



Aussois 2019 - 21-25 jan. 2019 - Rupture des Matériaux et des Structures - Mécanismes et modélisations face aux applications industrielles

Caractérisation et quantification des mécanismes de rupture par imagerie

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+ ...

CNRS - INSA de LYON – Université de LYON

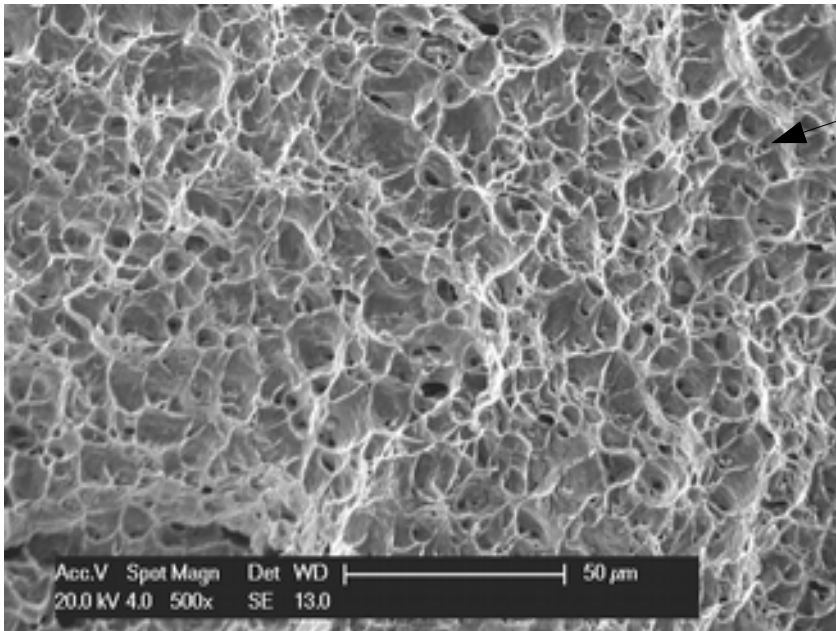
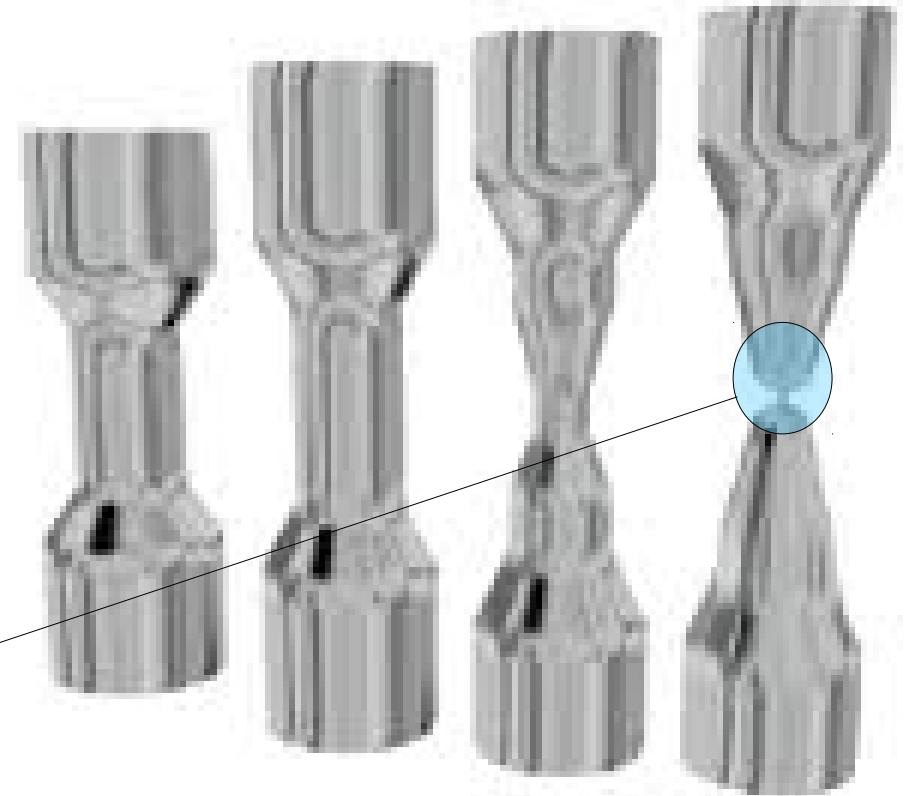


Plan

- T3 Introduction, cadre du cours
- T10 Classification
 - Méthodes expérimentales de mesure
 - Imagerie 2D puis Imagerie 3D
- T46 Essais de traction in situ en tomographie RX
 - Endommagement ductile
 - Routine
 - Quantification amorçage
 - Croissance
 - Coalescence
 - Tracking de cavités
 - Haute résolution, grande vitesse, lamino
 - T98 Autres exemples (composites, matériaux architecturés)

APPROCHE « MATERIAUX »

- Essais de laboratoire
- Aspects Microscopiques
- Evolution ?



Idée : connaissant la
microstructure
de départ + les mécanismes
+ l'évolution
Peut on prédire la rupture ?

BROAD CLASSES OF FRACTURE MECHANISM

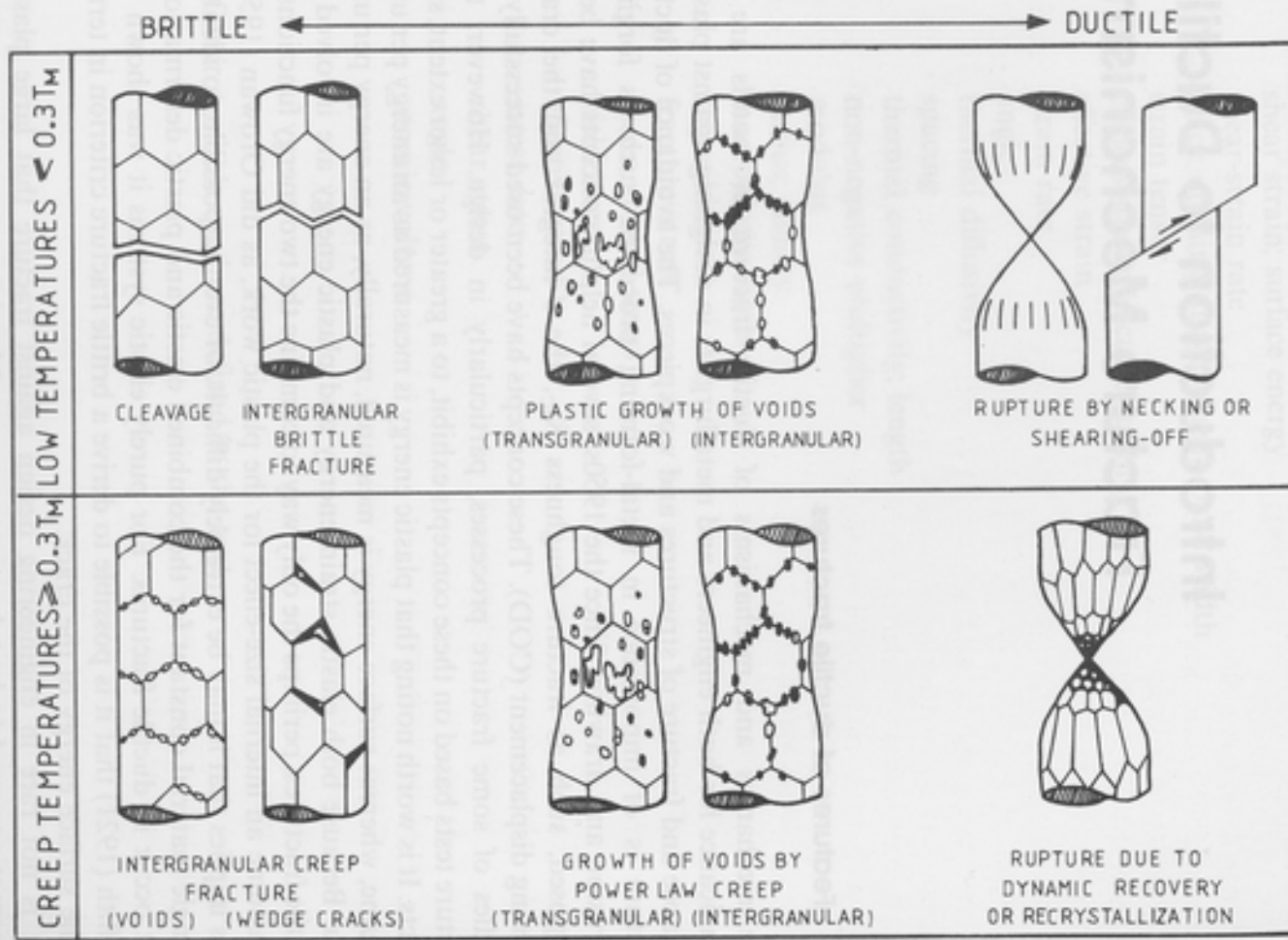
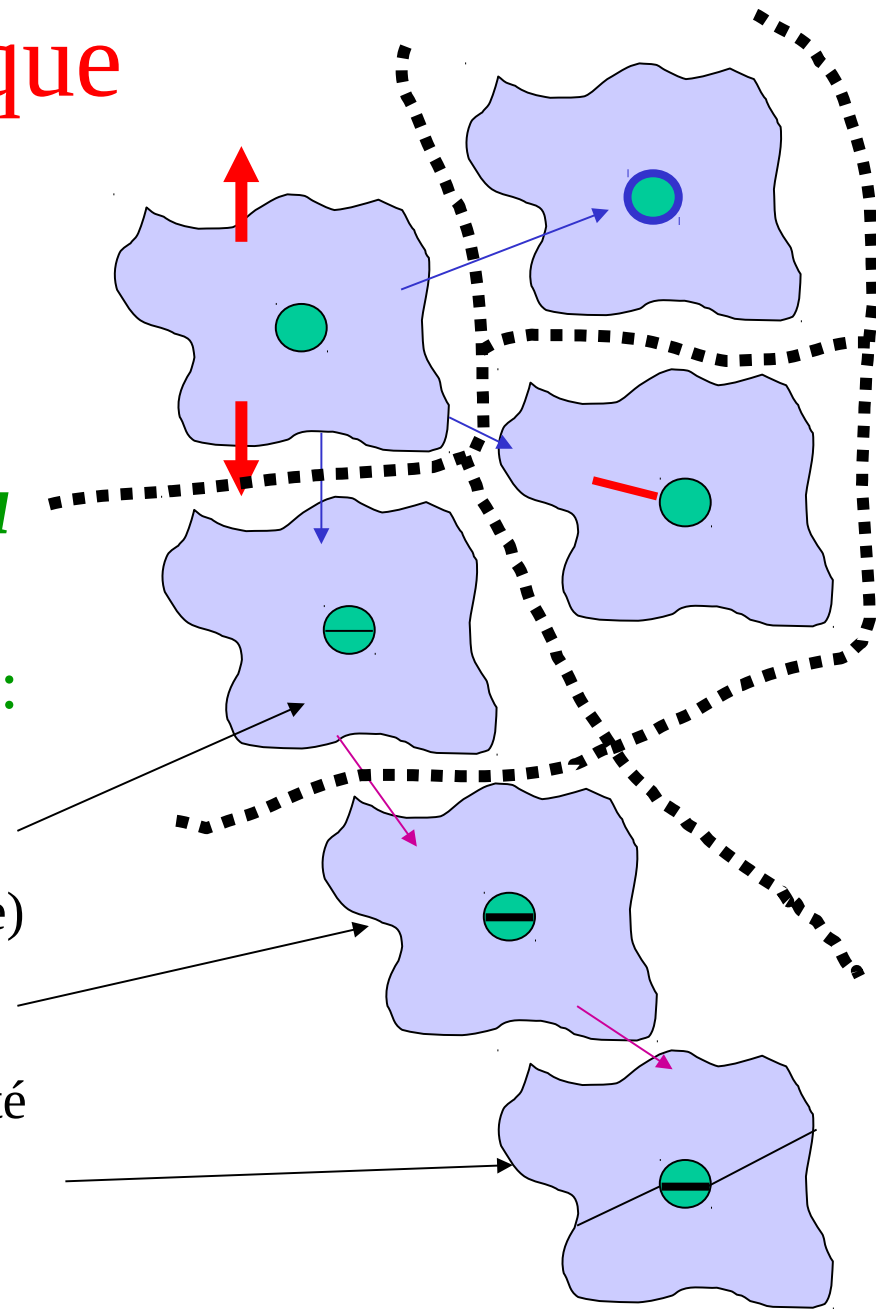


