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TEXTURE EVOLUTION ANALYSIS IN OXIDE
DISPERSION STRENGTHENED FERRITIC STEEL
TRANSFORMED BY A TUBE PILGERING PROCESS

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18th International Conference on Textures of Materials
ICOTOM 18, ST GEORGE (UTAH)

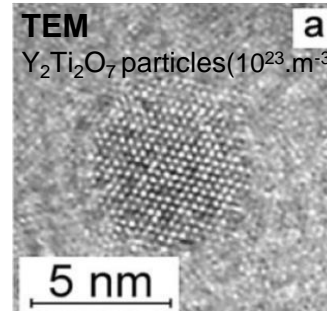
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GENERAL CONTEXT

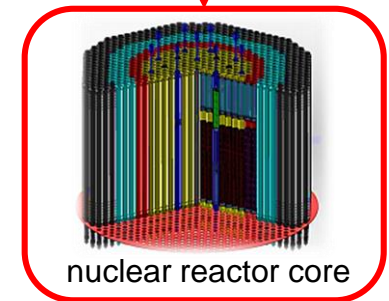
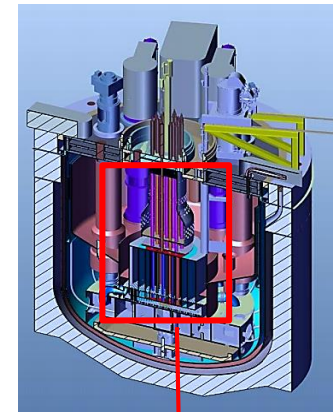
Core material for Sodium Fast Reactor (ASTRID) Gen IV (2030s)

Required properties:

- Resistance to irradiation : low swelling
- Resistance to high temperature corrosion
- Mechanical properties: creep resistance

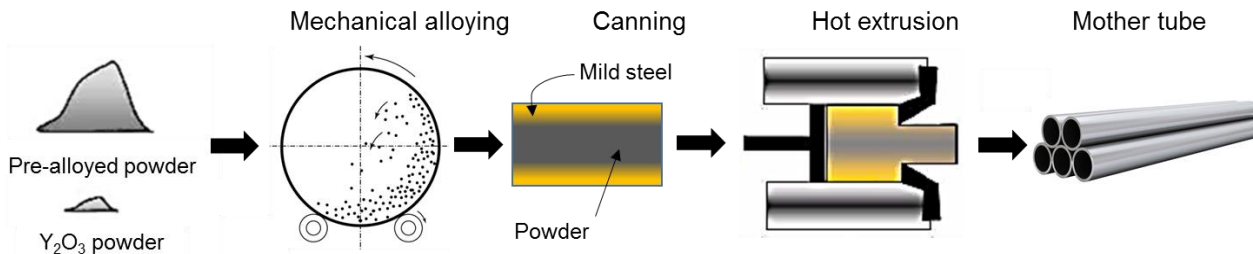


[Klimiankou et al., 2004]

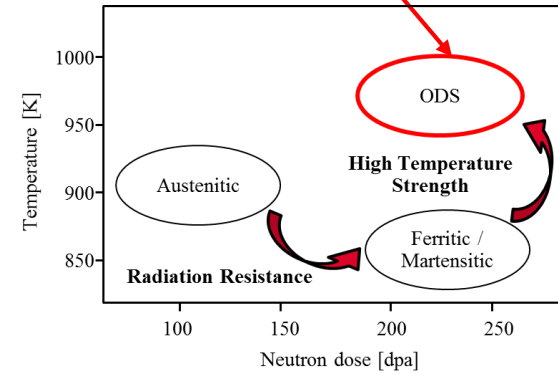
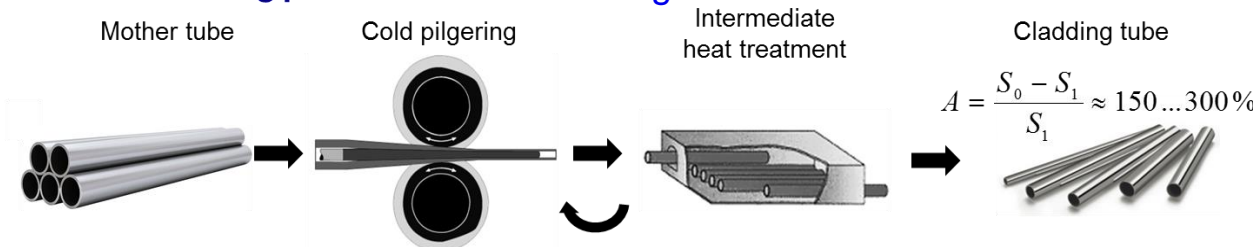


Analysis of microstructural and mechanical properties evolution during thermomechanical processing

Manufacturing process 1: Hot forming



Manufacturing process 2: Cold forming



Motivation:

- ❑ Characterization of structure and properties evolution of ODS steels during “Mannesmann” pilgering
- ❑ Modeling of ODS steel behavior during the cold rolling
- ❑ Using the results of this study to improve rolling technology process

