



Essais in situ en Microscopie Electronique à Balayage.

Intérêts et limitations

E. Héripré⁺, J. Crépin,

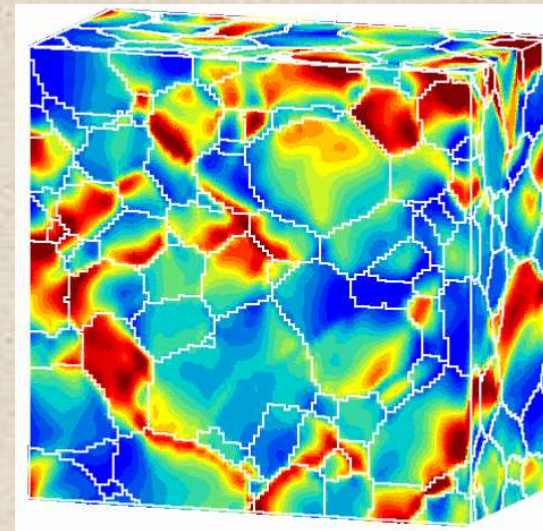
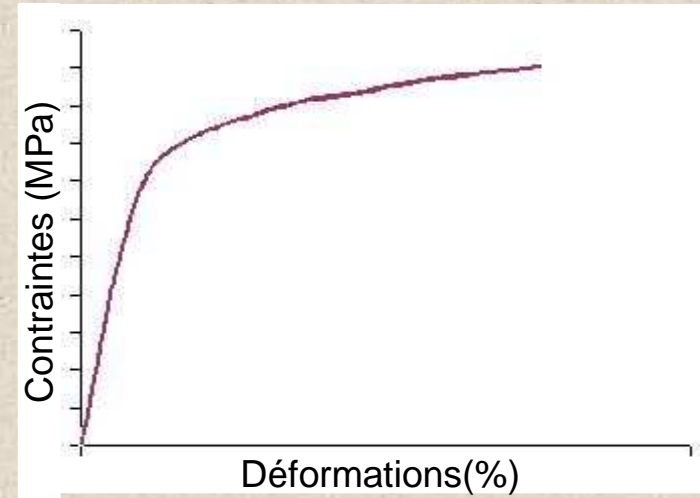
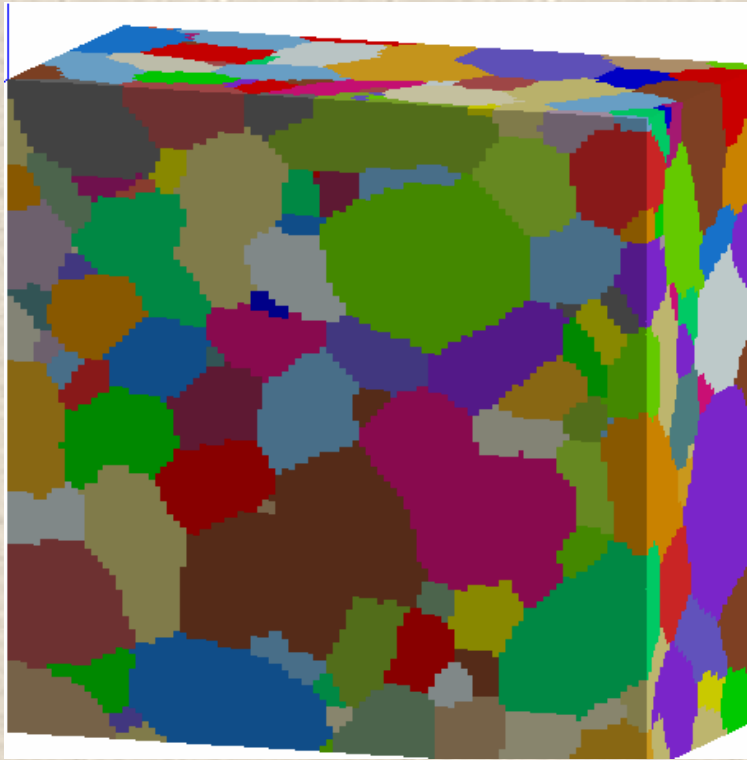
LMS,UMR 7649,

Département de Mécanique, Ecole Polytechnique,

Palaiseau, France

⁺ Centre des Matériaux,
Ecole Nationale Supérieure des Mines de Paris.

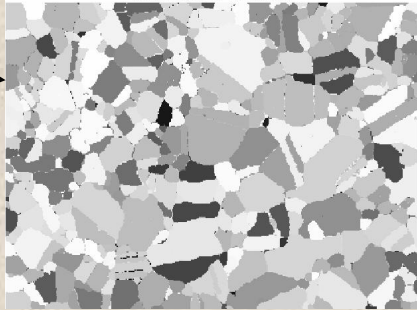
Introduction



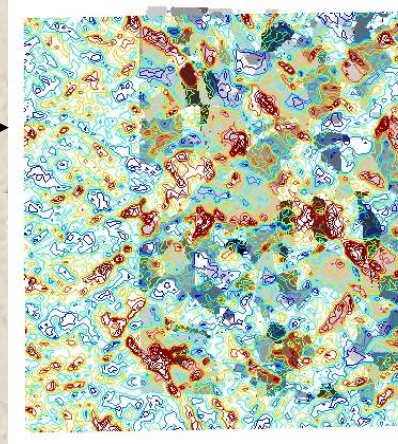
Amélioration des lois de comportement à base physique
Optimisation des coefficients

Démarche adoptée

✓ Caractérisation microstructurale

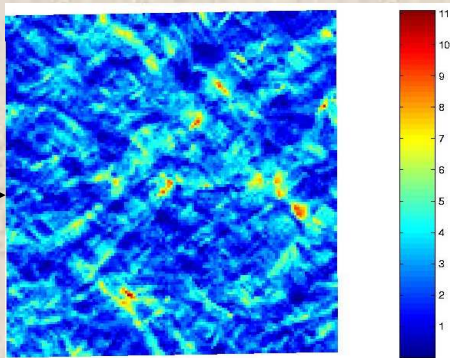


✓ Superposition
Microstructure / champs
de déformation



✓ Identification/
Optimisation/ Validation

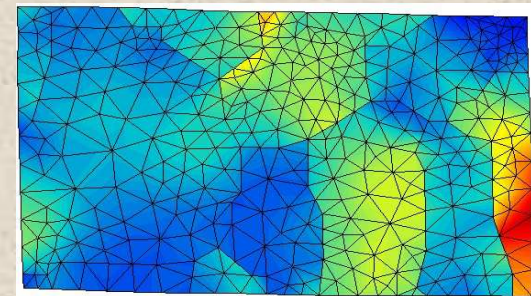
Essai mécanique



✓ Mesure de champs par
Microextensométrie

Conditions
aux limites

✓ modèles multi-échelles
(analytique/ numérique)



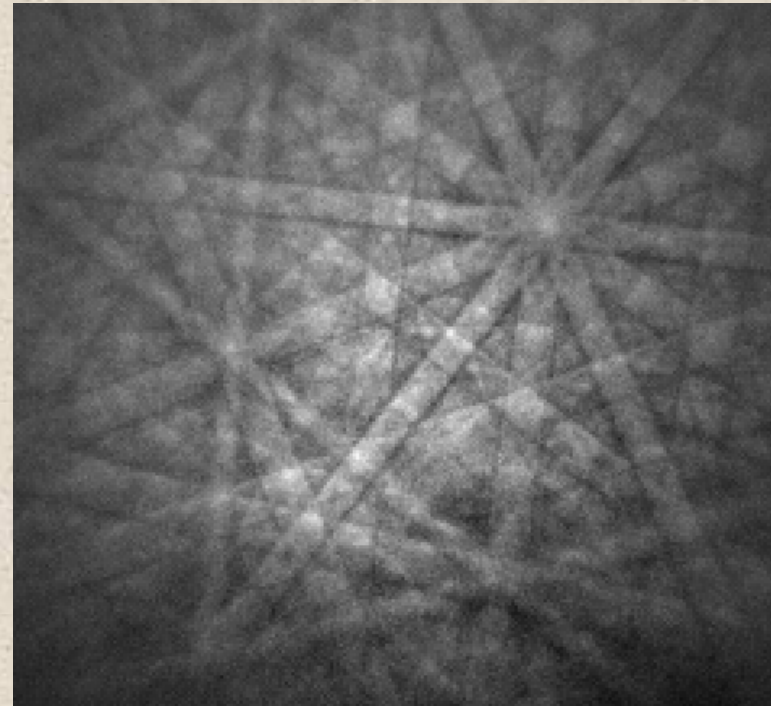
Caractérisation microstructurale

Taille de grain ?

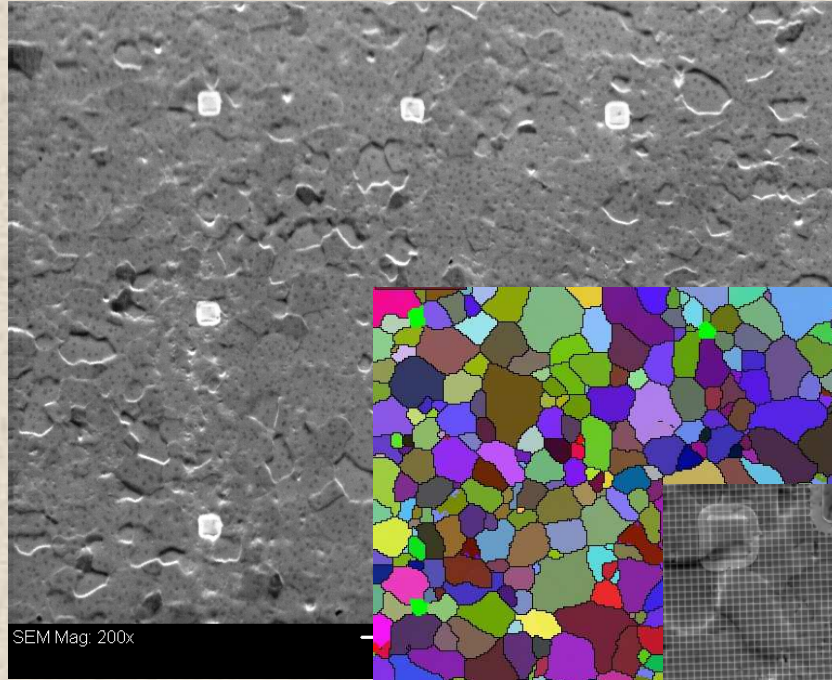
Texture ?

Distribution de phase?

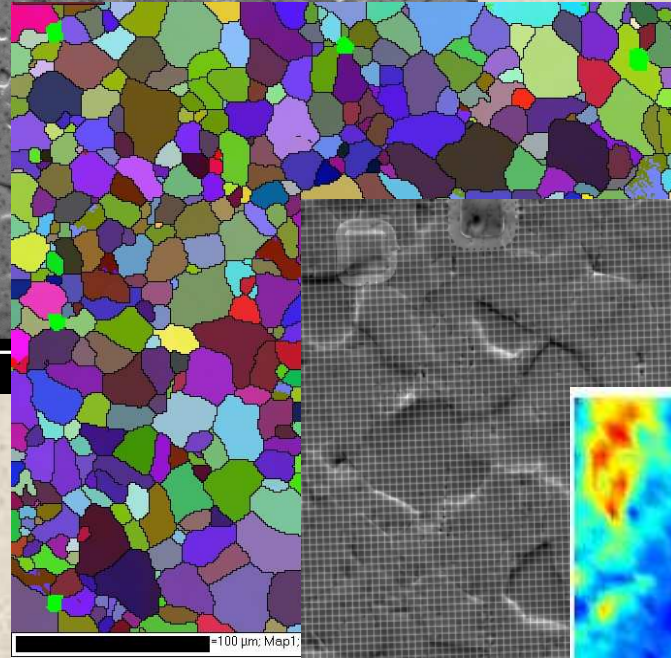
Kikuchi pattern



Analyses de champs locaux
(EBSD) (pas 1 μ m)



SEM Mag: 200x



100 μm; Map1

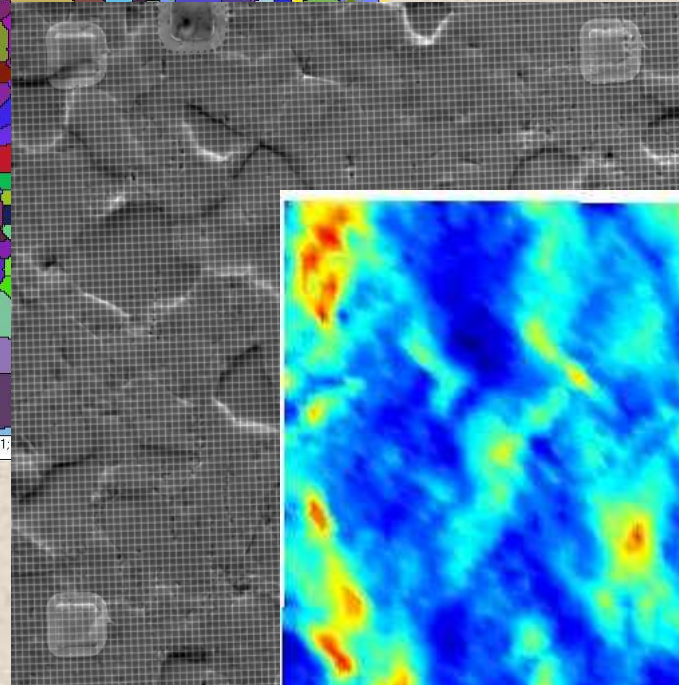
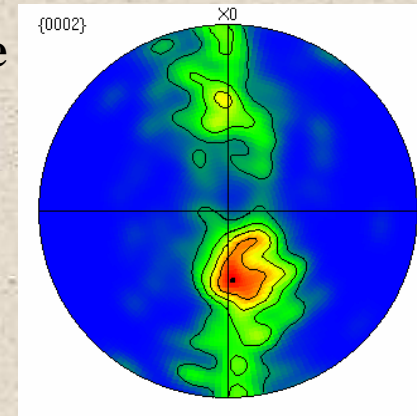
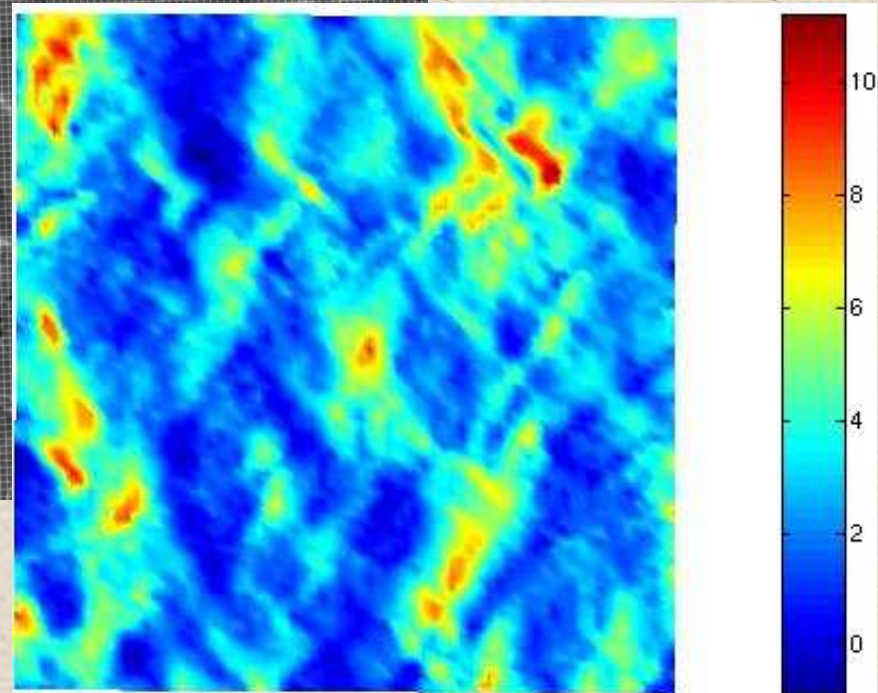


