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► **To cite this version:**

E. Vakhitova, D. Sornin, Manuel François. Texture evolution analysis in oxide dispersion strengthened ferritic steel transformed by a tube pilgering process. 18th International Conference on Textures of Materials (ICOTOM-18), Nov 2017, Saint George, United States. cea-02437072

**HAL Id: cea-02437072**

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Submitted on 13 Jan 2020

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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)

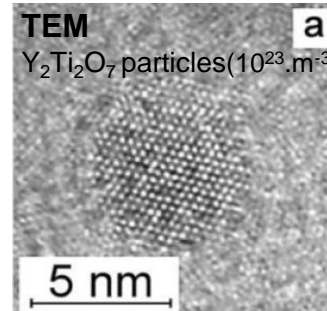
6 - 10 NOVEMBER 2017

# GENERAL CONTEXT

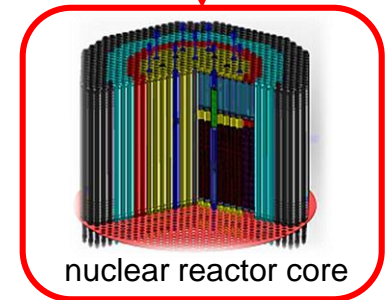
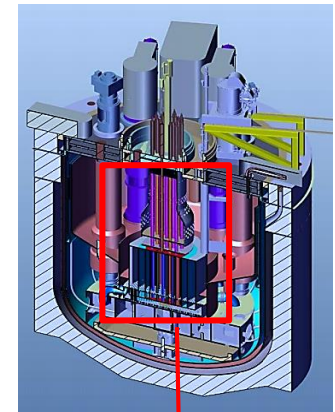
## Core material for Sodium Fast Reactor (ASTRID) Gen IV (2030s)

### Required properties:

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

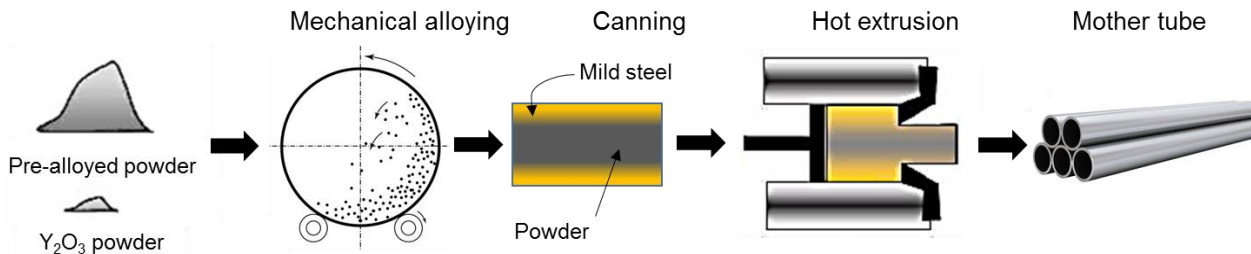


[Klimiankou et al., 2004]

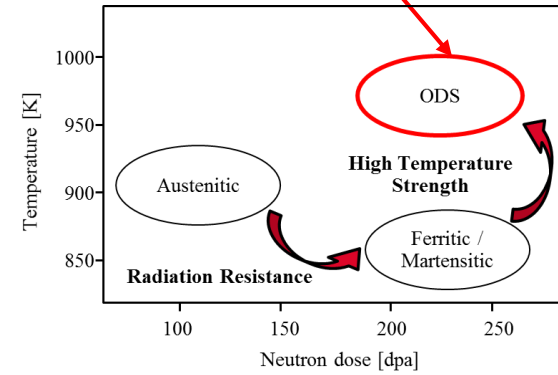
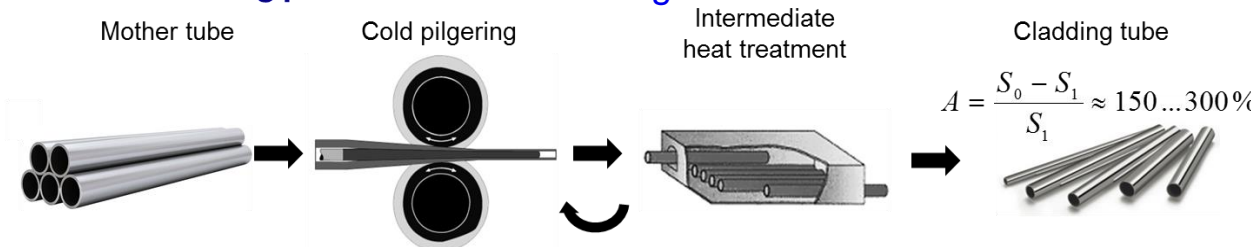


