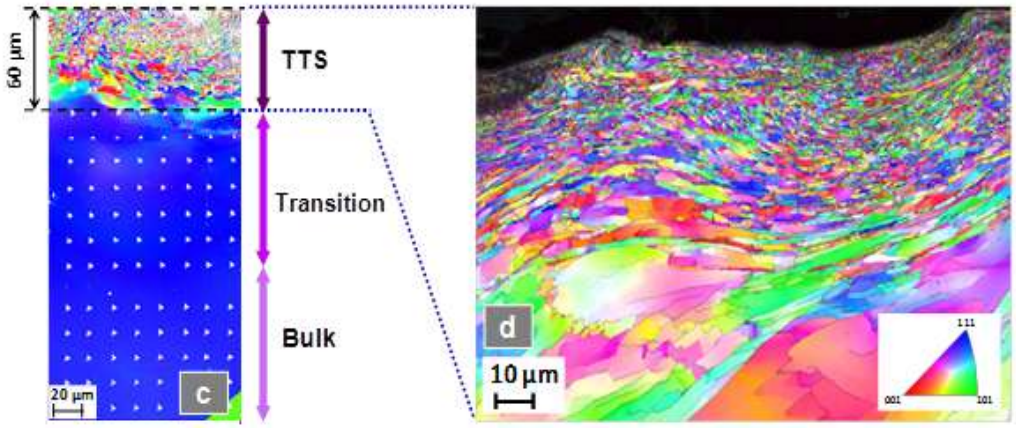
MINES
Saint-Étienne

Surfaces à gradient de propriétés mécaniques par l'optimisation des microstructures

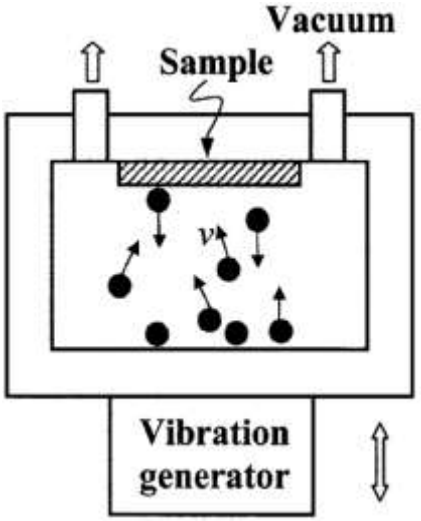


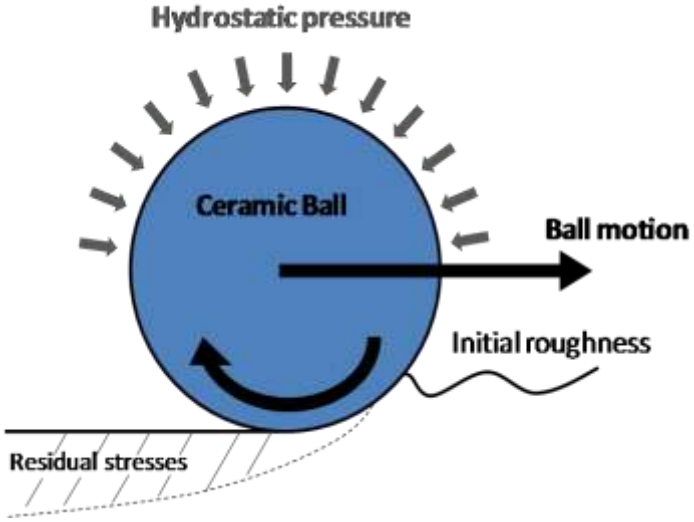
G. Kermouche, …

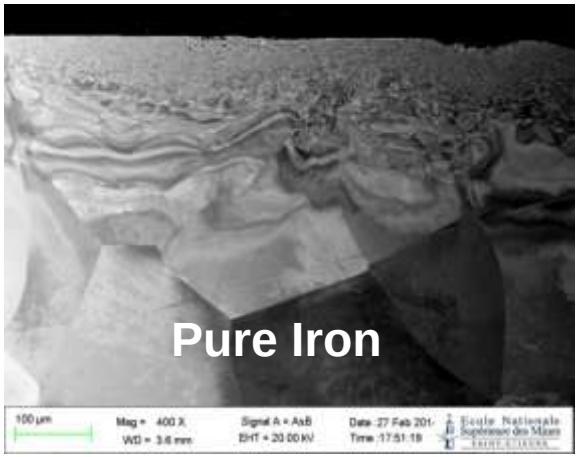
Le 31 mars 2016

Surface mechanical treatments

- *Process based on contact loadings to create a gradient of mechanical properties in the near-surface*



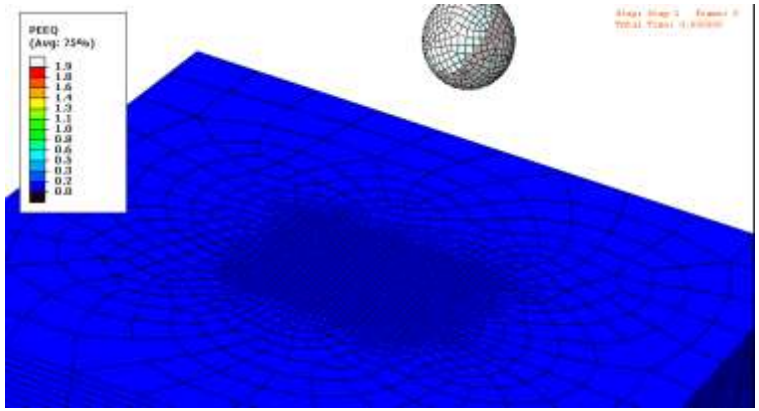


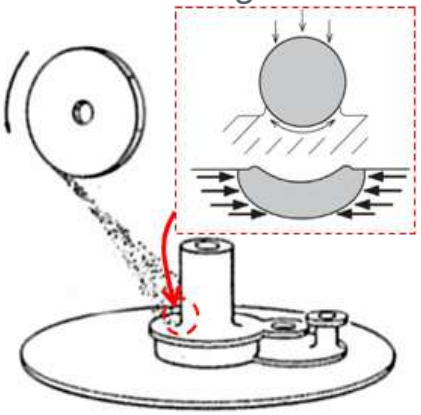


- *Compressive residual stress-field* -> improve fatigue resistance
- ***Near-surface microstructure refinment*** -> increase hardness and wear resistance.
- *Enhance diffusion* -> improve subsequent thermochemical process .

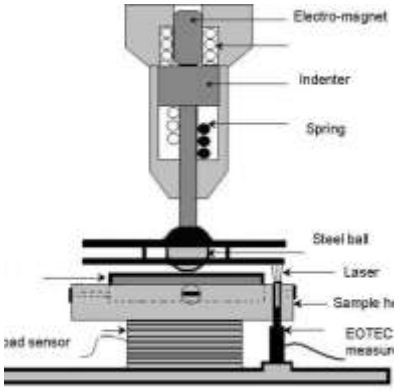
Surface mechanical treatments

- *Kind of SMT*
  - *Impact-based SMT (cold deformation, medium to high strain rate : 10^2-10^4 s^{-1})*





Shot peening



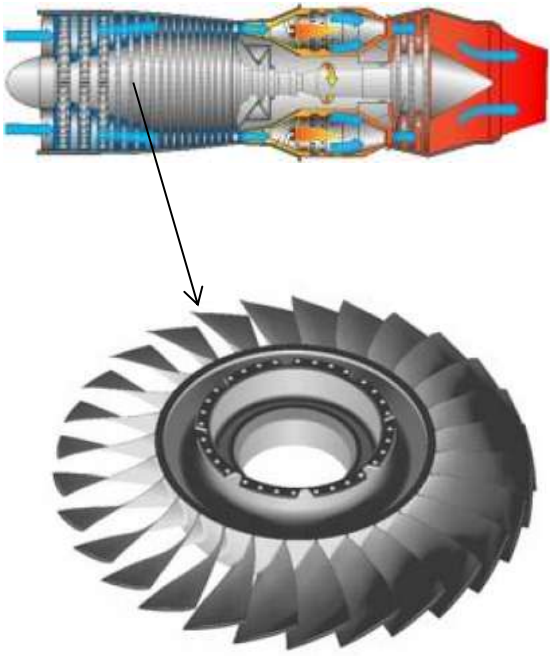
Percussion

  - *Scratch-based SMT (cold or hot deformation, medium strain rate : 10^2-10^3 s^{-1})*

