MONDRAGON UNIBERTSITATEA

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ESCUELA POLITÉCNICA SUPERIOR

4th International Conference on High Speed Forming

# Texture Evolution of AZ31 Mg Alloy Sheet at High Strain Rates

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GKSS FORSCHUNGSZENTRUM
in der HELMHOLTZ-GEMEINSCHAFT

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Ingeniamos el futuro

Columbus, 09 March, 2010

# OUTLINE



- Introduction and motivation
- High strain rate material characterization
  - Mechanical testing
  - Microstructure and texture analysis
- Conclusions and ongoing work

# INTRODUCTION



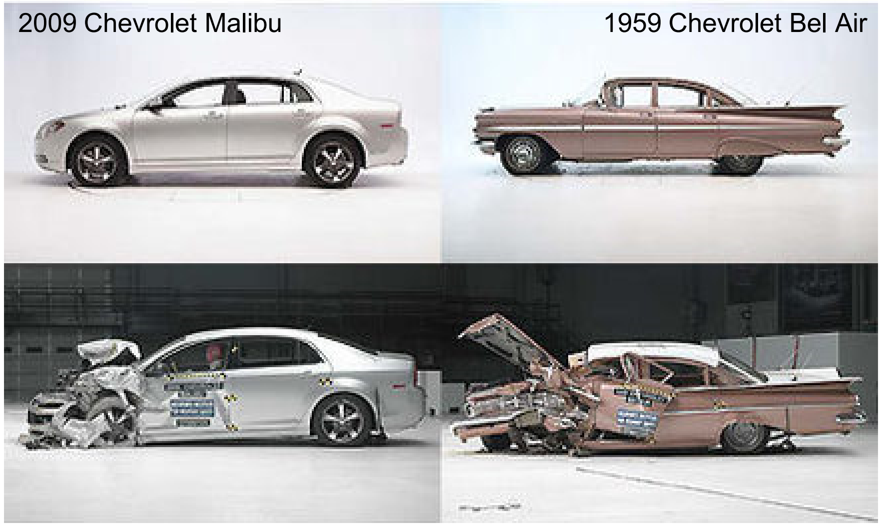
Magnesium alloys are attractive for weight reduction in vehicles and other structures.

Bringing Mg parts to the market requires:

- To decrease anisotropy in order to improve **formability**

- To enhance **corrosion** behaviour

- To optimize the behaviour of Mg alloys under **crash** conditions (e.g. Easton et al., 2008)



# INTRODUCTION

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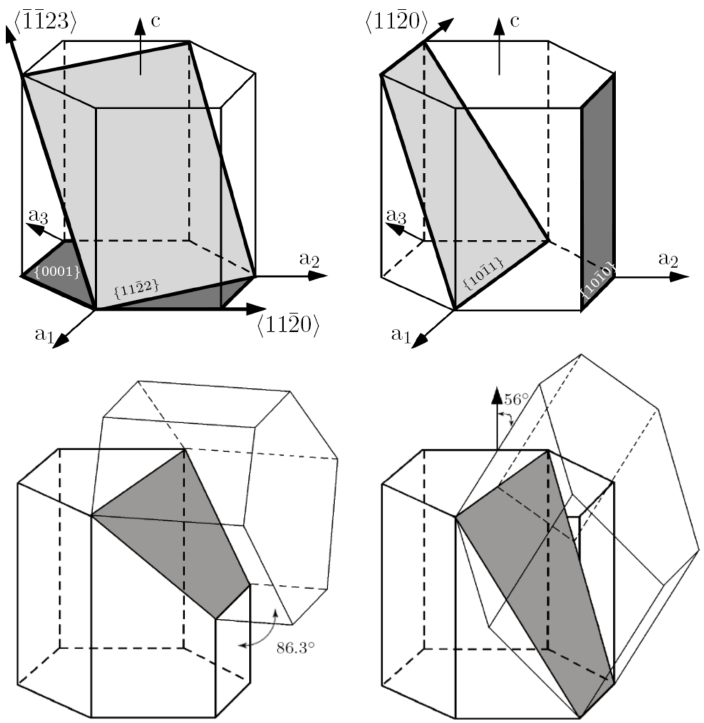
## Deformation mechanisms in Mg




$\{10\bar{1}2\}$ Tensile Twin (86.3°) $\langle 1\bar{2}10\rangle$

$\{10\bar{1}1\}$ Compression Twin (56.2°) $\langle 1\bar{2}10\rangle$

**Quasi-static** strain rates:

Limited slip systems at room temperature

Increasing temp, CRSS decreases and slip in other planes become active

Deformation Twinning

- Polar nature (depending on c/a ratio)
- Reorientation (further slip)

It is generally accepted*: $CRSS_{basal} < CRSS_{twinning} < CRSS_{prismatic} < CRSS_{pyramidal}$

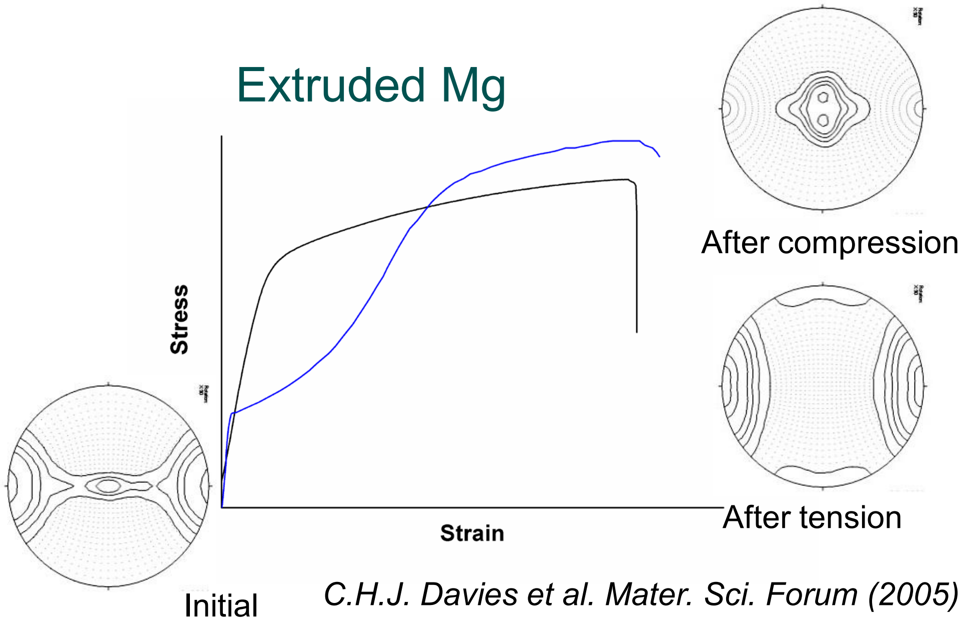
* At room temperature and quasi-static loading conditions [Barnett et al. 2003 ,Agnew et al. 2005, Lou et al. 2007]