Fig. 1.1 Classification of fracture mechanisms. (After M. F. Ashby, *Prog. Mat. Sci.; Chalmers Anniversary Volume*, pp. 1-25 (1981).)

Matériau/microscopique

- Une vision unifiée
 - Tous les matériaux sont : microHÉTÉROGÈNES
 - *Systemes*
Matrice/Interface/inclusion
 - Endommagement sur ces sites :
 - Processus :
 - Amorçage
 - Rupture inclusion (microfissure) ou *interface* (cavité) ou *matrice*
 - Extension / croissance
 - Augmentation de la taille (cavité ou microfissures)
 - Coalescence dans la matrice entre sites amorcés, percolation pour la rupture finale



Observations anciennes : Influence du taux d'inclusions sur la ductilité (en traction)

Cuivre

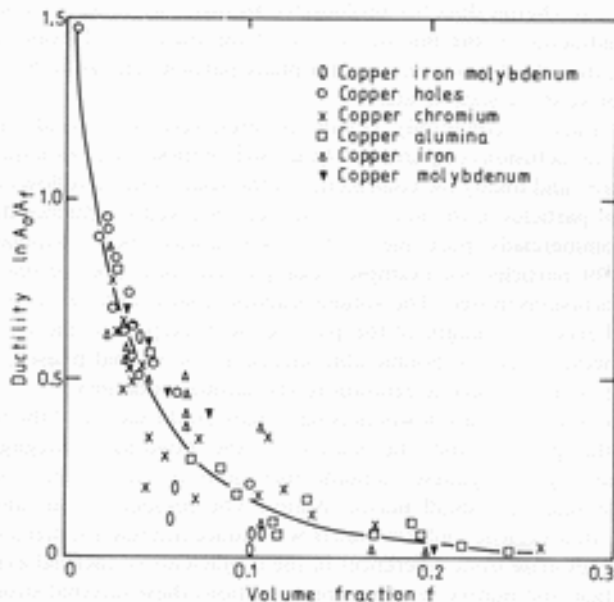


Fig. 4.1 Ductility in tension versus volume fraction of second phases/inclusions for various copper alloys. (After Edelson, B. L., Baldwin, W. M., *Trans. ASM*, 55, American Society for Metals, Metals Park, OH 44073, 1962, pgs. 230-250.)

Acier

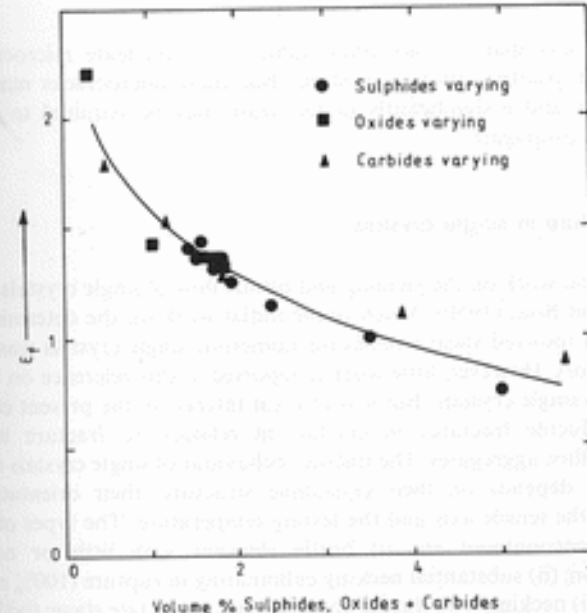
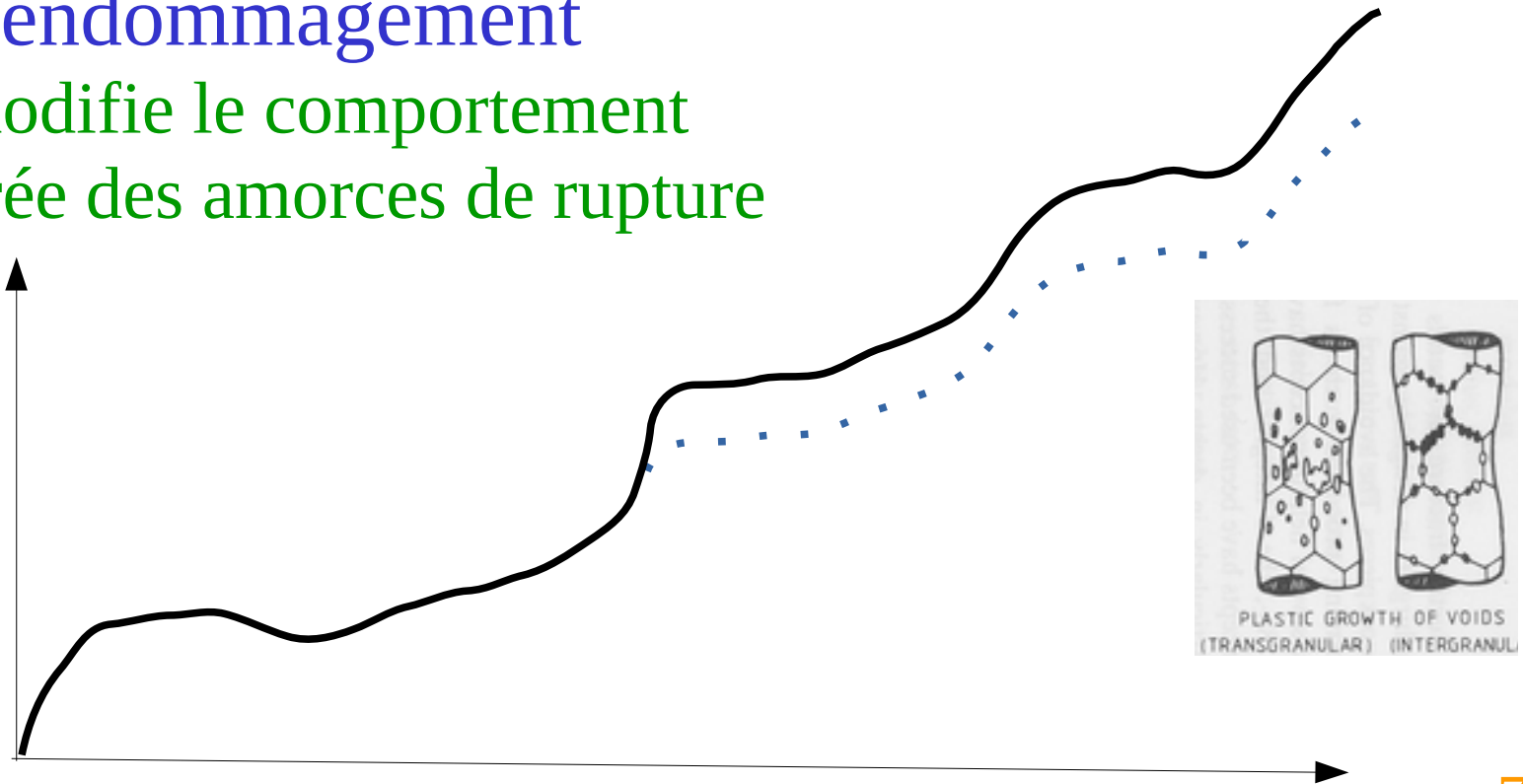


Fig. 4.2 Effect of total volume fraction of second phase particles on the tensile ductility of steel. (After F. B. Pickering, *Physical Metallurgy and the Design of Steels*, 1978, with permission from Elsevier Applied Science Publishers Ltd.)