## Analysis of microstructural and mechanical properties evolution during thermomechanical processing

### 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

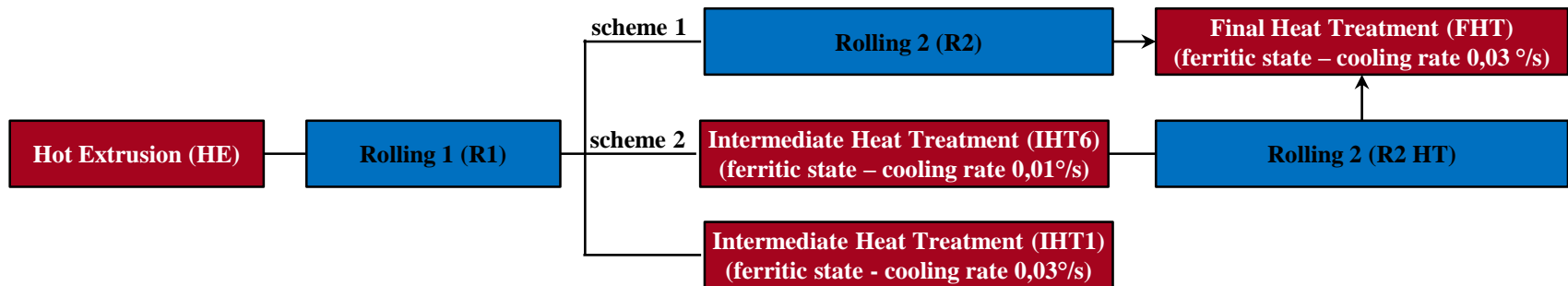
## Materials and methods:

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

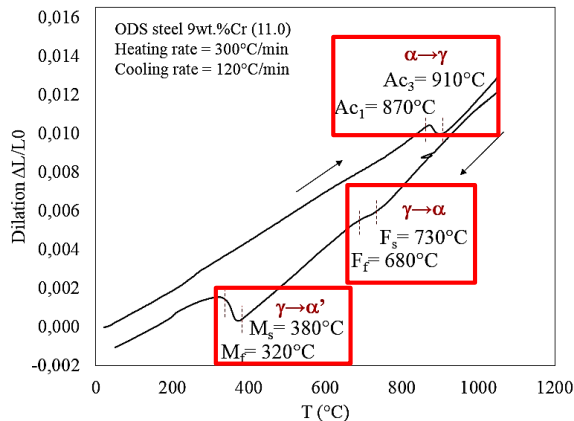
Chemical composition of ODS steel tubes (wt.%)

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 $\epsilon_p^*$ (%)	Q factor**
HE	-/-	-/-
R1	110	1,4
R2	140	1,6

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

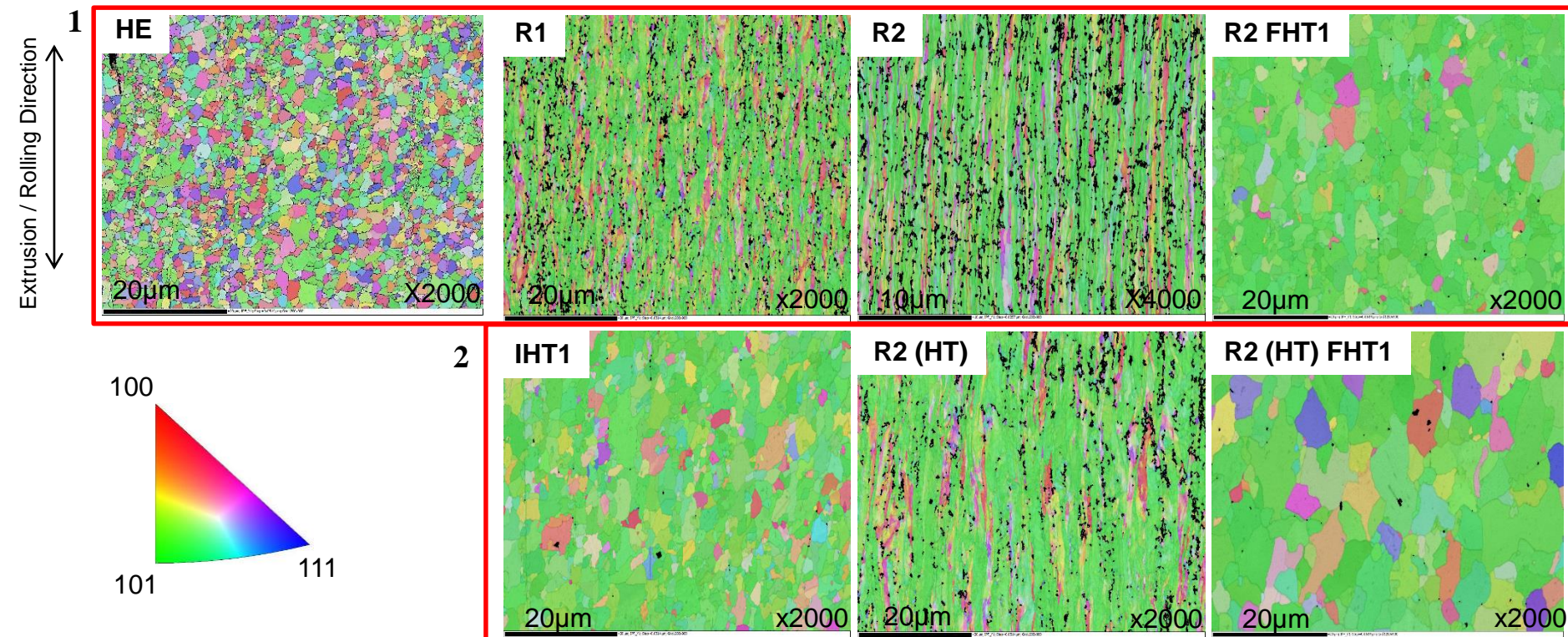
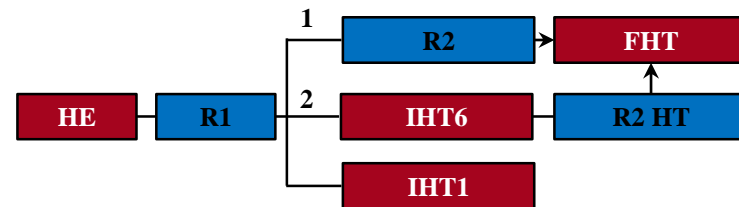
$$\Delta \epsilon_{zz} = -\ln \left( \frac{S_0}{S} \right)$$