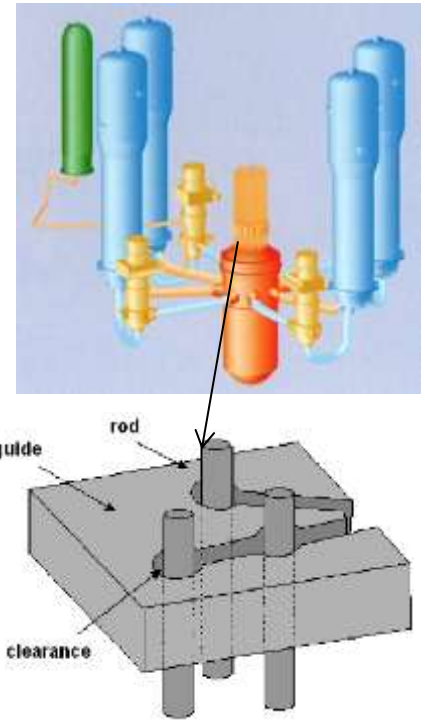
superfinishing

Burnishing

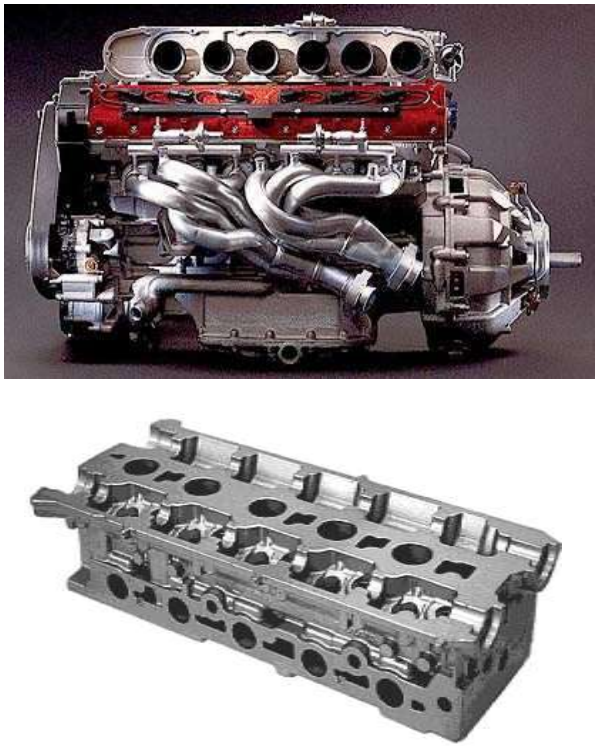
Academic research or an industrial need ?



Aircraft industry



Nuclear industry



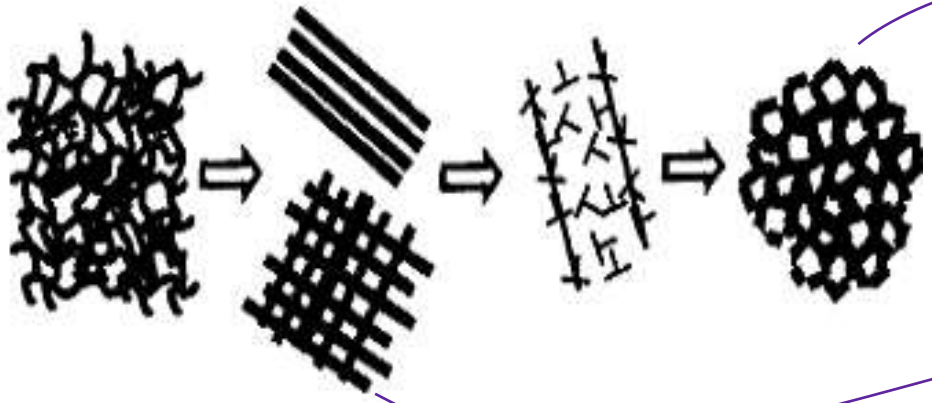
Automotive industry

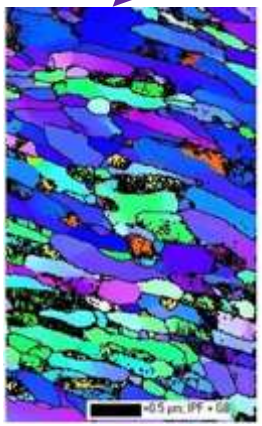
- *Successfully used by industry for years*
- Process parameters are empirically chosen

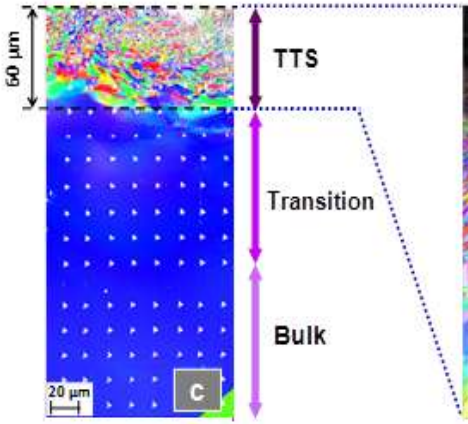
→ *A high need of academic research*

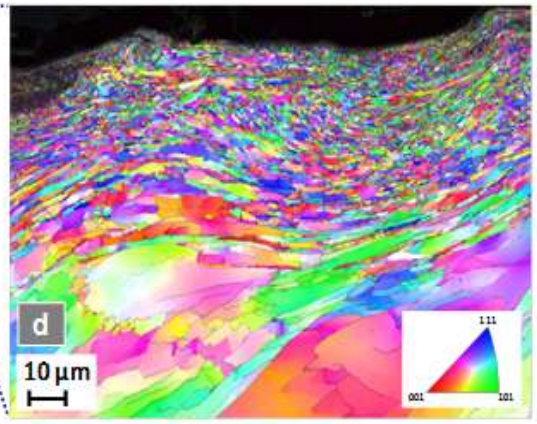
SMT-induced grain refinement (TTS)

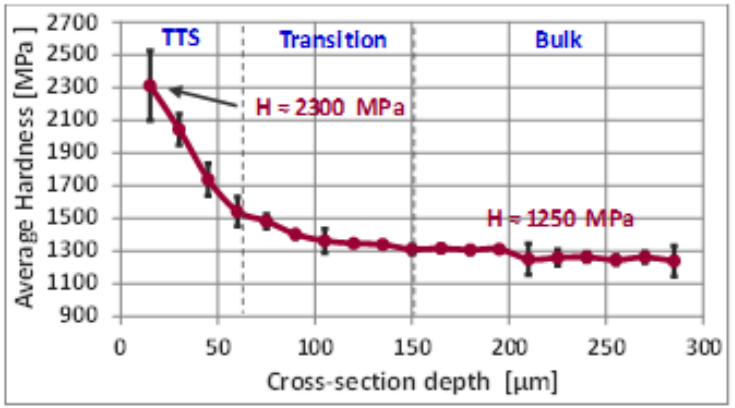
- **About grain refinement induced by Severe Plastic Deformation**





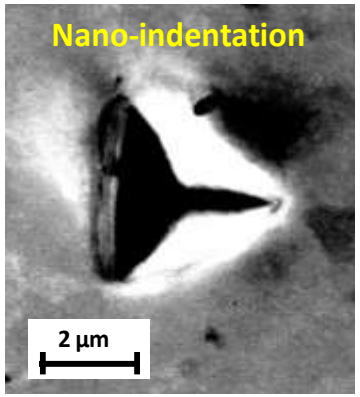


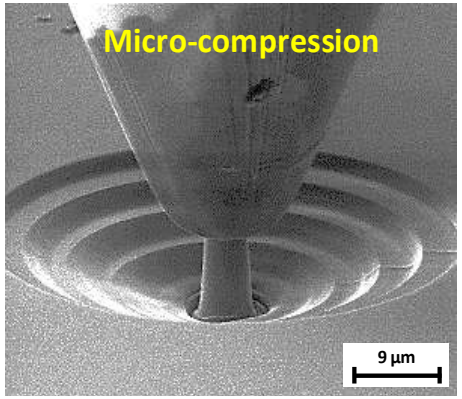


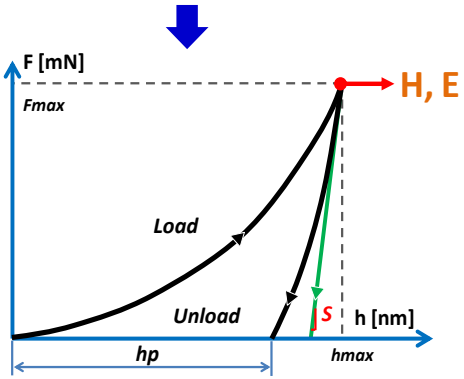


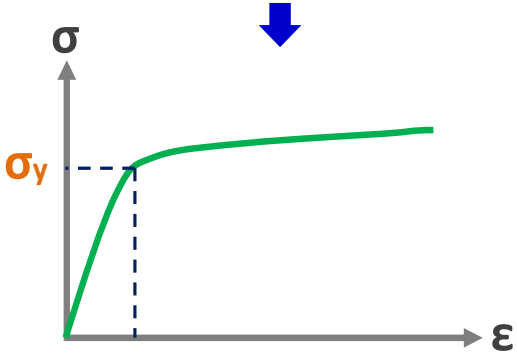
Surface mechanical treatments and quantification of induced mechanical properties

