Investigations of the role of SIM α'' phase in the plasticity of β-metastable Ti alloys exhibiting TRIP and TWIP effects

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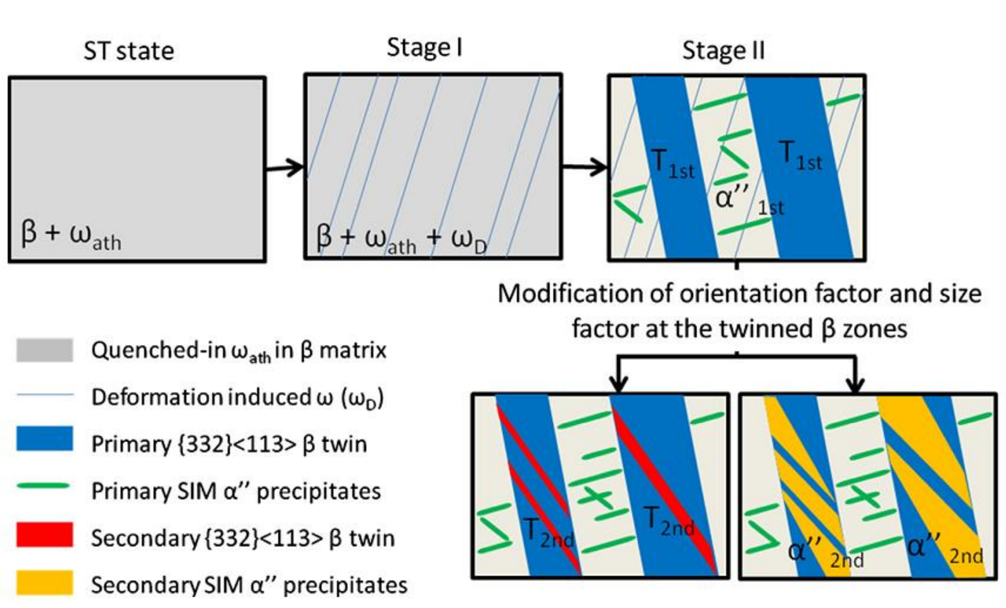
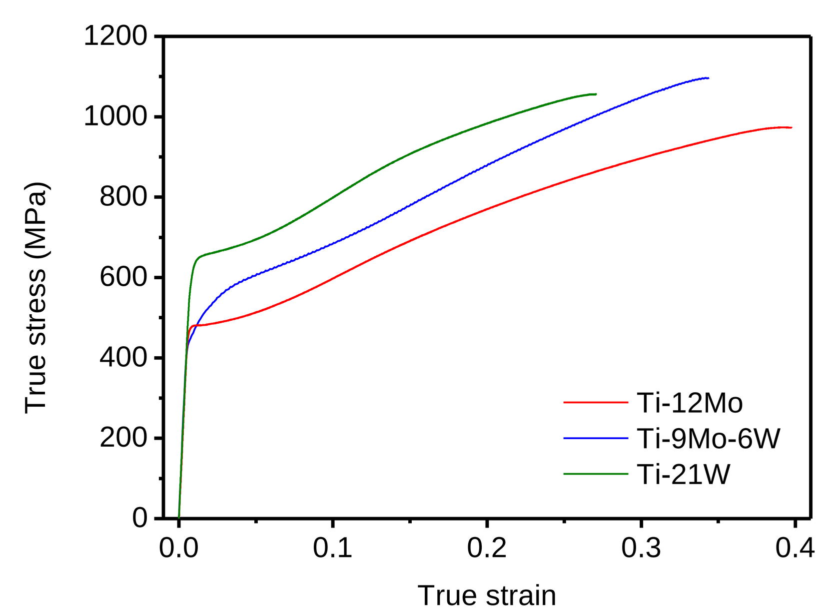
1. Introduction

β titanium alloys are becoming more and more used in several application fields thanks to their unique combination of properties. However, they still suffer from a lack of work hardening resulting in a rapid strain localization and low ductility levels, which can be a serious drawback in applications requiring plasticity. In previous studies, a design strategy had been developped to predict compositions allowing the activation of multiple plastic deformation mechanisms [1]. Various characterization methods confirmed the activation of TWIP (Twinning Induced Plasticity) and TRIP (Transformation Induced Plasticity) effects [2]. Understanding the role of each mechanisms is thus a key issue for their optimization. *In-situ* tensile tests with synchrotron X-ray diffraction (SXRD) have been performed to investigate the role of the β to α'' stress-induced martensitic transformation.