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

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

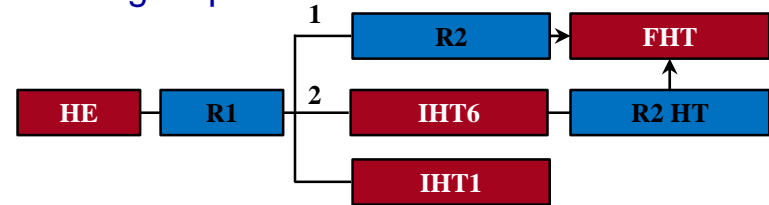
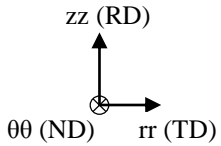
# EBSD OBSERVATION RESULTS

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

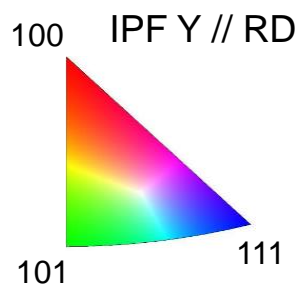
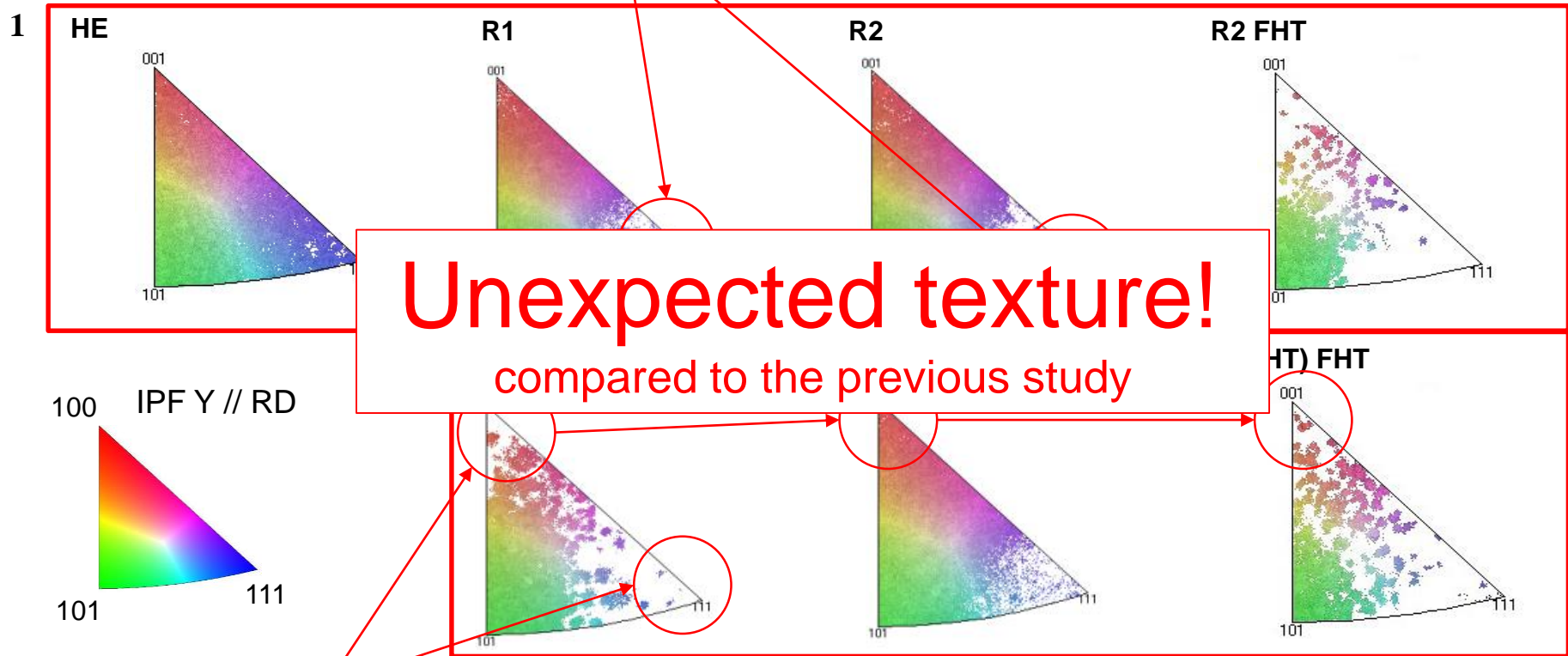