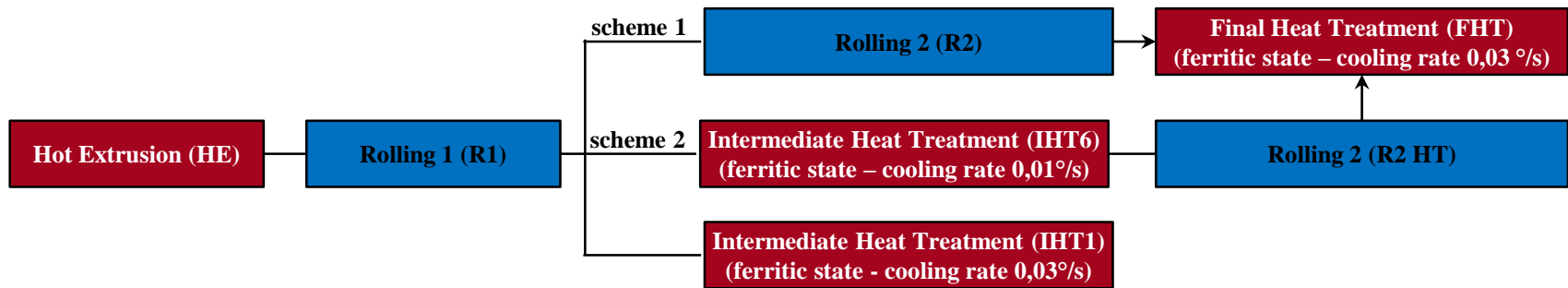
Materials and methods:

- ❑ ODS steel tubes with 9wt% Cr deformed by rolling process
- ❑ Analysis of the material behavior after each processing steps:

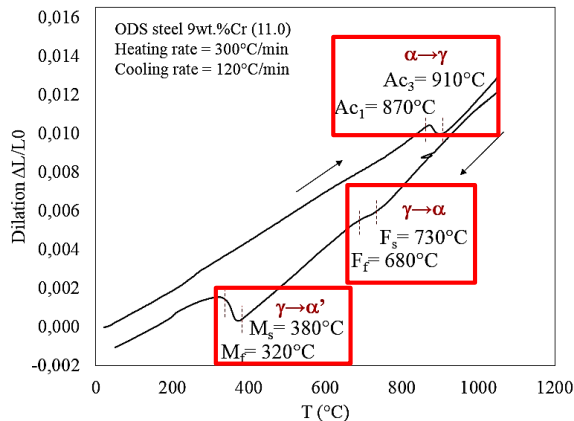
Chemical composition of ODS steel tubes (wt.%)

| | | | | | | | |
|----|-----|-----|-----|-----|-----|------|---------|
| Cr | W | Ti | Ni | O | Y | C | Fe |
| 9 | 0.9 | 0.2 | 0.2 | 0.1 | 0.1 | 0.08 | Balance |

Hot Extrusion of powder material, Cold rolling and Heat treatments



Deformation history of 9%Cr ODS steel during the rolling process



| Step | Total deformations ϵ_p^* (%) | Q factor** |
|------|---------------------------------------|------------|
| HE | -/- | -/- |
| R1 | 110 | 1,4 |
| R2 | 140 | 1,6 |

$$*\epsilon_p = \sqrt{\frac{2}{3}(\Delta\epsilon_{rr}^2 + \Delta\epsilon_{\theta\theta}^2 + \Delta\epsilon_{zz}^2)}$$

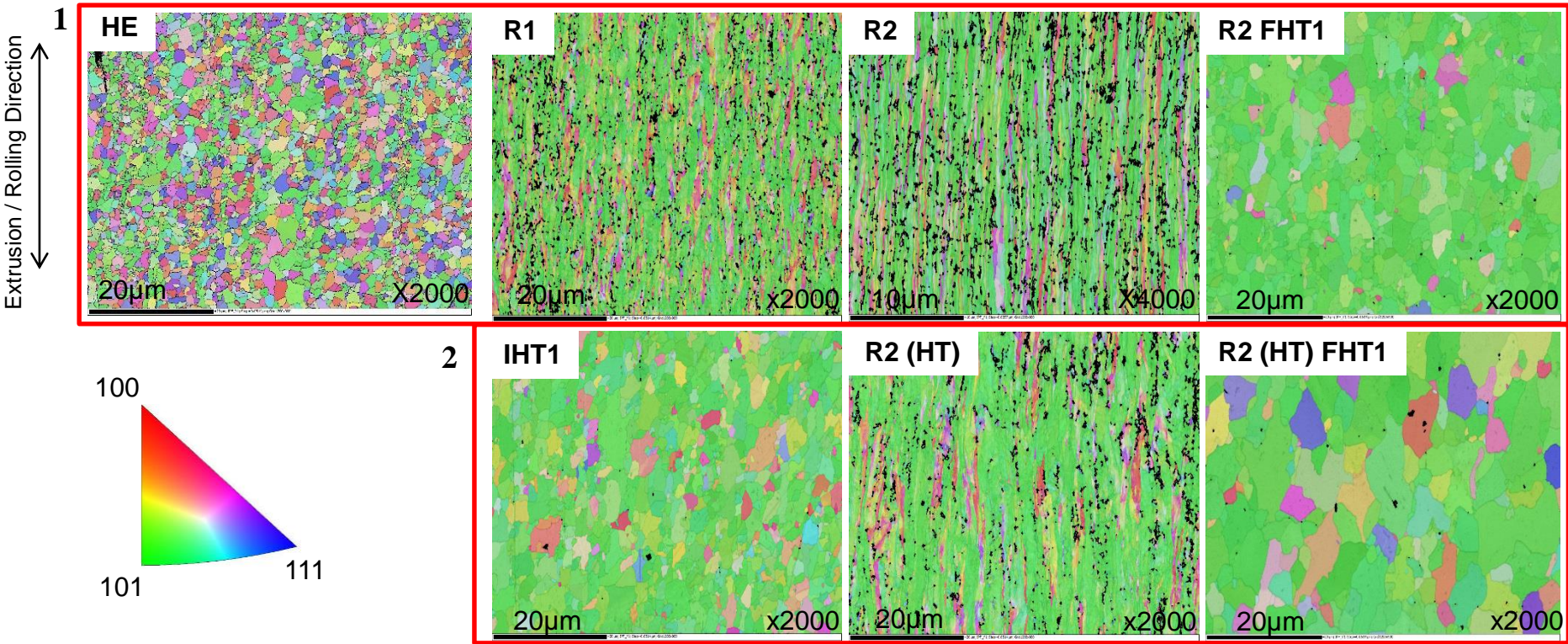
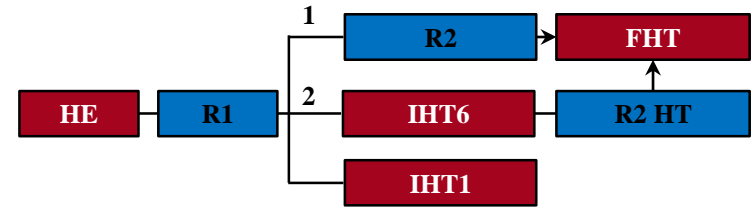
$$\Delta\epsilon_{zz} = -\ln\left(\frac{S_0}{S}\right)$$