Rupture/endommagement

- La rupture macroscopique est précédée par l'apparition d'endommagement microscopique
- Définition : création de surface au sein du matériau
- Cet endommagement
 - modifie le comportement
 - crée des amorces de rupture



Nomenclature

- Physique :
 - f fraction de cavités dans le matériau
 - N densité de cavités (/mm³)
 - ω proportion de particules cassées
 - R rayon des cavités formées
- Mécanique
 - σ, ε contrainte et déformation
 - E module d'Young ($\sigma = E\varepsilon$)
 - D paramètre d'endommagement $E = (1 - D)E_0$
 - T Triaxialité des contraintes

Classification des méthodes de mesure du micro- endommagement

Mesure expérimentale de l'endommagement

- Méthodes indirectes

- Densité
- Modules
- Acoustiques
- Résistivité

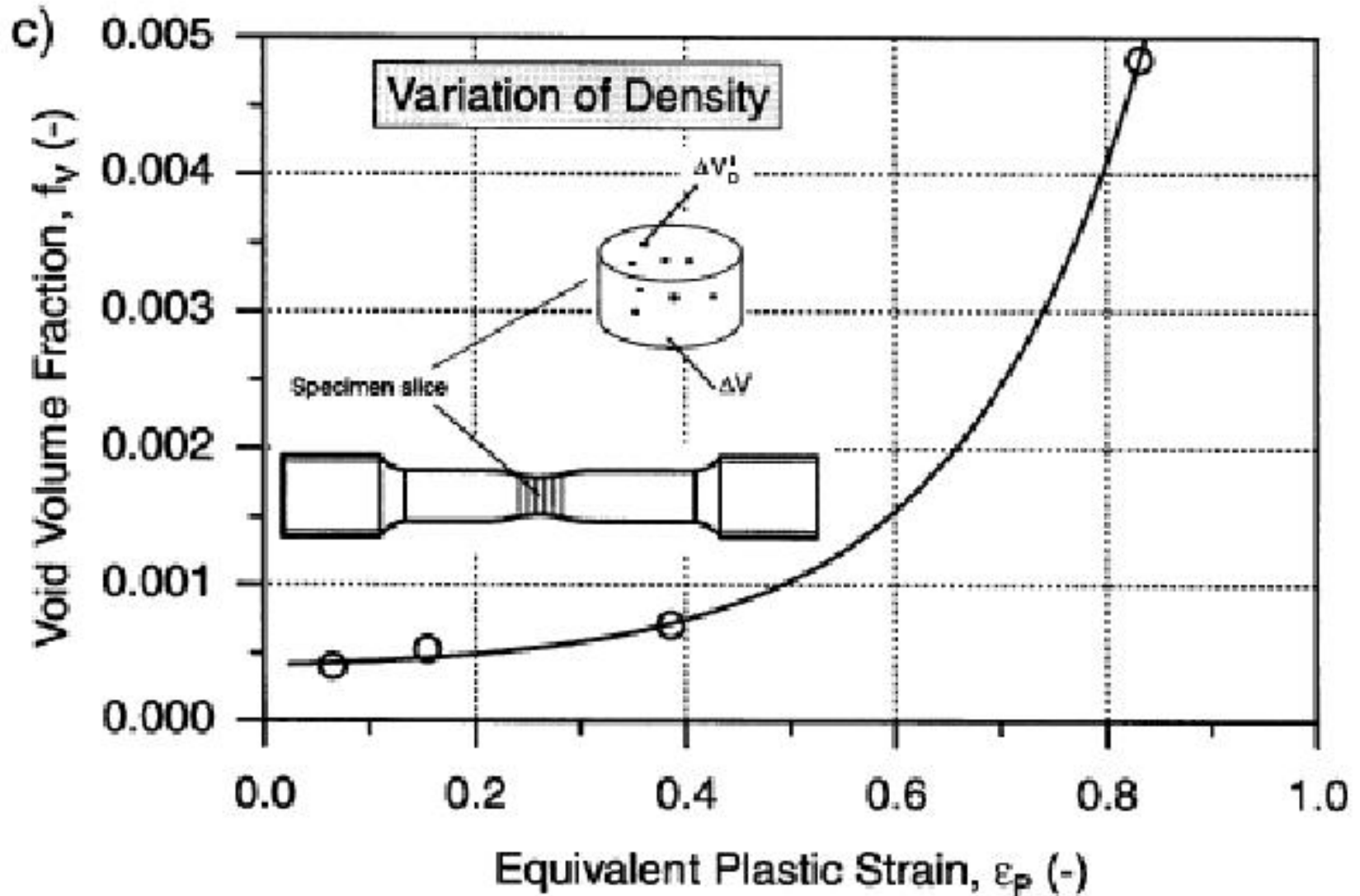
- Méthodes directes

- Imagerie en surface
 - sur surface polie
 - fractographie
- Imagerie proche de la surface (SAM)
- Imagerie en volume (radio et tomographie)
 - RMN
 - Rayons X
 - Neutrons
- In situ / ex situ
- Traitement et analyse des images

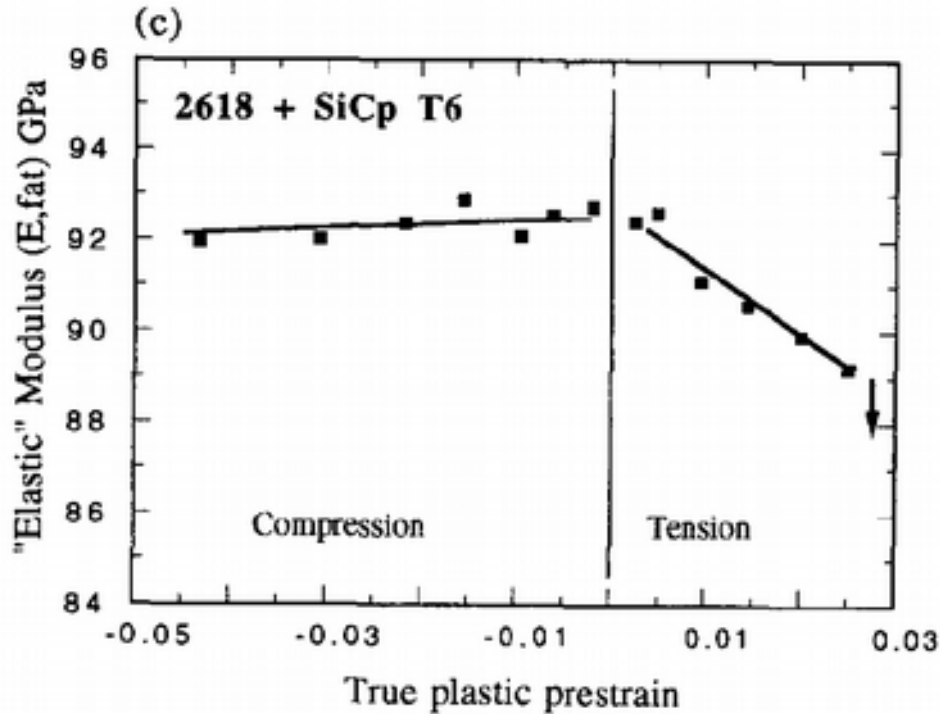
Méthodes indirectes

- Mesure d'une *grandeur* physique ou mécanique dont la variation traduit la variation de l'endommagement
- Densité, Modules, Mesures acoustiques, Résistivité
- Suppose une connaissance de la relation entre la *grandeur* et f (ou D)
- Paramètre scalaire ou parfois tensoriel

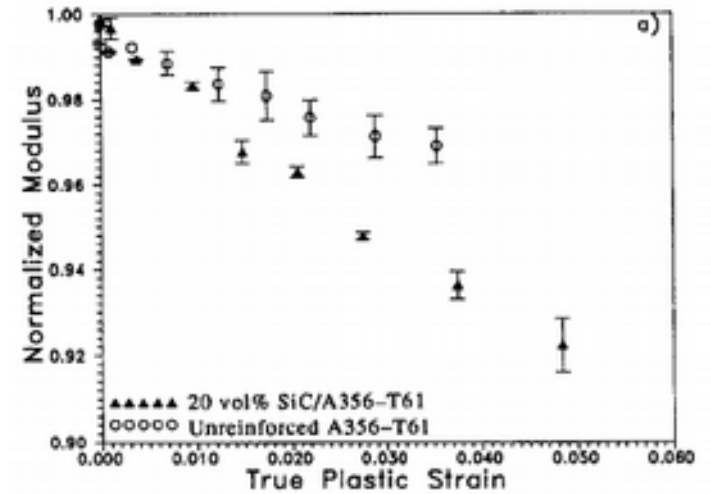
Densité



Modules



Llorca et al.