Inverse pole figures maps IPF Y // RD for 9wt%Cr ODS steel at the different processing steps

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



<111> oriented grain disappear progressively during rolling steps

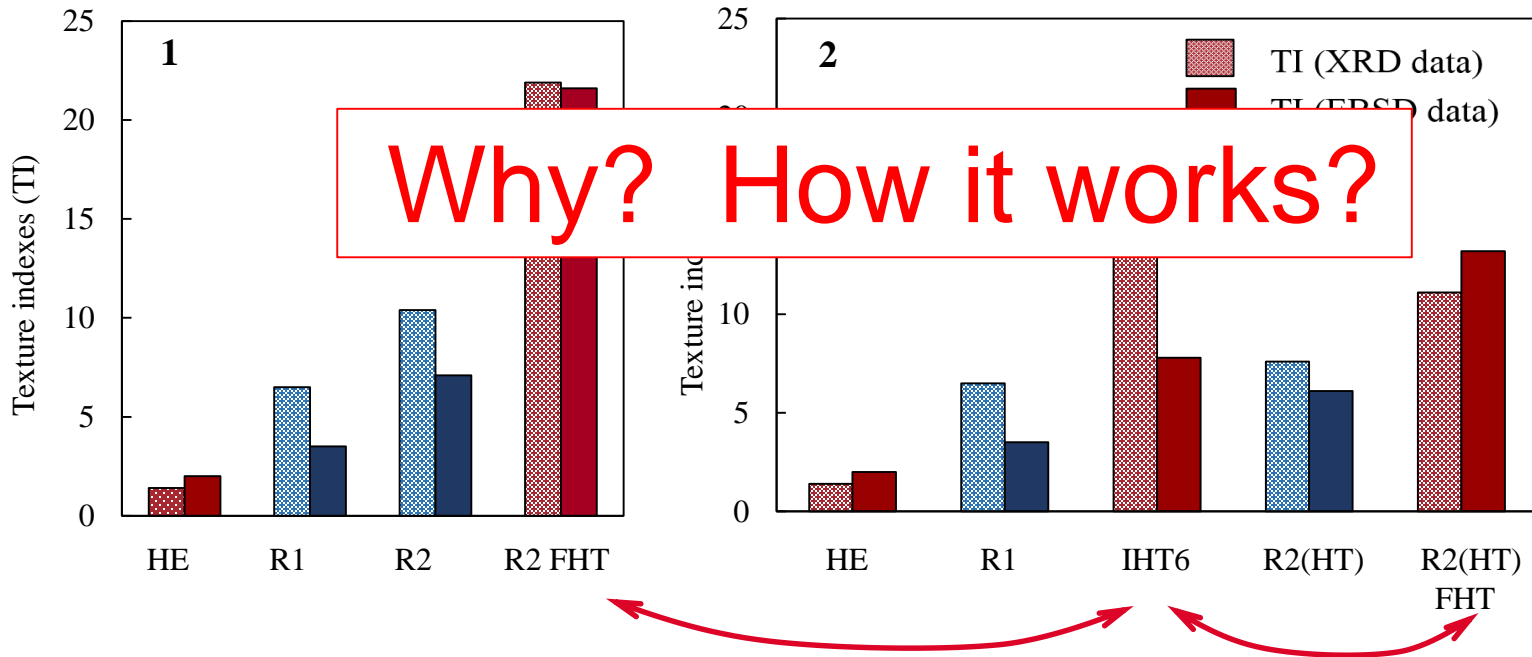
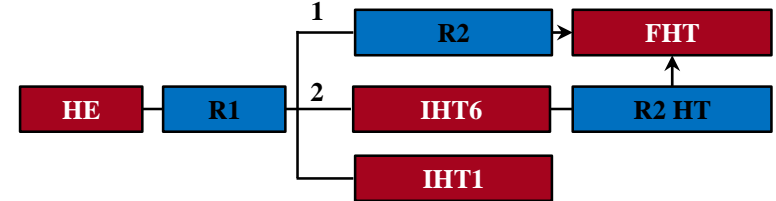