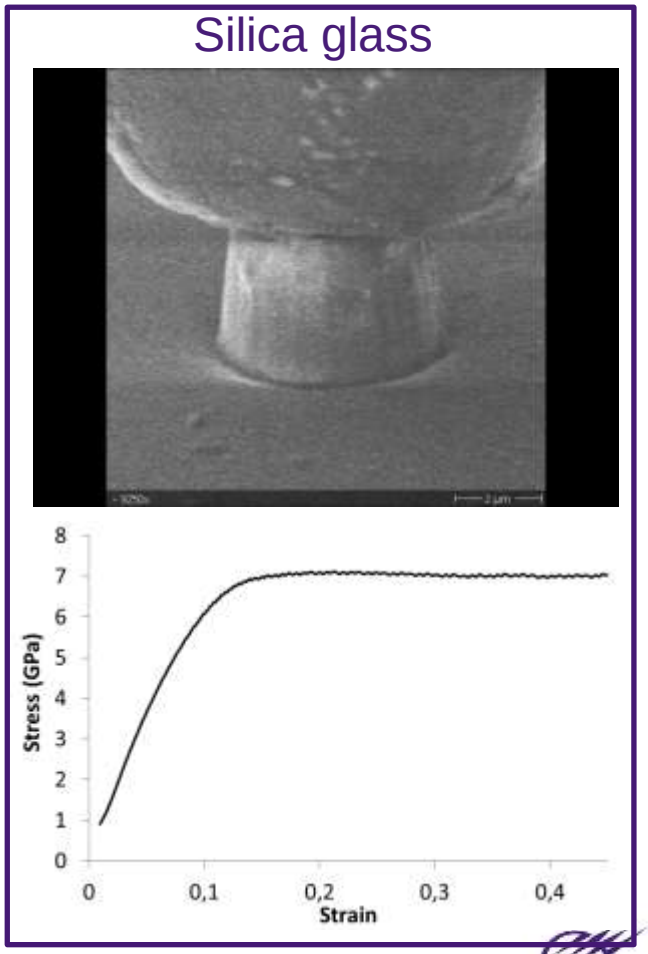
- **How to quantify small scale mechanical properties ?**





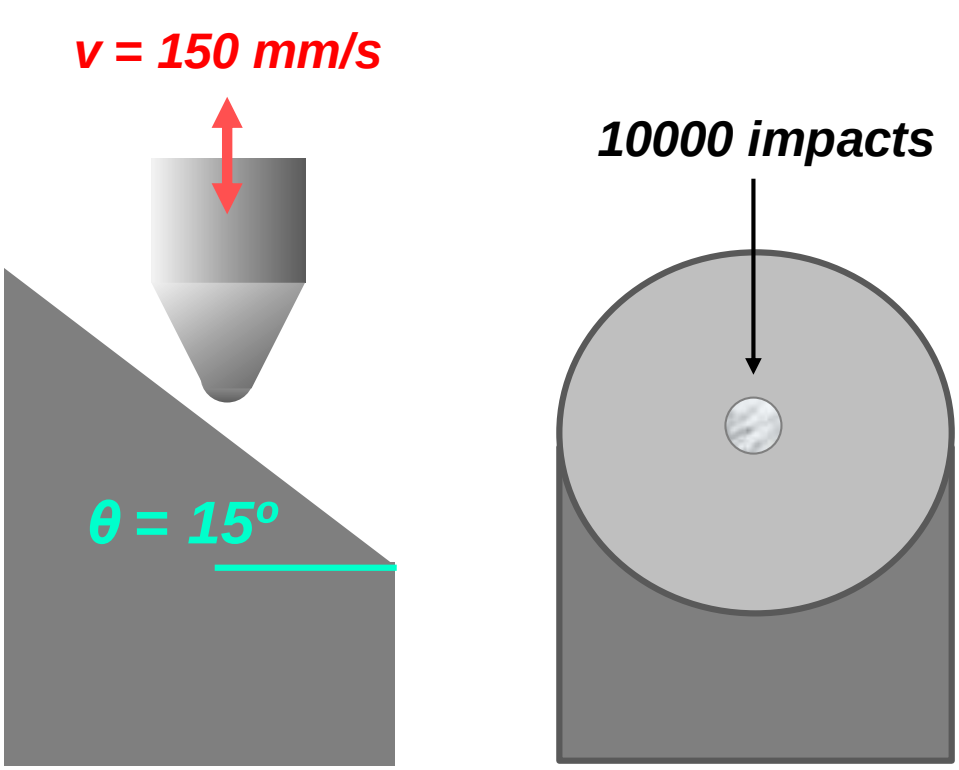


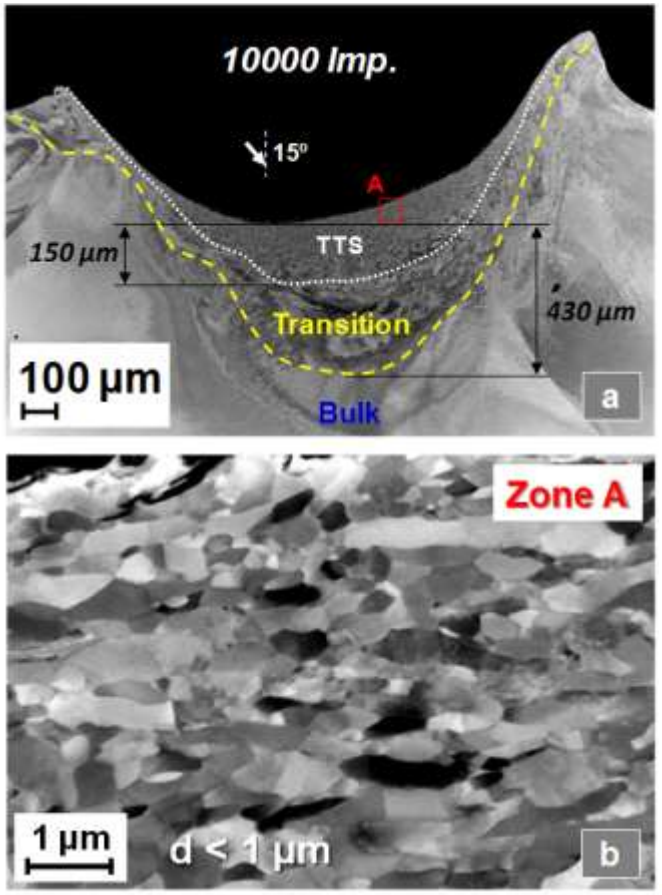




Surface mechanical treatments and quantification of induced mechanical properties