# MOTIVATION



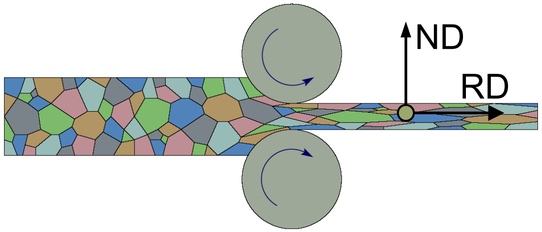
Tension/compression asymmetry @ RT and **QS**

Due to initial texture




*C.H.J. Davies et al. Mater. Sci. Forum (2005)*
*SB.Yi et al, Acta Mater. (2006)*

High strain rate tension/compression behaviour of rolled Mg alloys is still **unknown**




Strongly Textured

→ Interesting not only for metal forming operations but also for any kind of high strain rate event (e.g. crashworthiness)

# APPROACH



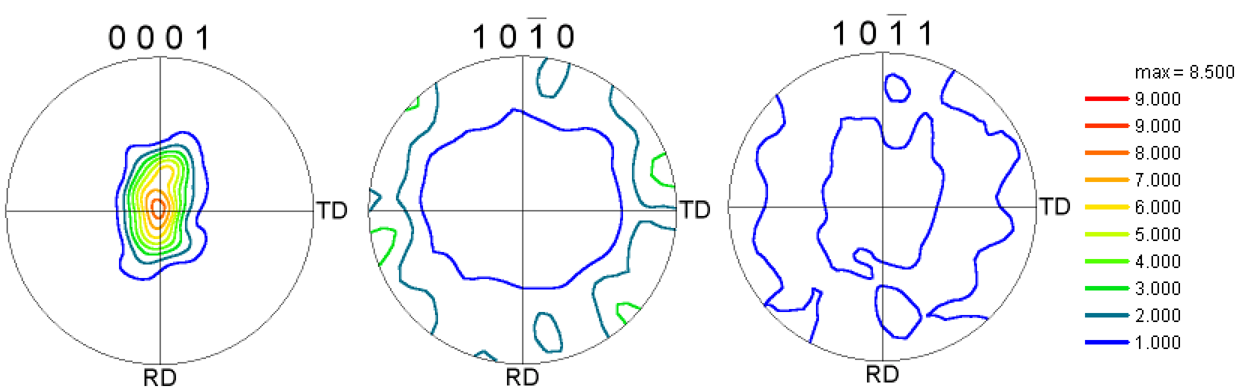
Current research:

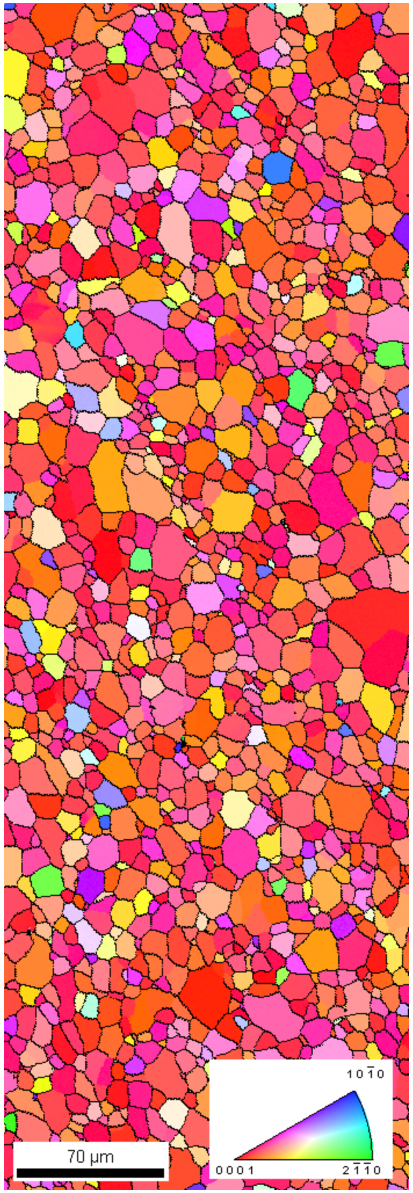
- Uniaxial tensile and compression tests at high strain rates
- Microstructure and texture analysis (EBSD & Neutron diff.)

Initial material:

AZ31B (commercial). Grain Size = 10μm

| Element | Zn | Al | Si | Cu | Mn | Fe | Ni | Ca | Sn | Others |
|---|---|---|---|---|---|---|---|---|---|---|
| wt% | 0.96 | 2.7 | 0.01 | ≤0.01 | 0.21 | 0.002 | ≤0.001 | ≤0.01 | 0.00 | ≤0.30 |



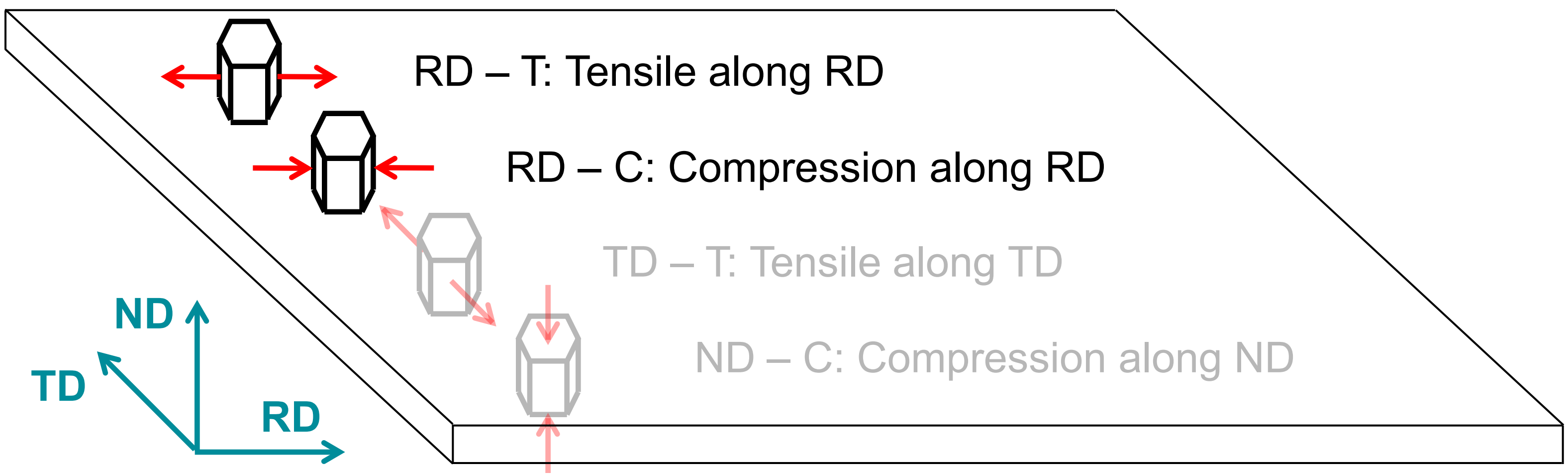



# MECHANICAL TESTING



Uniaxial tension and compression tests at different strain rates and temperatures:

| Technique | Strain rates | Temperatures |
|---|---|---|
| Conventional load frame | **0.001 $s^{-1}$**, 0.01 $s^{-1}$, 0.1 $s^{-1}$ | **20**, 100, 150, 200, **250ºC** |
| Hopkinson Pressure Bar | 500 $s^{-1}$, **1000 $s^{-1}$** and 1500 $s^{-1}$ | **20**, 100, 150, 200, **250ºC** |



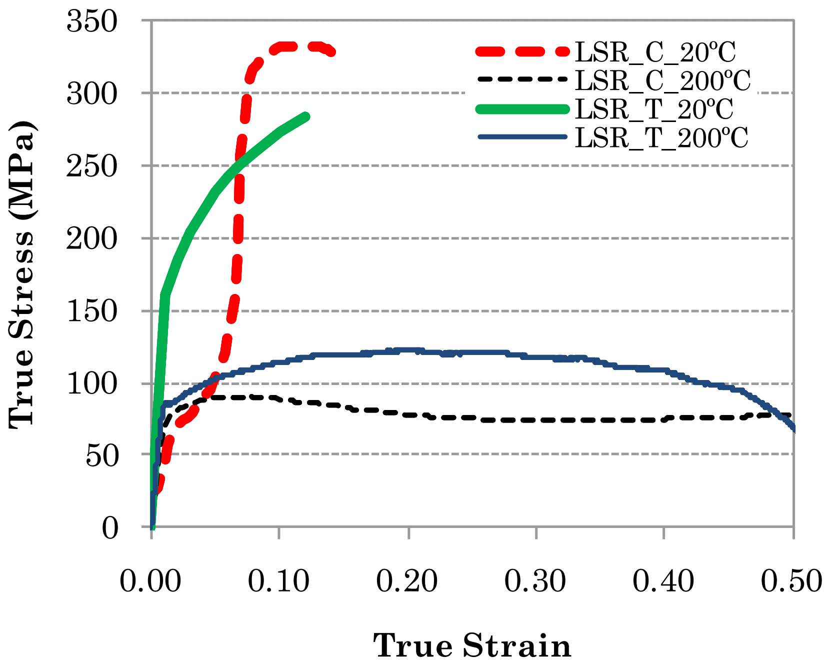

*I. Ulacia et al. Mechanical behavior and microstructural evolution of a Mg AZ31 sheet at dynamic strain rates, Acta Mater. (2010).*

# MECHANICAL TESTING

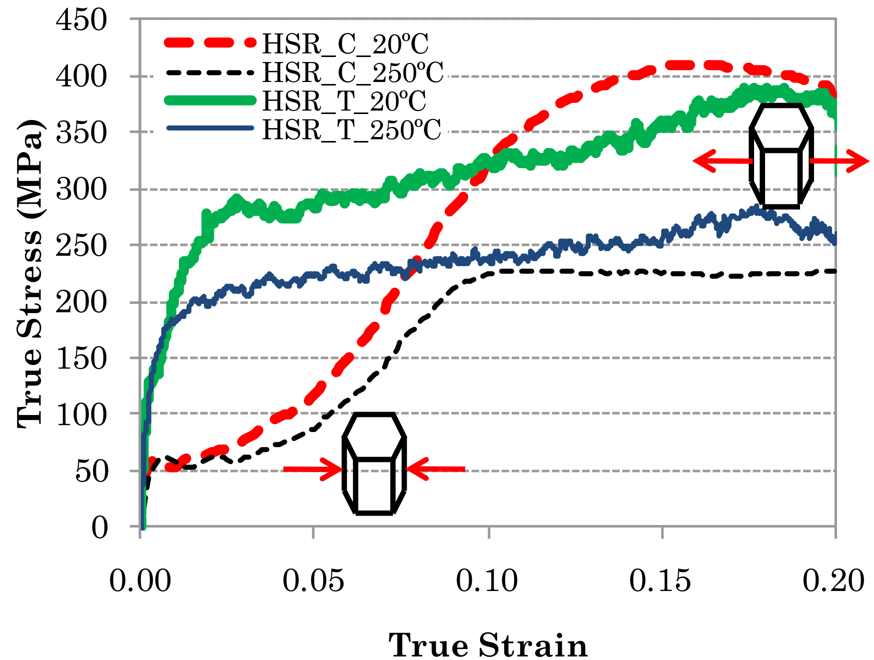


## Results

$0.001\ s^{-1}$




$1000\ s^{-1}$




- At high strain rates, tension: higher flow stress (YS and UTS).

compression: similar YS (tensile twinning), higher UTS

- Increasing temperature, flow stress decreases (@ both strain rate ranges)
- Tension/Compression asymmetry is also observed at high strain rates (∀ Temp)