Corbin et Wilkinson

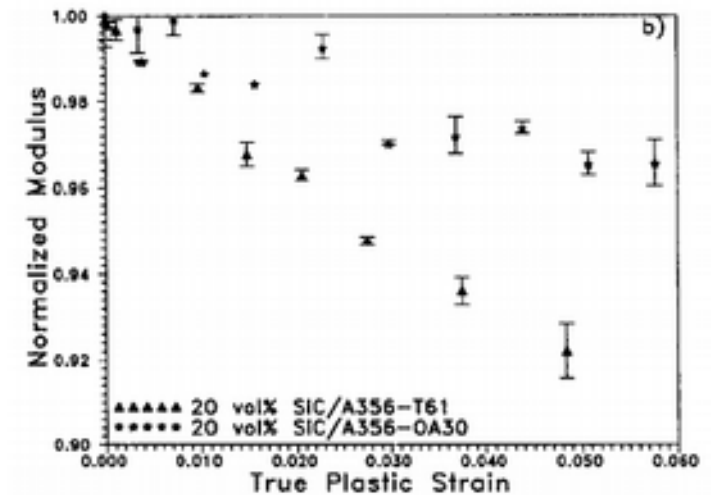
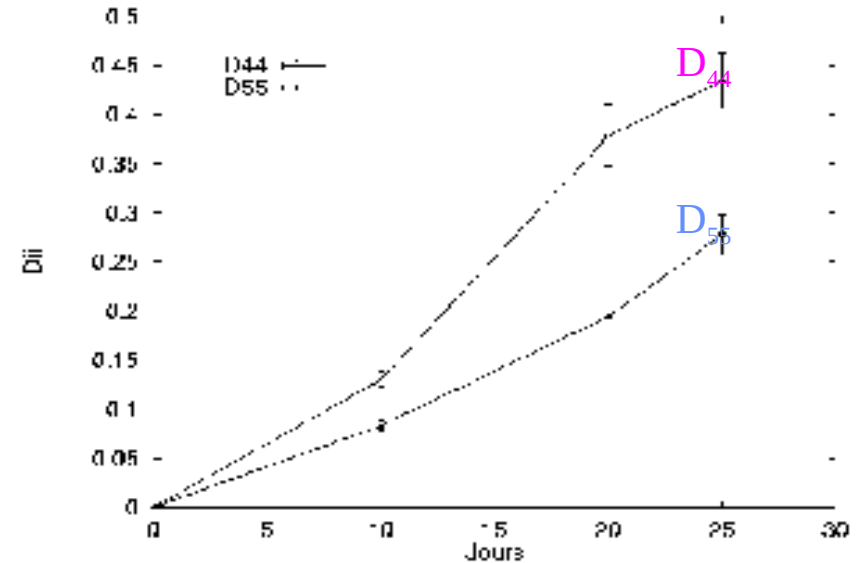
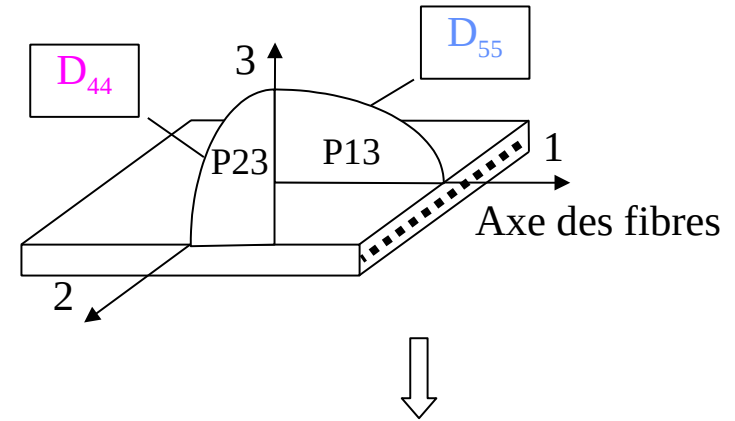
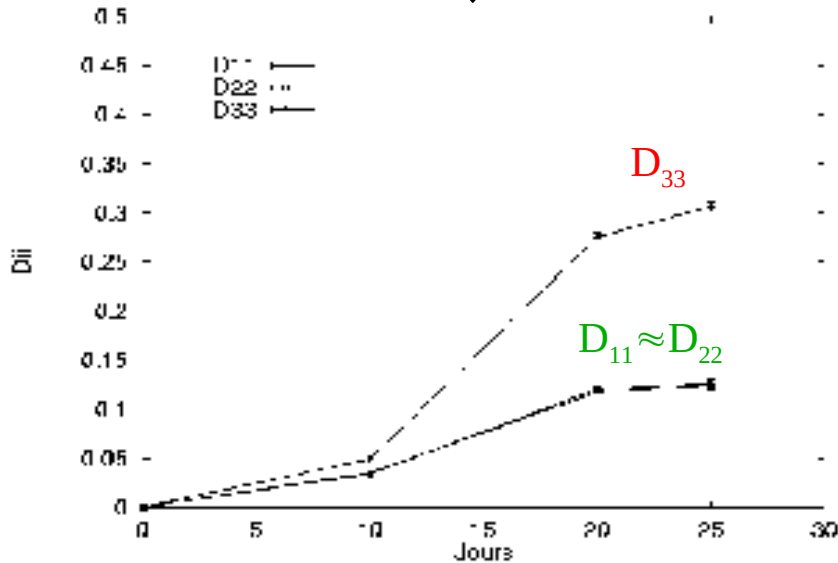
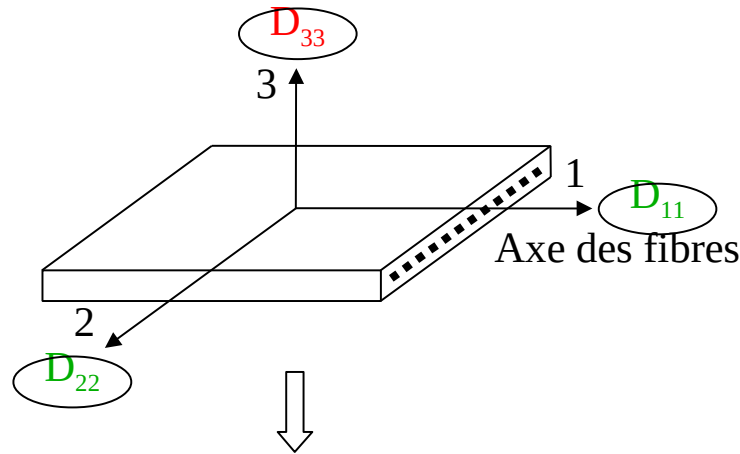


Fig. 4. Normalized elastic modulus (E_{pt}/E_i); (a) comparing the 20 vol. % composite and unreinforced alloy; (b) comparing the 20 vol. % composite in the T61 and OA300 conditions.

Vitesse ultra-sonore

Vieillessement dans de l'eau à 70° C



- Evolution anisotrope des variables d'endommagement
- Evolution la plus importante observée pour D_{44}

Résistance électrique

- Acier
- Evolution de l'endommagement en fatigue
- Comparaison des mesures de résistance électrique avec des mesures du type : rupture monotone d'échantillons fatigués (by ductility)

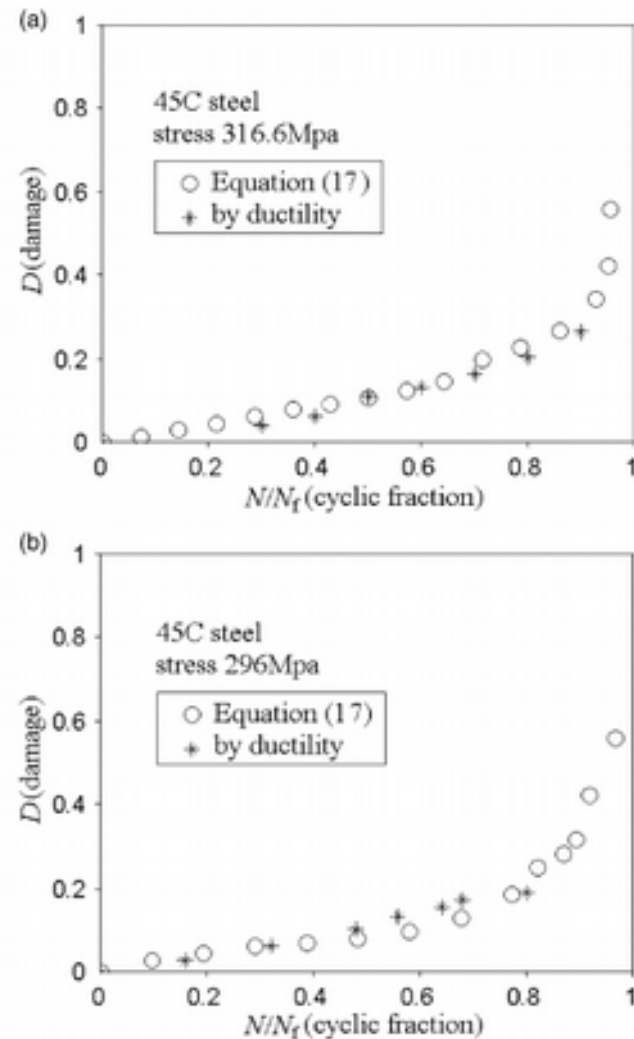


Fig. 2. Damage measurement for 45C steel by electrical resistance change and static ductility.