- *A scholar investigation : the oblique micro-percussion test*



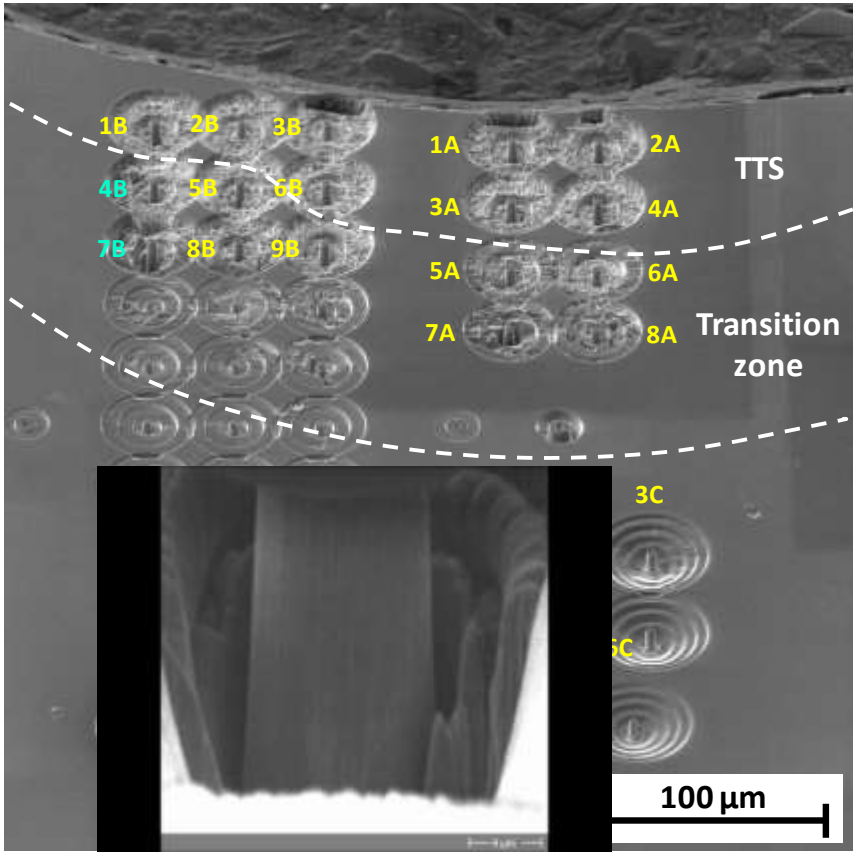


A scholar material : High purity iron

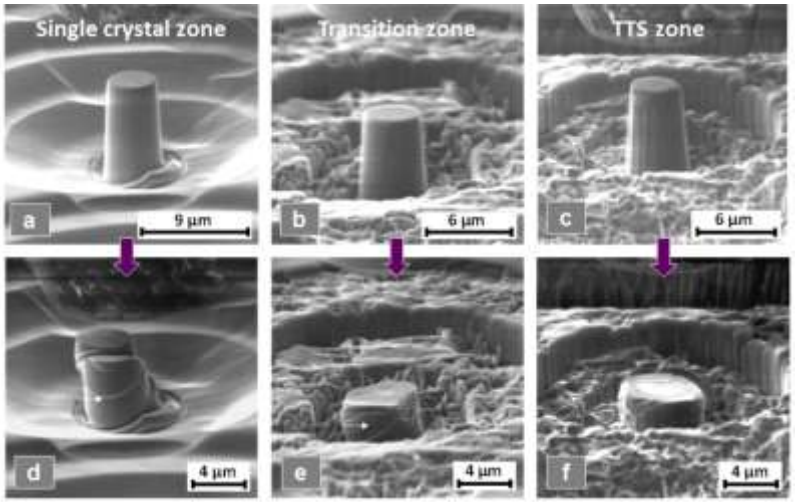
PhD of D. Tumbajoy-Spinel

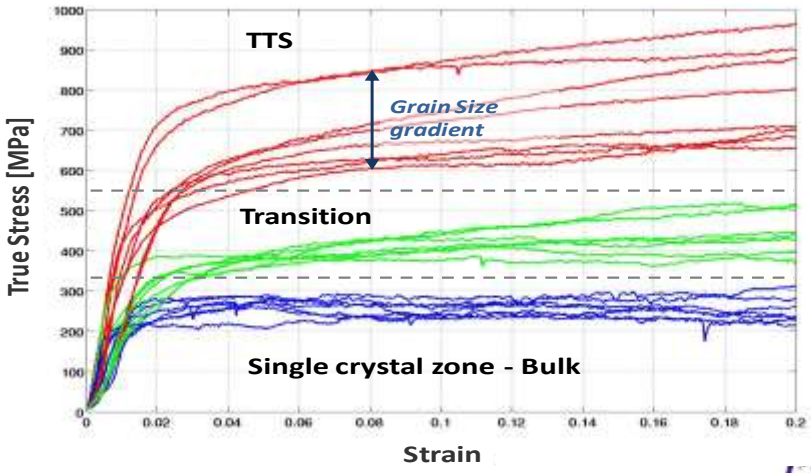
Surface mechanical treatments and quantification of induced mechanical properties