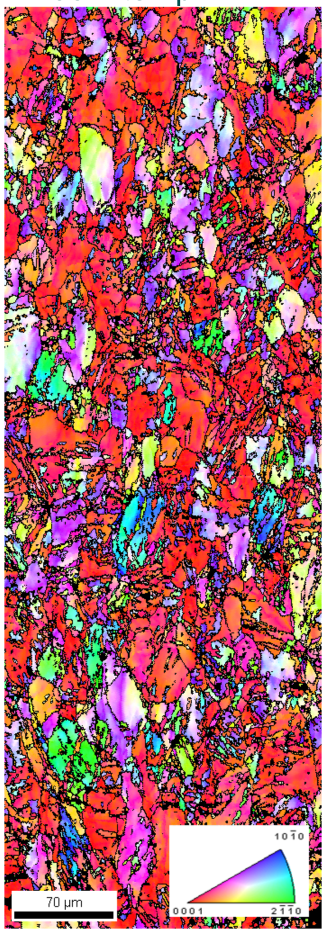
# MICROSTRUCTURE ANALYSIS



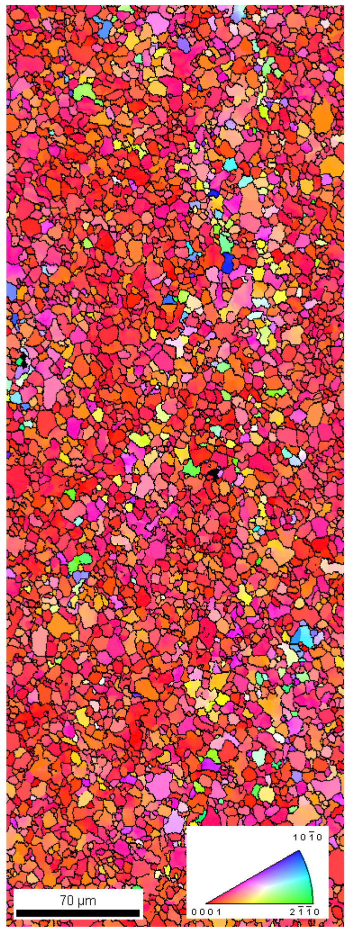
## EBSD: Orientation Mapping

$0.001\ s^{-1}$

Room temp

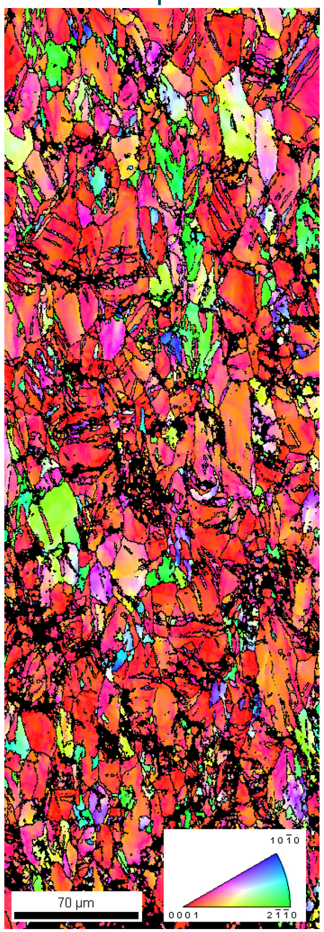



250ºC

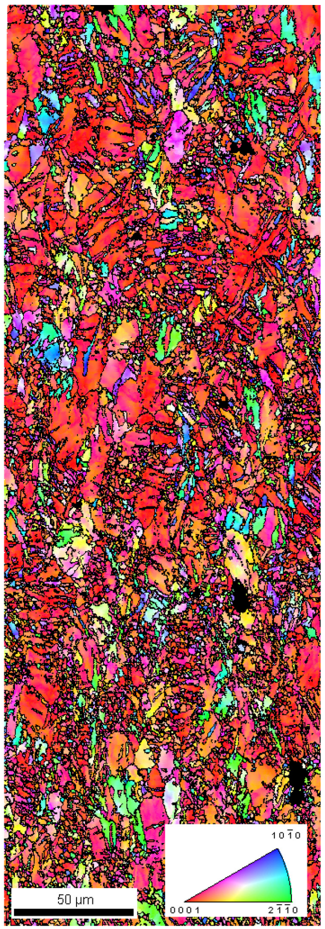



$1000\ s^{-1}$

Room temp




250ºC




RD = LD

TD

* EBSD measurements were performed close to the broken tip

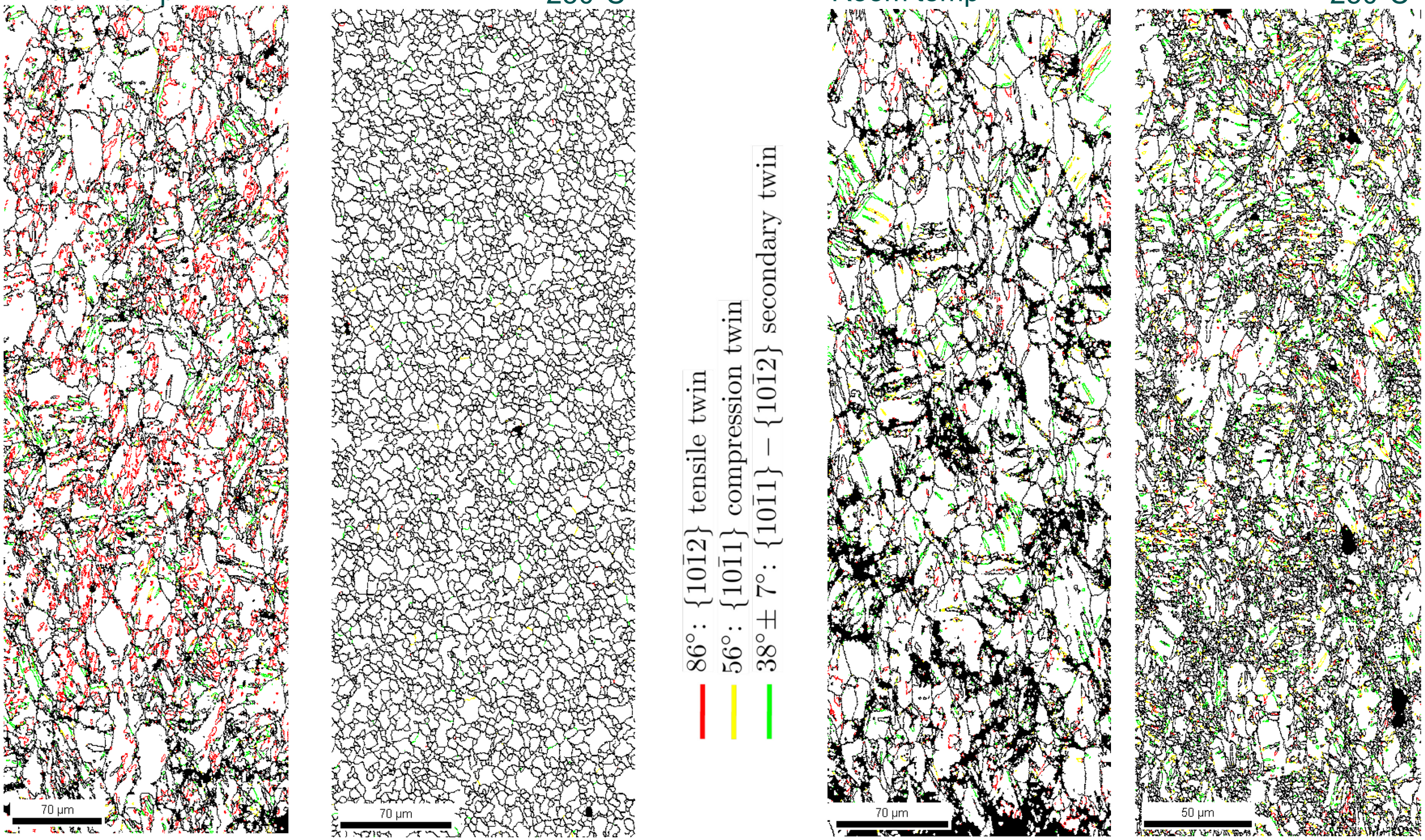