2. Mechanical behavior & plasticity sequence [2]



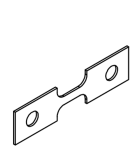


Localization of secondary events within the primary β twins

3. Material & characterization techniques

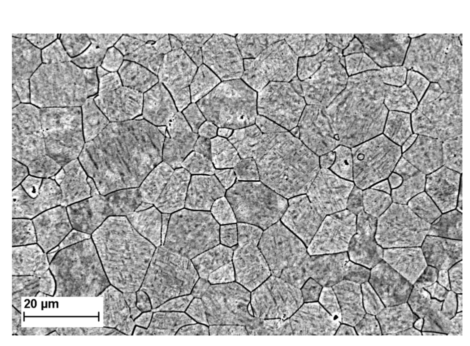
Generic alloy exhibiting TRIP/TWIP effects :

Ti – 12 wt.% Mo in as-quenched state ($\beta + \omega_{ath}$)



Tensile sample :

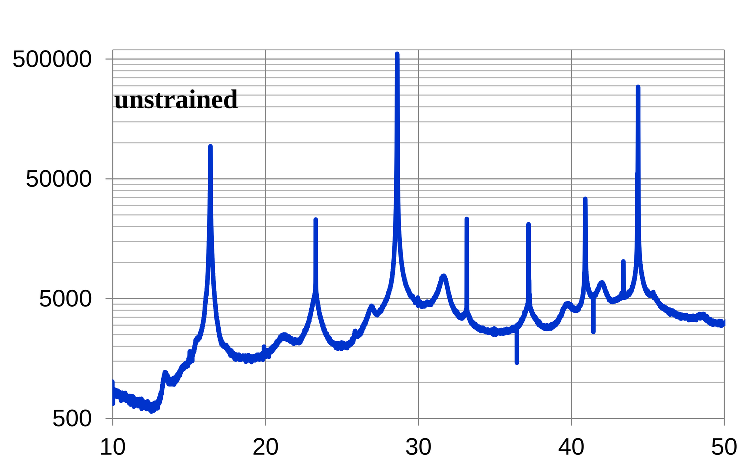
- cross section of 150*1250 µm
- Gauge length of 2750 µm



β grain size : 7±3 µm (equiaxed)

- **Synchrotron** *(beamline MS-powder, SLS)*
  2,4 GeV, λ=0.6598 Å, angular range 5-25°, step size 0.0038°
- **FEG – SEM** *(Leo Supra 55)* + **EBSD** *(HKL Channel 5)*
  20kV, 60µm ap., SE + FSD — *Step size from 0.2 to 0.05µm*

4. Full pattern analysis



Strong initial texture of β
Stress/strain state

} Reliable phase quantification not achieved yet !