Dominant <101> orientation after heat treatment

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

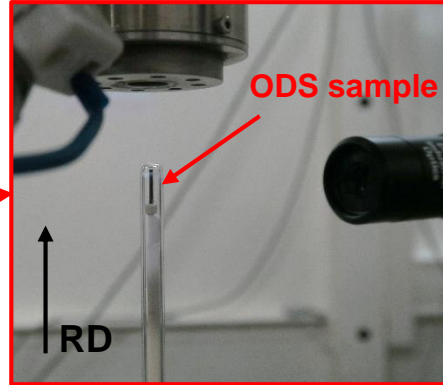
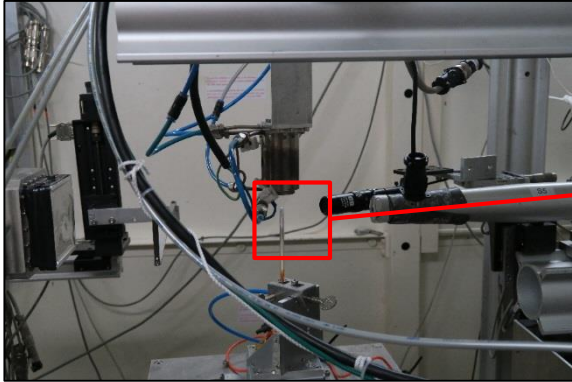
# EBSD OBSERVATION RESULTS

- Texture Index (Gaussian approximation of 5° halfwidth)



- Strengthening of the  $\alpha$ -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 :

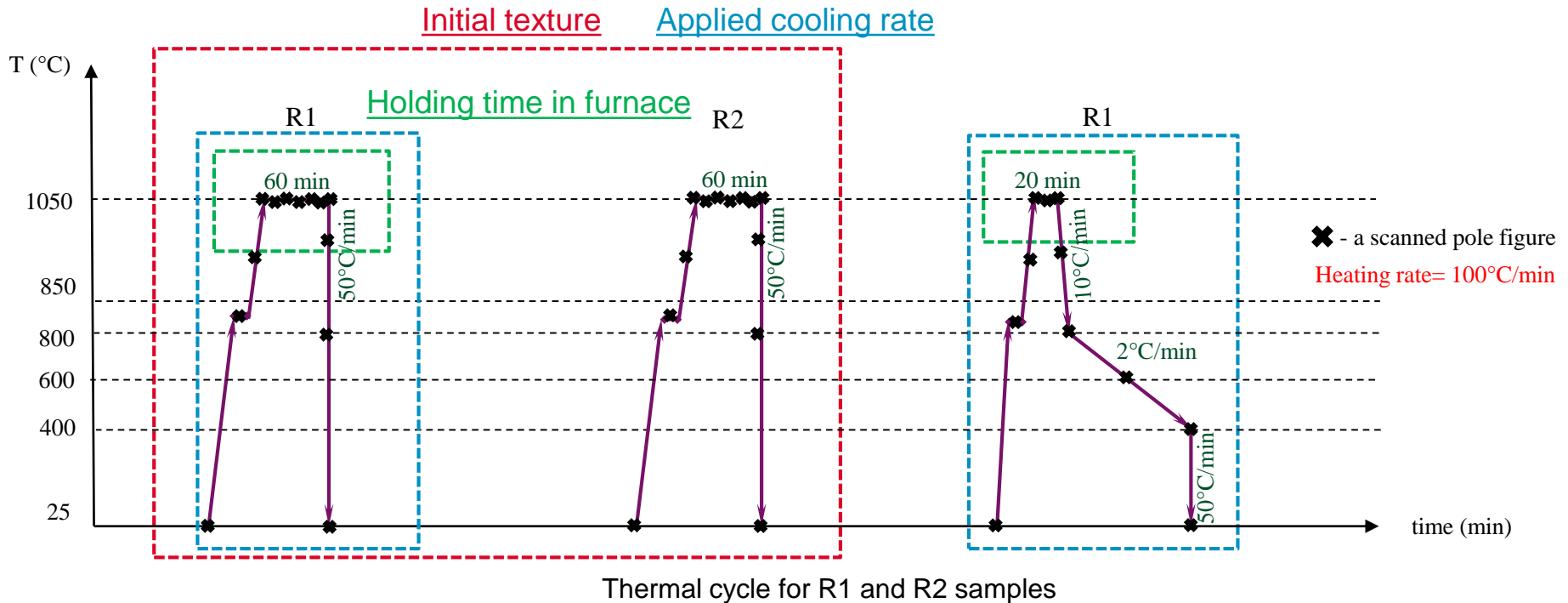
- Initial texture ?
- Holding time in furnace ?
- Applied cooling rate ?