# MICROSTRUCTURE ANALYSIS



## EBSD: Misorientation maping

$0.001\ s^{-1}$ | $1000\ s^{-1}$

Room temp | 250ºC | Room temp | 250ºC




RD = LD

TD

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# MICROSTRUCTURE ANALYSIS

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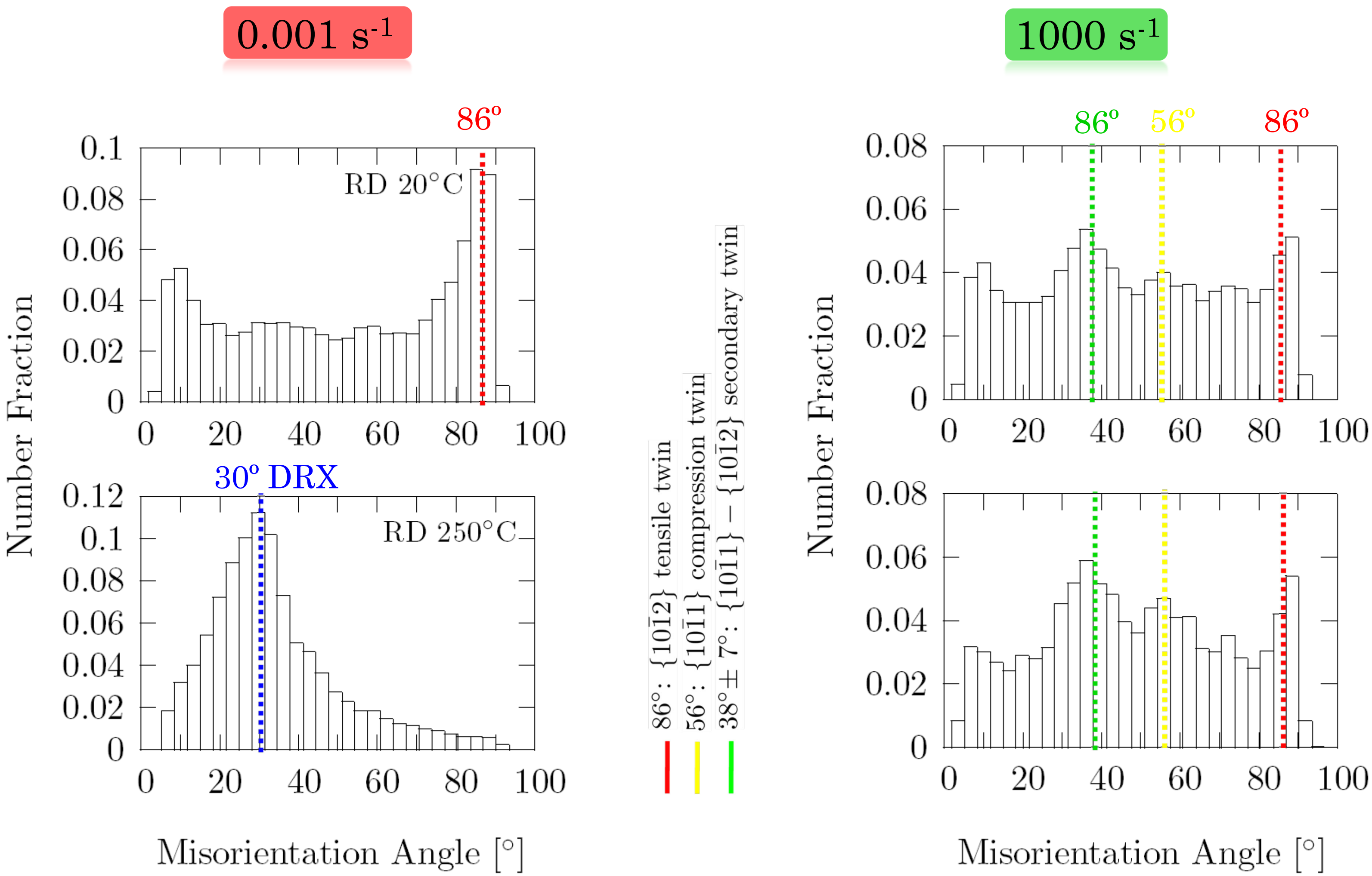
Misorientation angles:



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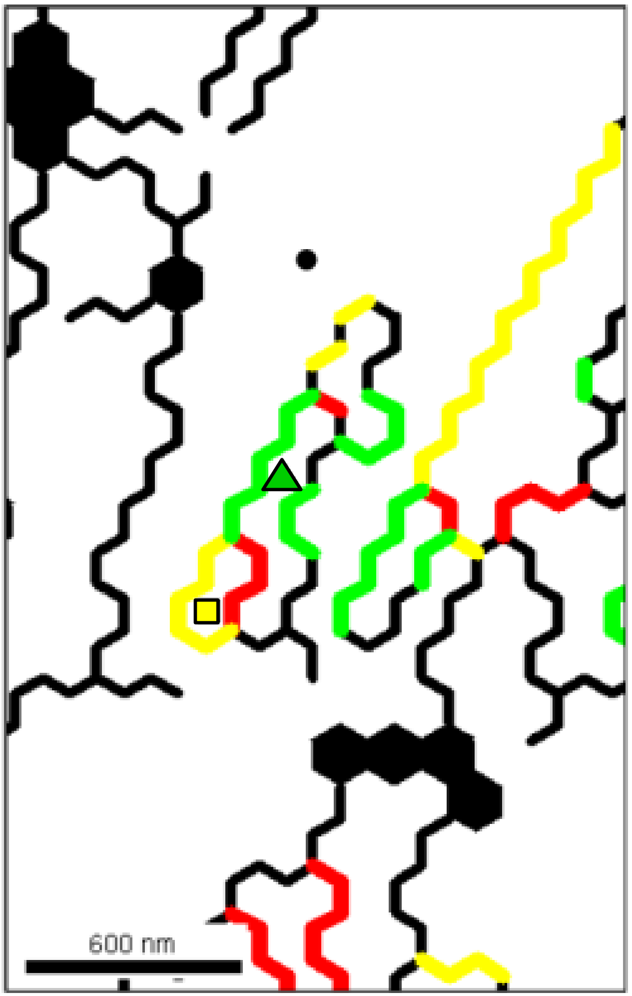
## Secondary twin formation