Figure de pôle
{0002}

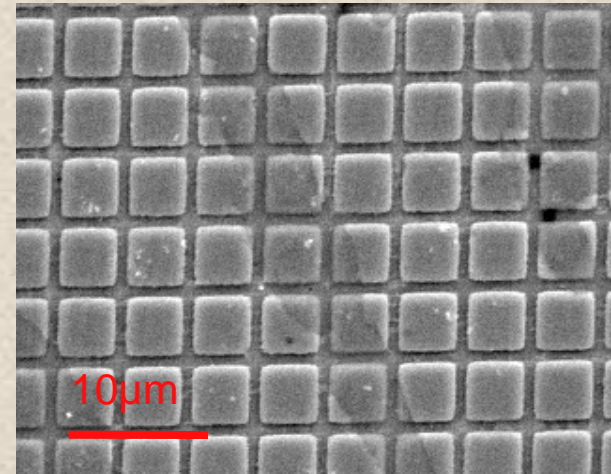
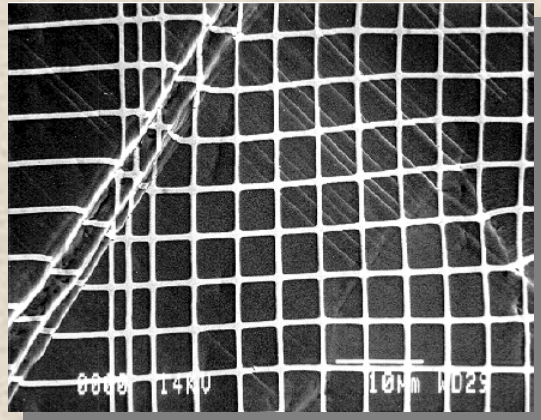


Champ de déf.
expérimental (\square_{11})

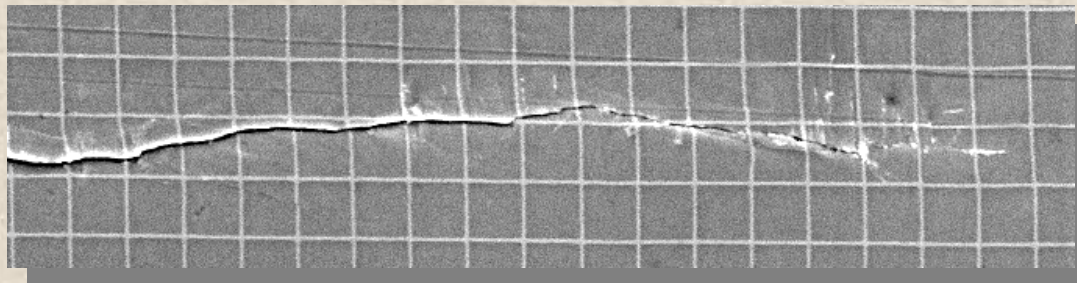


Orientation Imaging
Microscopy (X - Y - \square_1 - \square_2)

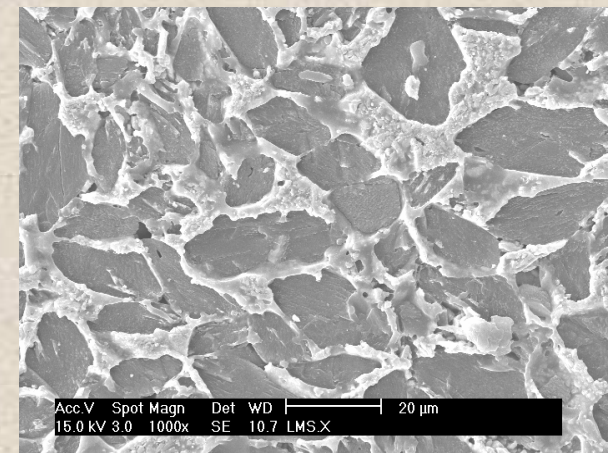
Contraste pour la corrélation d'images



- **Microgrilles (attaque chimique)**



- **Microgrilles (dépôt)**

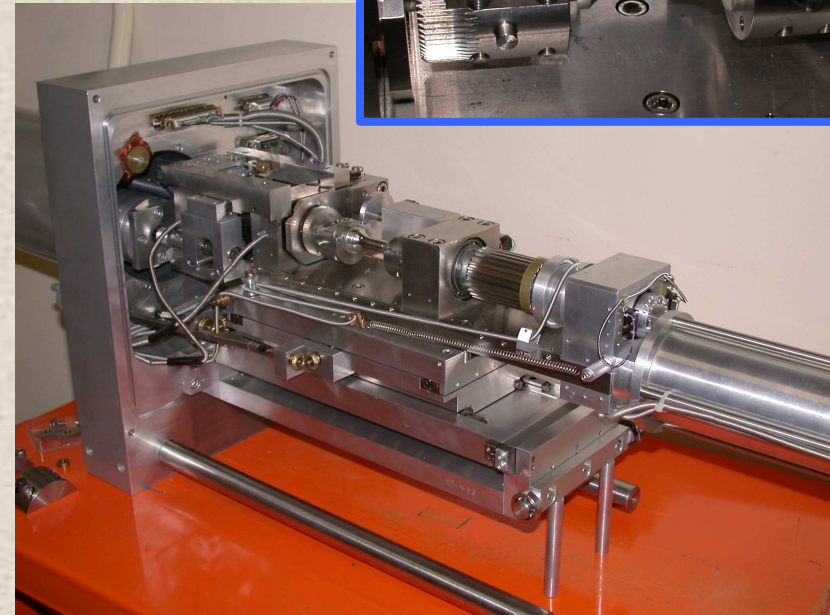
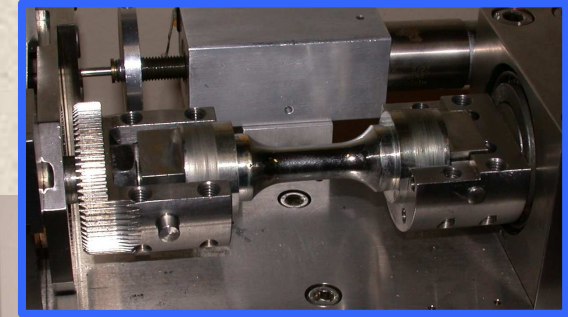
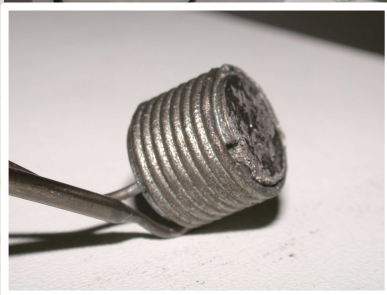
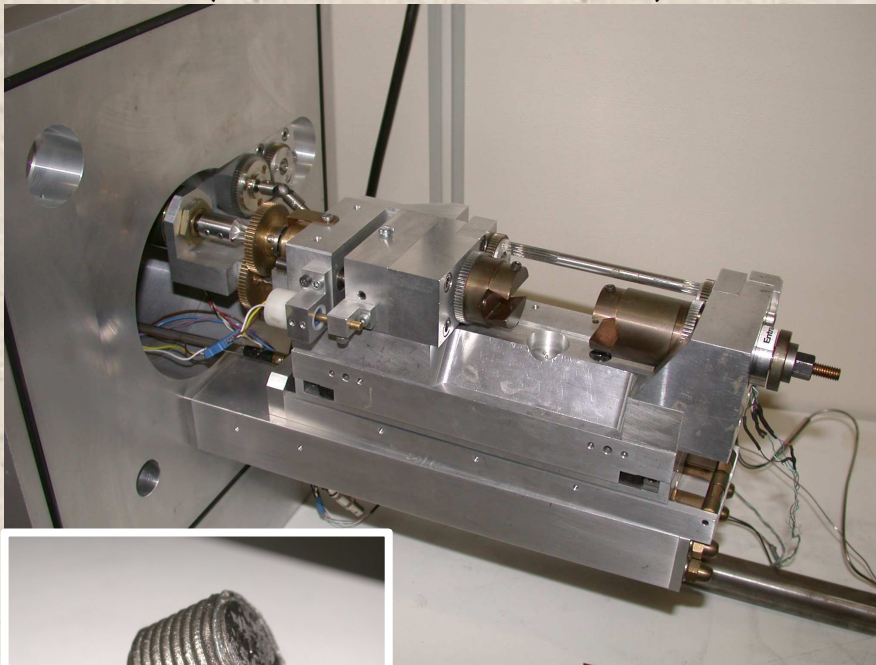


- **Naturel**

Solliciter et observer

- **Sous MEB : machines « *in situ* »**

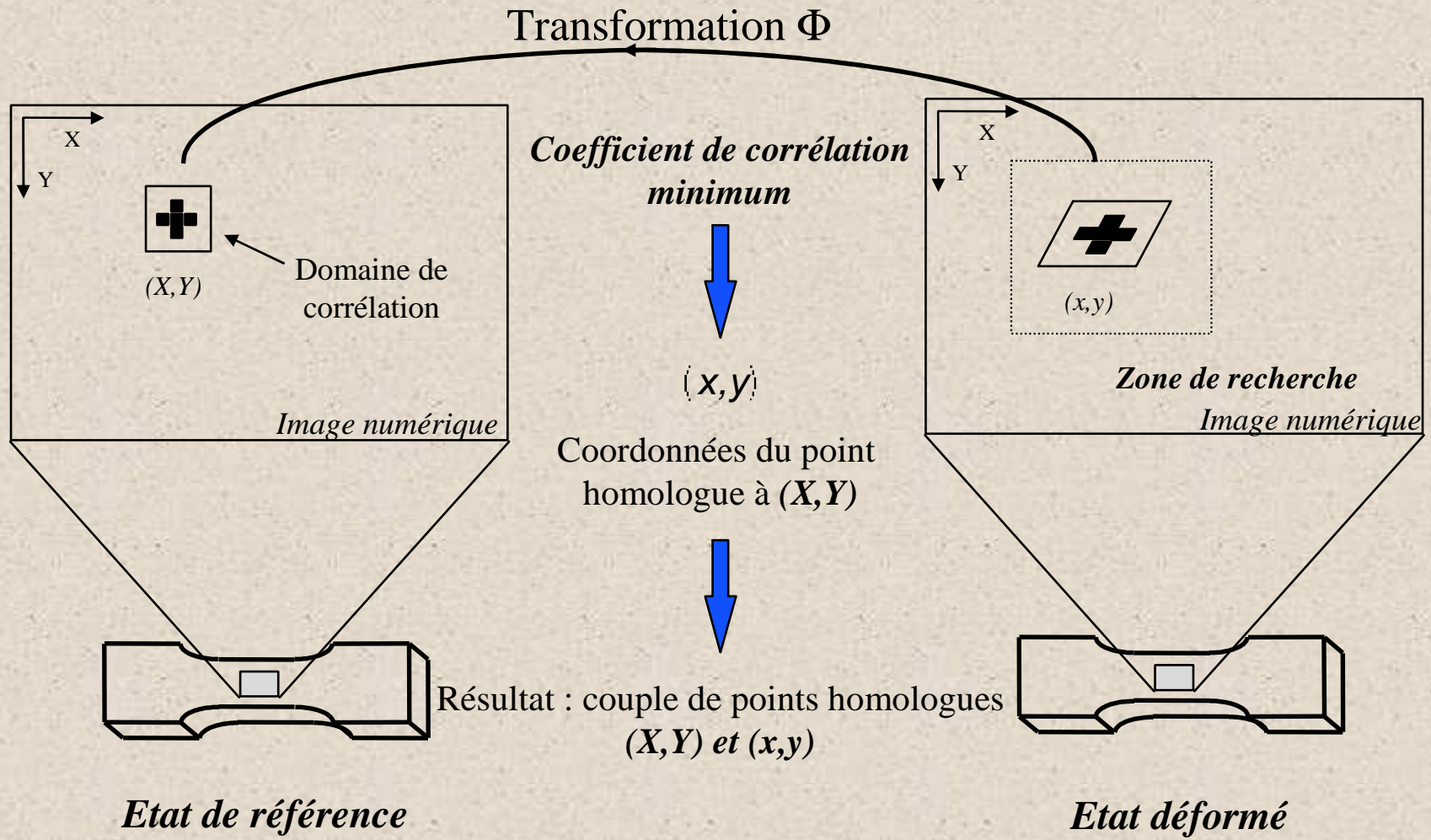
traction ou compression ou flexion
(**Raith**, 5kN, 500°C)



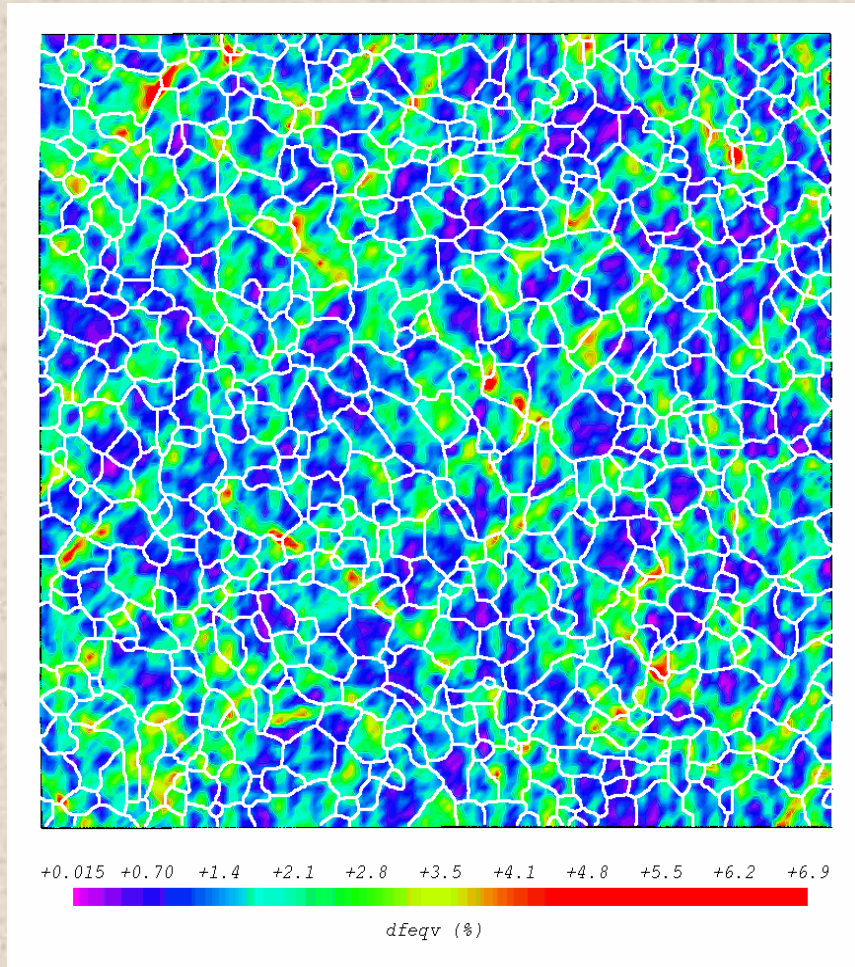
traction/compression/torsion
cyclique
(**Raith**, 10kN, 50Nm, 1Hz)

+ **Essai mécanique sous MO** (sous atmosphère)