**Beam Line:** ESRF ID11 (XRD in transmission mode)

**Beam Line manager :** Jonathan WRIGHT

**Photons energy range requested:** 80,005 keV

**Spot size requested:** 200x200  $\mu\text{m}$

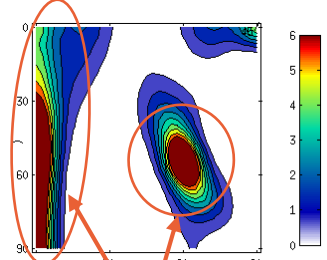
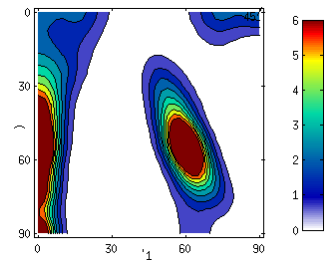
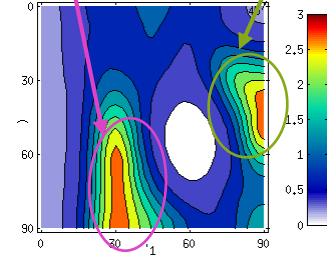




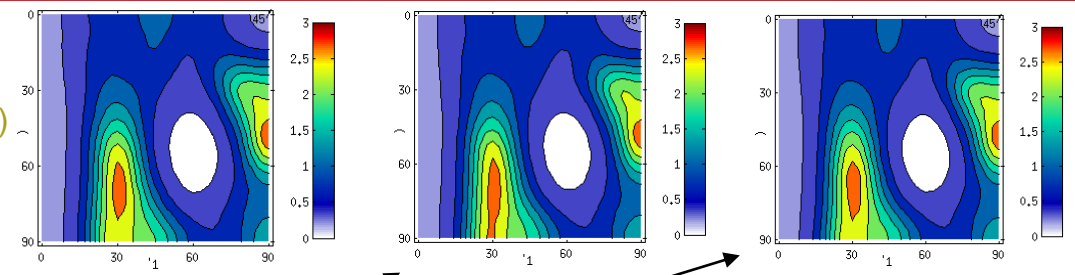
# SLOW COOLING / LOW DEFORMED SAMPLE (R1)

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

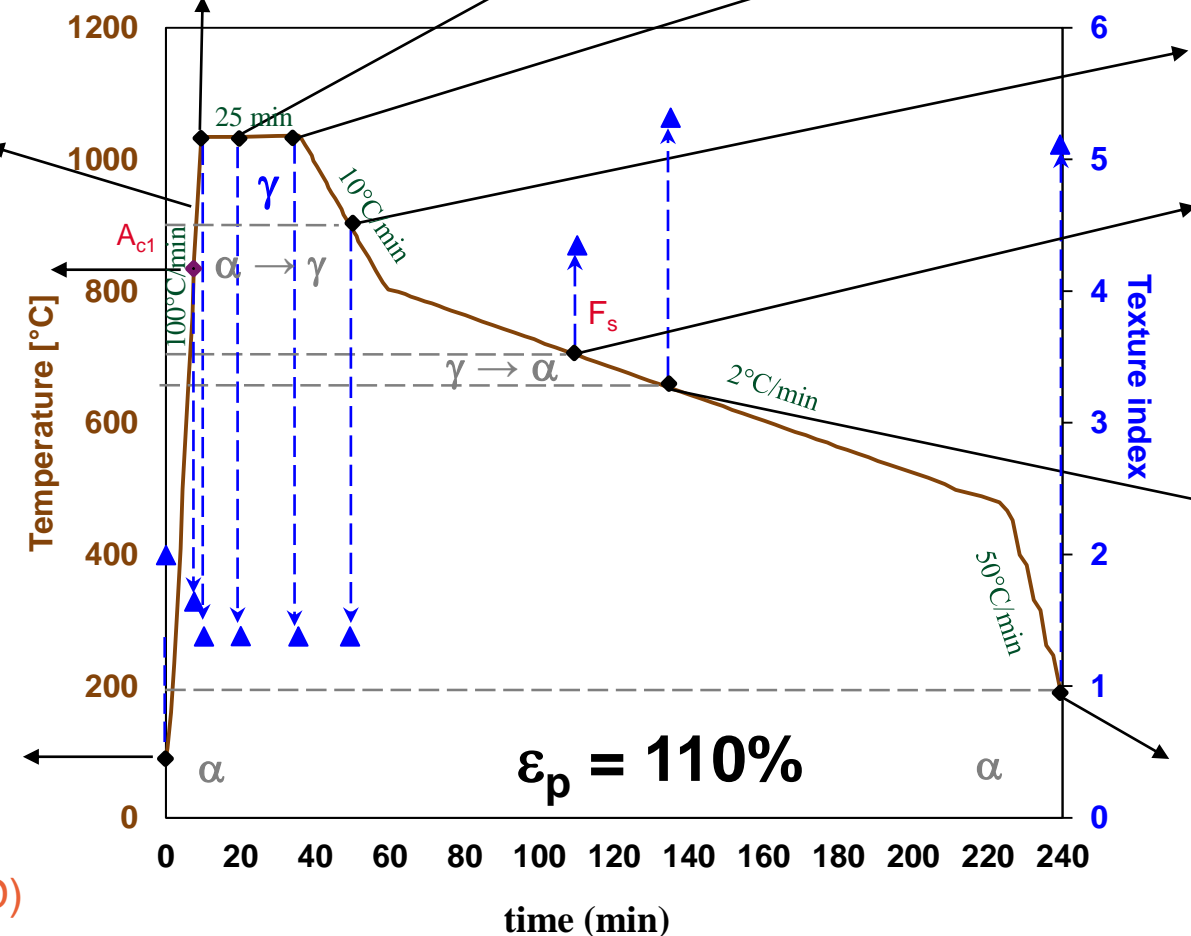
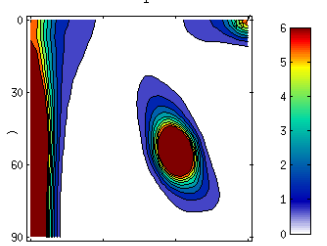
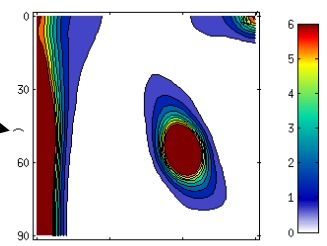
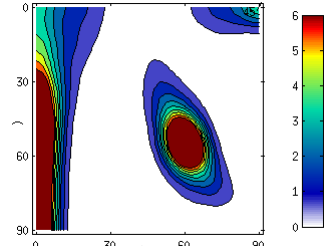
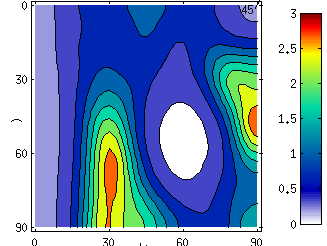
Cu fiber ( {112}<111> // RD)