$$\Delta\epsilon_{\theta\theta} = \ln\left(\frac{D_0}{D}\right)$$

$$**Q \text{ facteur} = \frac{e_0 - e}{e_0} \times \frac{d_0}{d_0 - d}$$

EBSD OBSERVATION RESULTS

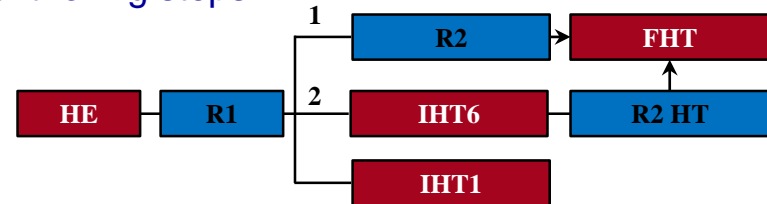
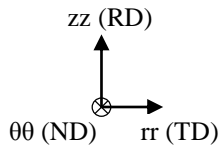
- Initial Structure : isotropic, without preferred orientation
- Rolled samples : anisotropic structure with small elongated grains according to the rolling direction



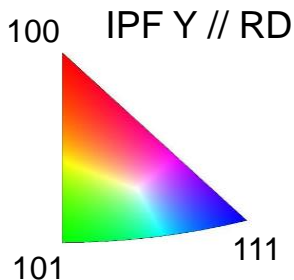
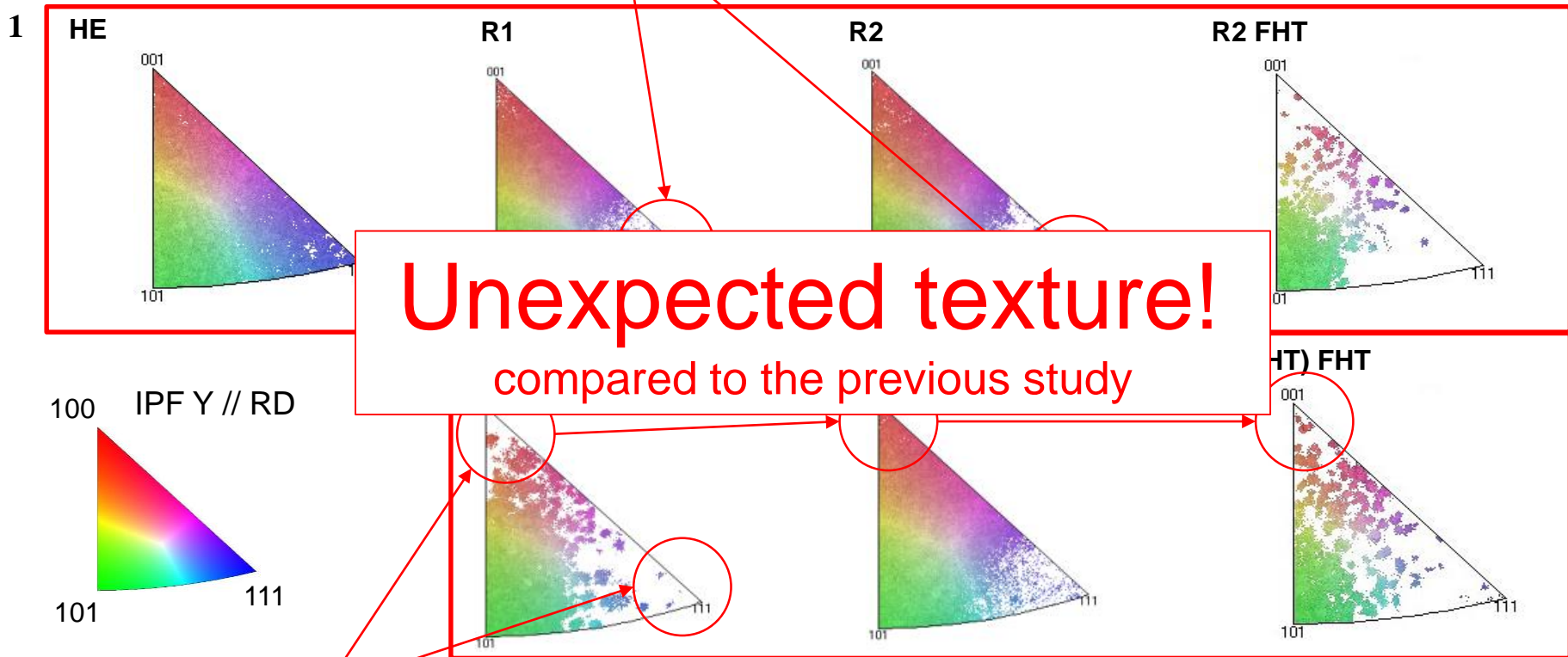
Inverse pole figures maps IPF Y // RD for 9wt%Cr ODS steel at the different processing steps