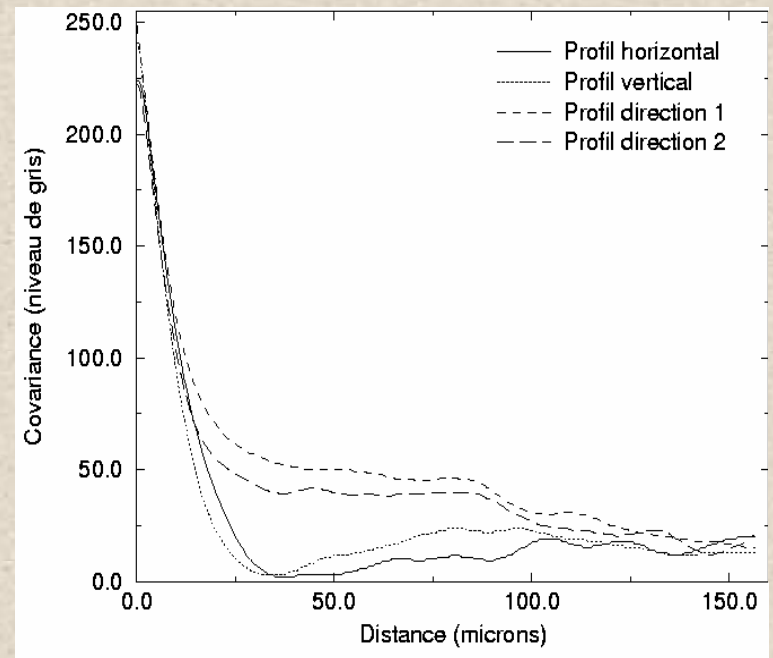
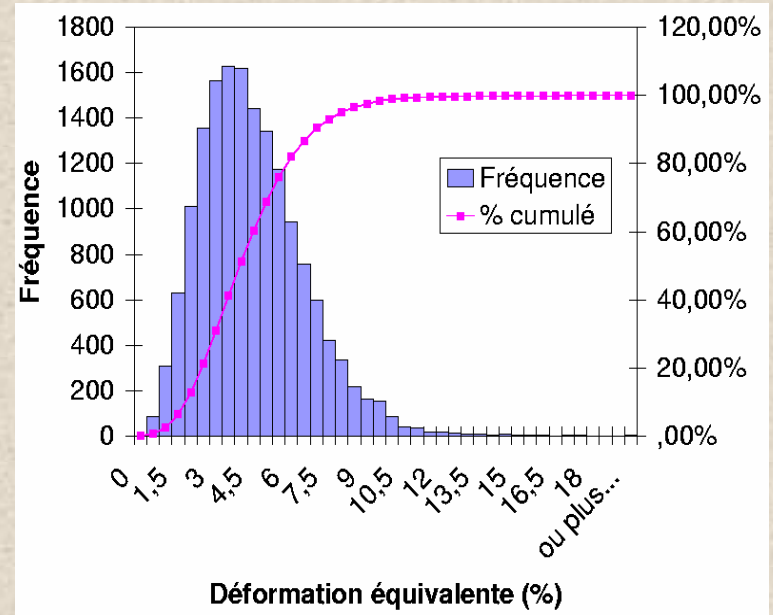
Principe de la technique de corrélation



Analyse statistique sur un VER



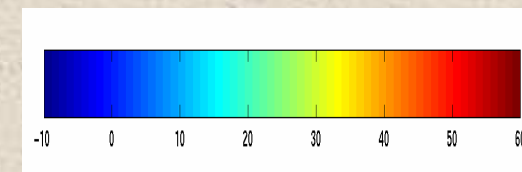
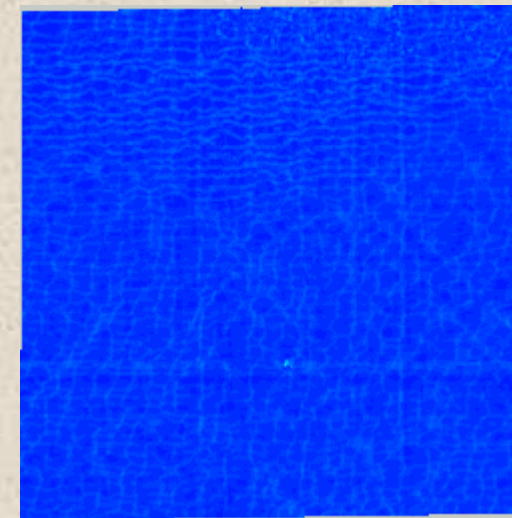
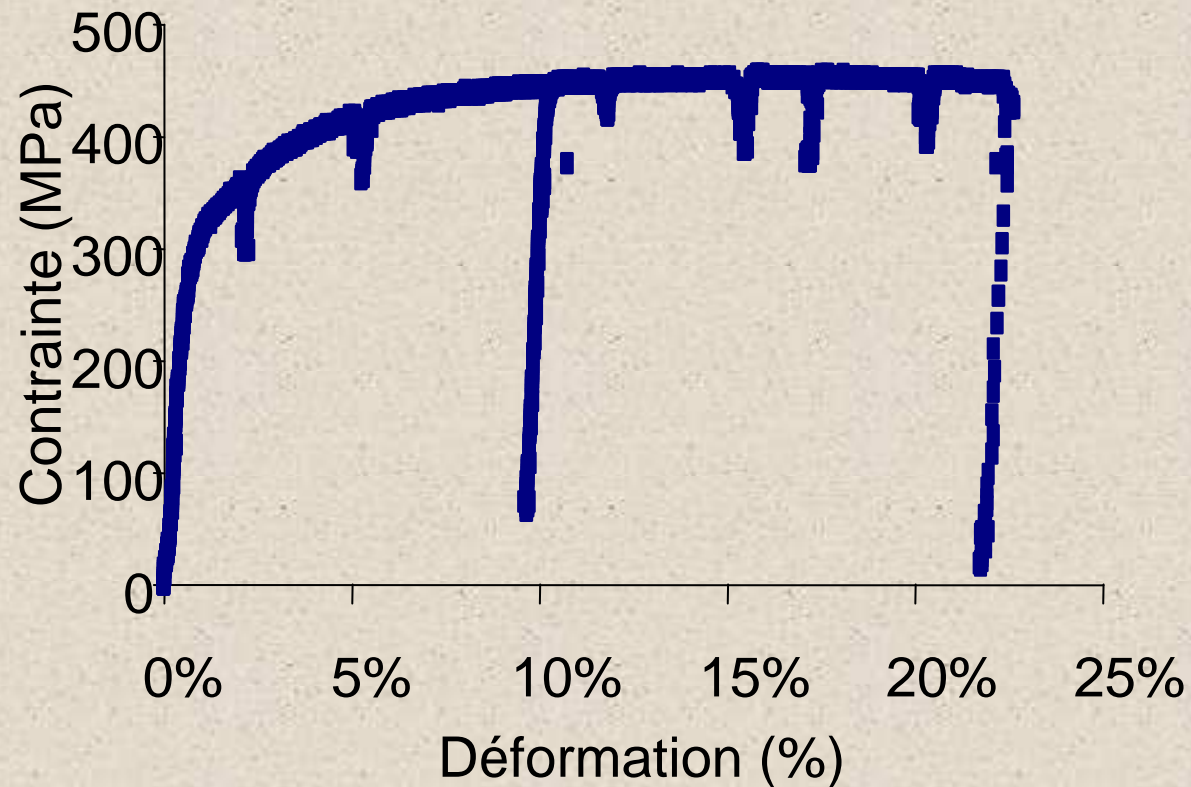
Localisation en bandes dans le Zr



Evolution de l'hétérogénéité des déformations au cours du chargement

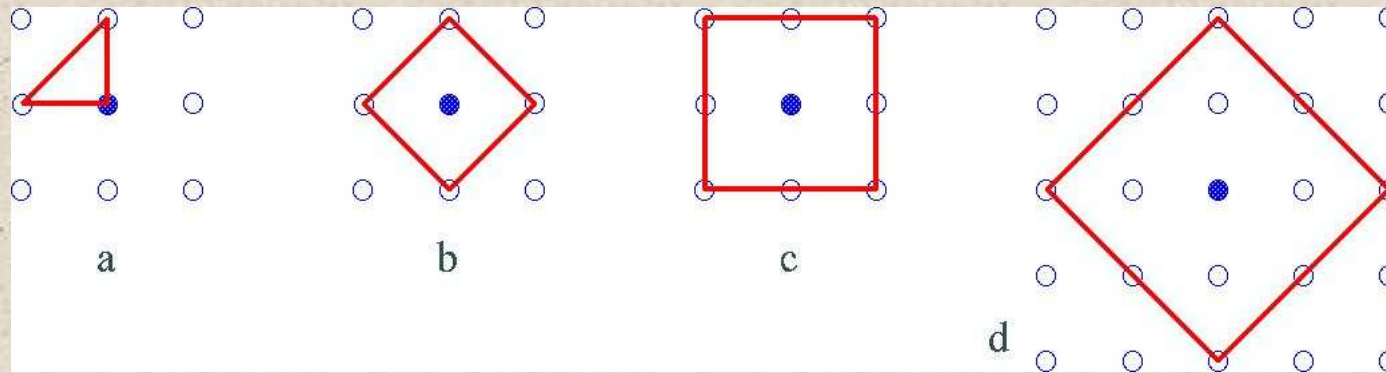
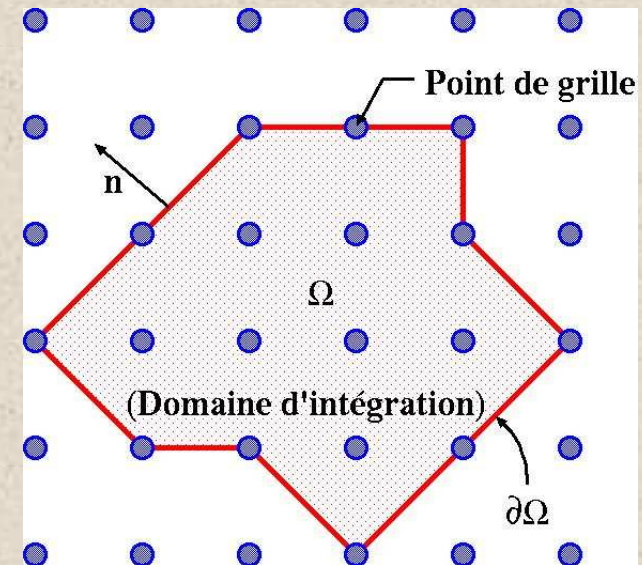
K. Elbachiri

Essai de compression in-situ sur M5[®] à 20°C, direction de laminage



Calcul des déformations

- Fonction d'interpolation d'éléments finis
- Intégrales de contour



• **Précision :** $De = \frac{Du}{l}$

$Du = 0,01$ pixel (optique, optimal)

0,1 à 1 pixel (MEB, \pm bruité)

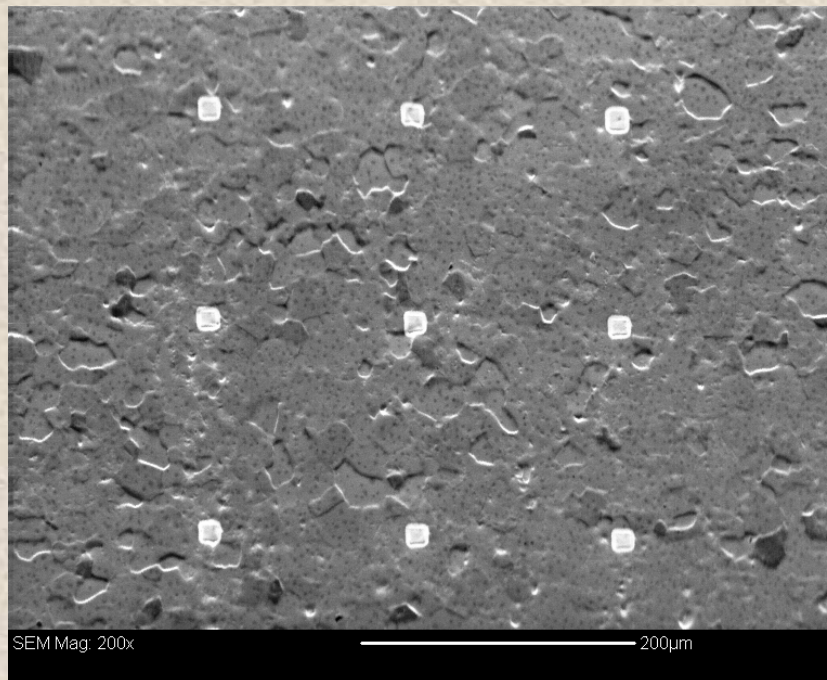
+ défauts géométriques des images...

Effet de la base de mesure ?

Zr 702

Champ de déformation : $800 \times 800 \mu\text{m}^2$

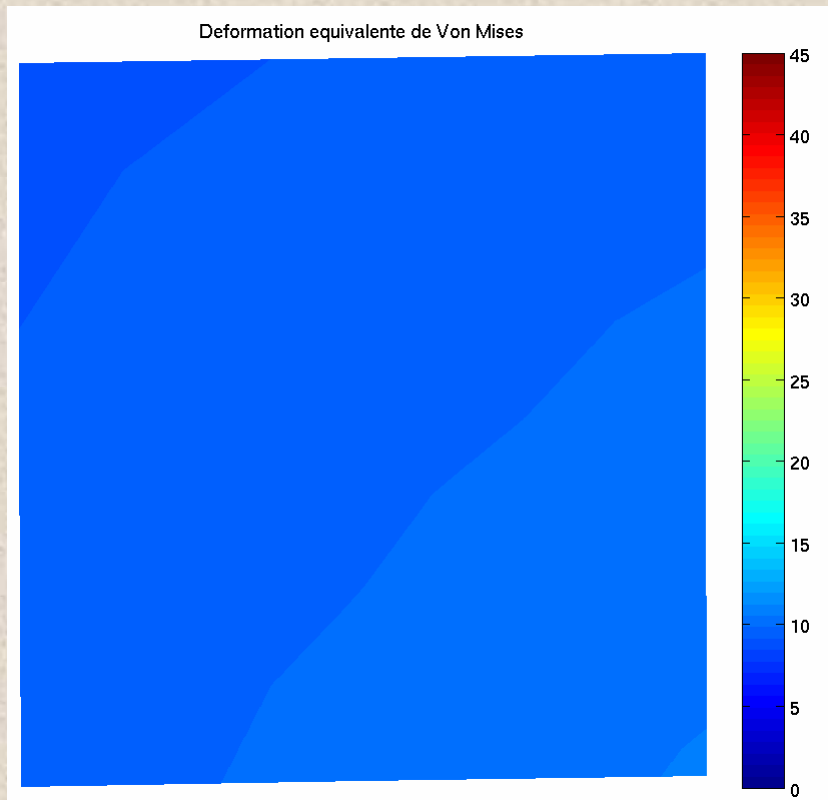
Variation de la base de mesure de $4 \mu\text{m}$ à $300 \mu\text{m}$



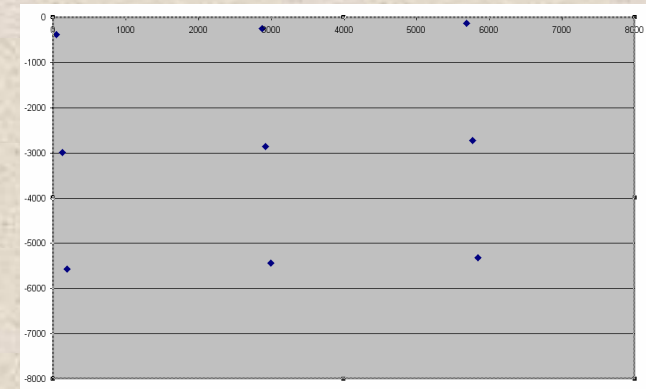
Effet de la base de mesure ?

Champ de déformation : $800 \times 800 \mu\text{m}^2$

Variation de la base de mesure de $4 \mu\text{m}$ à $300 \mu\text{m}$



Zr 702

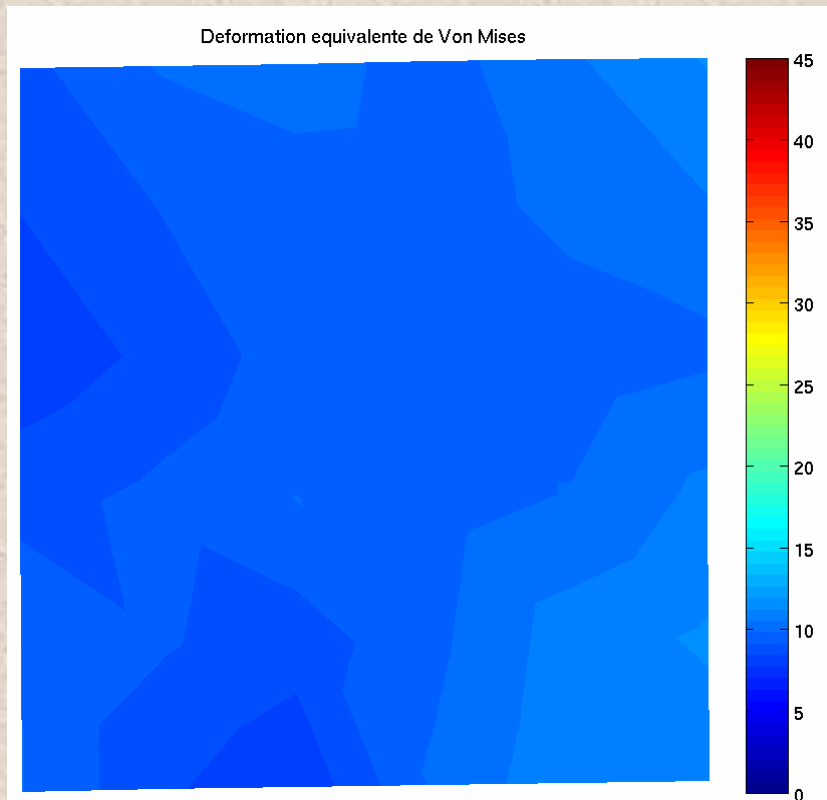


$300 \mu\text{m}$

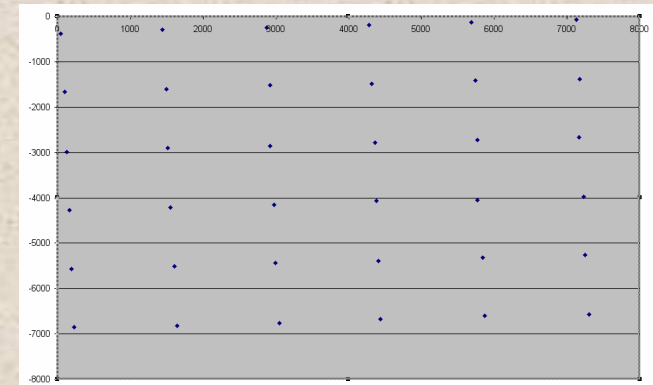
Effet de la base de mesure ?