Bilan

- Pratique
- Pas cher
- Efficace
- Mais
 - Aucune de ces méthodes ne distingue
 - Amorçage
 - Croissance
 - Coalescence

Méthodes directes

- Imageries
- Modes :
 - Surface
 - Optique
 - Electronique (MEB)
 - AFM, EBSD,...
 - Surface polie / faciès de rupture
 - Sous la surface, microscope acoustique à balayage (MAB)
- Volume
 - Radio et tomographie
 - Des rayons X
 - Des neutrons
 - RMN pour les éléments légers
- Dans tous les cas :
 - in situ / ex situ
 - qualitatif/quantitatif

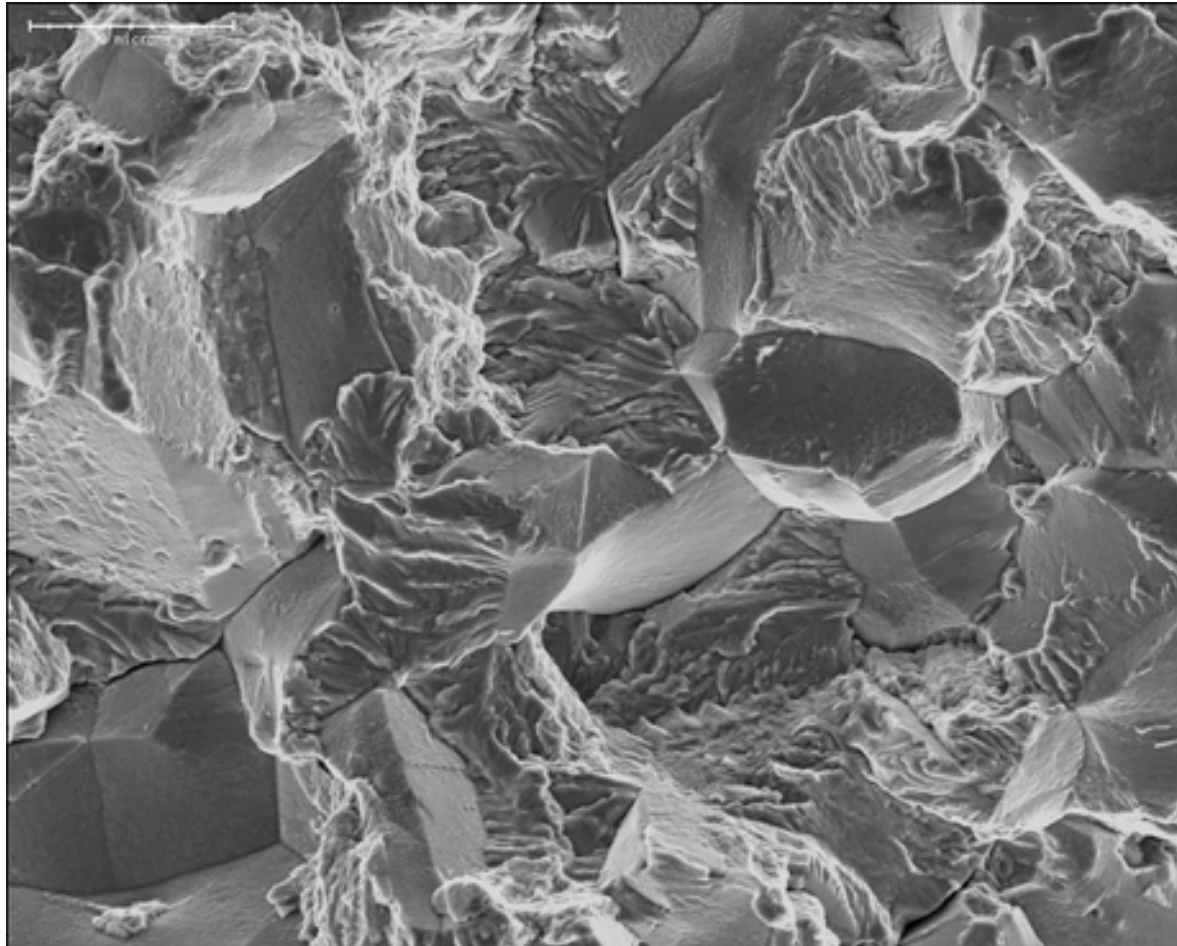
Surface

MEB, MO, AFM

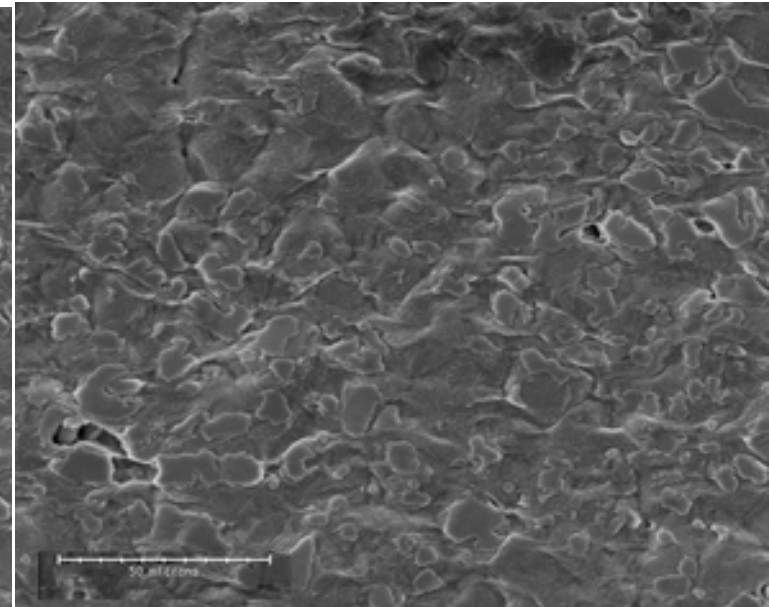
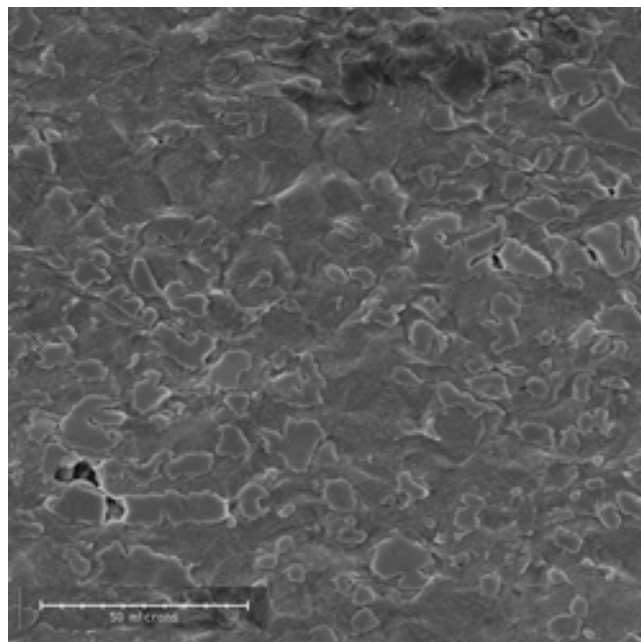
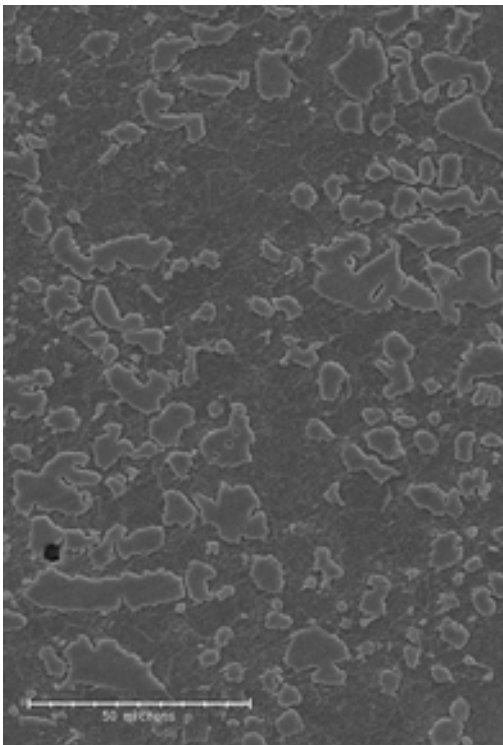
Nécessité de propreté :

- surfaces polies
- fractographie

Fractographie

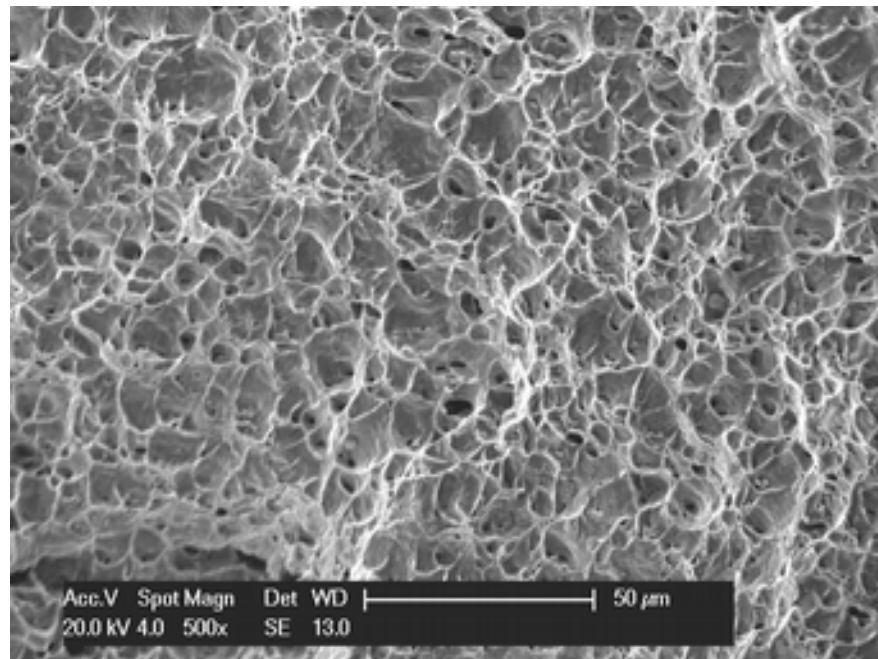


Traction in situ :