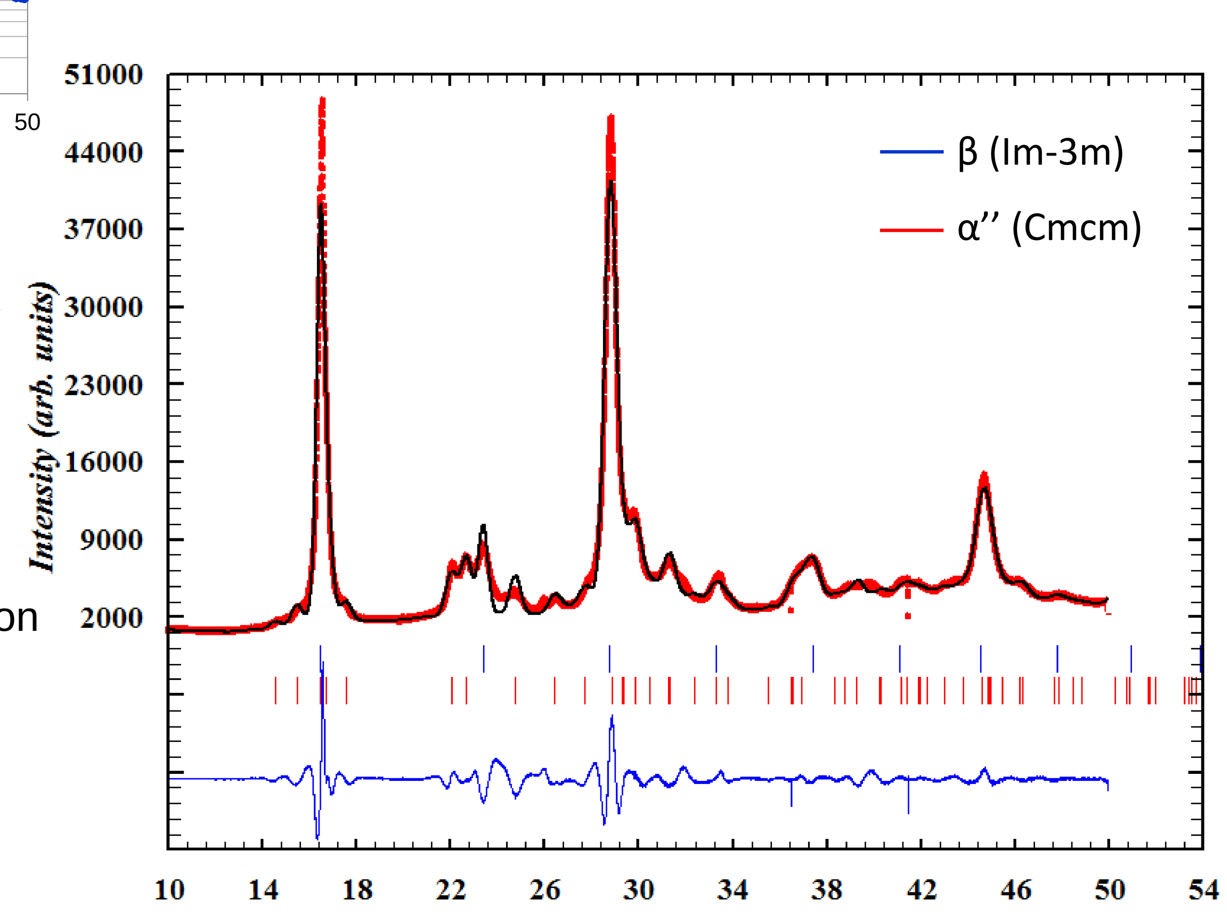
ε = 25%

Disappearance of ω

β → α'' martensitic transformation

$[001]_{\alpha''} // <110>_{\beta}$

$(110)_{\alpha''} // \{112\}_{\beta}$

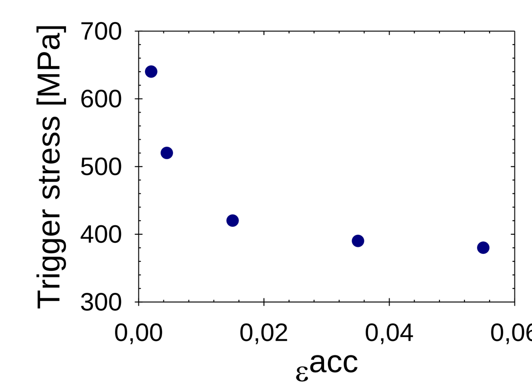


(performed with Fullprof v5.30)