Champ de déformation : $800 \times 800 \mu\text{m}^2$

Variation de la base de mesure de $4 \mu\text{m}$ à $300 \mu\text{m}$



Zr 702



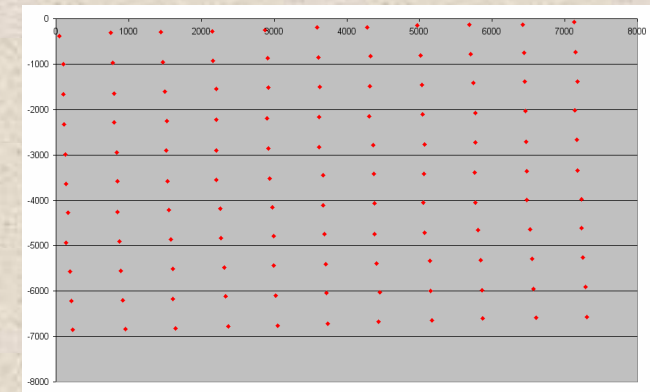
$150 \mu\text{m}$

Effet de la base de mesure ?

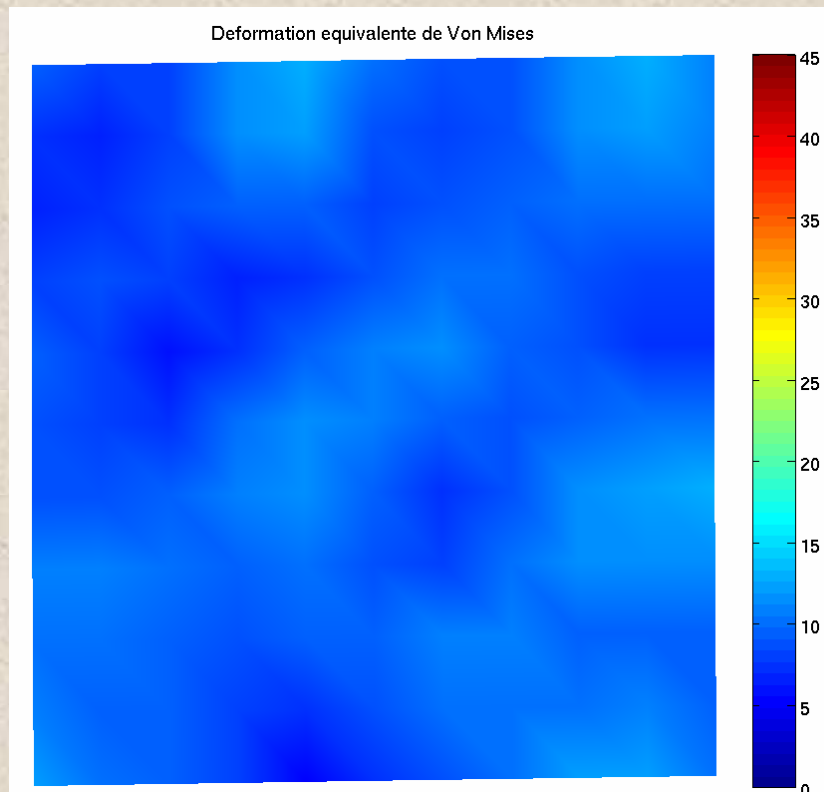
Champ de déformation : $800 \times 800 \mu\text{m}^2$

Variation de la base de mesure de $4 \mu\text{m}$ à $300 \mu\text{m}$

Zr 702



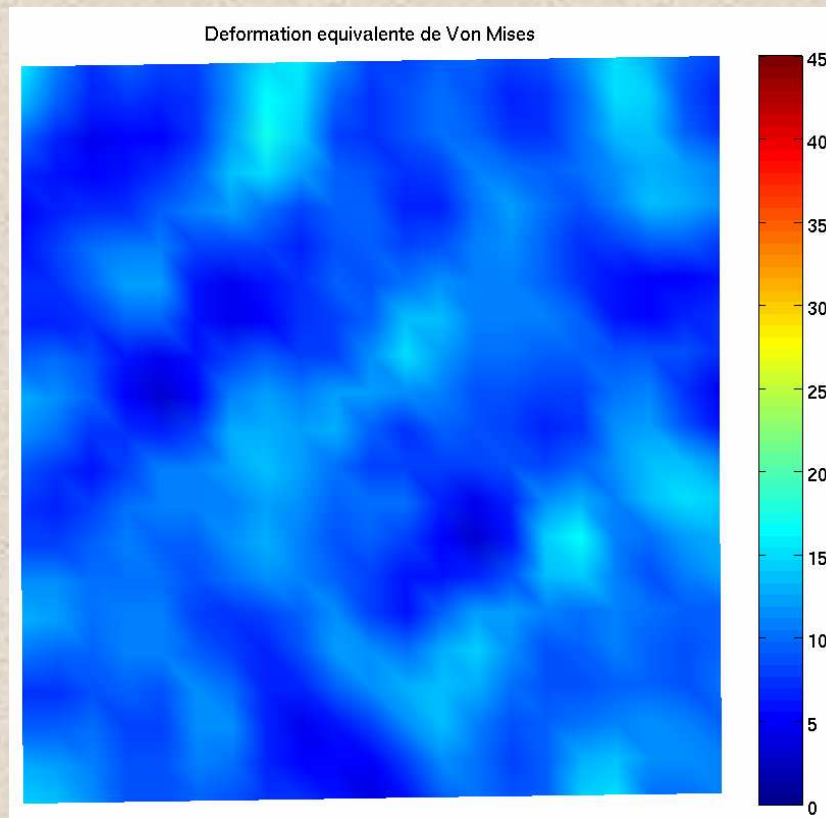
$75 \mu\text{m}$



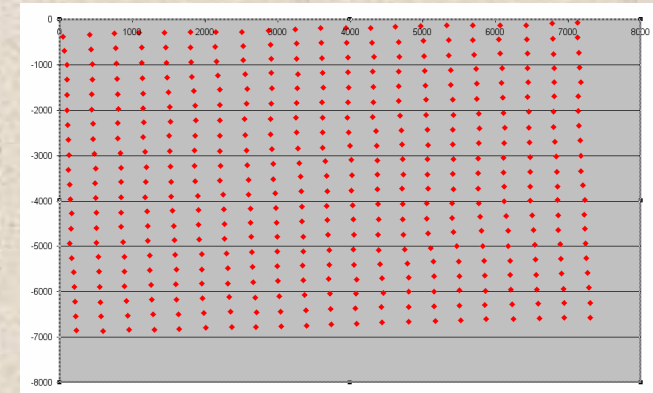
Effet de la base de mesure ?

Champ de déformation : $800 \times 800 \mu\text{m}^2$

Variation de la base de mesure de $4 \mu\text{m}$ à $300 \mu\text{m}$



Zr 702



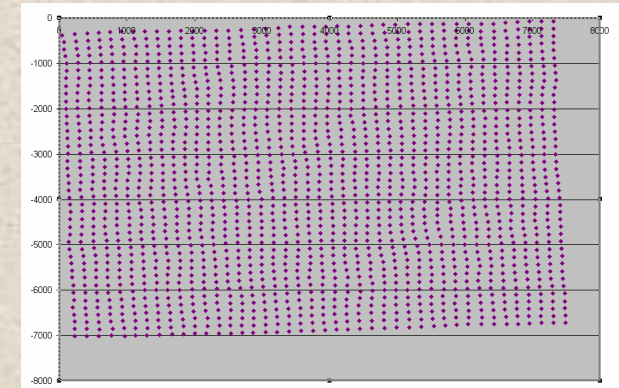
$37 \mu\text{m}$

Effet de la base de mesure ?

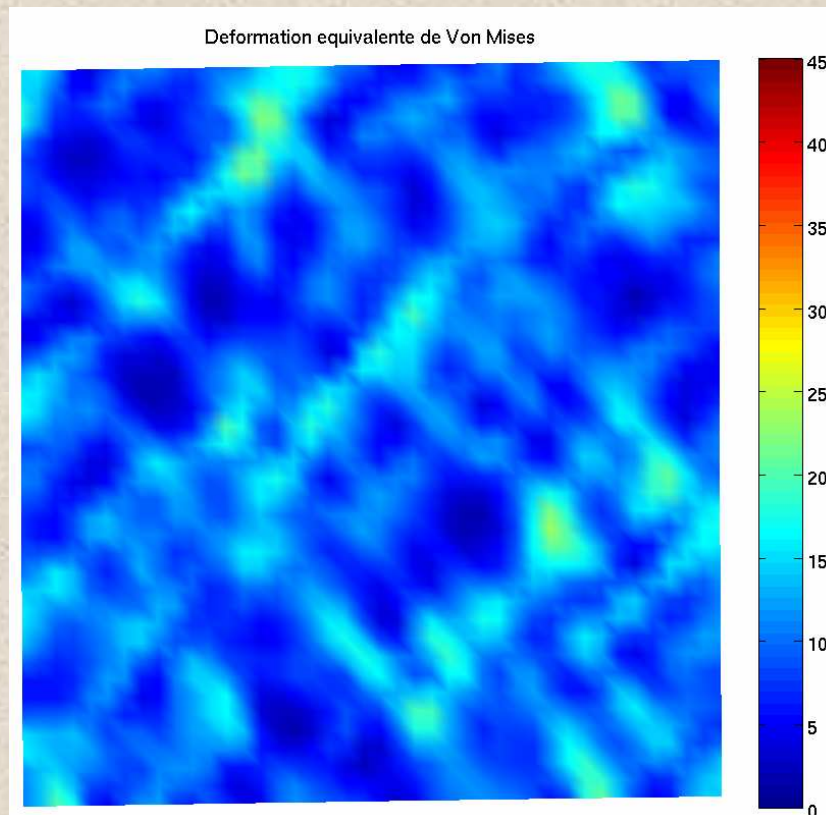
Champ de déformation : $800 \times 800 \mu\text{m}^2$

Variation de la base de mesure de $4 \mu\text{m}$ à $300 \mu\text{m}$

Zr 702



$18 \mu\text{m}$

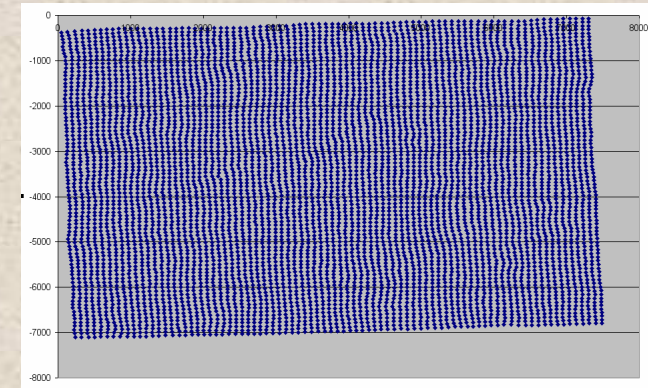


Effet de la base de mesure ?

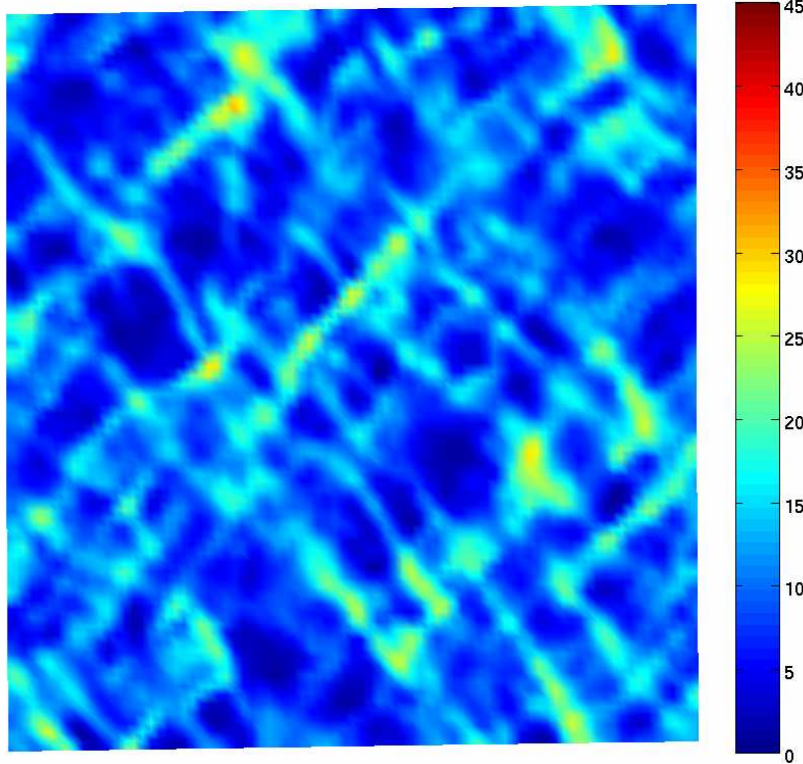
Champ de déformation : $800 \times 800 \mu\text{m}^2$

Variation de la base de mesure de $4 \mu\text{m}$ à $300 \mu\text{m}$

Zr 702



Deformation equivalente de Von Mises



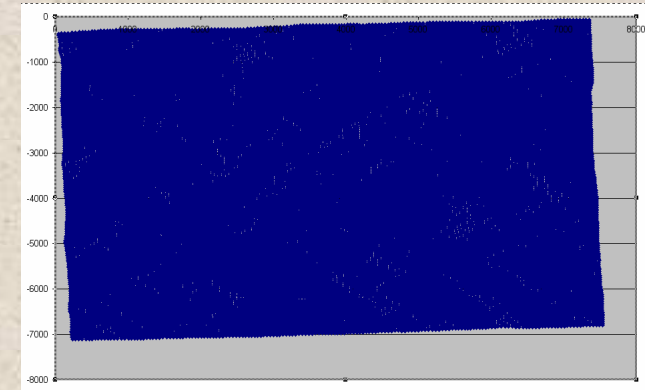
$9 \mu\text{m}$

Effet de la base de mesure ?