Fractographie :

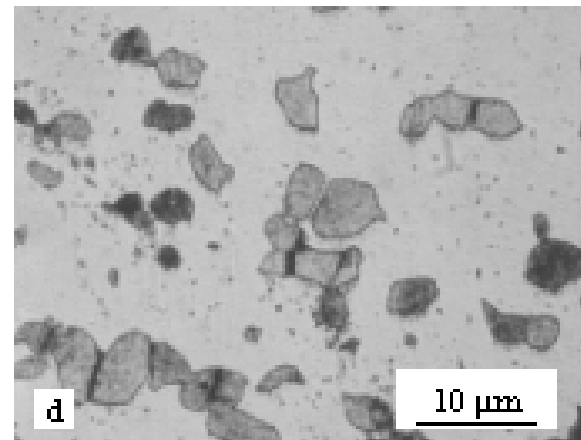
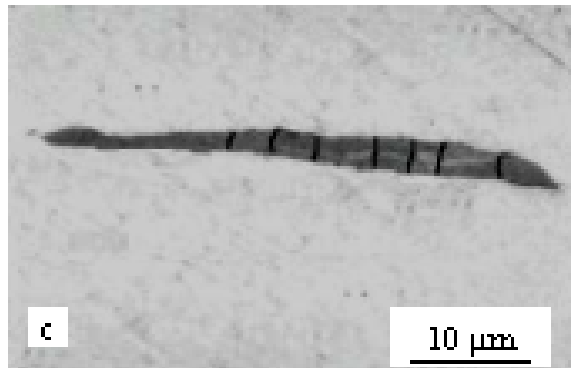
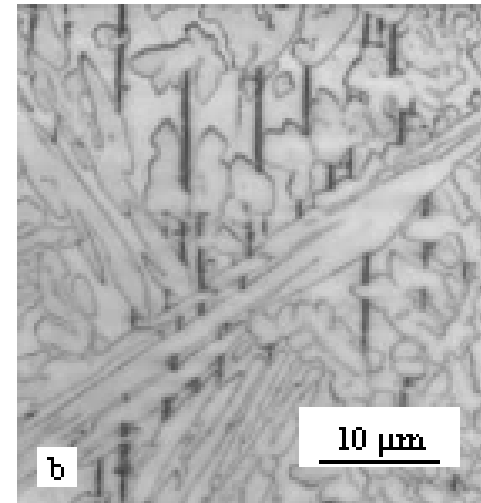
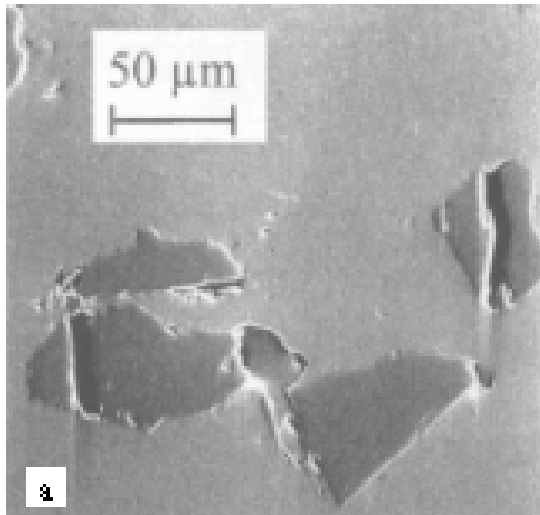
Au MEB



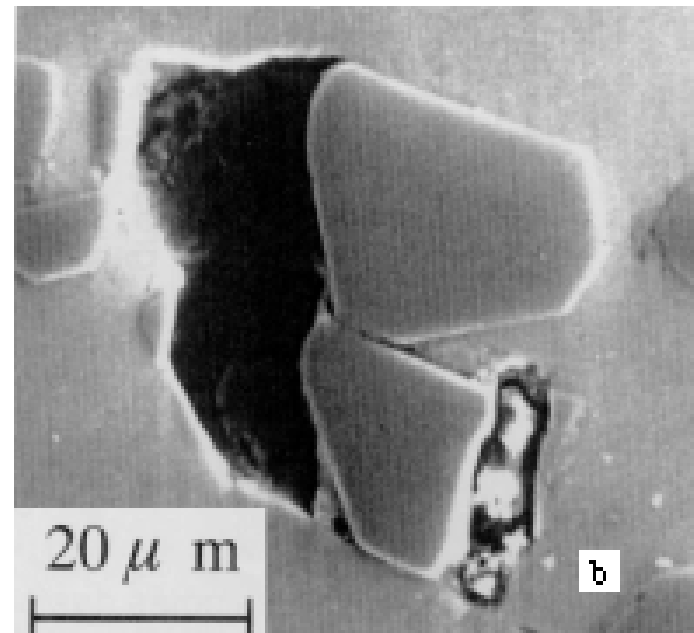
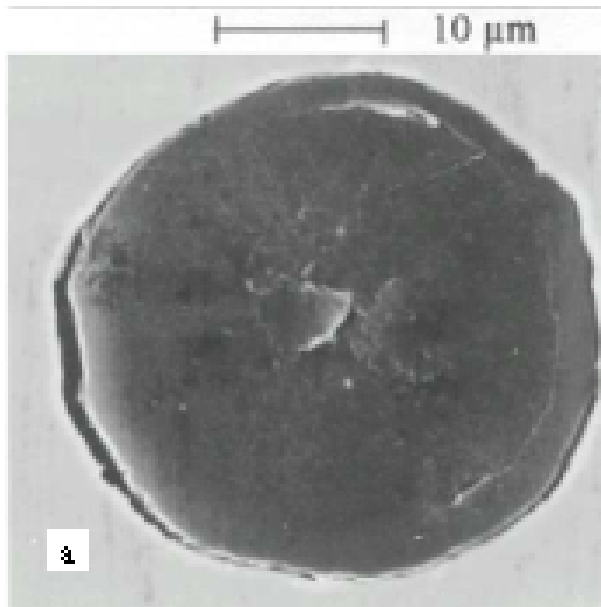
Imagerie de surfaces polies

Etats déformés

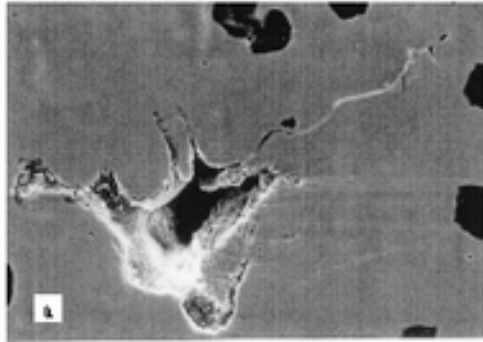
- Rupture des inclusions



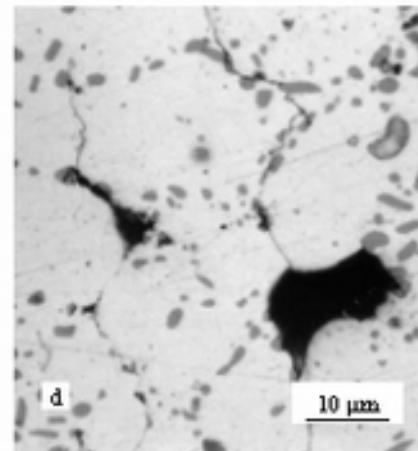
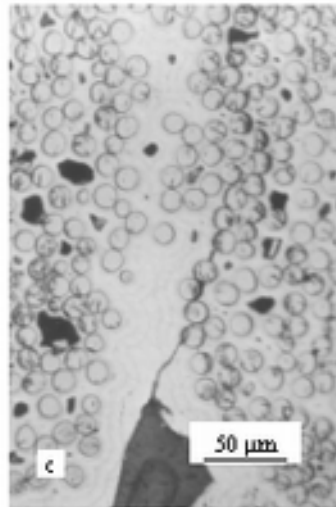
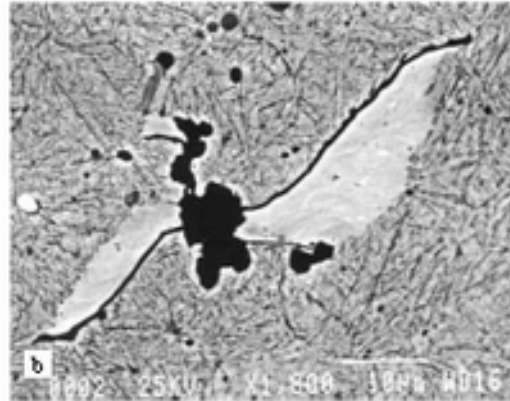
- Décohésion