EBSD OBSERVATION RESULTS

❑ Inverse Poles Figures of the ODS 9%Cr sample at different rolling steps



<111> oriented grain disappear progressively during rolling steps

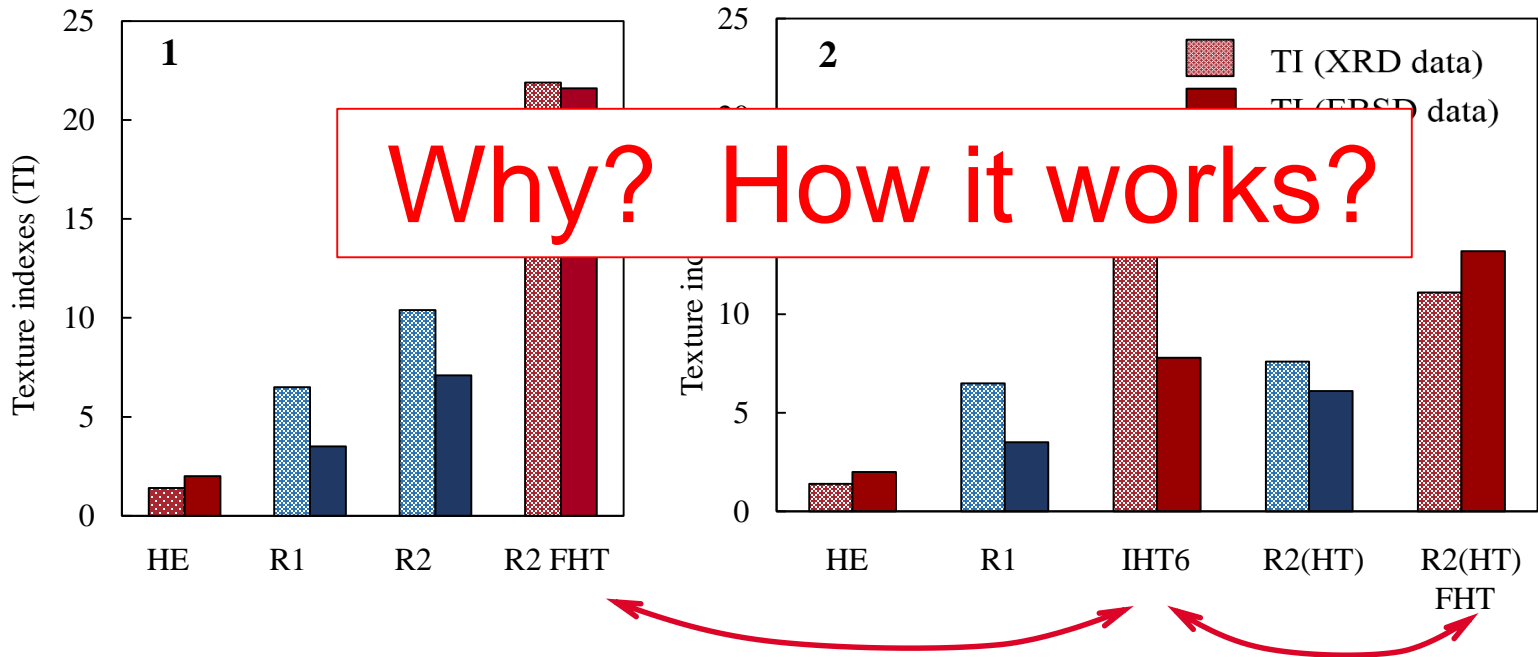
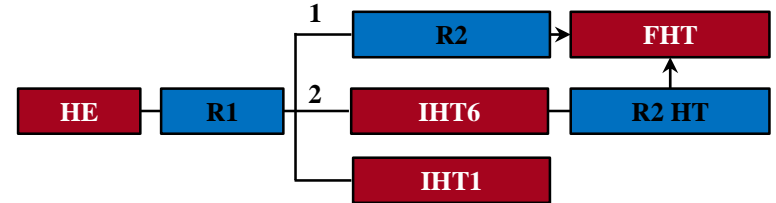


Dominant <101> orientation after heat treatment

Randomly oriented grains in recrystallized structure [Toualbi, 2012] ?