Champ de déformation : $800 \times 800 \mu\text{m}^2$

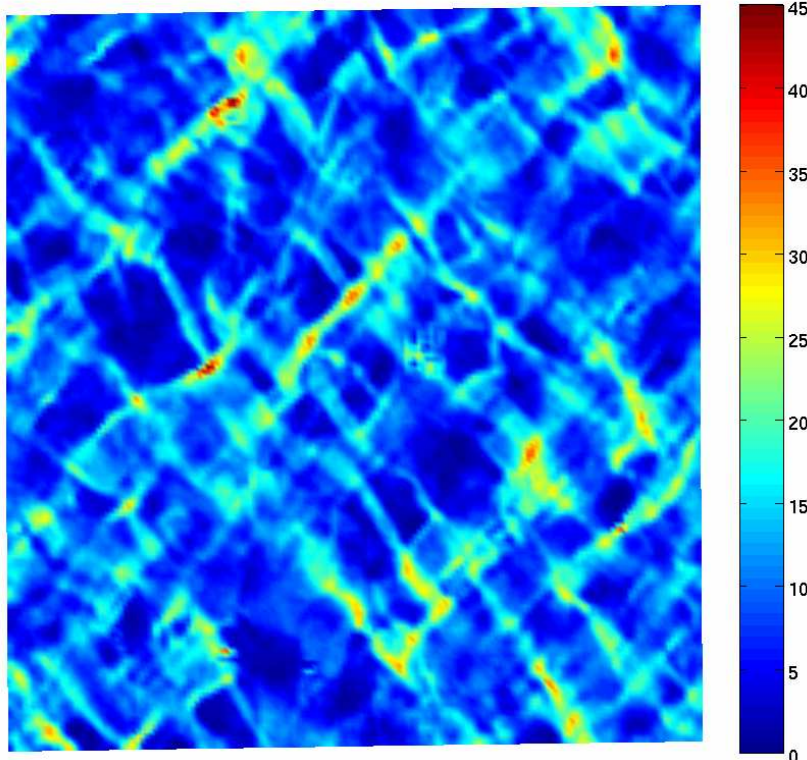
Variation de la base de mesure de $4 \mu\text{m}$ à $300 \mu\text{m}$

Zr 702



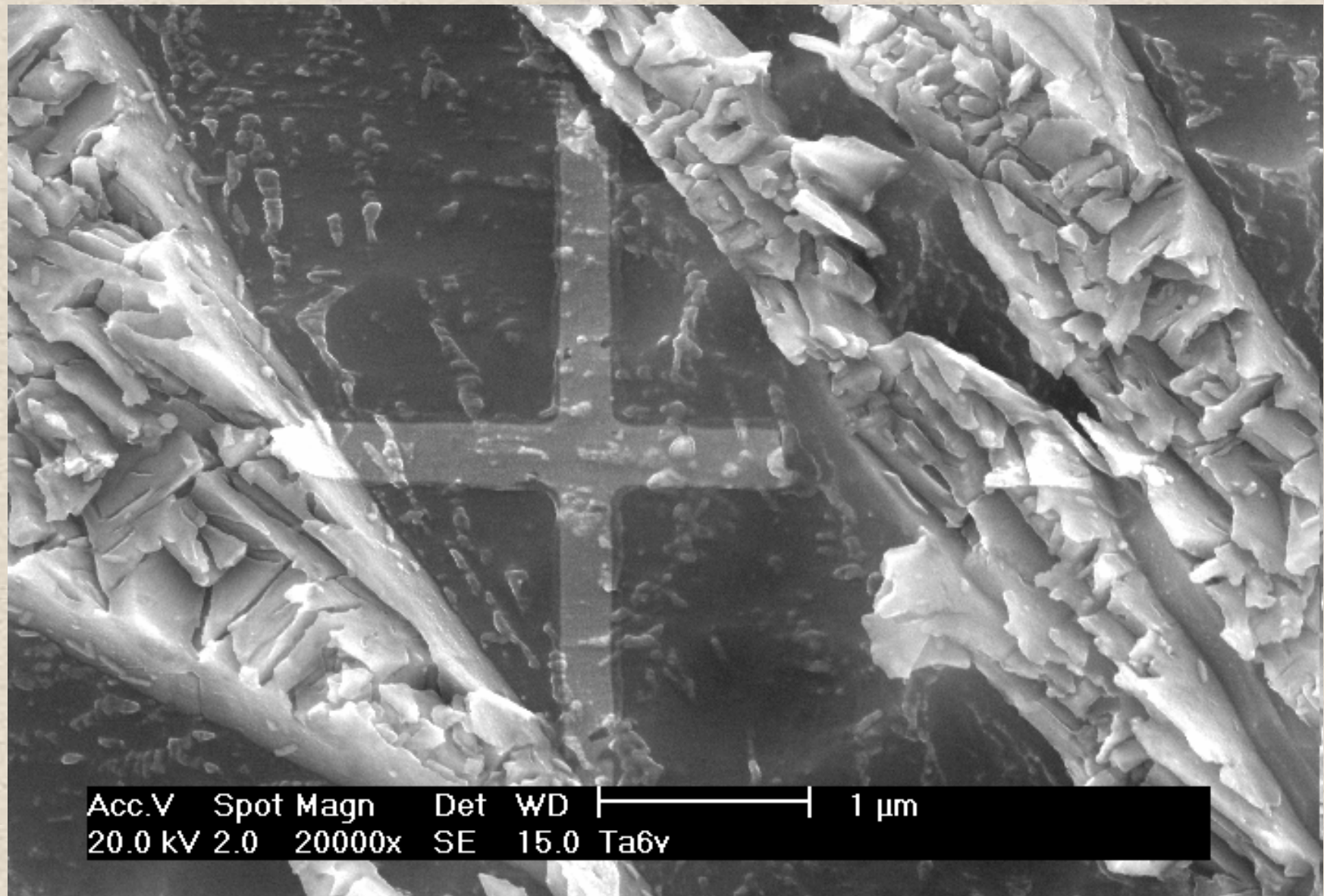
4 μm

Deformation equivalente de Von Mises



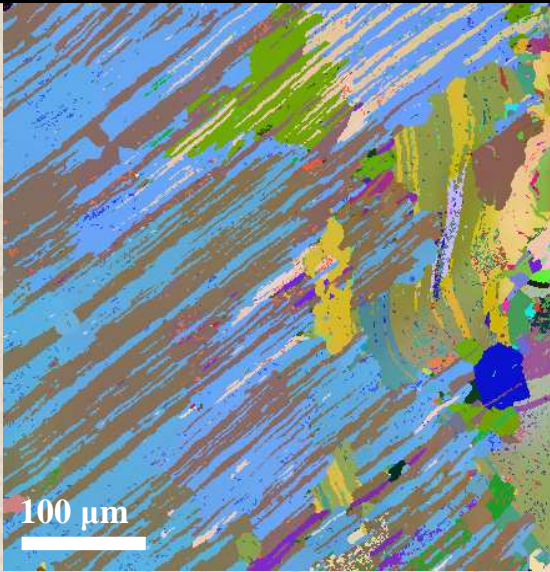
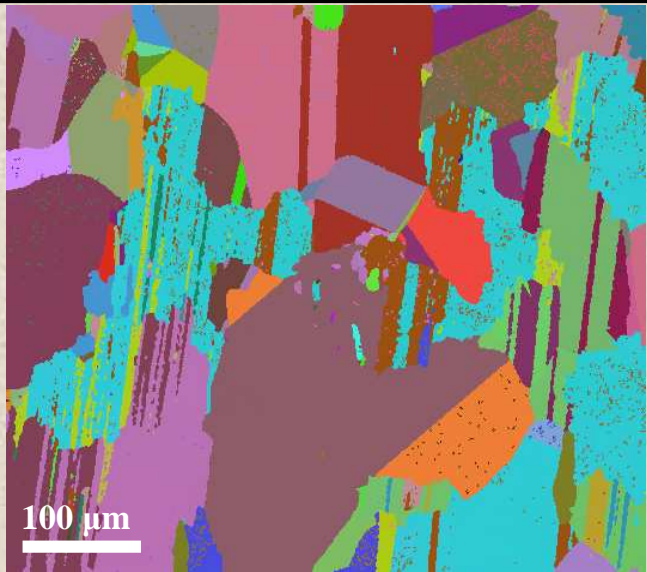
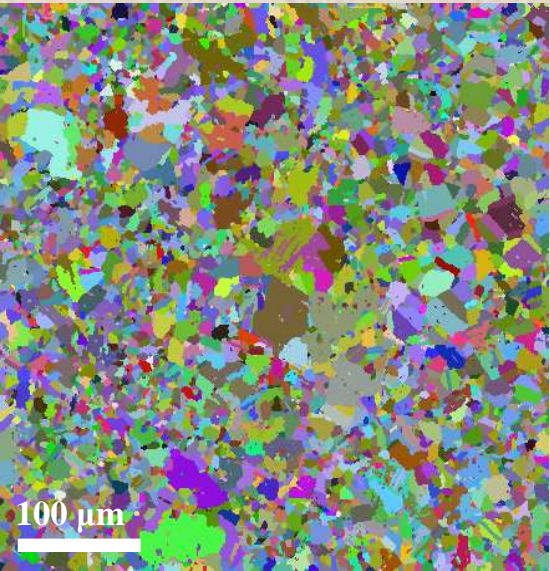
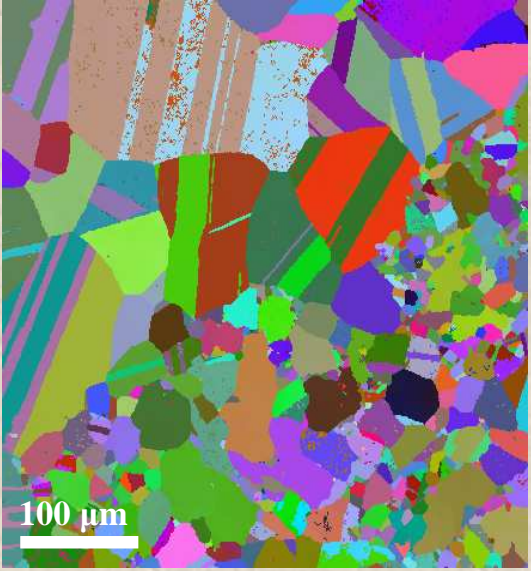
Images FEG MSSMAT, ECP (alliage biphasé de Ti)

F. Mignot, (thèse E.P. 2003)



Exemple : les alliages TiAl

Matériau fourni par DMMP / ONERA)

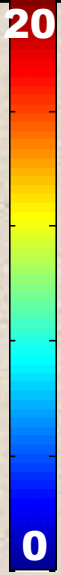
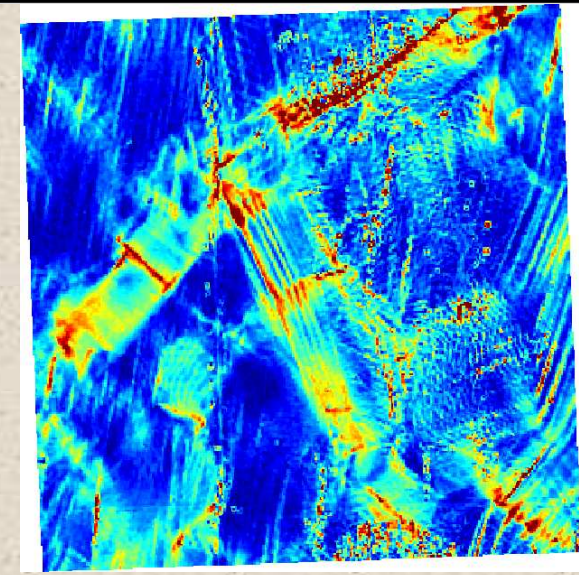
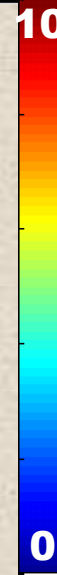
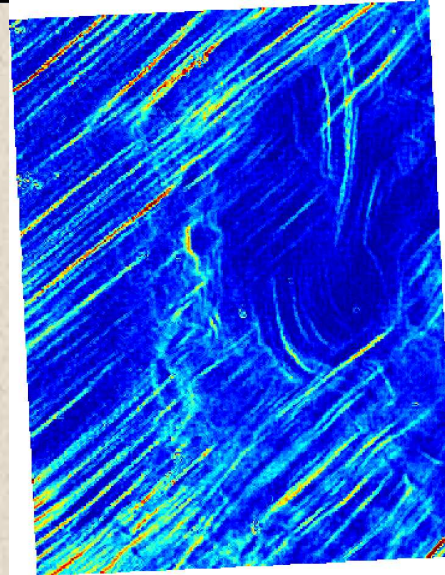
	Ti-47Al-2Cr-2Nb	Ti-48Al-2Cr-2Nb
Fonderie		
Métallurgie des Poudres		

Mesures de champs

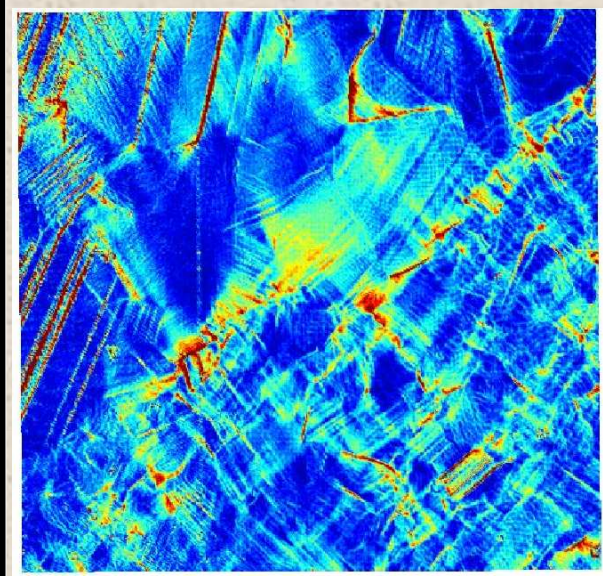
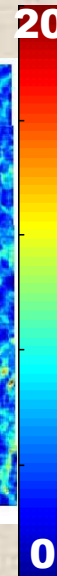
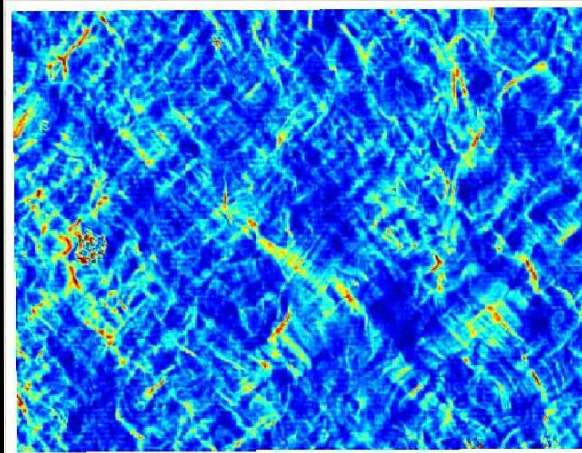
Ti-**47Al**-2Cr-2Nb