- *A scholar investigation : the oblique micro-percussion test*



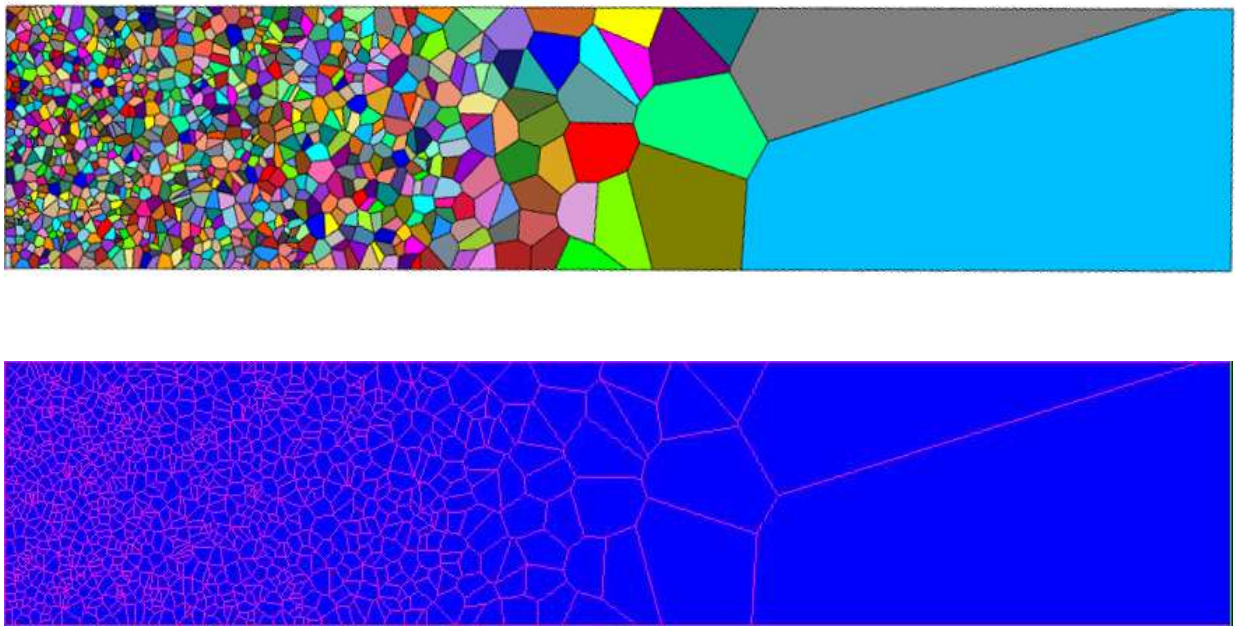
FIBed micropillars





Enhancement of subsequent thermochemical treatments

- *Grain boundary as a shortcut for diffusion : Application to nitriding*



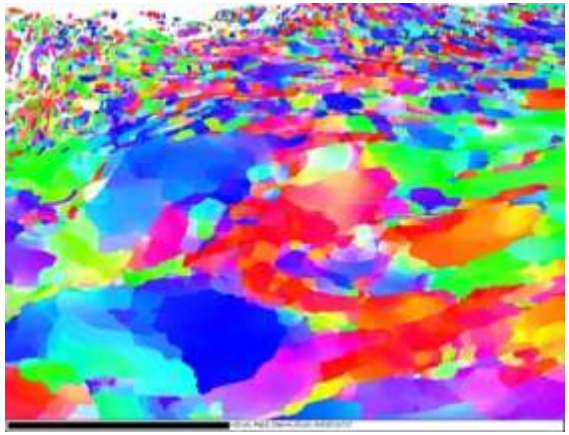
Polycristal

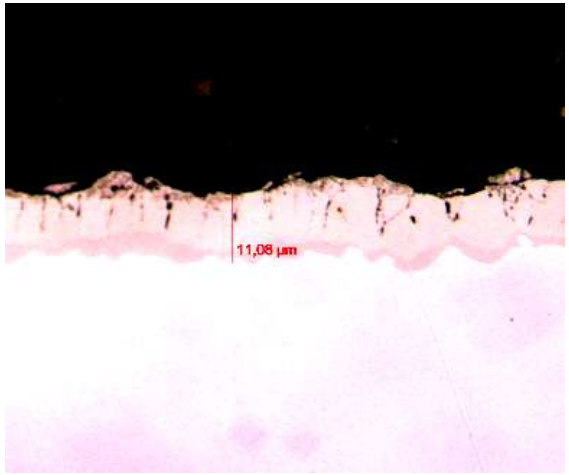
Nanostructure
Dgb x 10000

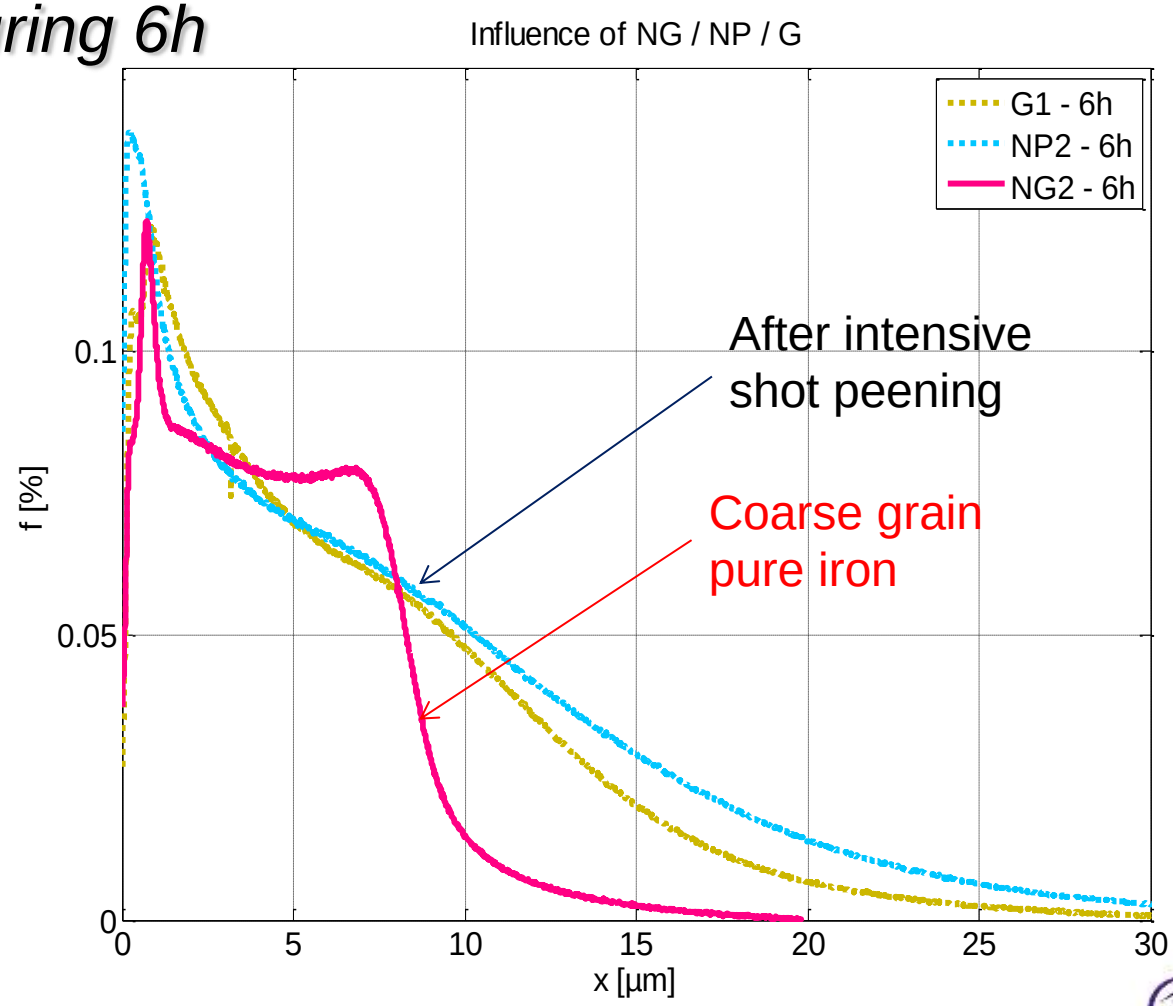
PhD of V. Lacaille

Enhancement of subsequent thermochemical treatments

- *Experimental investigation : gas nitriding of a pure Iron at 500°C during 6h*

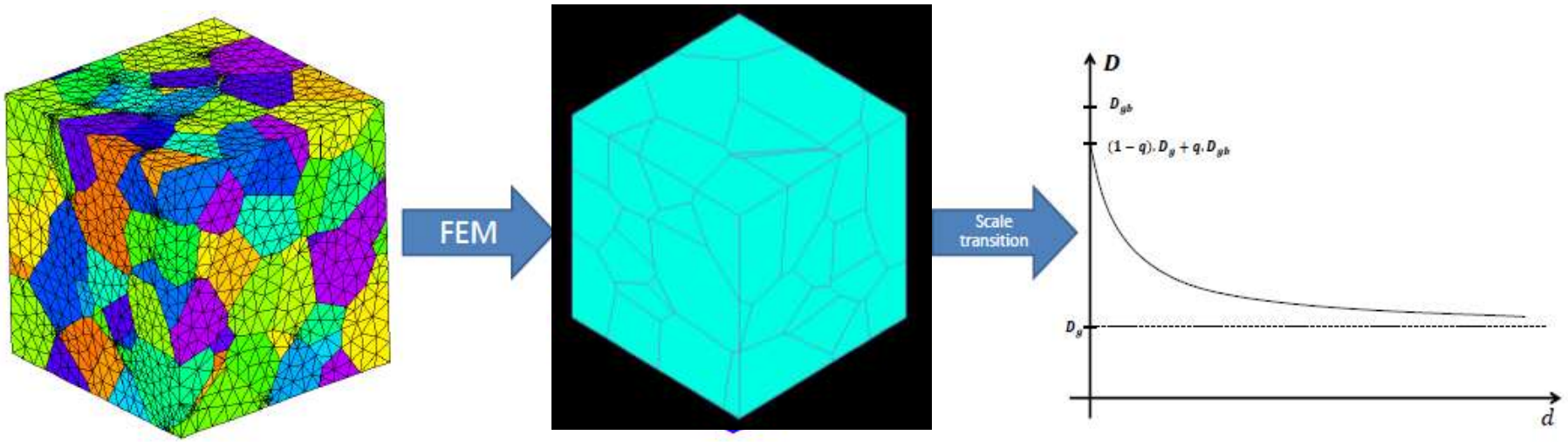






Enhancement of subsequent thermochemical treatments

- *Diffusion enhancement vs grain size*
  - *FEM of diffusion in a polycristalline sample*



Generation of Representative Volume Elements

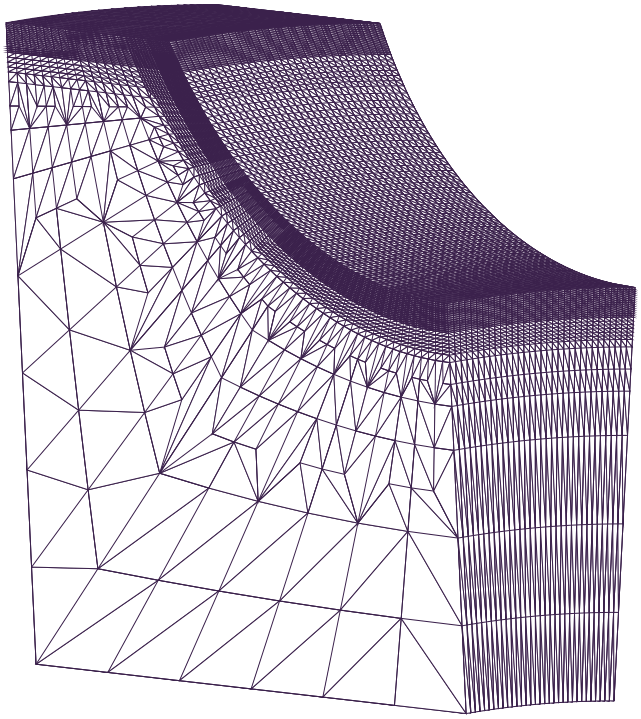
Diffusion simulation
Distinction of grains and grain boundaries

Diffusivity model as a function of the grain size

$$D = D_g + q\frac{\beta\delta}{d+\beta\delta}\left(\mathrm{D_{gb}} - \mathrm{D_g}\right)$$

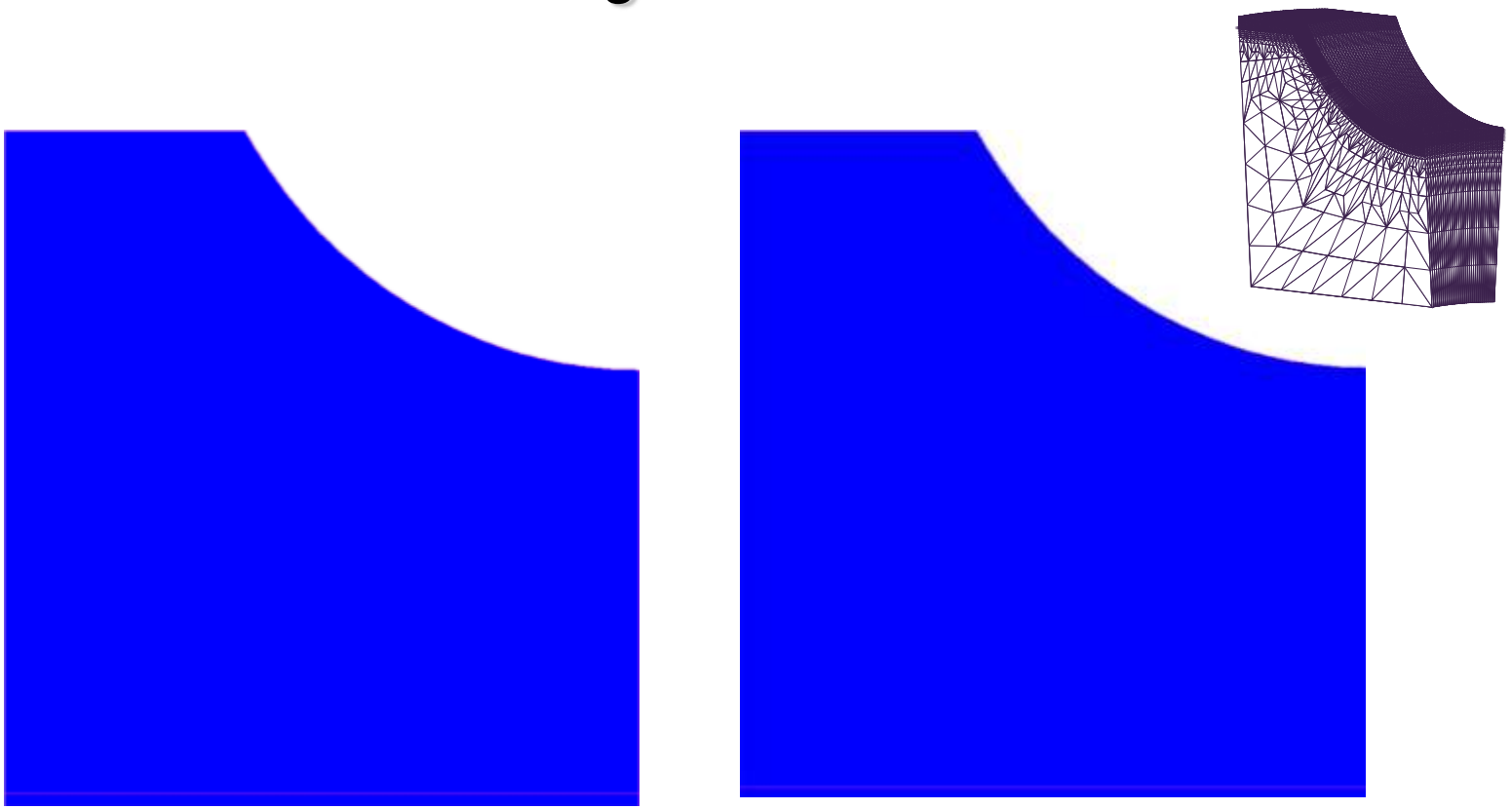
Enhancement of subsequent thermochemical treatments