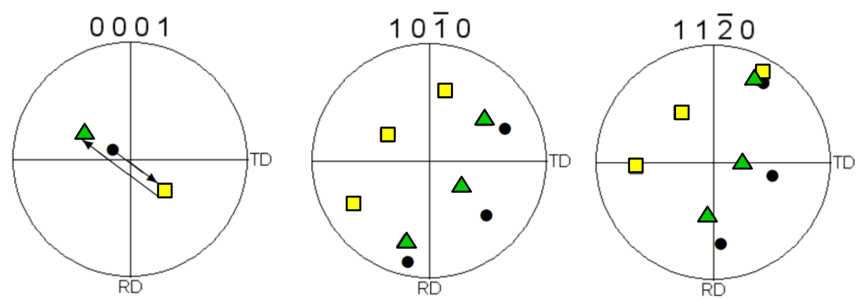



- $86°$: $\{10\bar{1}2\}$ tensile twin
- $56°$: $\{10\bar{1}1\}$ compression twin
- $38° \pm 7°$: $\{10\bar{1}1\} - \{10\bar{1}2\}$ secondary twin

Increase of secondary twins in high strain rate samples

The contribution of secondary twins to global texture:

- ● Parent grain
- □ Primary $\{10\bar{1}1\}$ compression twin
- △ $\{10\bar{1}1\} - \{10\bar{1}2\}$ secondary twin