Ti-**48Al**-2Cr-2Nb

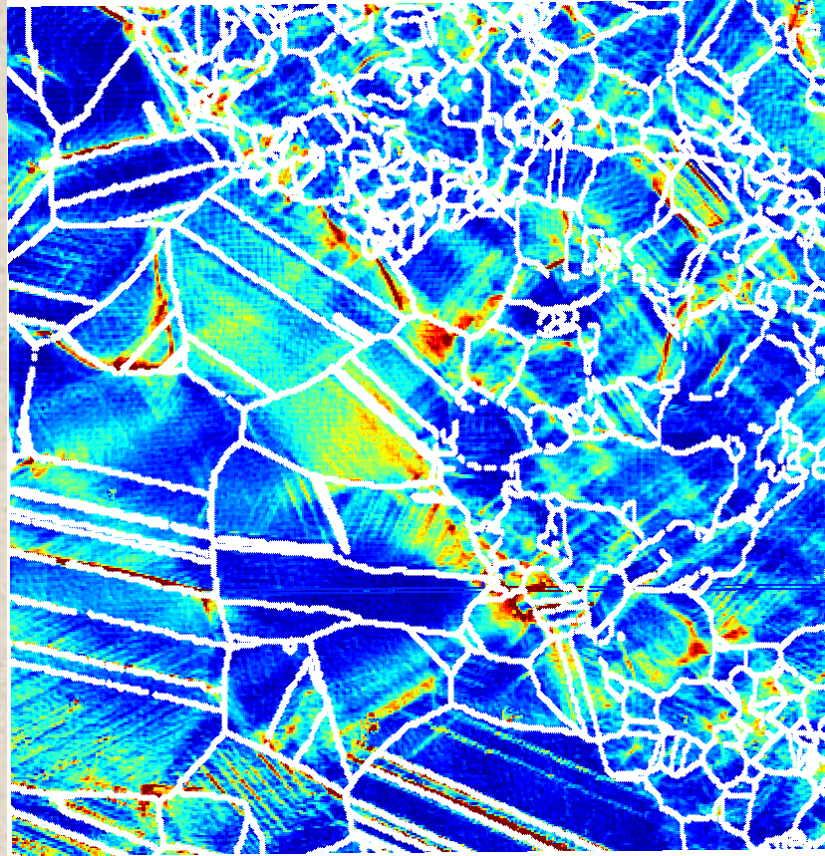
Fonderie



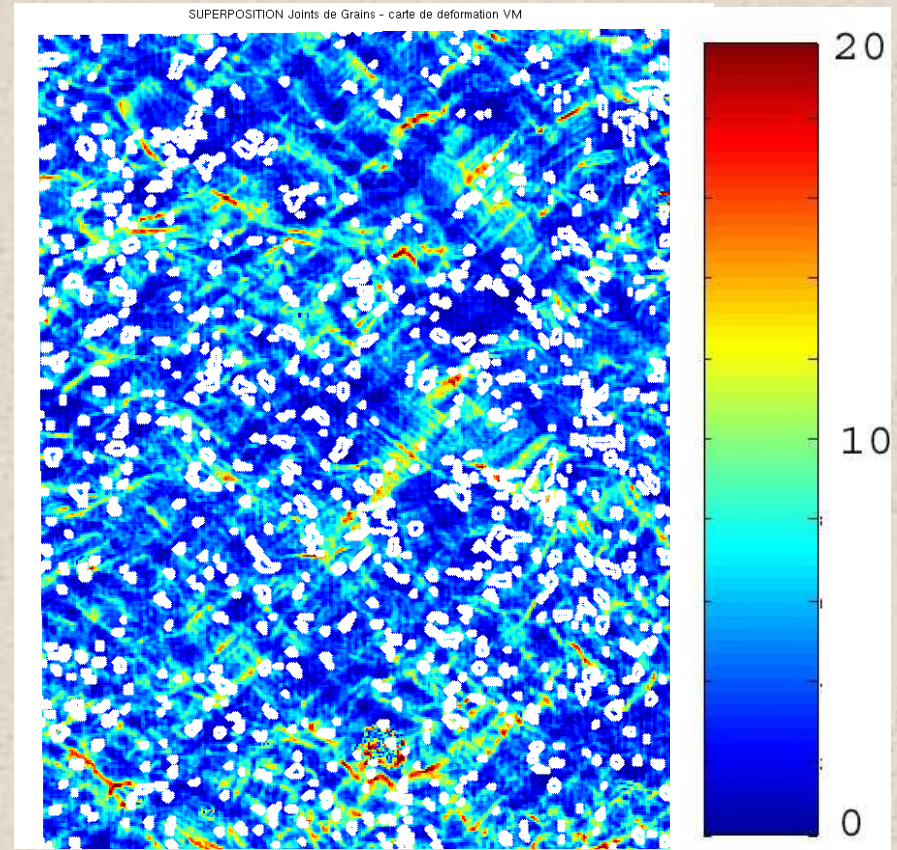
Métallurgie des Poudres



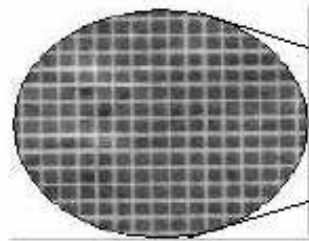
Superposition à la microstructure



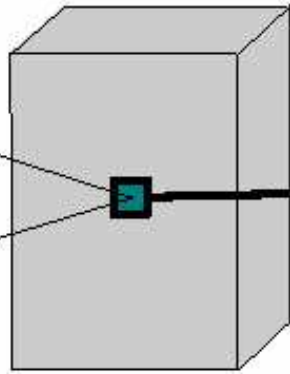
Ti-48Al-2Cr-2Nb MdP



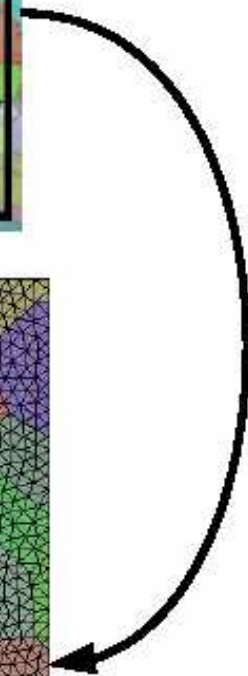
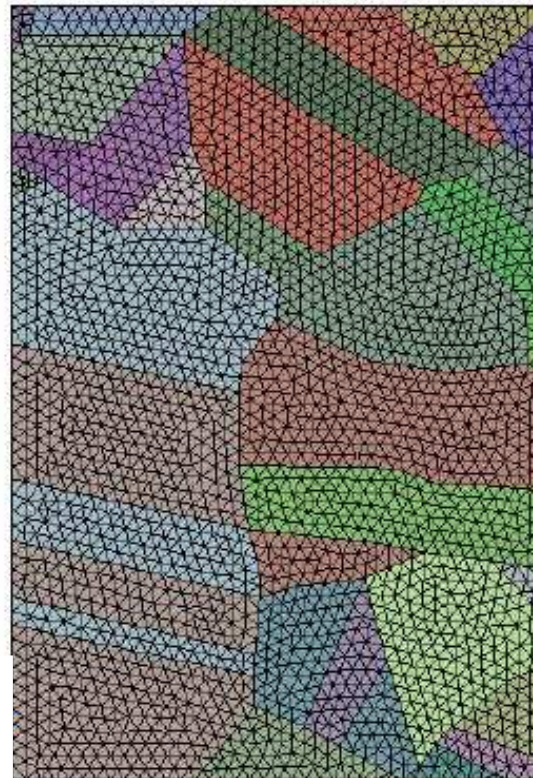
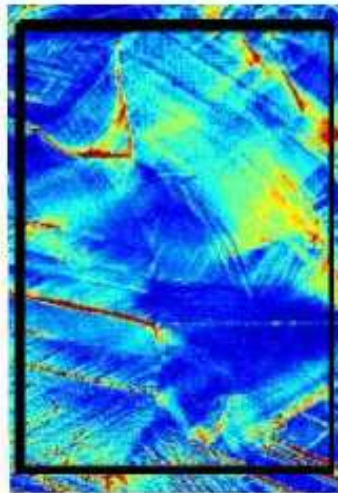
Ti-47Al-2Cr-2Nb MdP

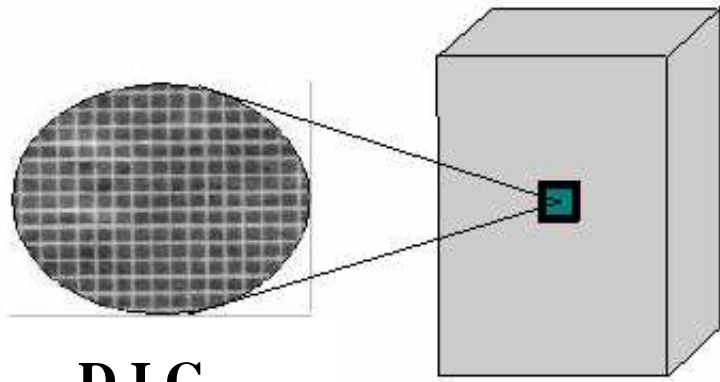


D.I.C.
(correlmanuv)



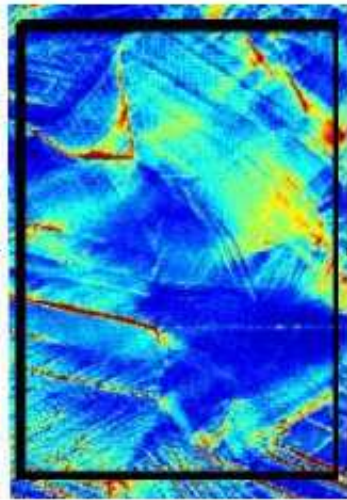
EBSD



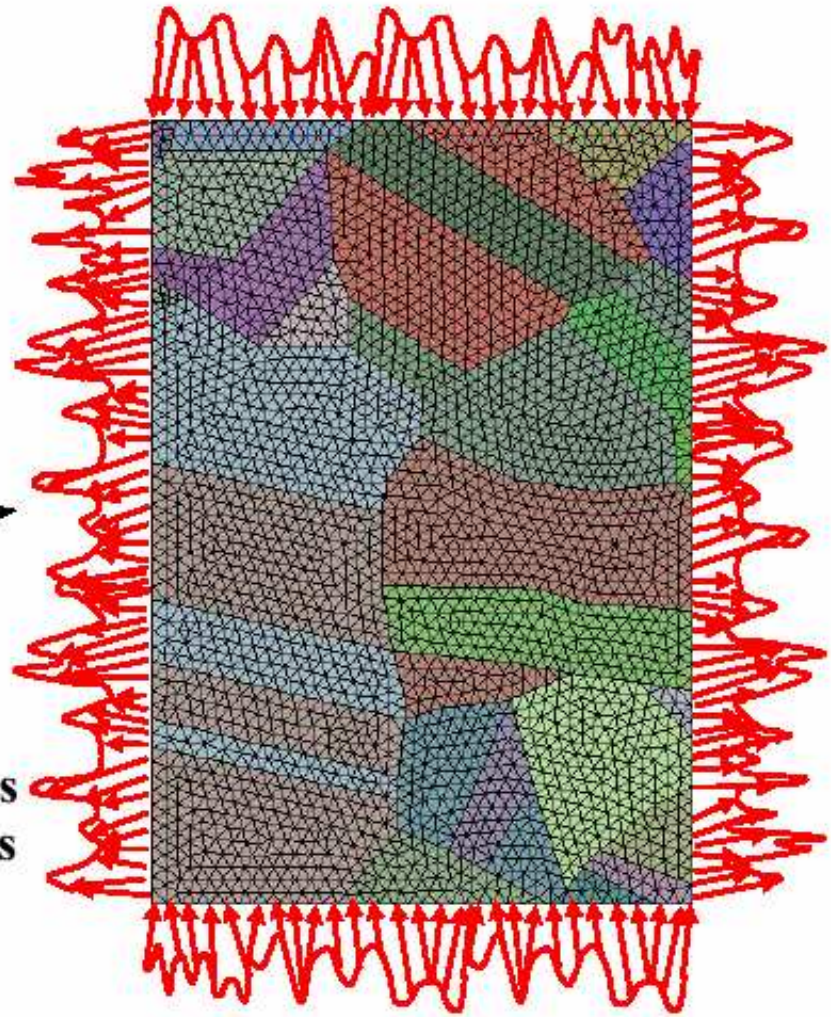


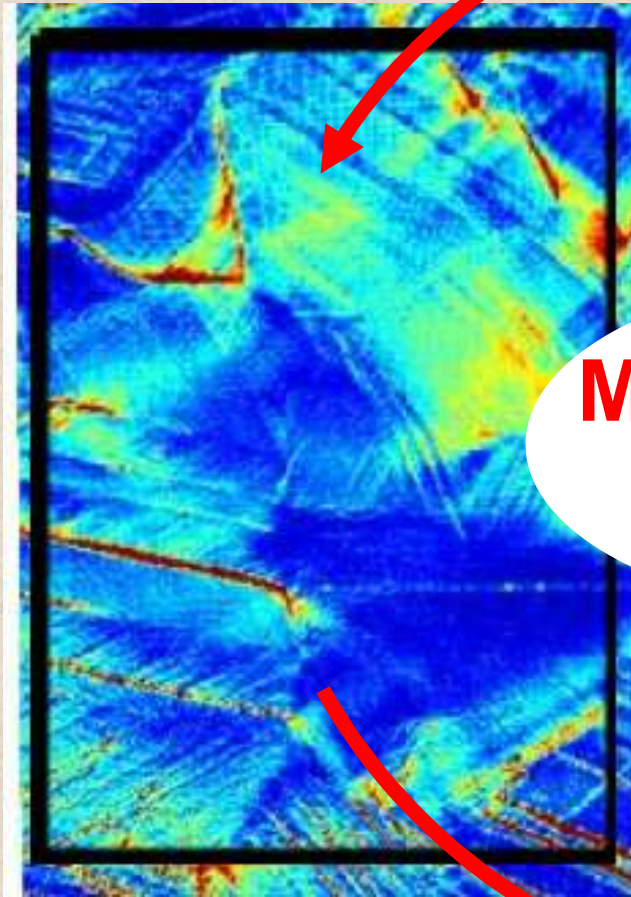
D.I.C.

(correlmanuv)

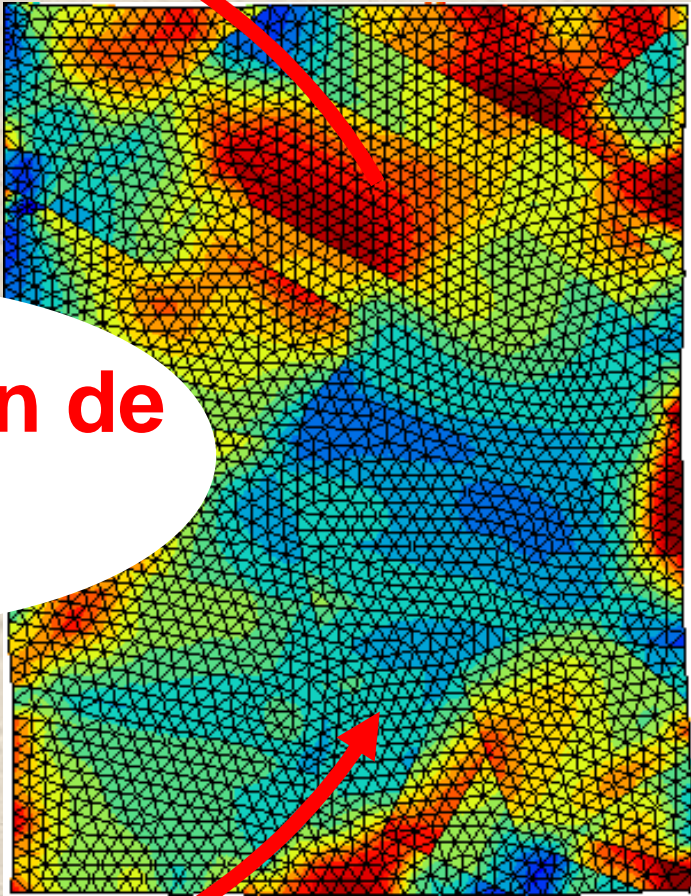


**Conditions
aux limites**



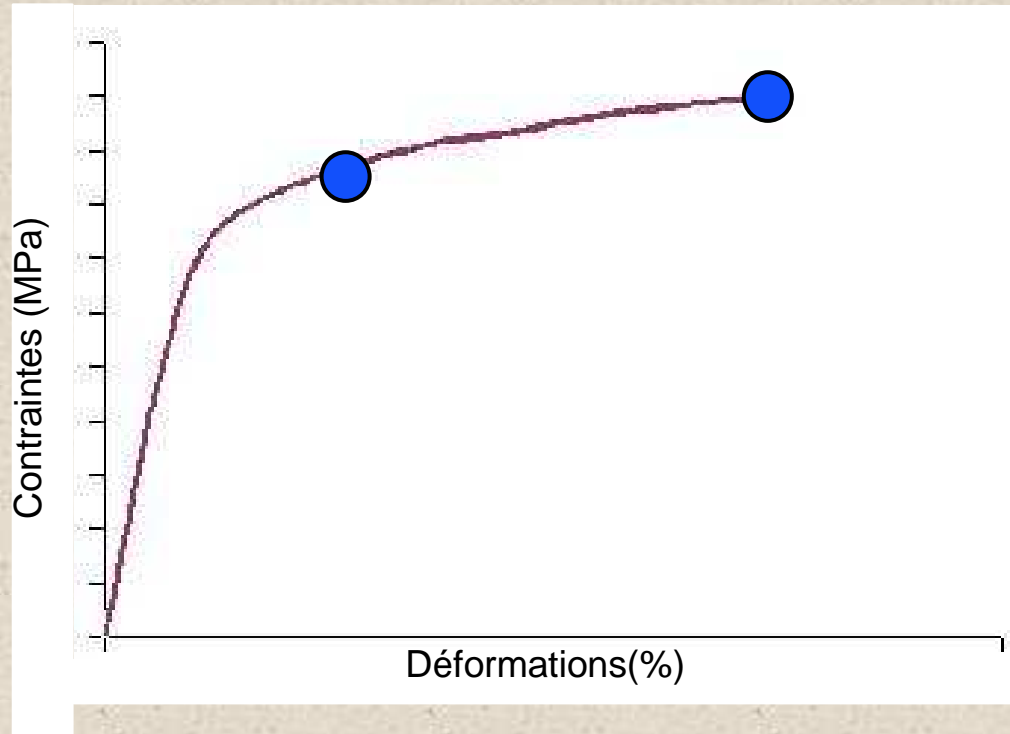
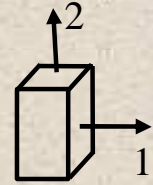


Minimisation de l'écart

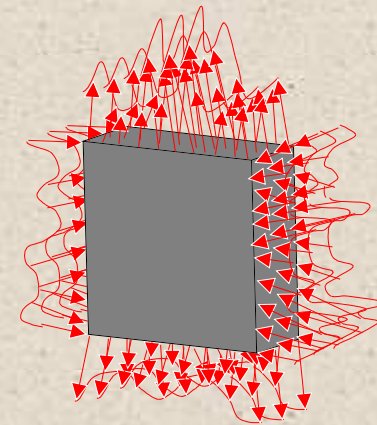
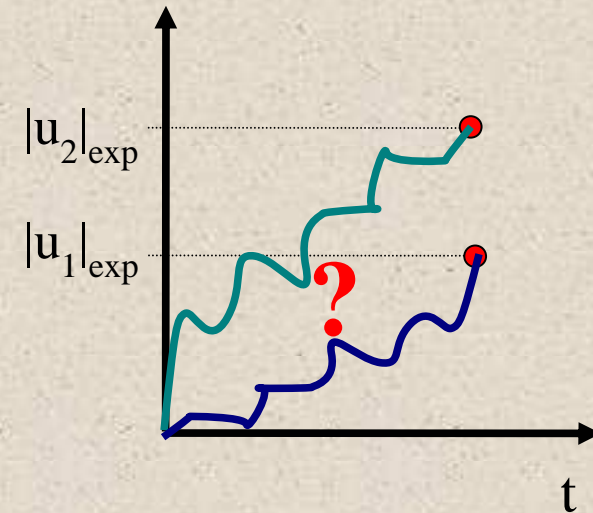


(Zébulon)

Evolution du chargement ?

