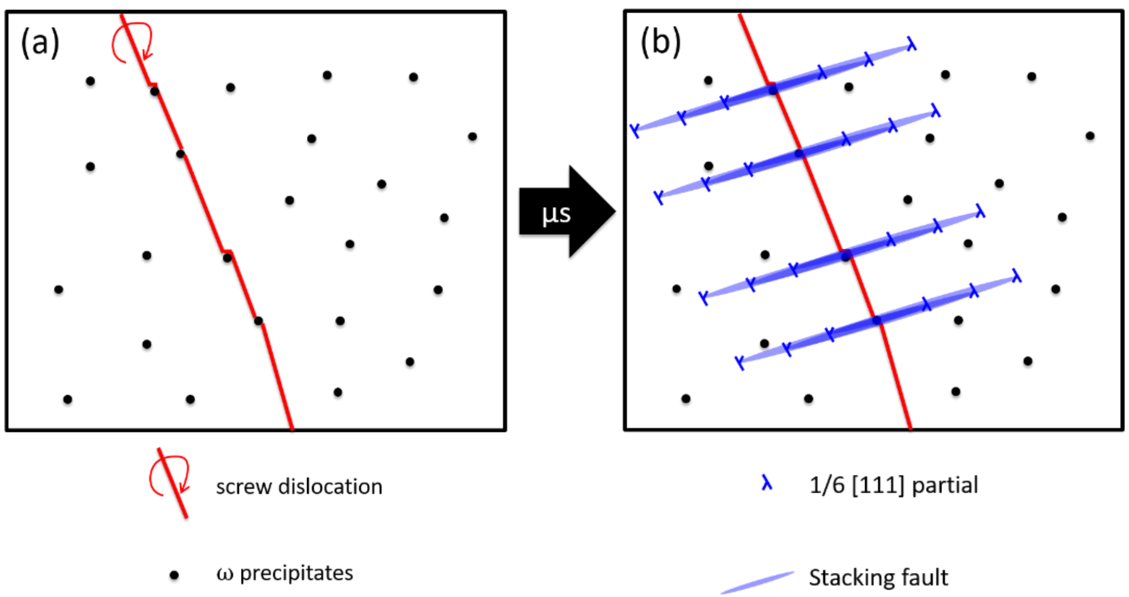
In situ TEM tensile test



Proposed sequence of twin formation

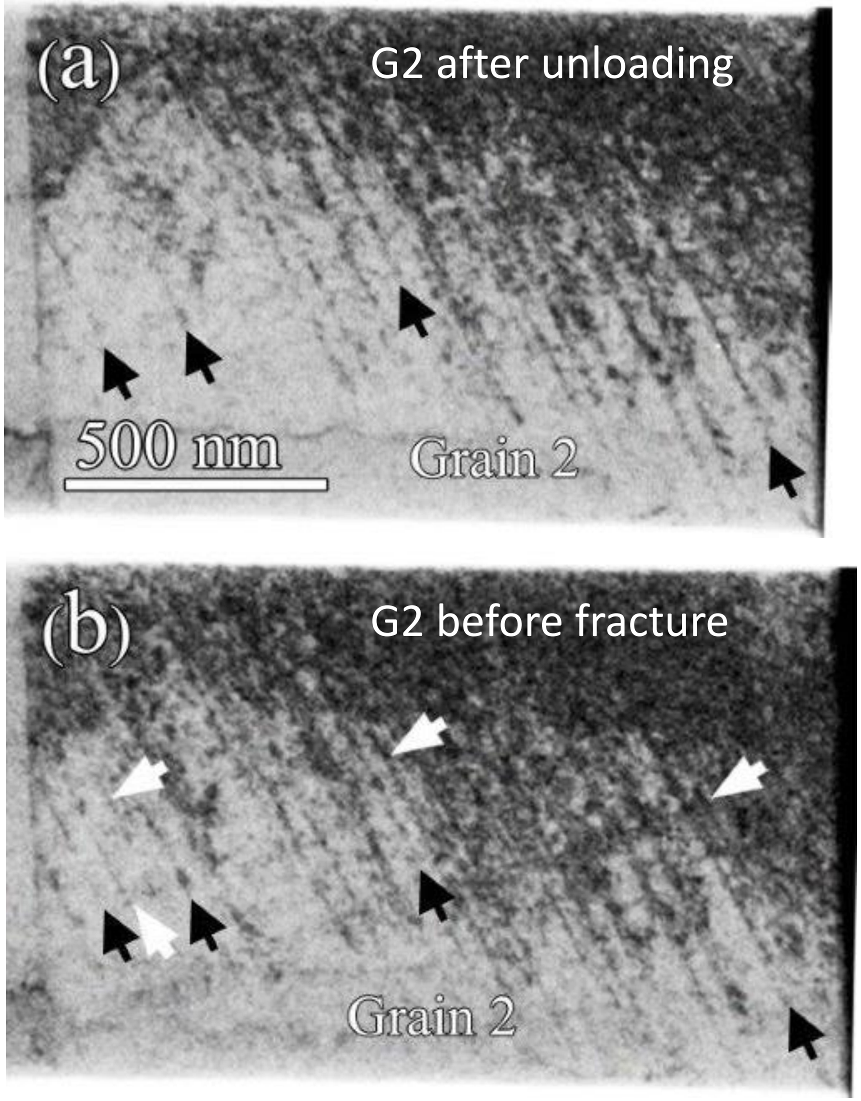
- First event seems to be the formation of a {321}-type screw dislocation
- Interaction of dislocation with ω_{ath} precipitates forms jogs
- Triggering of dissociation reaction for {112} twinning on newly formed jogs