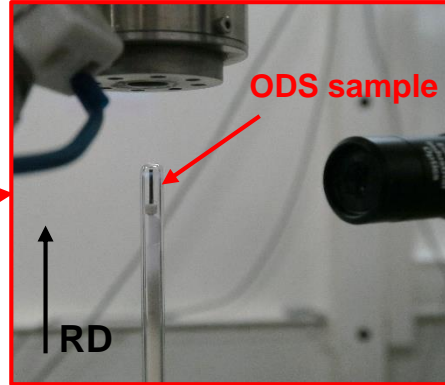
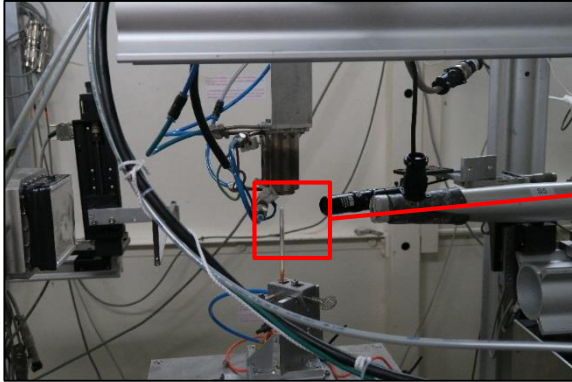
EBSD OBSERVATION RESULTS

- Texture Index (Gaussian approximation of 5° halfwidth)



- Strengthening of the α -fiber with plastic strain
- Reorientation of $\langle 001 \rangle$ and $\langle 111 \rangle$ oriented grains in the $\langle 101 \rangle$ during the thermal treatment
- Memory effect of deformation texture

TEXTURE EVOLUTION ANALYSIS



Impact of :

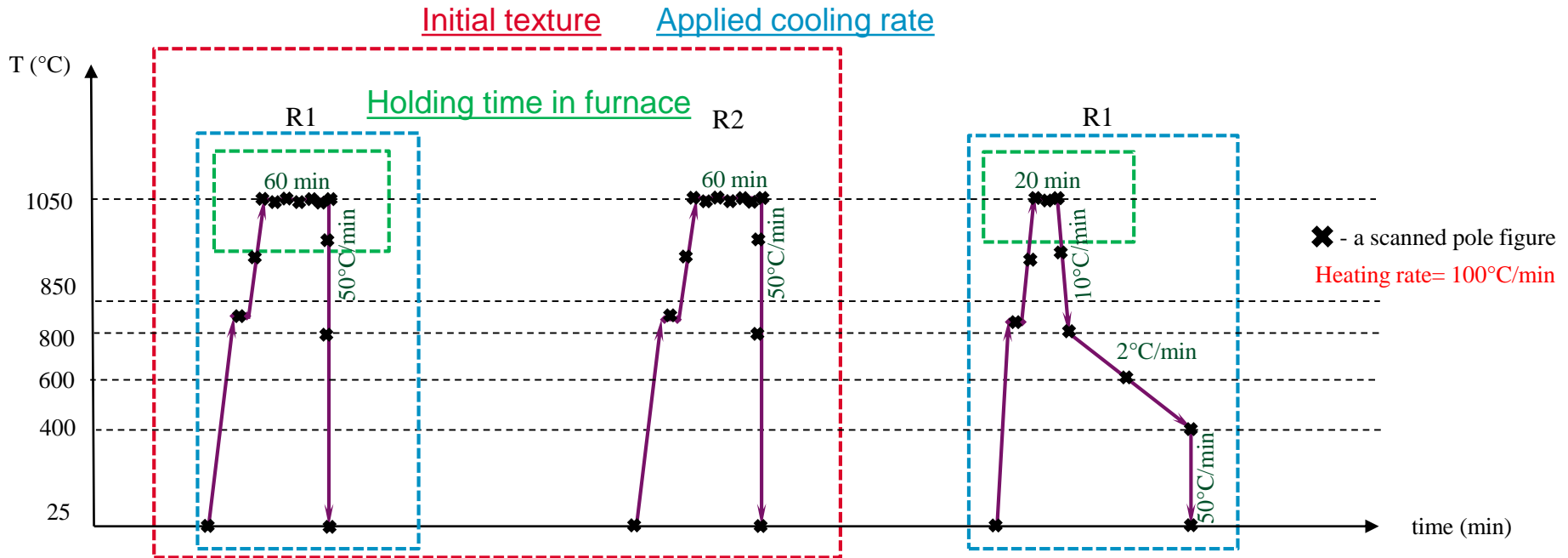
- Initial texture ?
- Holding time in furnace ?
- Applied cooling rate ?

Beam Line: ESRF ID11 (XRD in transmission mode)

Beam Line manager : Jonathan WRIGHT

Photons energy range requested: 80,005 keV

Spot size requested: 200x200 μm

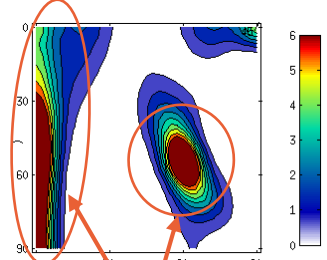
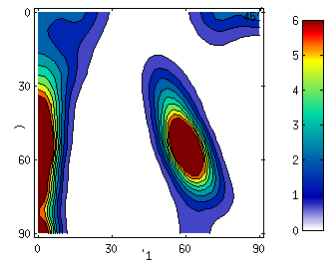
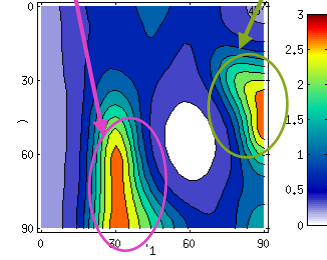