- *Finite element modelling*



Enhancement of subsequent thermochemical treatments

- *Finite element modelling*

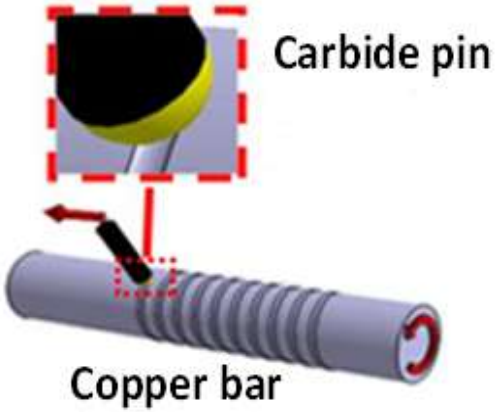


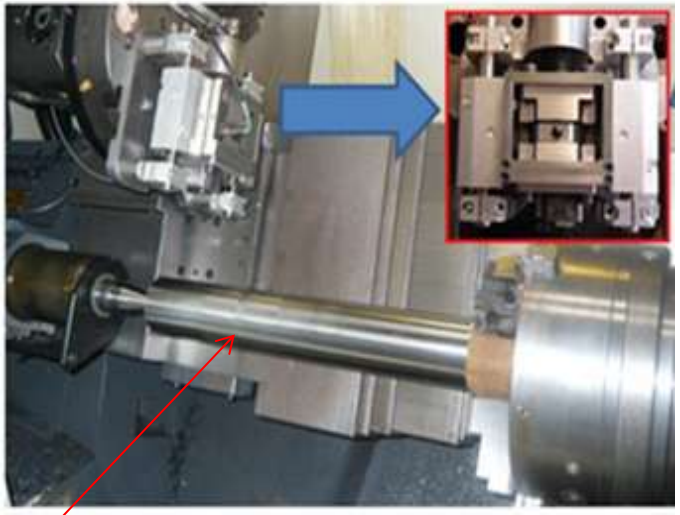
Coarse grain

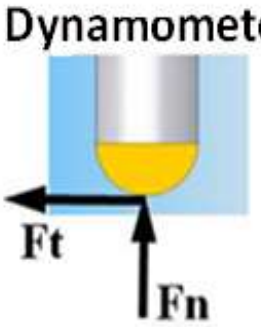
After intensive shot peening

Toward a new kind of SMT

- *Use of an instrumented high speed tribotest previously designed for research on turning processes*