α-fiber ( 110 // RD)

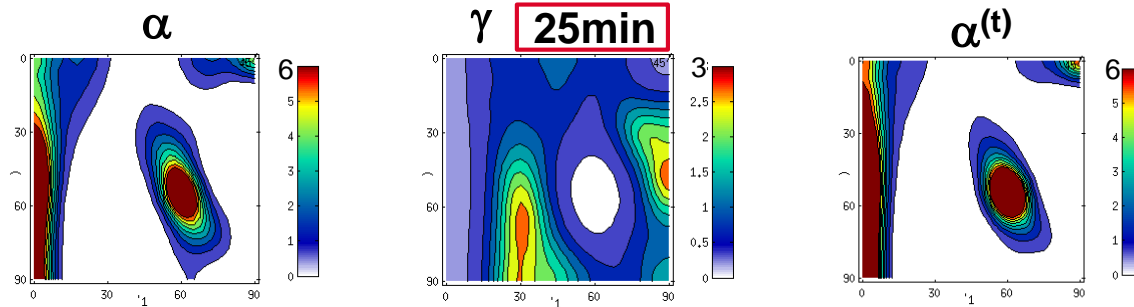


ODF  
φ2 = 45°

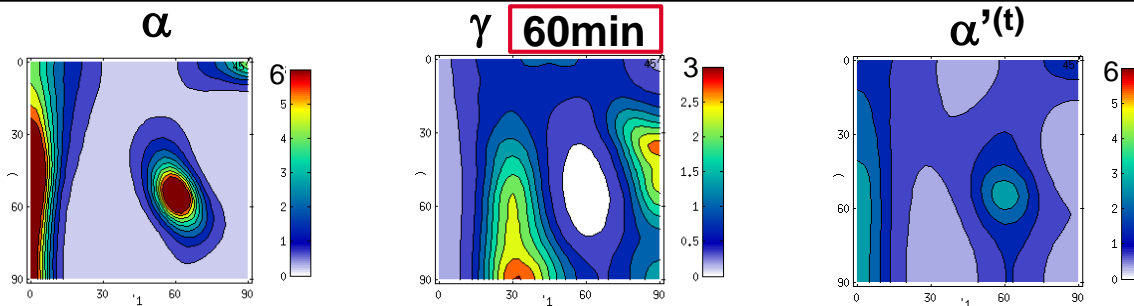


# TEXTURE EVOLUTION AS THE FUNCTION OF T [°C], STRAIN, APPLIED COOLING RATE AND HOLDING TIME

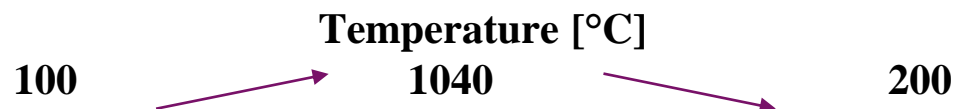