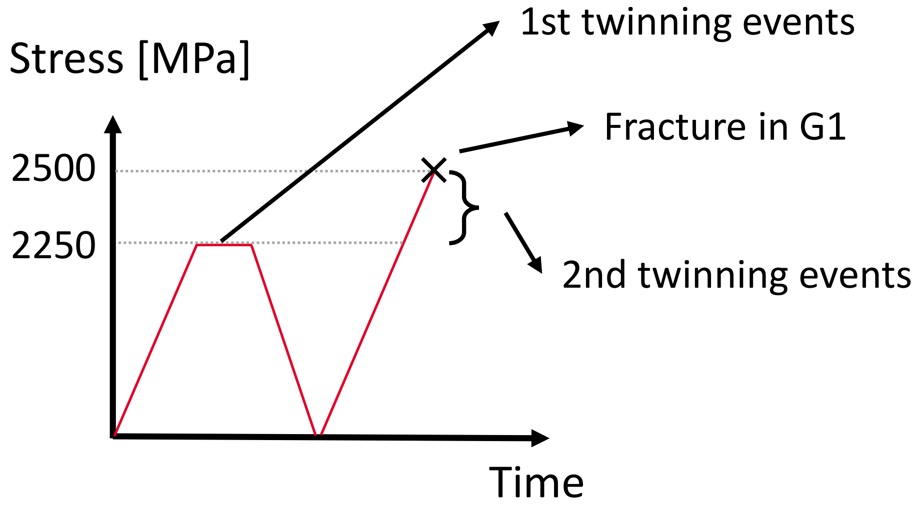


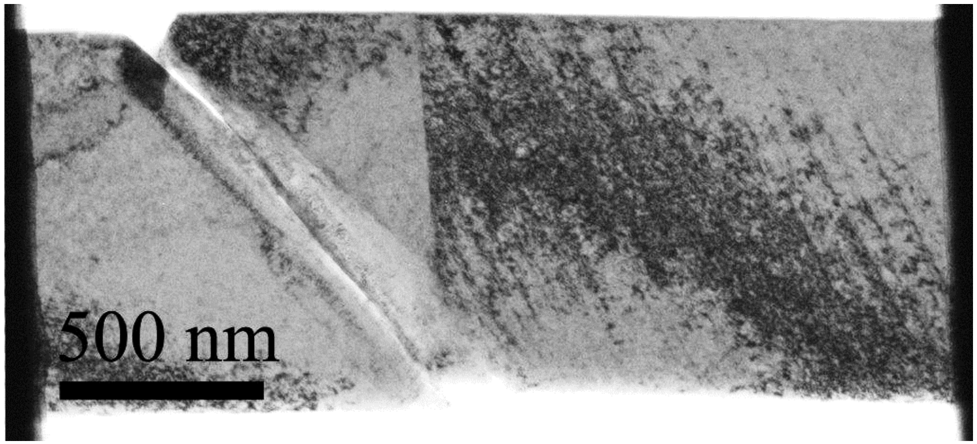


	Slip system	Schmid factor
G1	$[\bar{1}11](1\bar{1}2)$	0.351
	$[111](1\bar{2}1)$	0.351
	$[\bar{1}11](\bar{1}10)$	0.322
	$[111](2\bar{3}1)$	0.352
G2	$[11\bar{1}](2\bar{1}1)$	0.386
	$[\bar{1}\bar{1}1](\bar{1}10)$	0.334
	$[\bar{1}\bar{1}1](101)$	0.334
	$[11\bar{1}](3\bar{1}2)$	0.379
	$[11\bar{1}](3\bar{2}1)$	0.379

Second loading : twins multiplication







Conclusions

- Investigation of the $\{112\}\langle 111\rangle$ twin nucleation mechanism in Ti-12 wt.% Mo grade
- $\{112\}\langle 111\rangle$ twin nucleation at the onset of plasticity
- Precipitation of a ribbon of ω_{ath} phase at TBs to relax elastic strain field
- Initial defects mandatory for nucleation step, as proposed by Hsiung and Lassila
- *in situ* tensile tests confirm the need of crystalline defects for nucleation step
- Growth of twins by partial dislocation incorporation, forming superjogs at TBs
- Superjogs act as new dislocation sources for further deformation mechanisms

Submitted to Materialia, under review

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