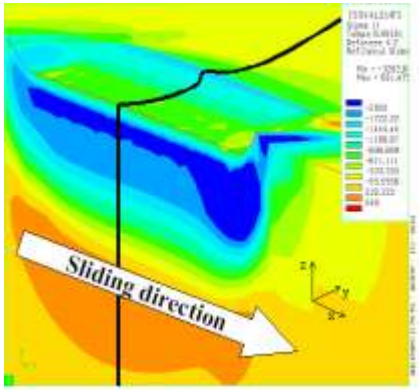


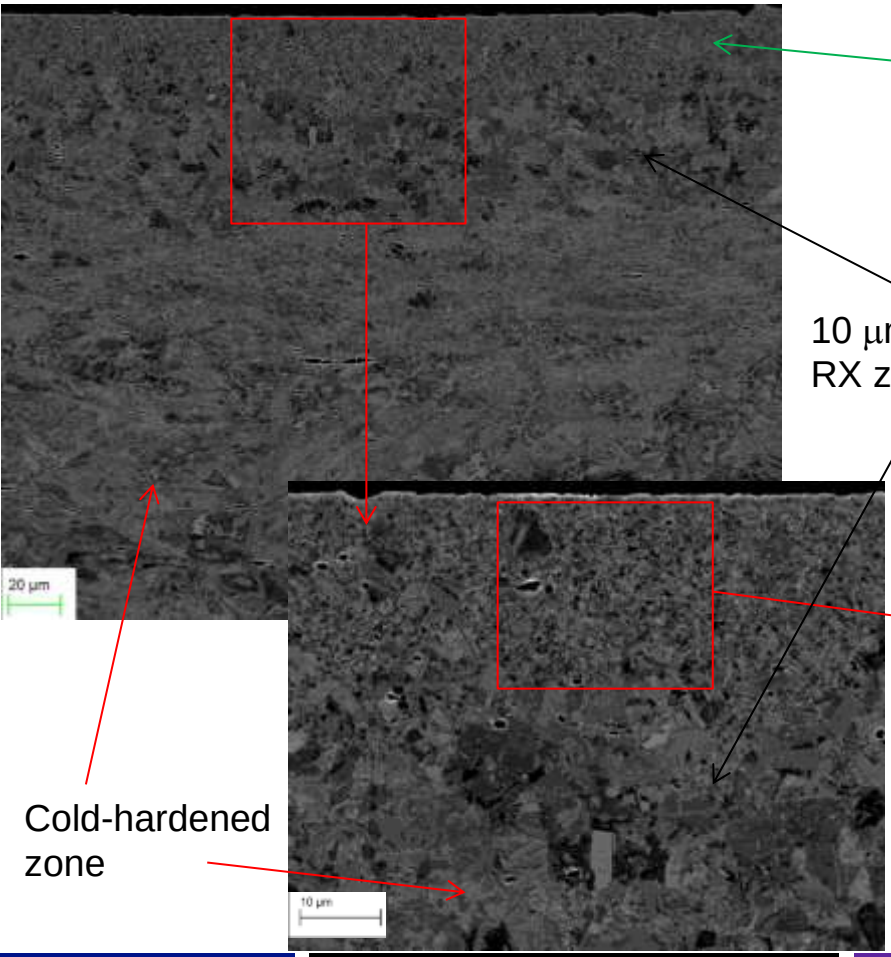




Experimental results

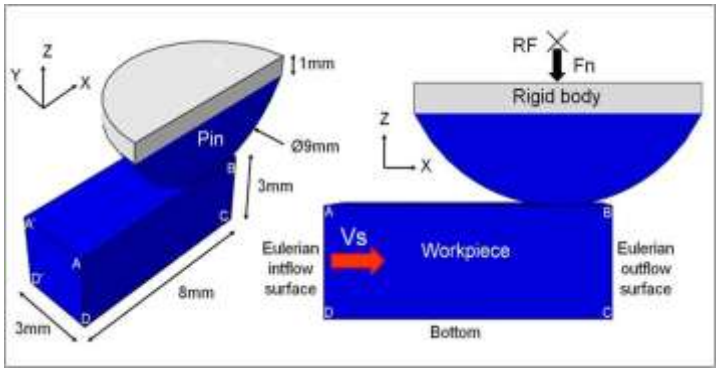
- *Cross-section (250 m/min)*



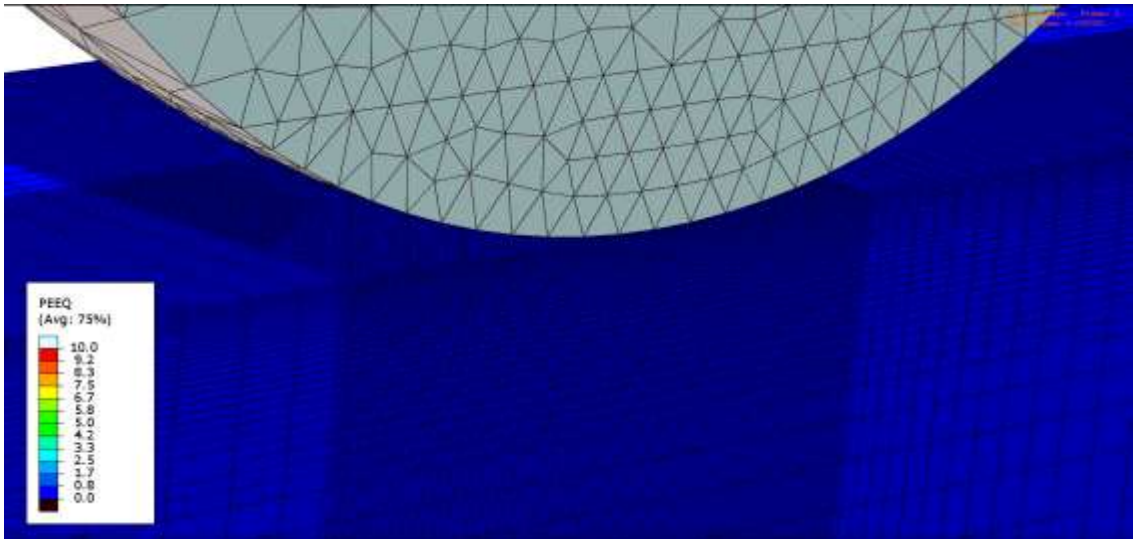


Finite element investigation

- *Thermomecanical modelling using an eulerian framework (Abaqus Explicit)*

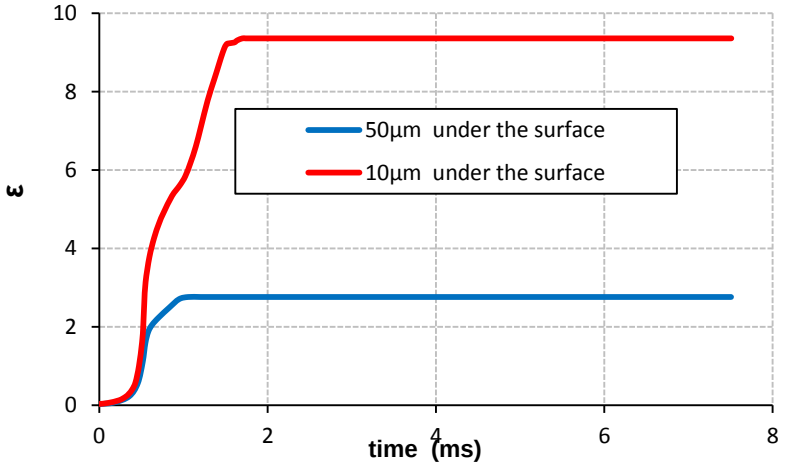


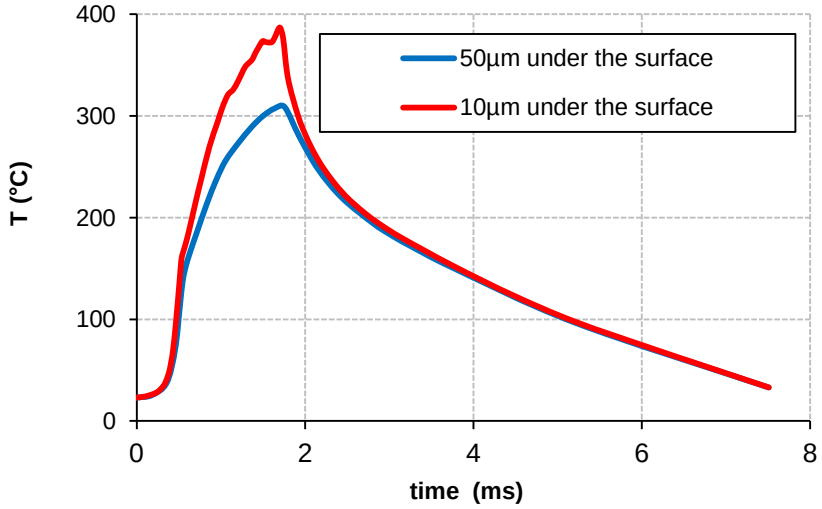
$$\sigma_{eq} = \left(A + B\,\varepsilon_p^{\,n}\right)\left[1 + C\ln\left(\frac{\dot{\varepsilon}_p}{\dot{\varepsilon}_p^{0}}\right)\right]\left[1 - \left(\frac{T - T_o}{T_m - T_o}\right)^m\right]$$

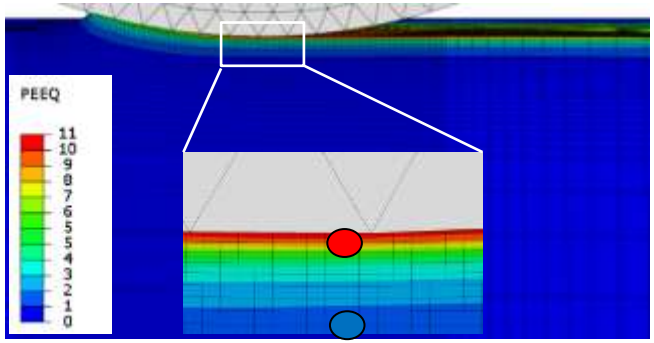


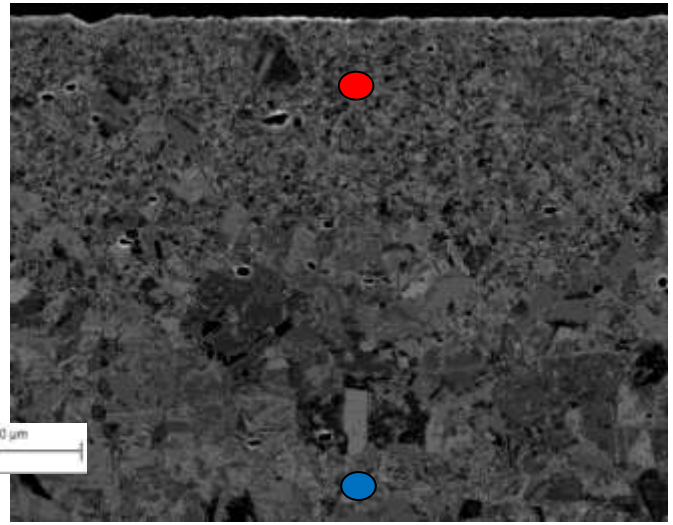
Finite element results

- *Relation with strain and temperature histories ?*

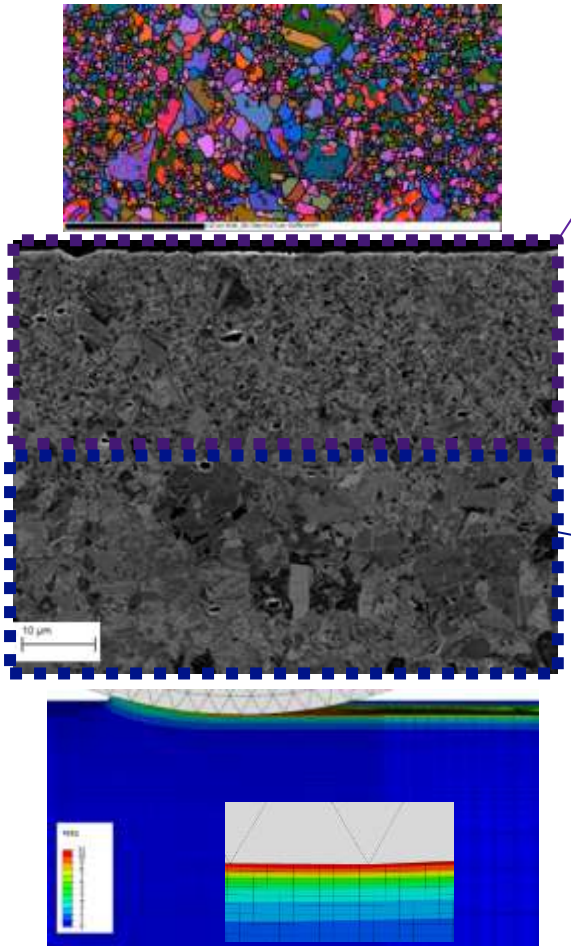








Discussion (V = 250 m/min)