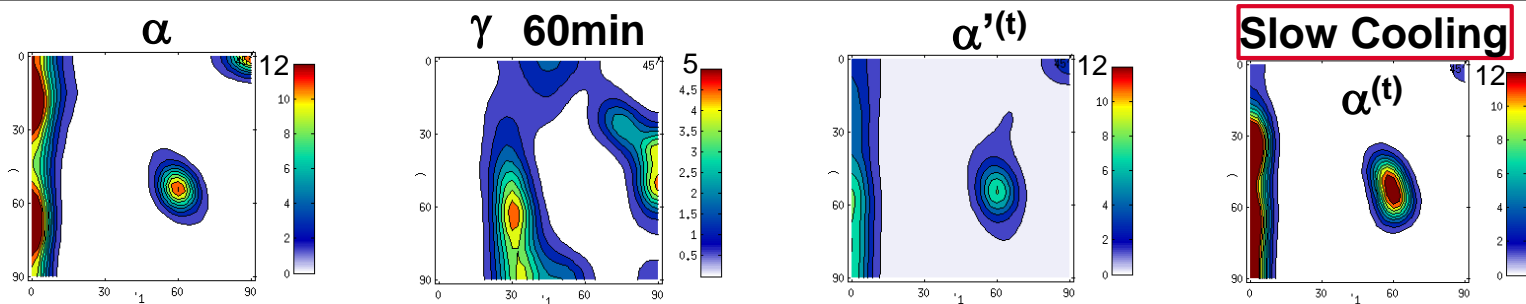
$\epsilon = 110\%$   
Slow Cooling



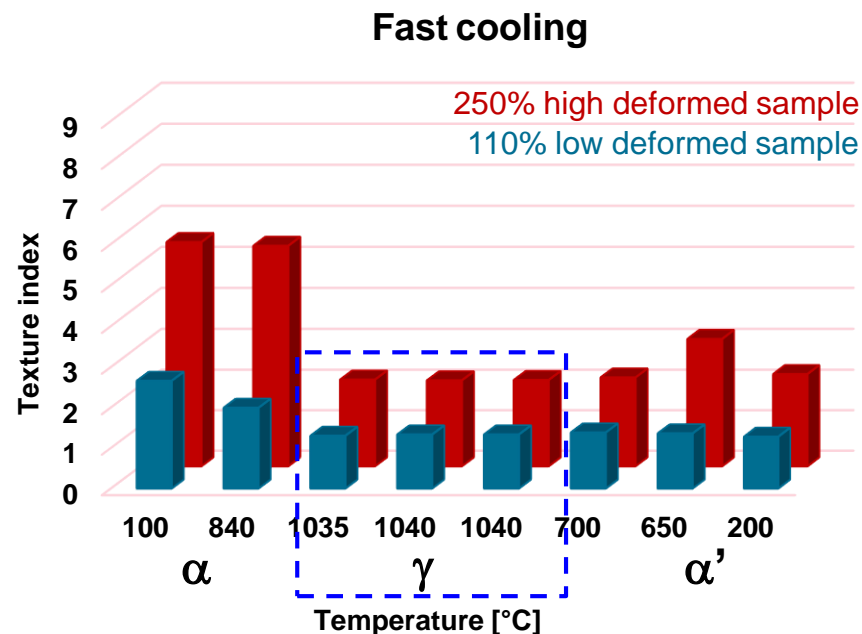
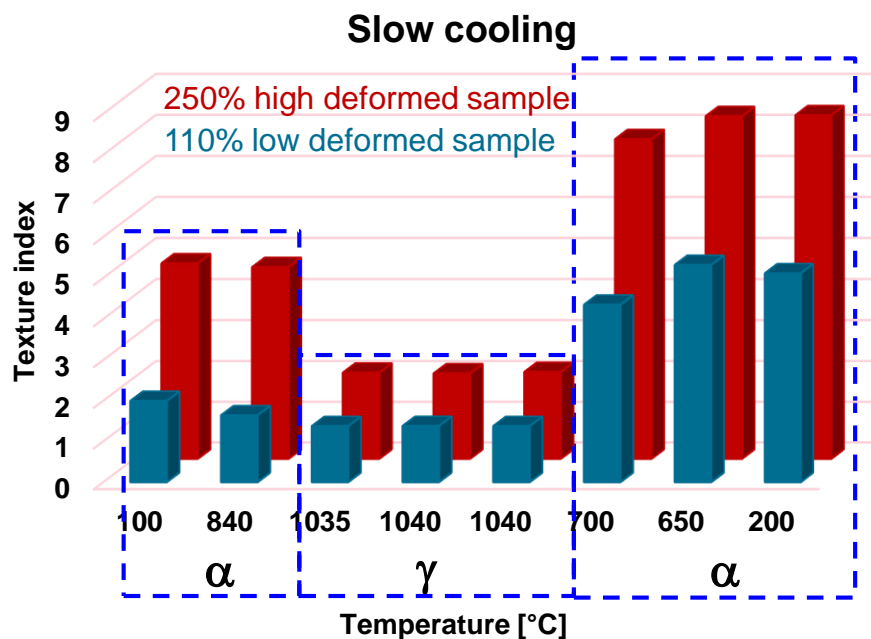
$\epsilon = 110\%$   
Fast Cooling



$\epsilon = 250\%$   
Fast Cooling



## ❑ 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?**