Thermal cycle for R1 and R2 samples

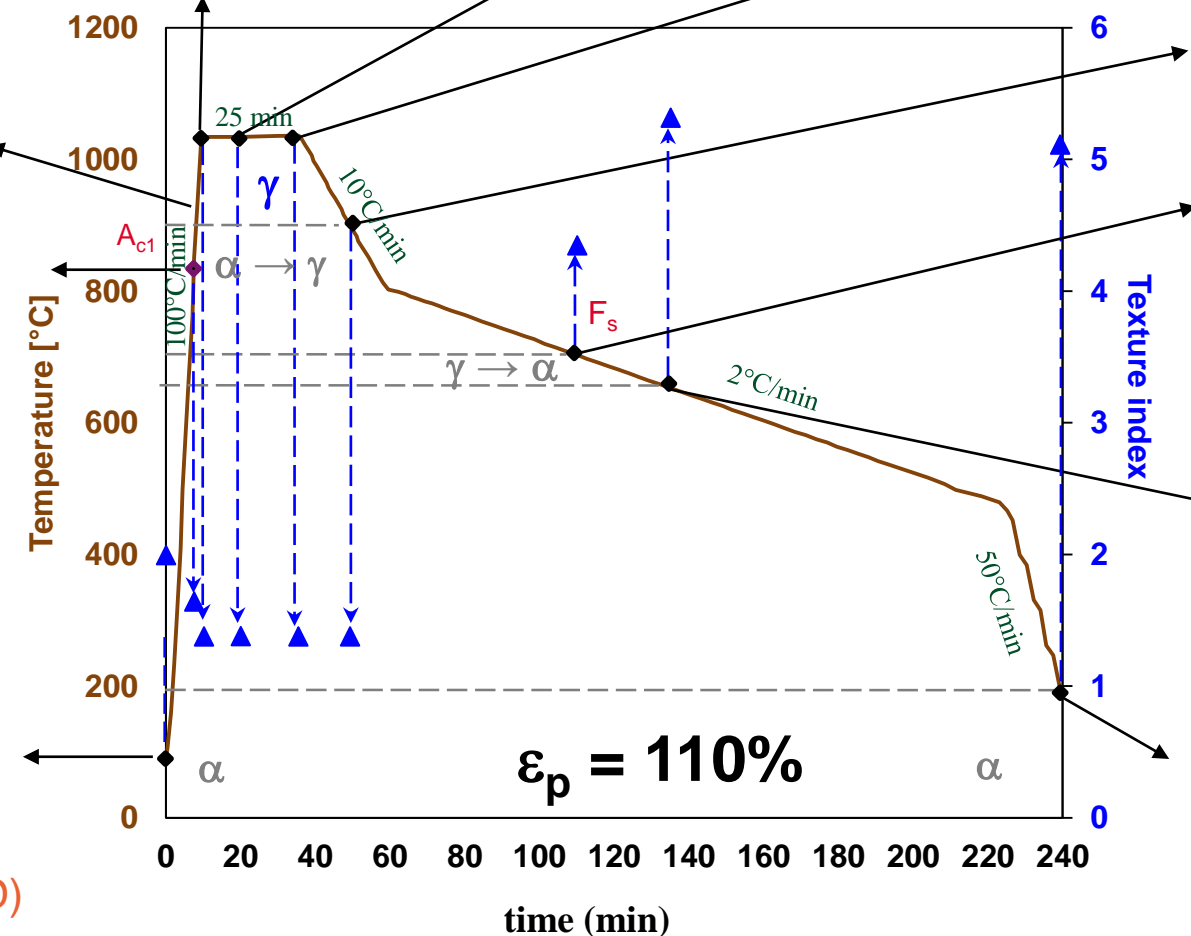
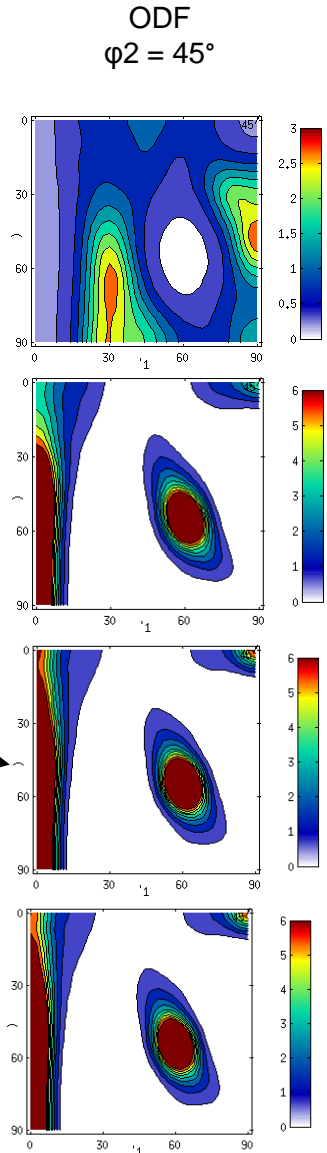
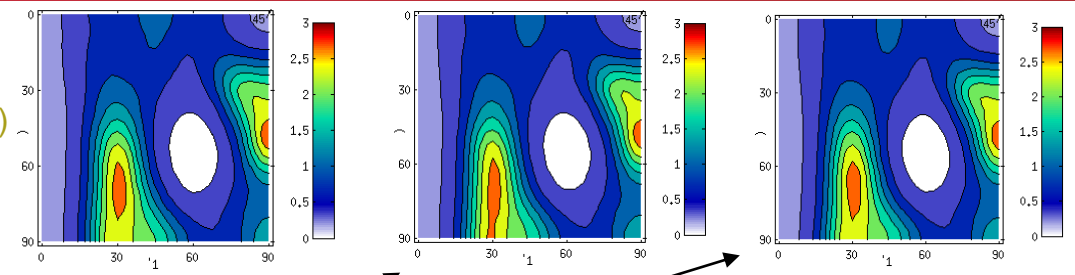
SLOW COOLING / LOW DEFORMED SAMPLE (R1)