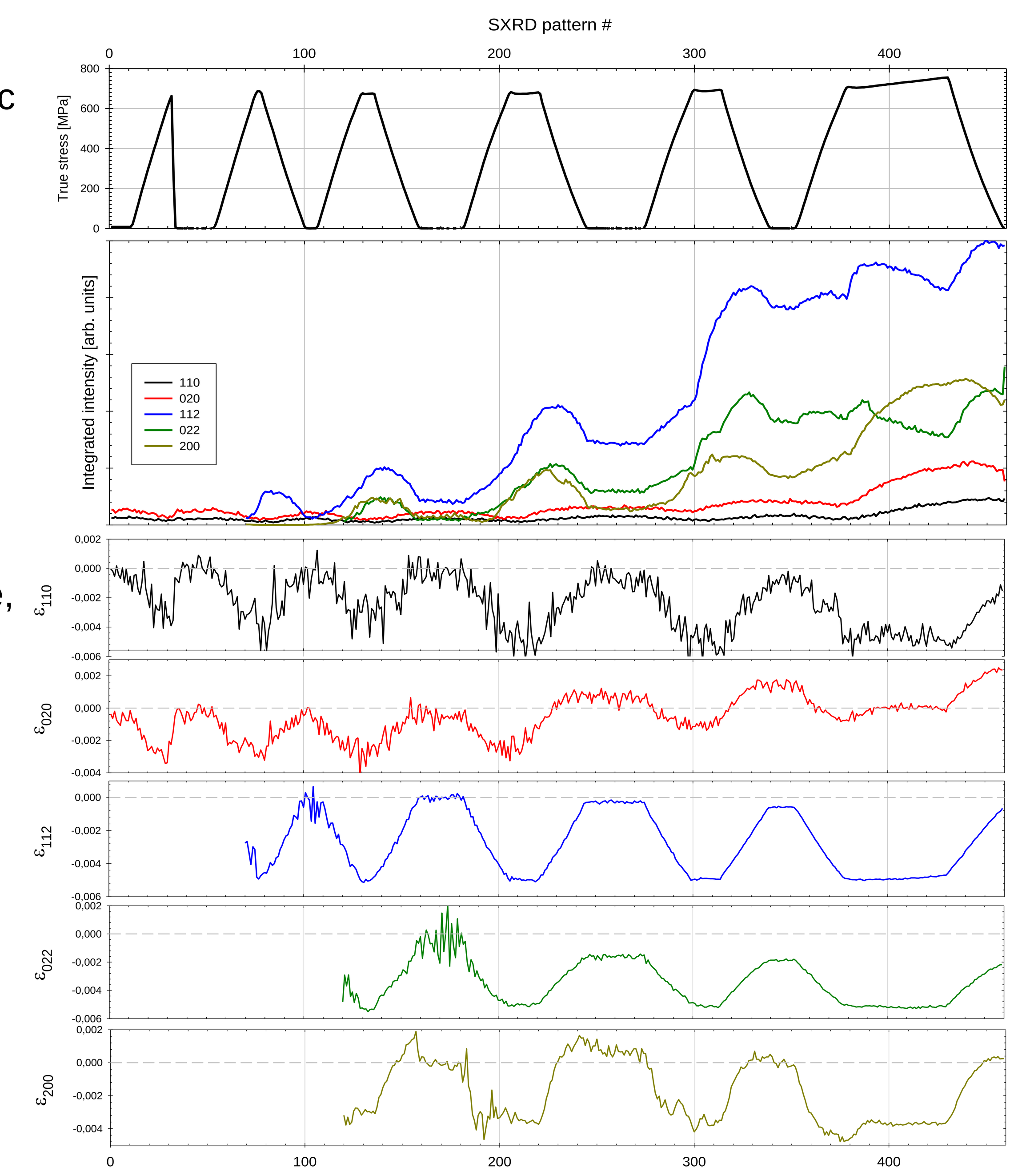
5. Detailed single peak analysis

A. Detailed single peak analysis during cycling

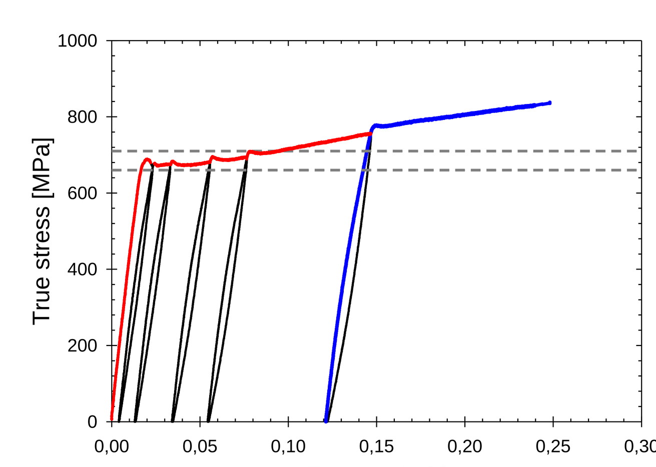
- Change of slope due to martensitic transformation evolving with accumulated plastic strain :



- Small part of martensite reversible, with reversible fraction decreasing with plastic strain
- Monotonic growth of all α'' peaks up to $\varepsilon^p \approx 10\%$, then only preferential orientations
- No lattice strain changes in α'' during SIM transformation
  (elastic strain only)