- Ruptures matricielles



à 50 pourcentage alcool dans le liquide, avec un 1' et 10 μm



Limites

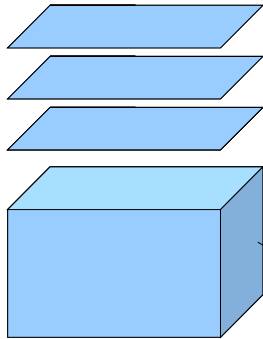
- Tout à fait valable (et encore très utilisé)
- A permis d'apprécier qualitativement les mécanismes
- A montré que l'amorçage avait lieu sur des micro-hétérogénéités
- A permis selon le cas de définir le type d'amorçage : décohésion, rupture, fissures matricielles, les trois...
- A permis de visualiser la phase de croissance
- Mais...
 - Semi quantitatif (évident en cas de striction)
 - Inclusion en surface <> en volume

Imagerie en volume

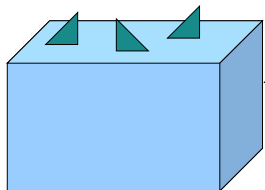
Destructive methods

Successive abrasion of layers

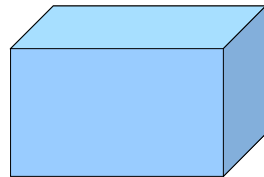
- mechanical polishing
- ion milling



Selective dissolution

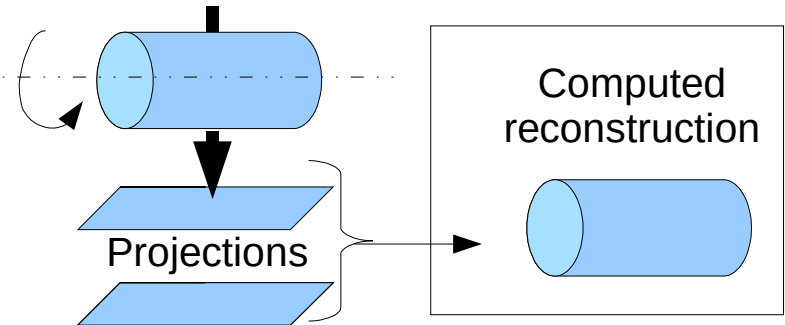


+ Imaging
ex situ : OM,
SEM
or in situ : SEM,
ion, atome
probing

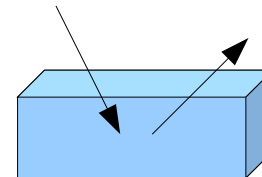


Non destructive methods

Transmission + rotation : electrons or X rays

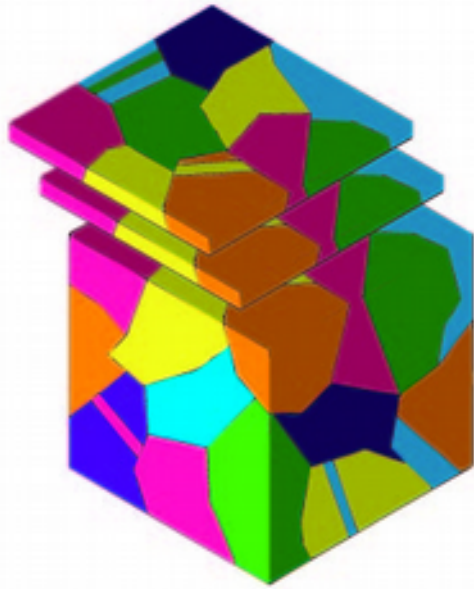


Reflexion, emission or scattering Acoustic waves, magnetic field, X rays

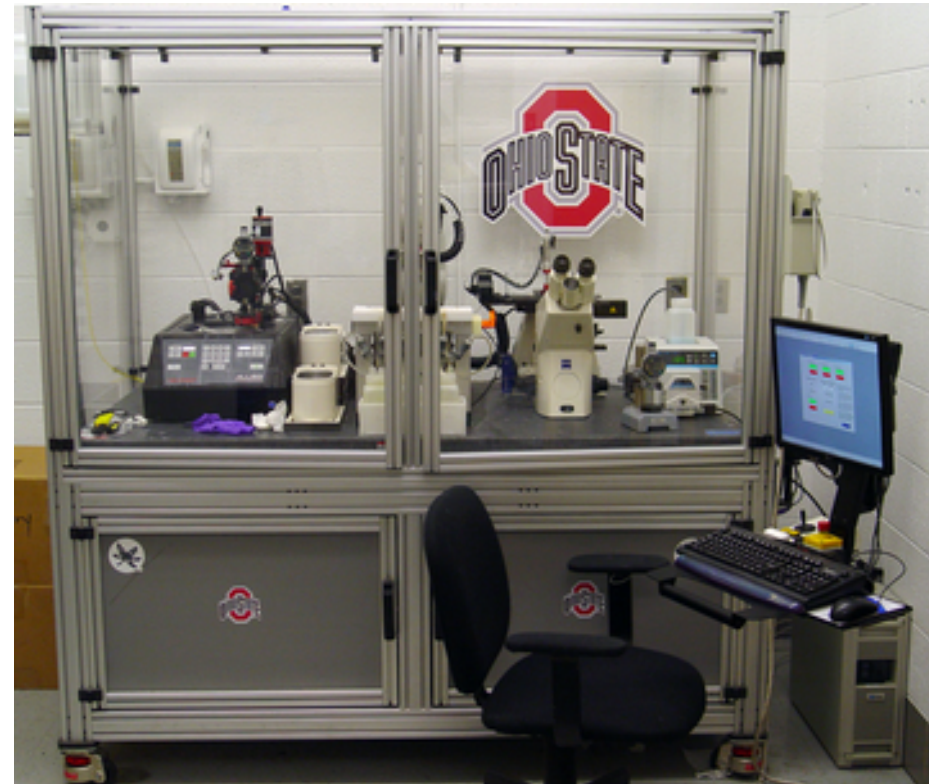


Dispositifs automatiques commerciaux

- Polissage + microscope optique



ROBO-MET.3D™
A UES PRODUCT



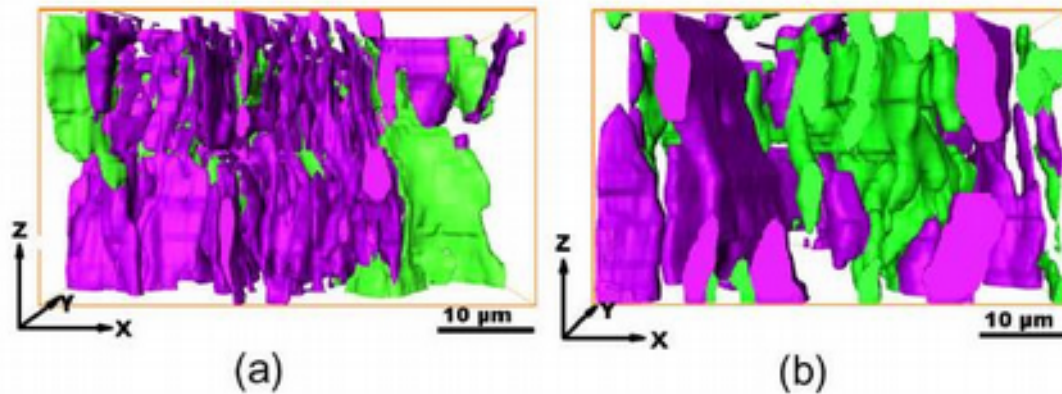


Fig. 5. 3D reconstruction of Si (purple) + aluminides (green) structure of AlSi12Ni alloy by LOT in (a) AC composed by 0.5 μm slices in a volume with $X = 51.75 \mu\text{m}$, $Y = 48.80 \mu\text{m}$ and $Z = 14.50 \mu\text{m}$; (b) ST of 0.6 μm slices in a volume with $X = 51.75 \mu\text{m}$, $Y = 48.80 \mu\text{m}$ and $Z = 16.50 \mu\text{m}$ conditions.