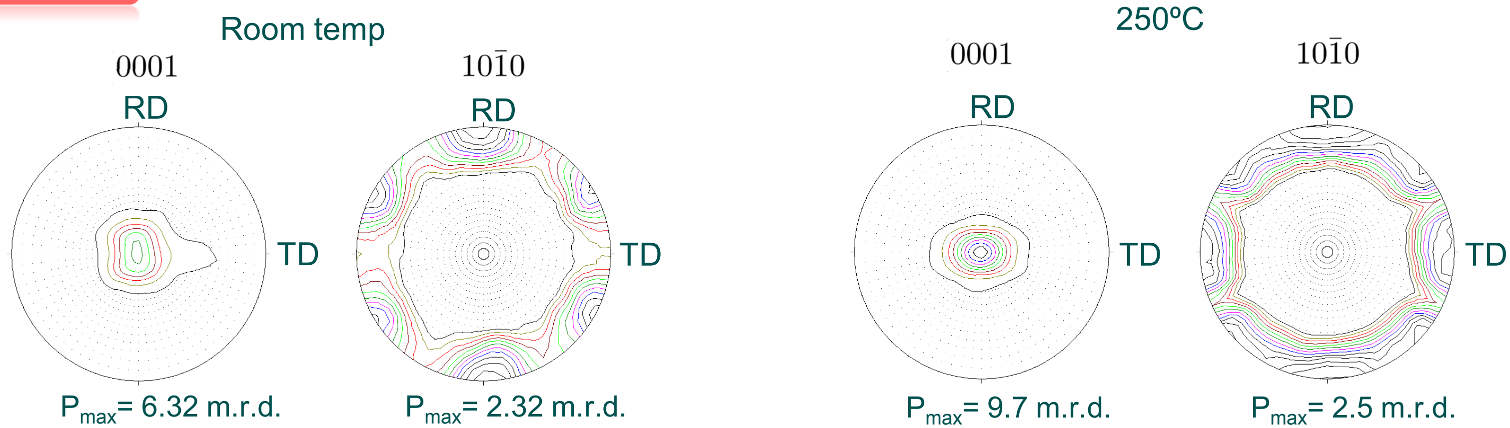


# MICROSTRUCTURE ANALYSIS

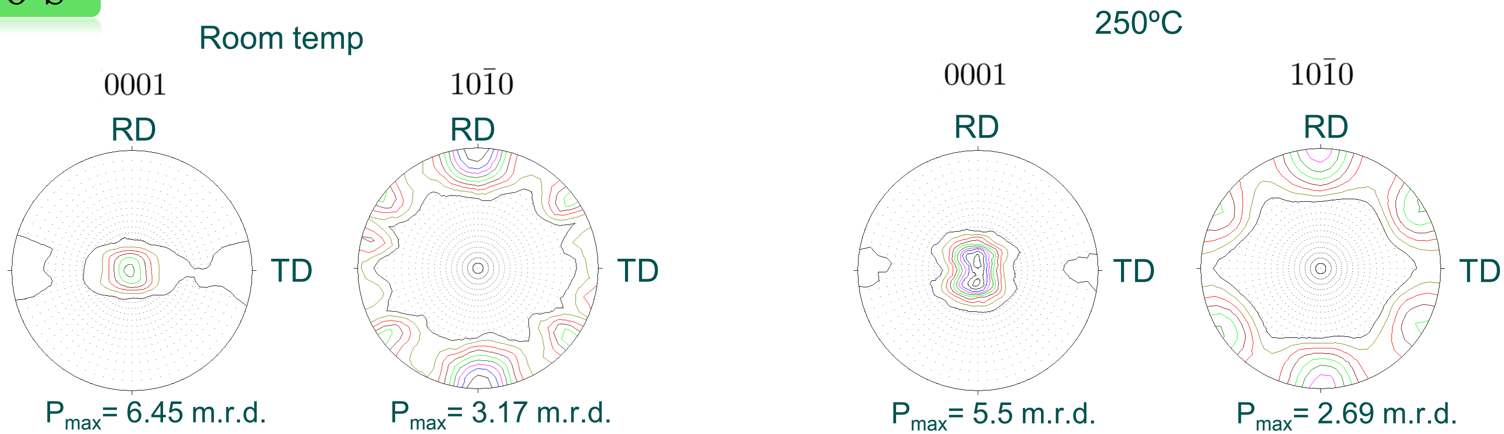


## Texture (Neutron diffraction analysis):

**0.001 $s^{-1}$**




**1000 $s^{-1}$**




* Neutron diff. measurements were performed in the deformed area

# MICROSTRUCTURE ANALYSIS

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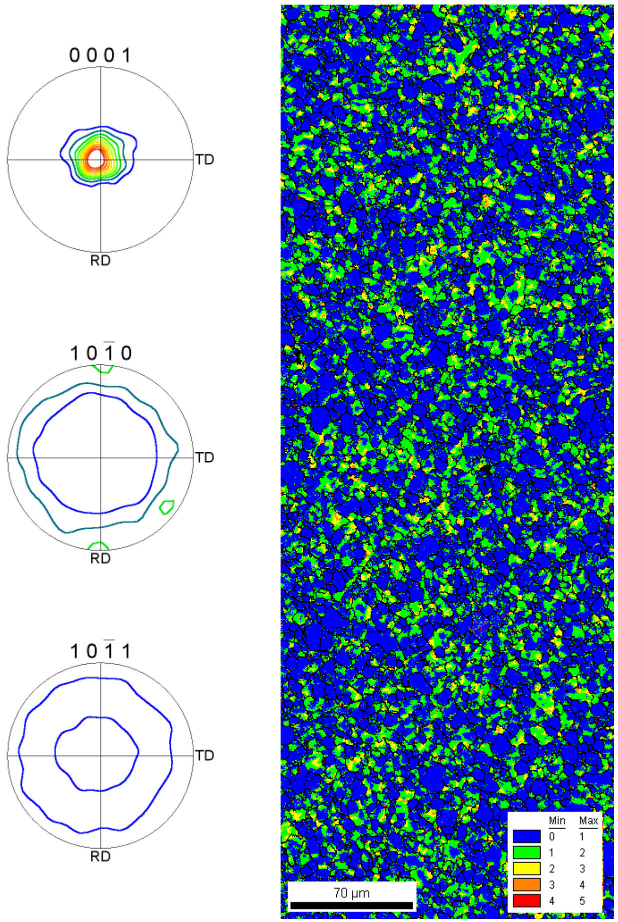
## Recrystallization phenomena (Kernel average misorientation maps)

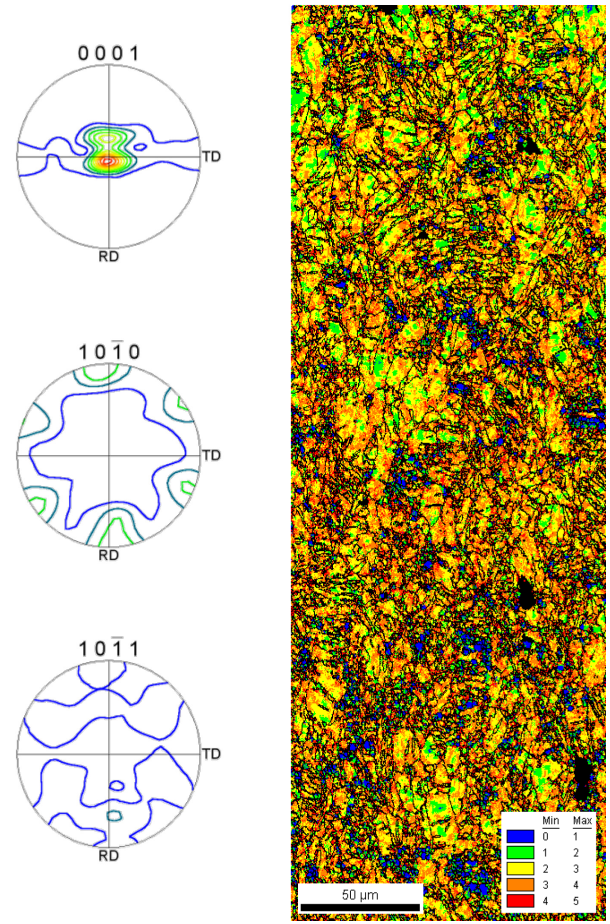
$0.001\ s^{-1}$

250ºC



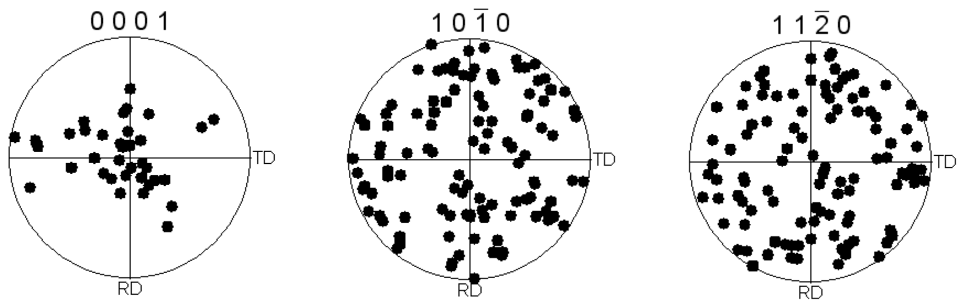

$1000\ s^{-1}$

250ºC



## Recrystallization study

Discrete orientations of the recrystallized grains




Rotational Dynamic Recrystallization:

- Some RX small grains are not strain free

- *c*-axis of some grains is tilted away from ND

# CONCLUSIONS



## Concluding remarks

At high strain rates, comparing with quasi-static rates:

- Increase of flow stress (YS and UTS)
- Strain hardening behaviour (∀ Temp) → Absence of generalized DRX
- Increase of secondary twins (their contribution to global texture).
- Prismatic slip to be active is suggested even at high temperature
- At 250ºC : Splitting of max. intensities in basal P.F. → <c+a> pyramidal slip

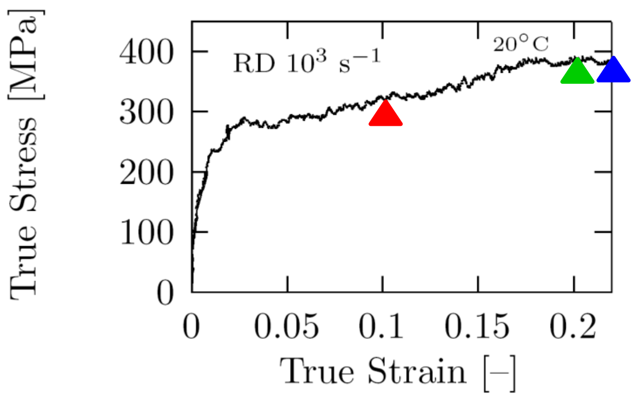
  Localized RX grains (RDRX)