P-fiber ({110}<122> // RD)

Cu fiber ({112}<111> // RD)

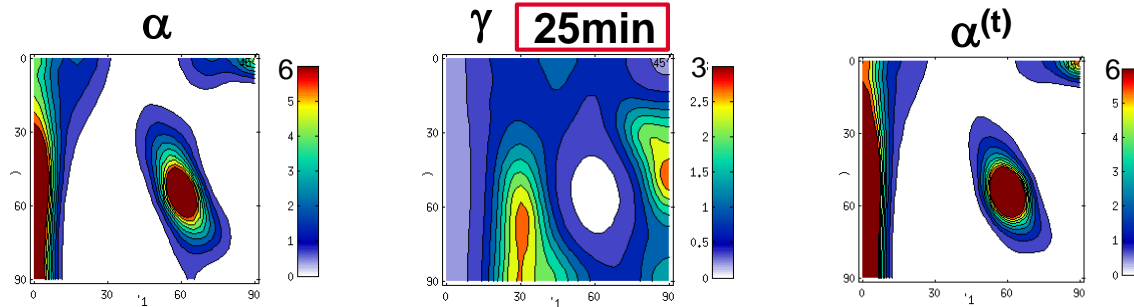


alpha-fiber (110 // RD)

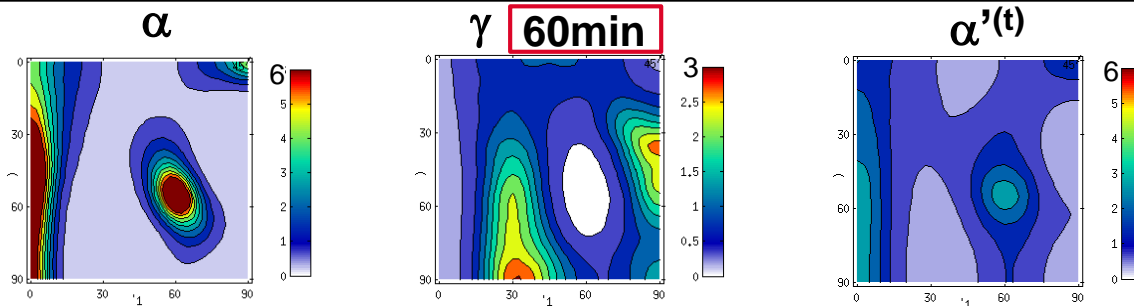


TEXTURE EVOLUTION AS THE FUNCTION OF T [°C], STRAIN, APPLIED COOLING RATE AND HOLDING TIME

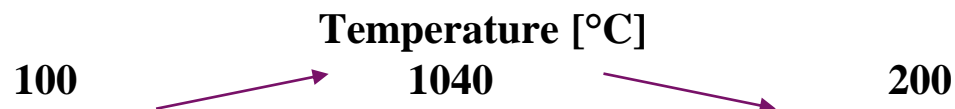
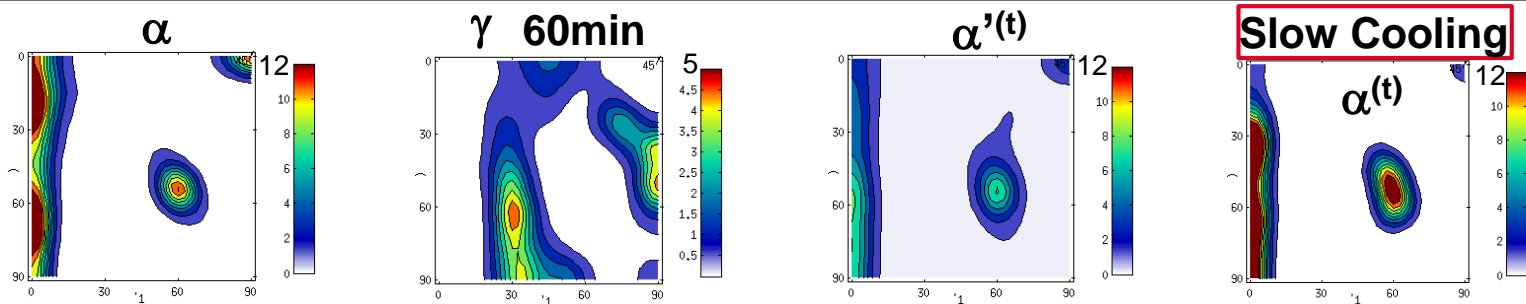
$\epsilon = 110\%$
Slow Cooling