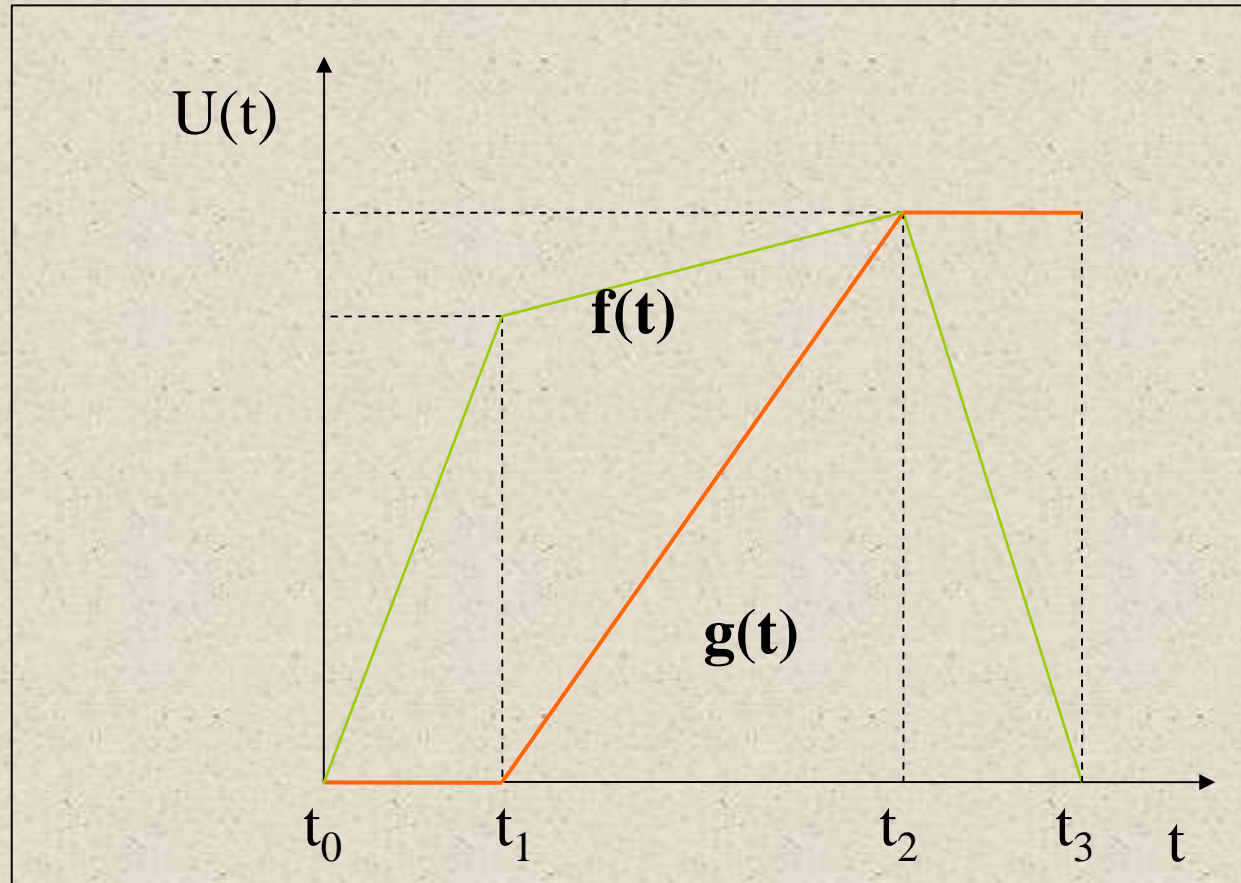


Mesures discrètes



Evolution des C.L. ?

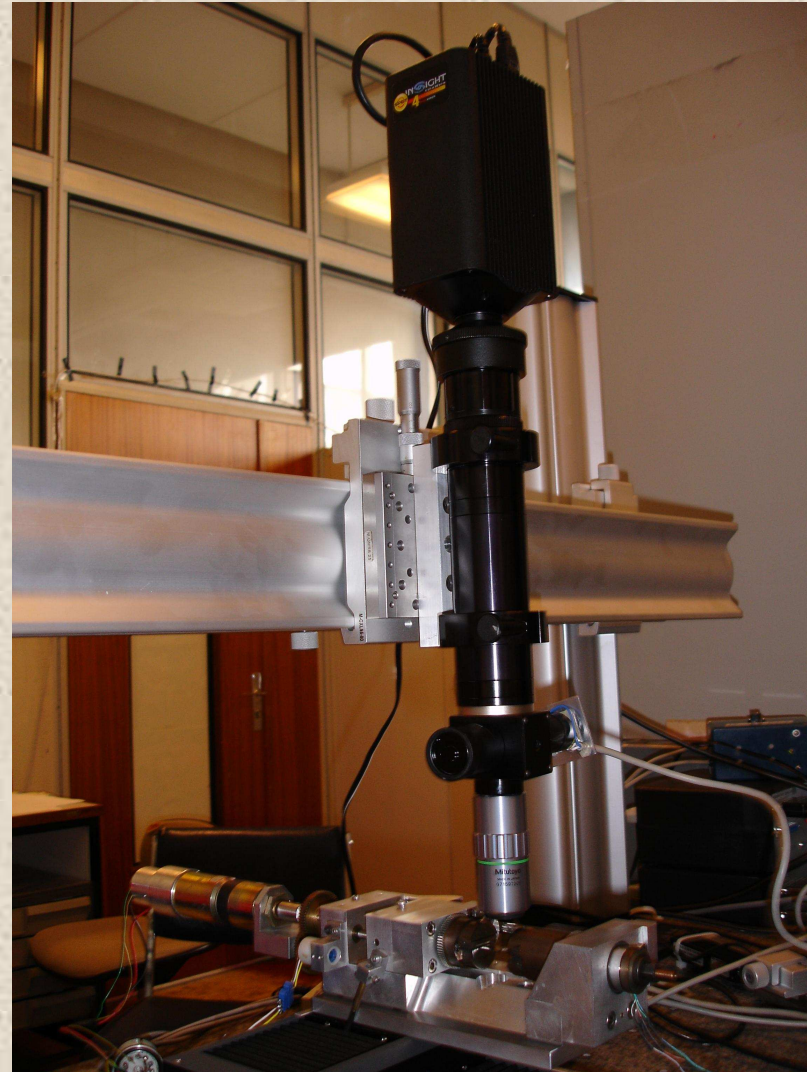
Solution ?



$$U(t) = U_{E \max} * f(t) + U_{P \max} * g(t)$$

Ou ?

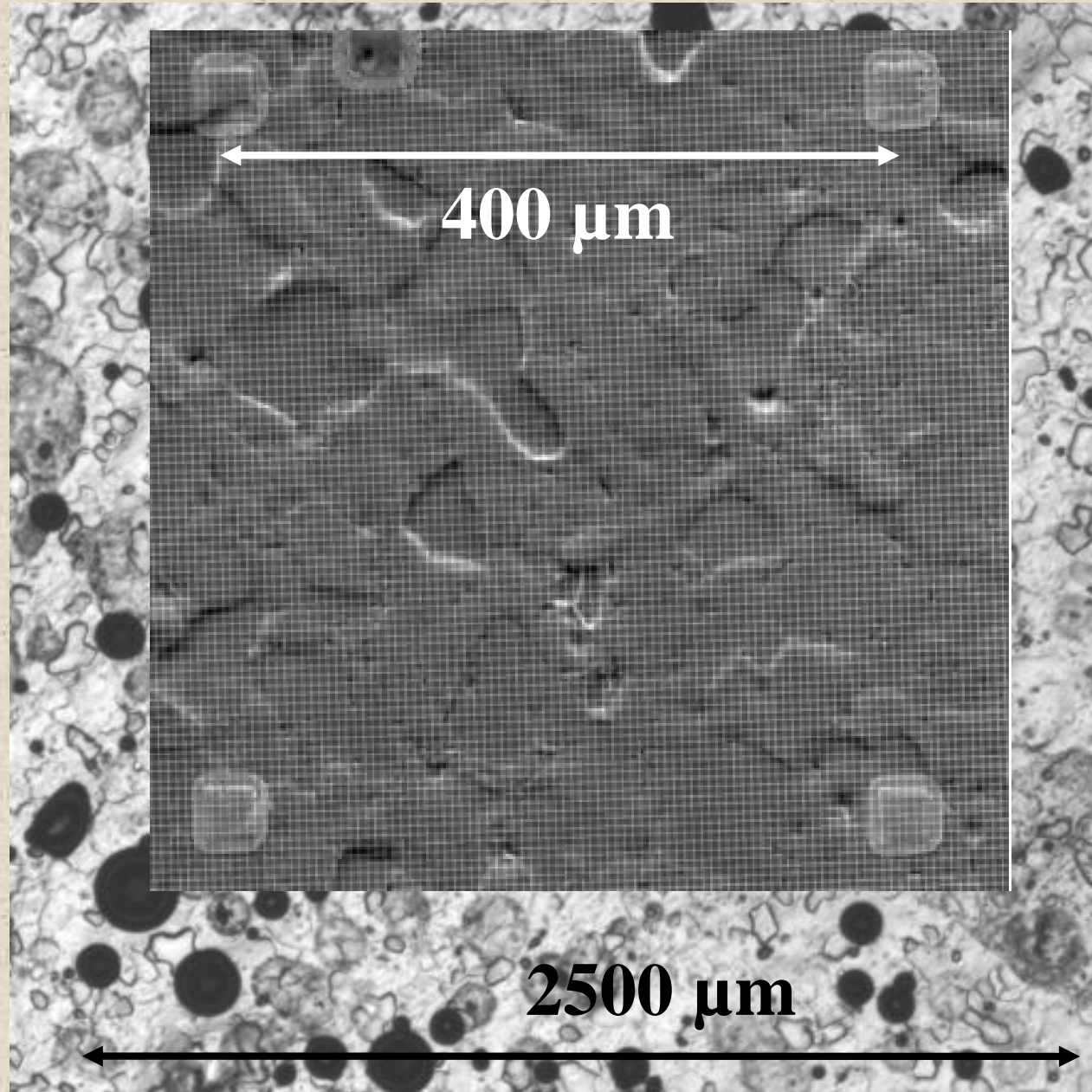
Test sous microscopie optique



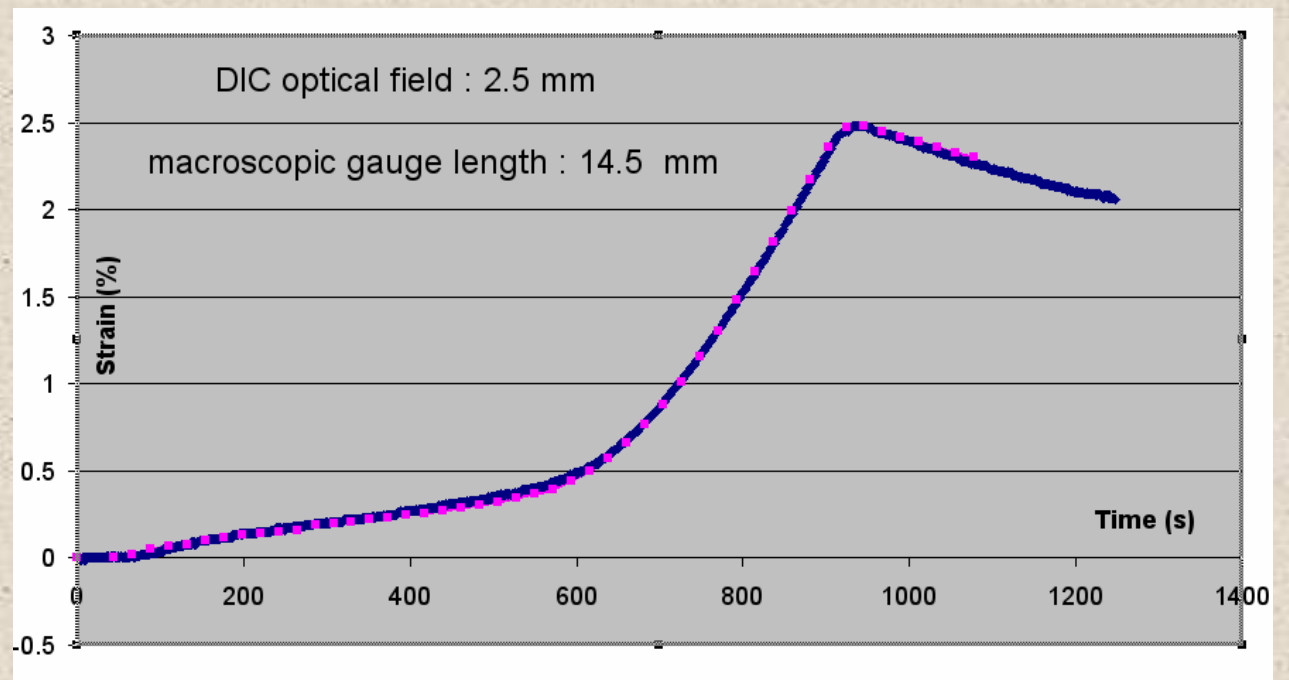
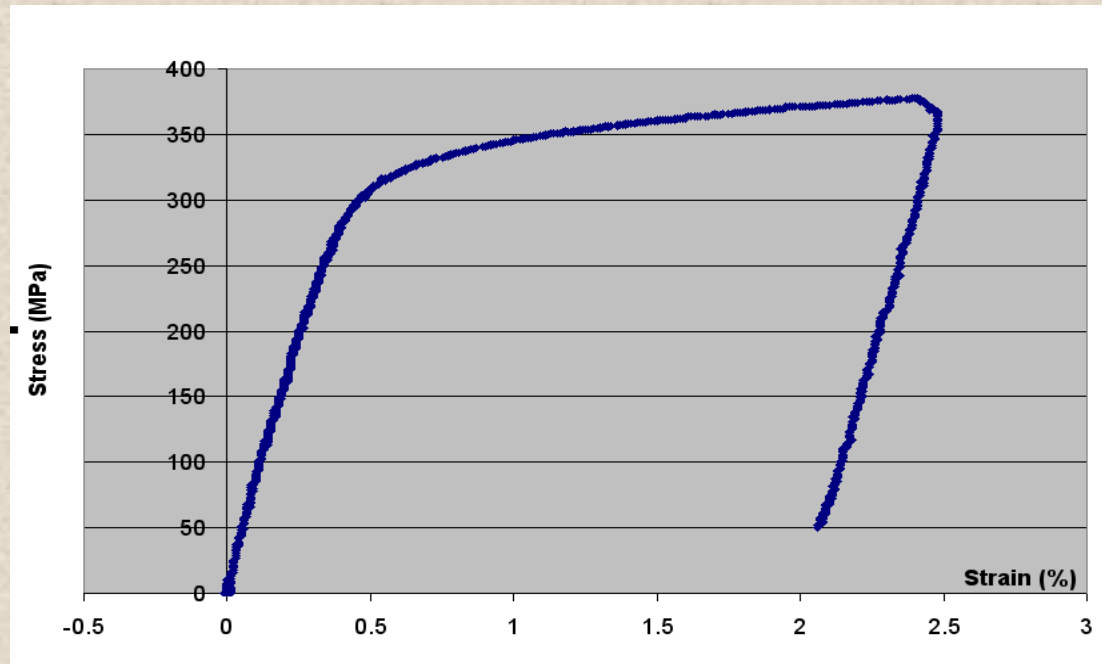
Comment est définie l'échelle locale?