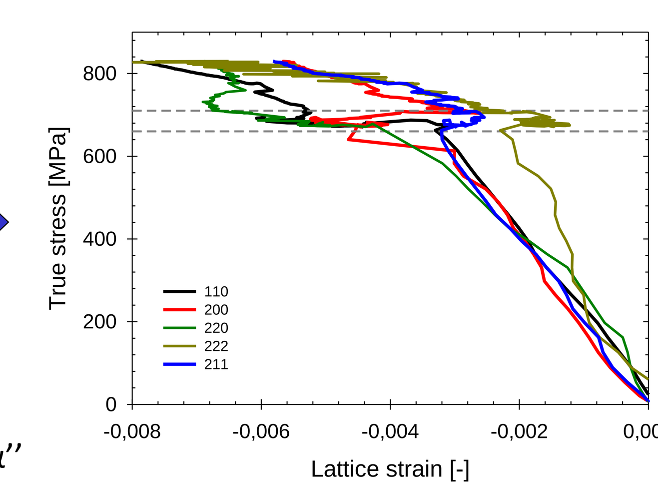


B. Stress partitionning during monotonic loading

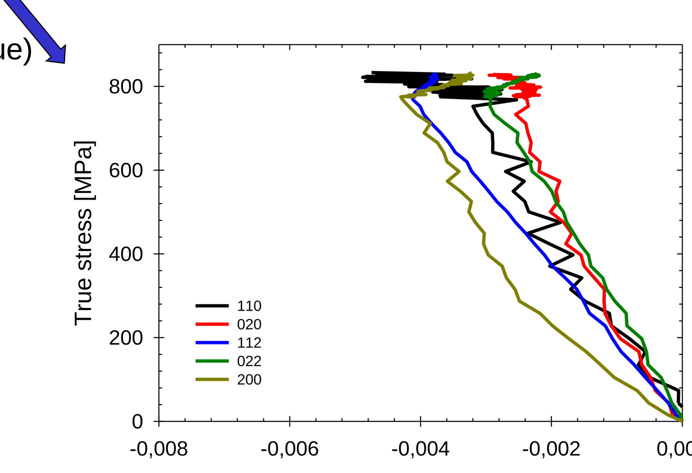


β (red)

α'' (blue)



Stress region where primary products arises
(β twins & α'' laths)
⬇
Intense plastic activity !



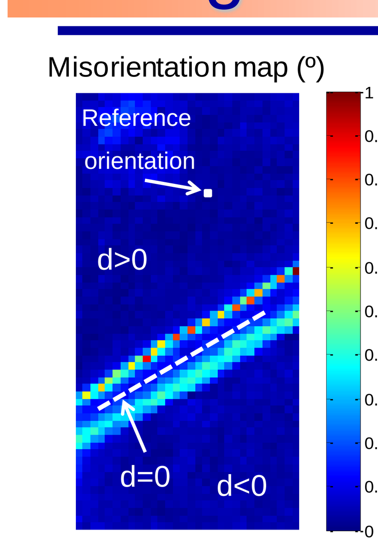
Relaxation of several planes after "yielding point"

Anisotropy of lattice stiffness
$E_{022} > E_{020} > E_{110} > E_{112} > E_{200}$

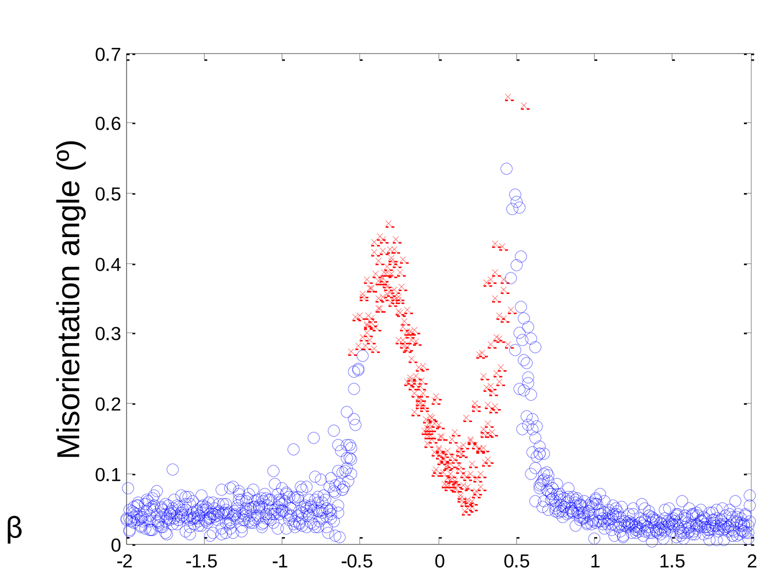
- Matrix undergoes most of the plastic strain at large deformation
- α'' plastic strain negligible in total elongation

➡ Must play an other role !

6. High angular resolution EBSD analysis



Kernel map of a α'' lath in the β matrix (ε^{tot} = 2%)



Continuous misorientation profile around the habit plane of ideal orientation relationship

Accomodation of shear strain by GND at phase boundaries

α'' as active dislocation source ?

7. Conclusion

Synchrotron XRD is a powerful tool for tracking mechanically induced phase transformation

Martensite does not support a huge part of plastic deformation once it has appeared, but seems rather to act as new dislocation source, promoting further hardening and deformation capabilities.

HAR-EBSD gives insight on elastic stress field around martensite laths.

Need of TEM analysis at phase boundaries to confirm the role of α'' as dynamic dislocation source

[1] Marteleur et al., Scripta Mat. 66 (2012) pp. 749-752
[2] Sun et al., Acta Mat. 61 (2013) pp. 6406-6417

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