$\epsilon = 110\%$
Fast Cooling

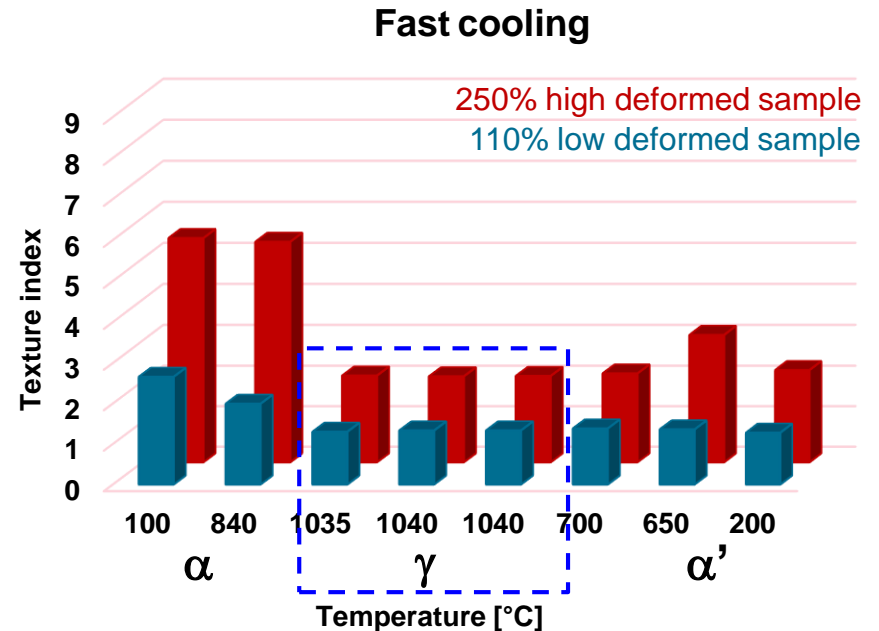
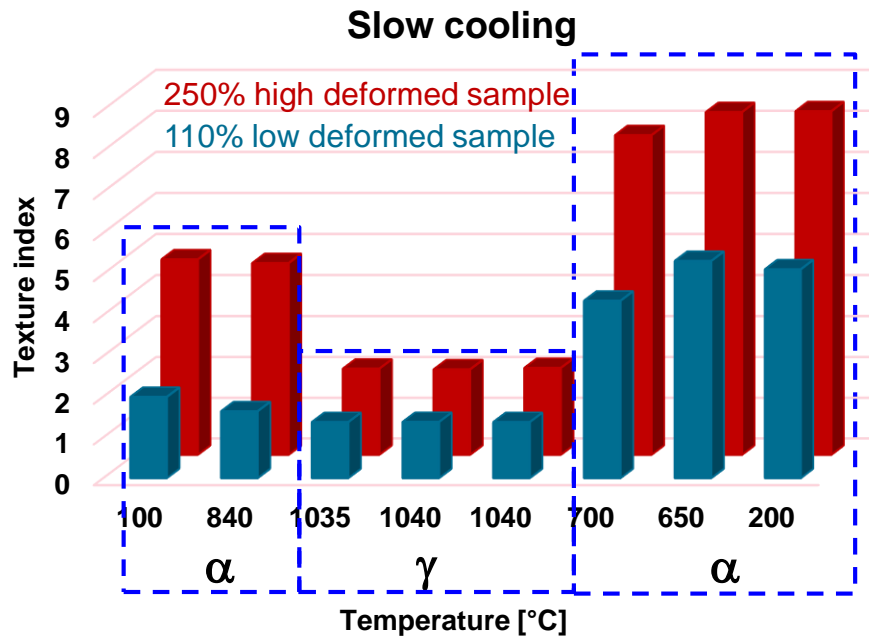


$\epsilon = 250\%$
Fast Cooling



CONCLUSIONS ON IN-SITU XRD TEXTURE ANALYSIS

❑ Synchrotron *in-situ* XRD crystallographic texture analysis during phase transformation



- Texture memory was confirmed during phase transformation at the slow cooling rate
- Texture is identified for the first time in austenitic domain and noted to be stable during HT
- The higher is the strain, the more remarkable is the texture level after heat treatment
- Possible mechanisms of variant selection (typically explained by K-S relation [1]):

(1) transformation strain; (2) precipitates; (3) special boundaries formed upon heating/cooling

Conclusions:

1. Analysis of the microstructure at each production step

- ❖ Influence of the deformation degree (rolling sequence) and heat treatments on texture evolution
- ❖ Texture study of ferrite and austenite phases by synchrotron radiation
- ❖ Variant selection rule is considered to explain texture memory effect

→ Recommendations for industrial application (cooling rate, holding time, forming sequence, mechanical properties, etc.)

Perspectives:

1. Identification and explanation of observed fibers in austenite domain

2. Precipitations role on texture memory *at the experimental and simulation parts*

3. Texture modeling using Visco-Plastic Self-Consistent model (VPSC) :

- ❖ Modification of the hardening law taking into account precipitation and its influence on selection of slip systems
- ❖ Improvement of the simulation on cyclic loading

Communications:

- E. Vakhitova, D. Sornin, F. Barcelo, M. François, Texture evolution in Oxide Dispersion Strengthened (ODS) steel tubes during pilgering process, Journal of Nuclear Materials, 494, pp.20-28, (2017)
- Texture Evolution Analysis in Oxide Dispersion Strengthened Ferritic Steel Transformed by a Tube Pilgering Process, 18th International Conference on Textures of Materials (ICOTOM-18), November 6-10, 2017, St George, Utah

THANK YOU FOR YOUR ATTENTION
QUESTIONS?