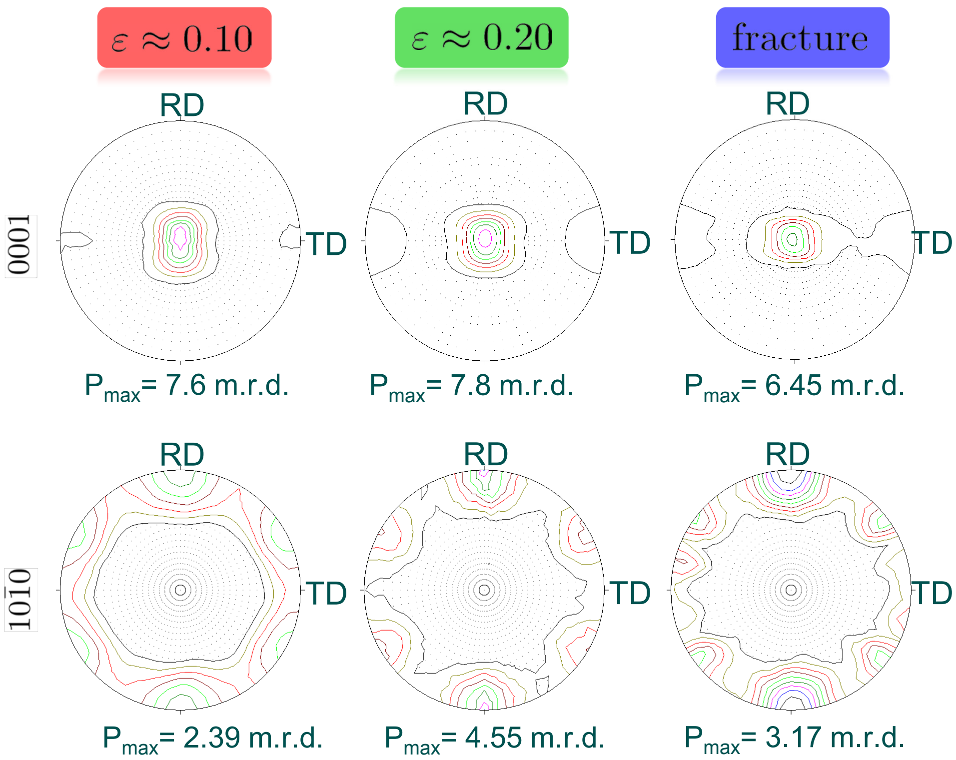
# ONGOING WORK



## Ongoing work

- Evolution of texture (def. mech.) with strain and temp.

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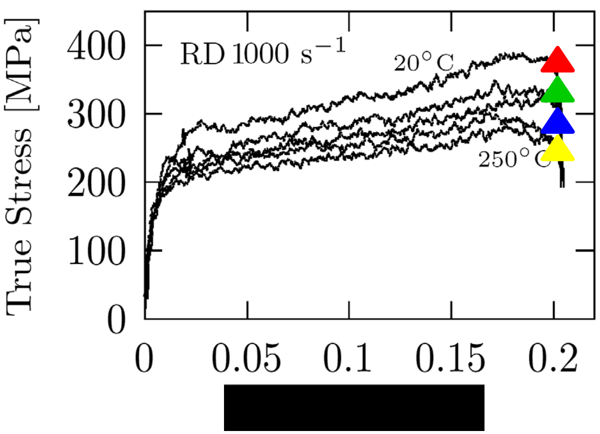
FRM II
Forschungs-Neutronenquelle
Heinz Maier-Leibnitz

## Ongoing work

- Evolution of texture (def. mech.) with strain and temp.



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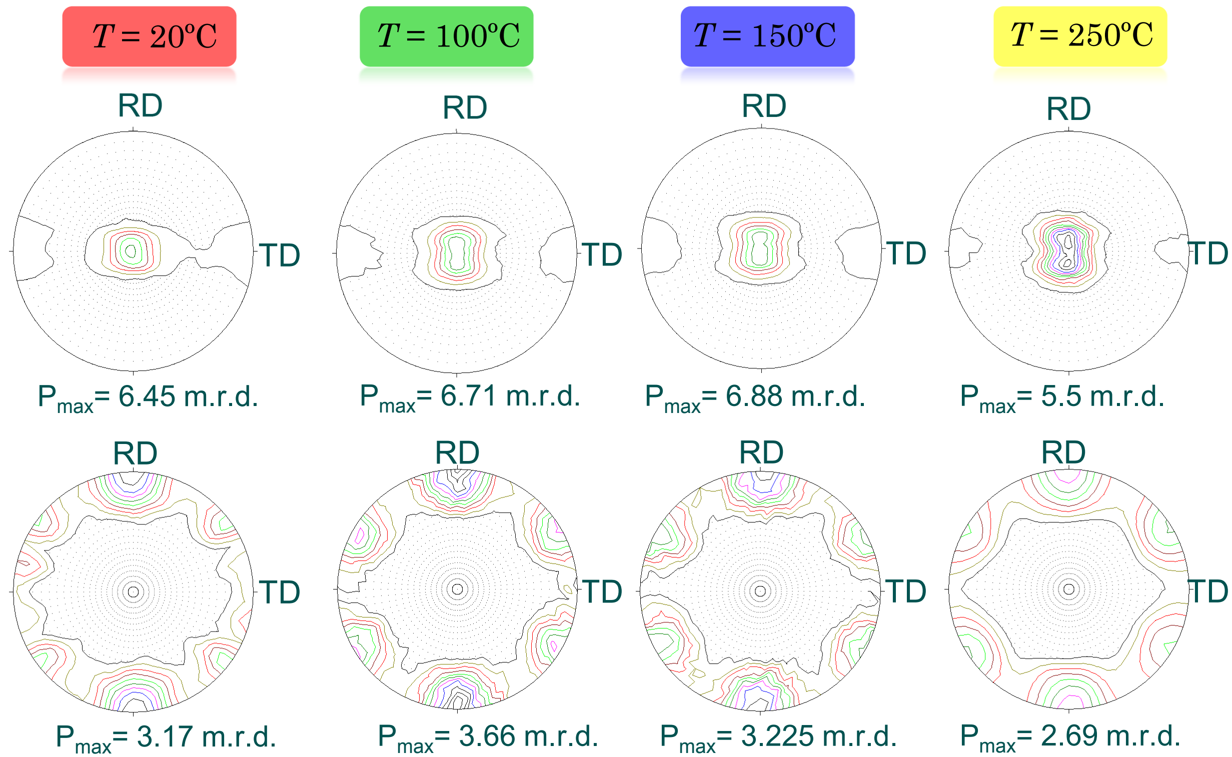


second order $\langle \mathbf{c} + \mathbf{a} \rangle$ pyramidal slip ?

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# Thank you for your attention!

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