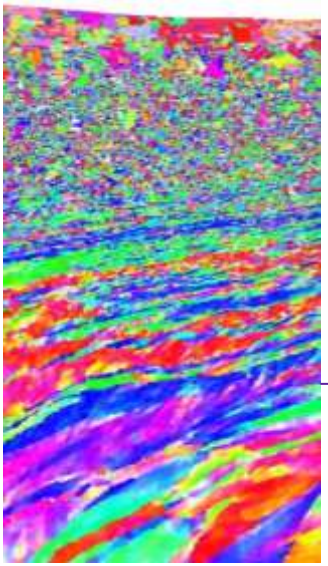


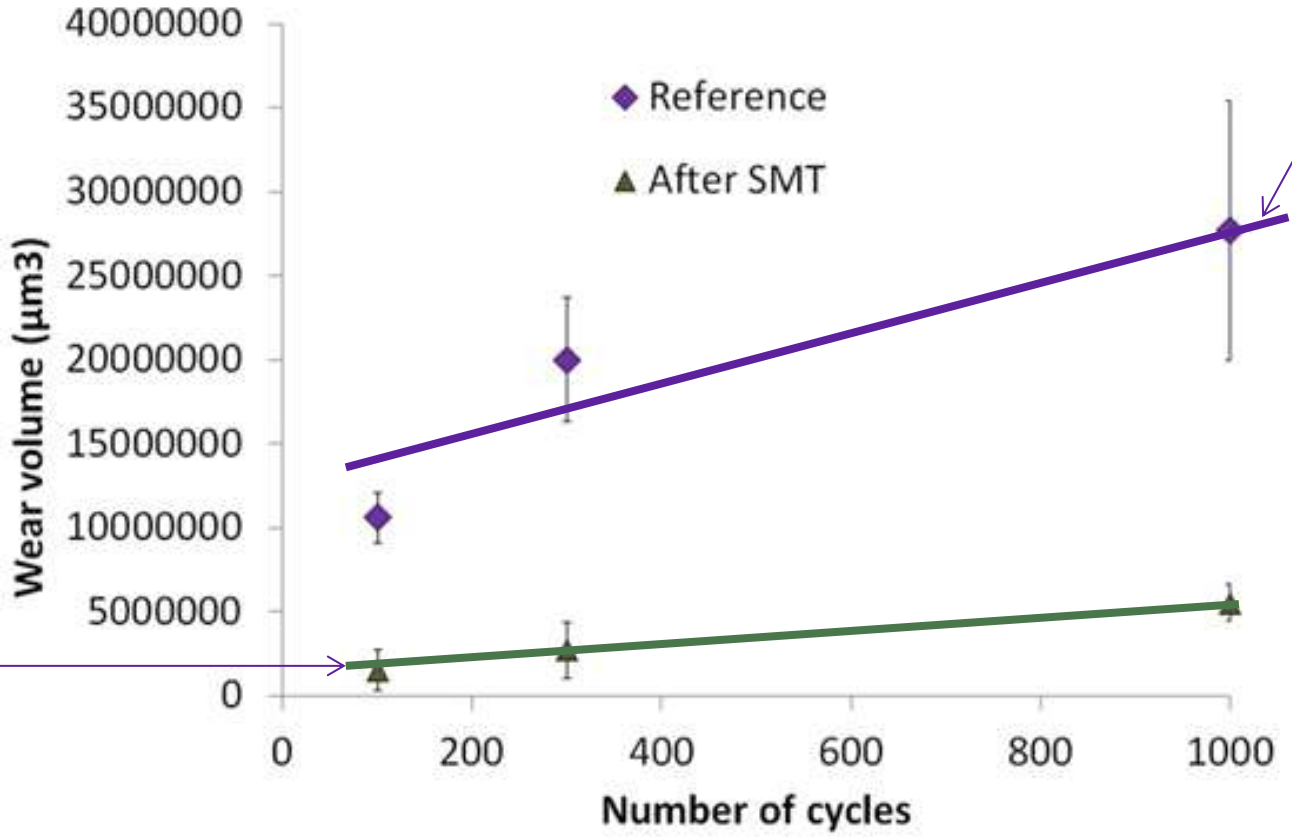
- ***nm grain size zone*** *: Severe plastic deformation (up to 10) at medium-hot temperature (400° C)*
  - *Interpretation : Grain fragmentation by SPD + DDRX + post dynamic RX*

- ***µm grain size zone*** *: medium plastic deformation (up to 2 or less) at medium-hot temperature*
  - *Interpretation : DDRX but unreached stationary regime + post dynamic RX*

Wear resistance of surface with in-depth gradient of mechanical properties

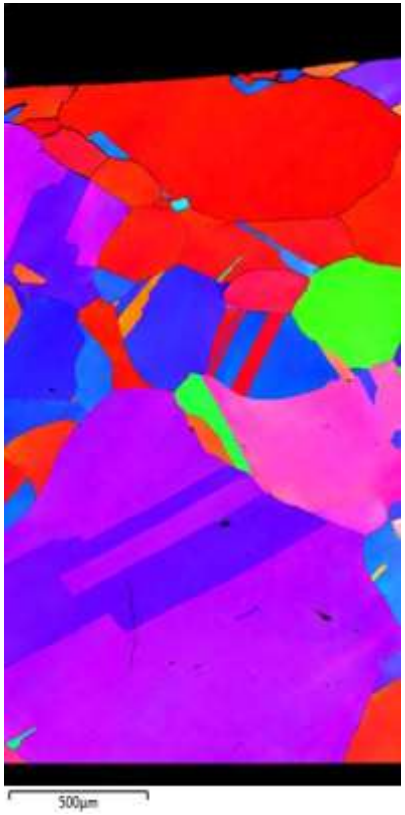
- *Tribological testing*



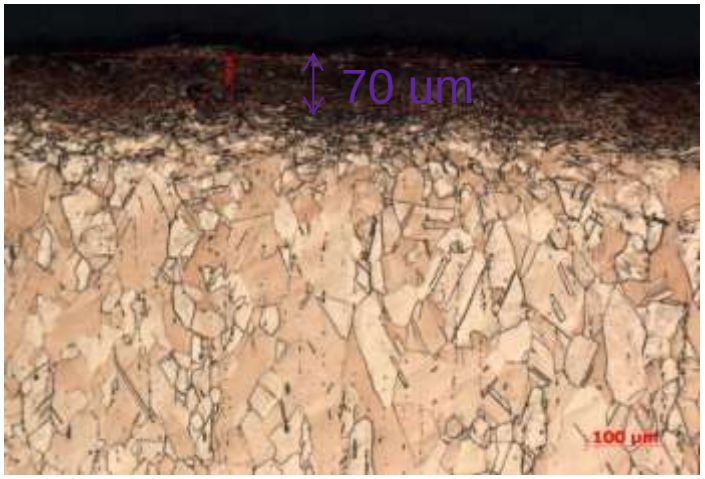


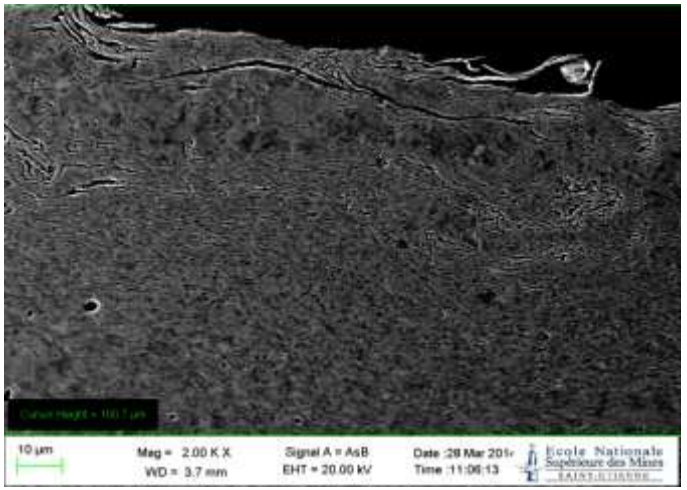
Toward a new kind of surface mechanical treatments
Impact-based SMT vs Scratch-based SMT ?

- **Repeated impact (intensive shot peening)**

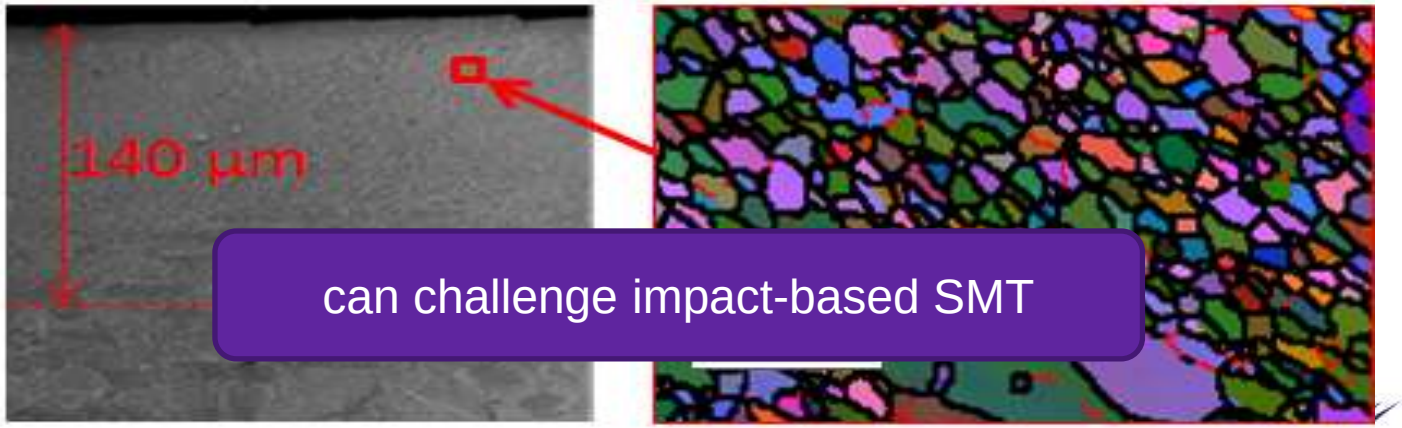


Initial microstructure





- **Repeated sliding**



can challenge impact-based SMT

Conclusions

About mechanical consequences of SMT

- Significant decrease of the grain size in the near surface by severe plastic deformation,
- Increase of the surface hardness of a pure iron evidenced by nanoindentation and micro-compression of FIBed pillars

Enhancement of thermomechanical treatments?

- Diffusion-precipitation simulation taking into account the grain size gradient and the grain shape
- Experimental validation
- First results on a pure iron are promising

Scratch-based Surface Mechanical Treatments

- can produce surface nanocrystallisation depending loading conditions
- can challenge impact-based SMT
- are promising for industrial applications

MINES Saint-Étienne

Merci pour votre attention

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