**Echelle du
V.E.R.?**

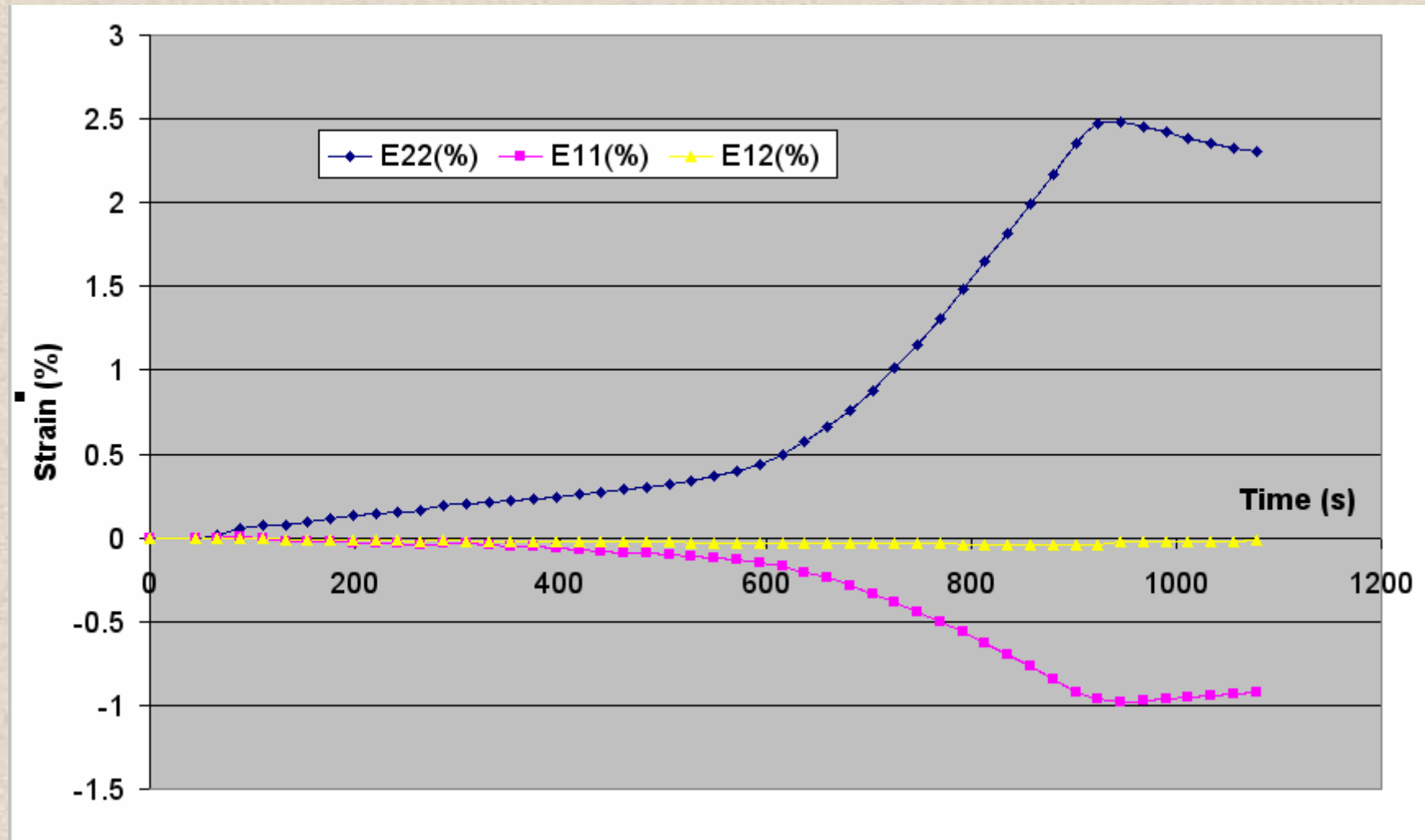
**Echelle
intragranulaire**



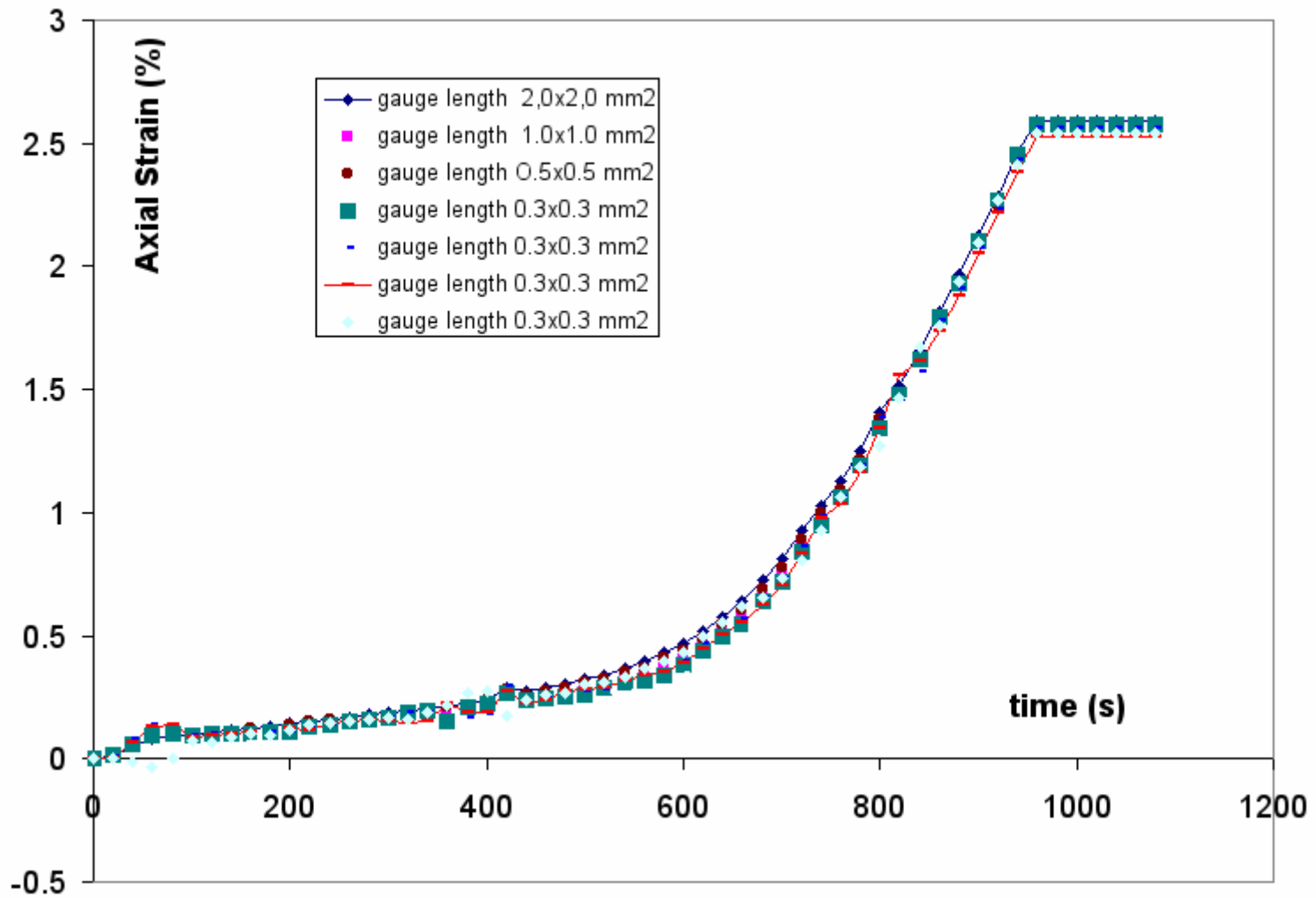
Réponse macroscopique



Evolution des déformations dans le plan

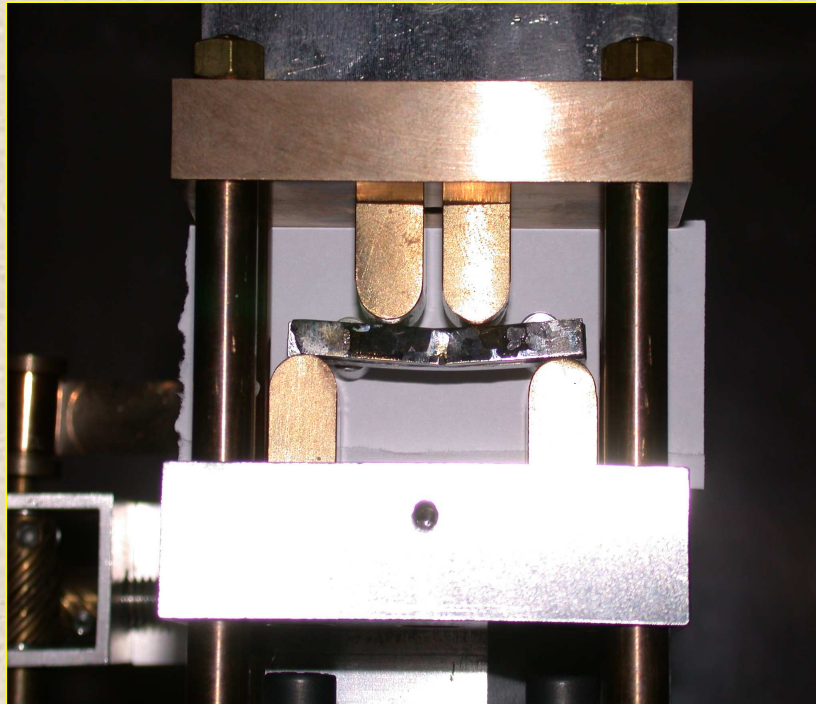


V.E.R. ?

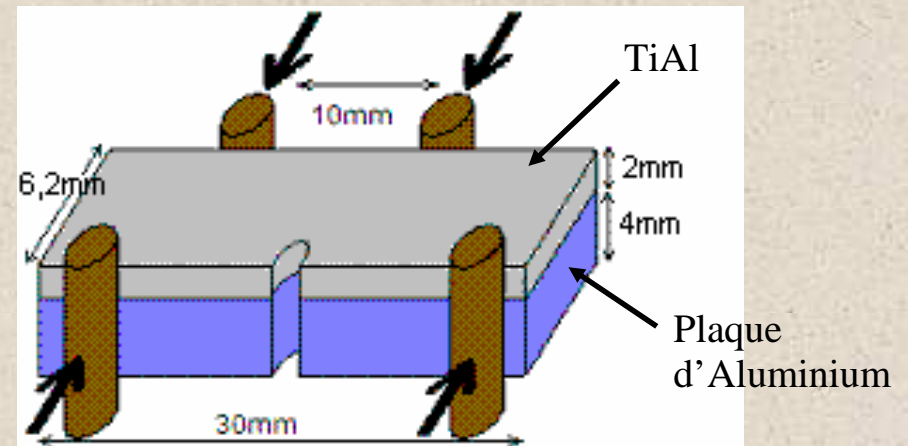


Autre application

Etude de la propagation des fissures



Montage de flexion 4 points in-situ

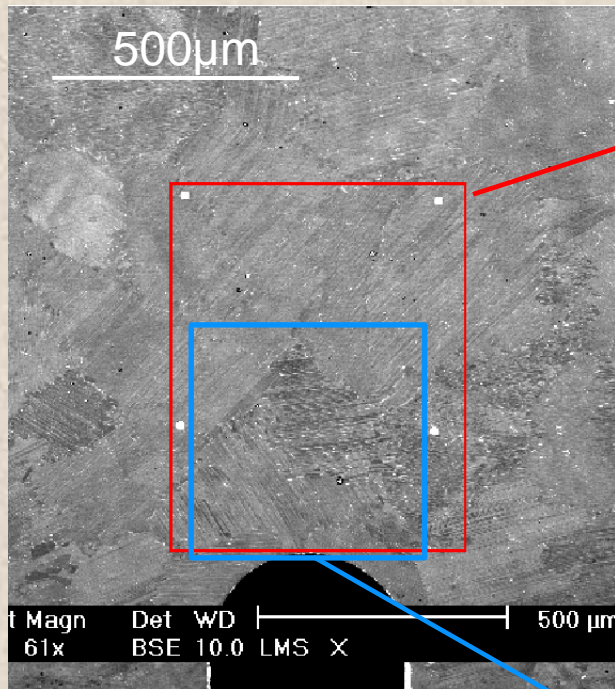


Mise en place d'un montage pour visualiser la propagation de fissures pas à pas.

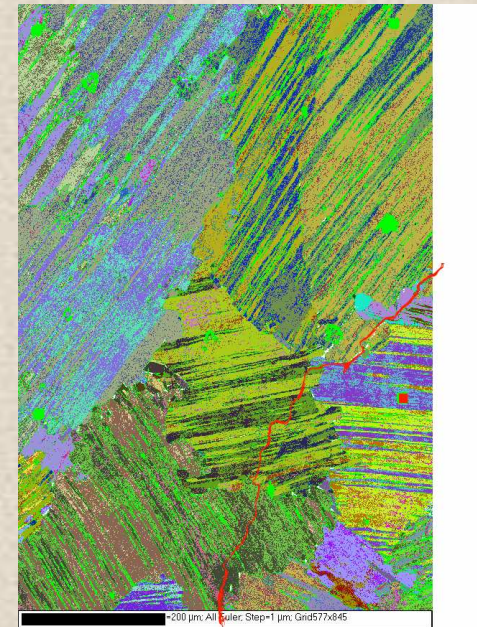
Essais de Flexion

Essais de Flexion

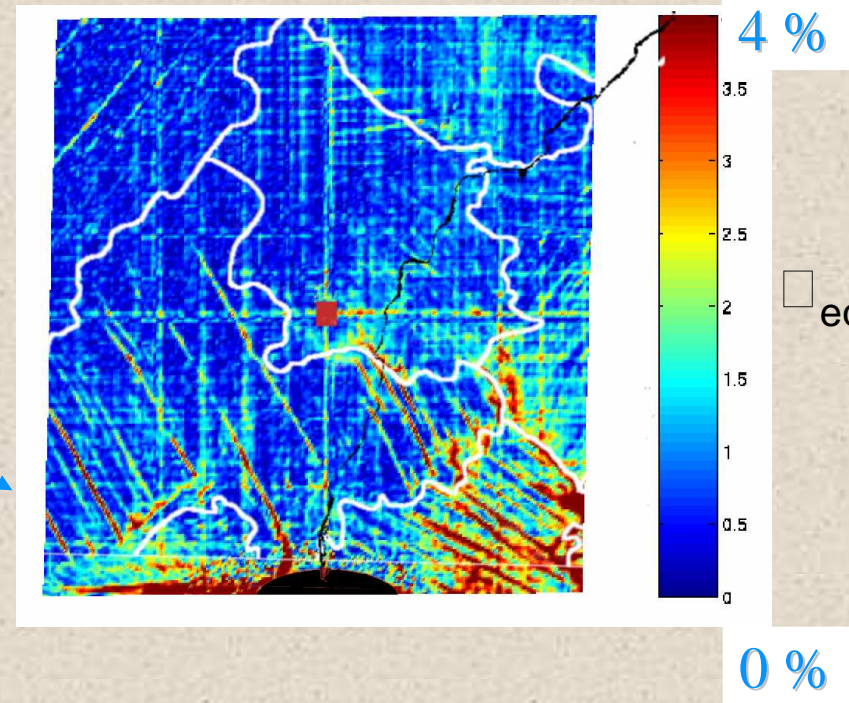
Ti-47Al-2Cr-2Nb Fond.



Analyse
EBSD



Micro-
extensométrie



Conclusions

- Mise en place d'une méthode permettant une comparaison directe mesures / calculs par EF
Optimisation des coefficients de LdC
- Application à l'étude de la plasticité et de la propagation de fissures
- Évolution des conditions aux limites ?
- Meilleure compréhension de l'influence de la microstructure sur le comportement mécanique