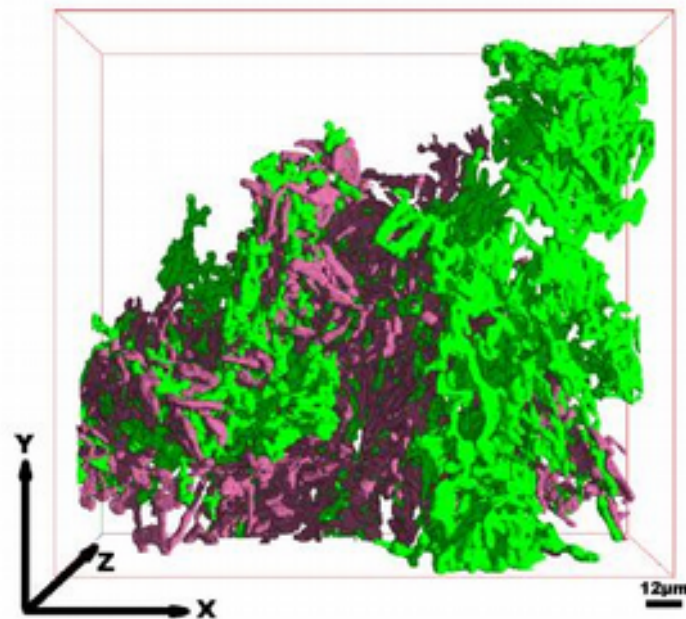
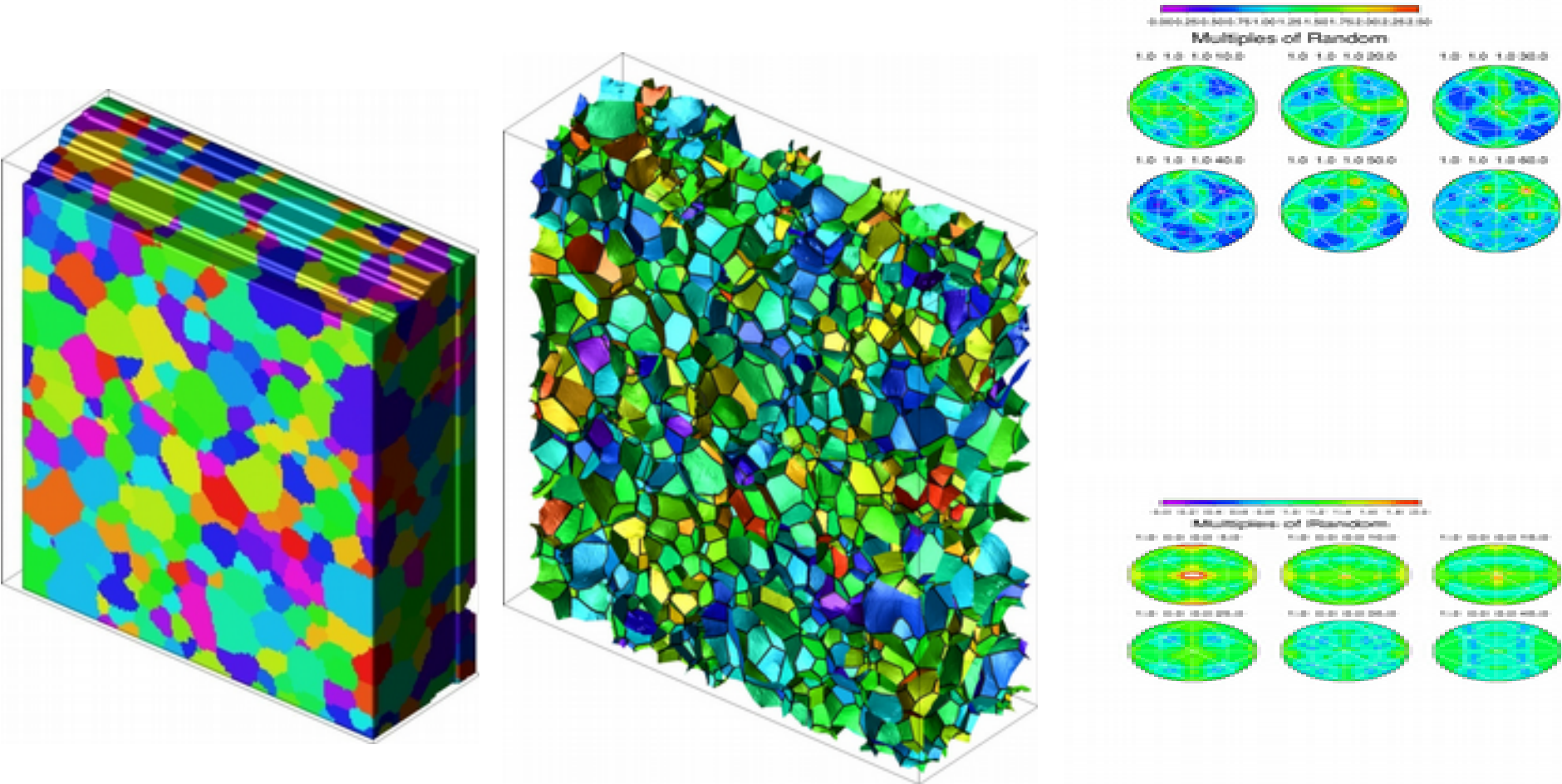


Fig. 8. Largest particle of Ni aluminides (green) + Si (purple) in ST condition reconstructed from the same sXCT volume as shown in Fig. 7 demonstrating the interpenetration of the two phases.

Zircone stabilisée à l'yttrium



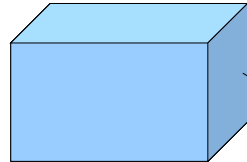
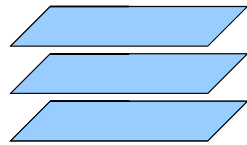
Reconstruction and smoothing by Sukbin Lee
Lee, Dillon, Rollett, Rohrer, *Microscopy and Microanalysis* 2007

Dissolution sélective

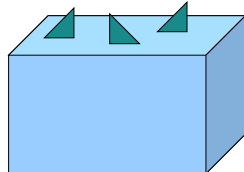
Destructive methods

Successive abrasion of layers

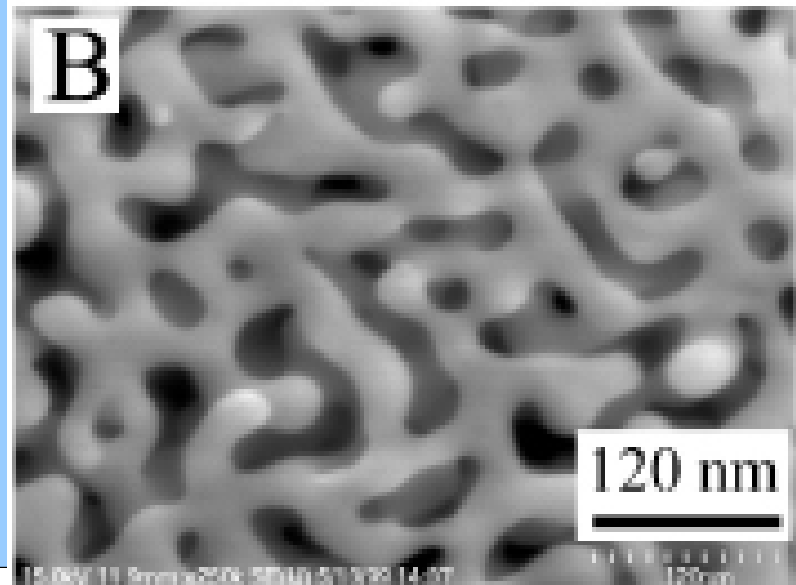
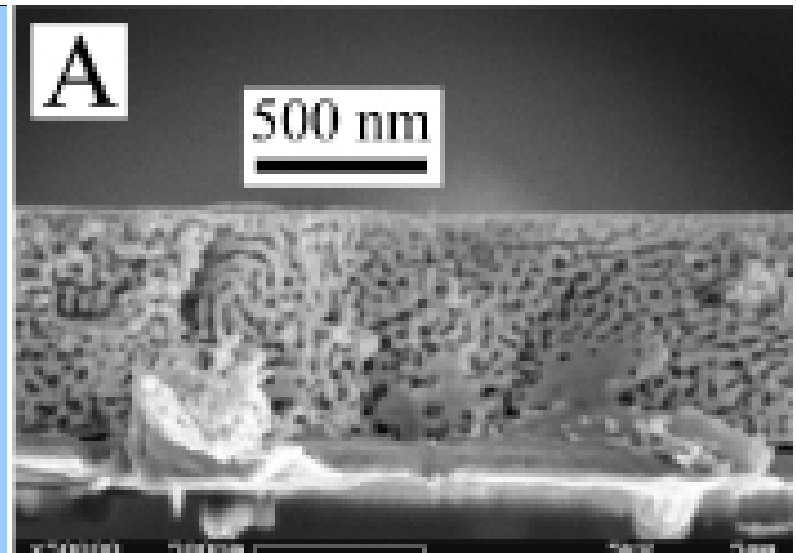
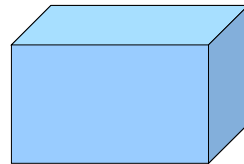
- mechanical polishing
- ion milling



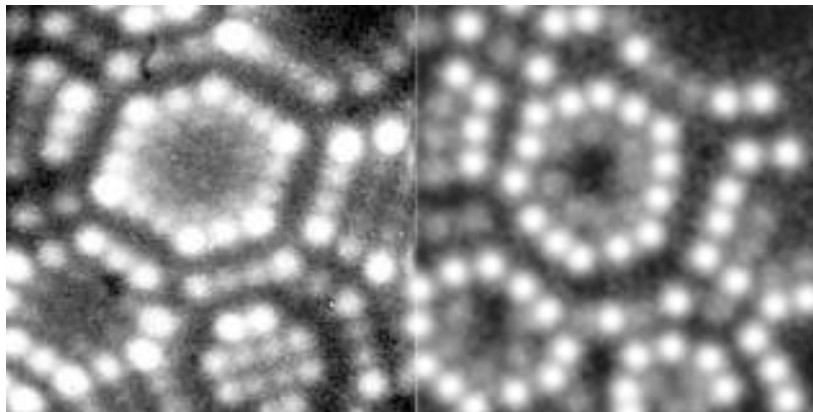
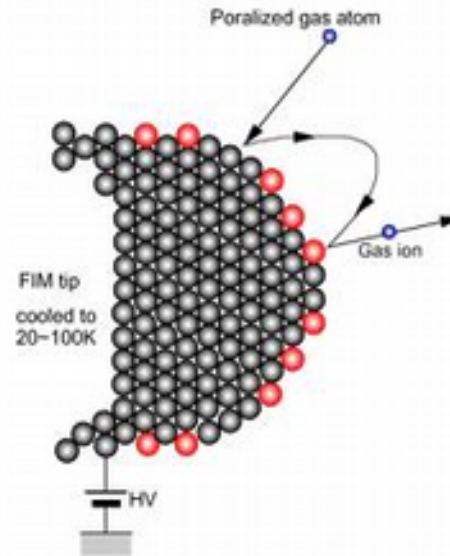
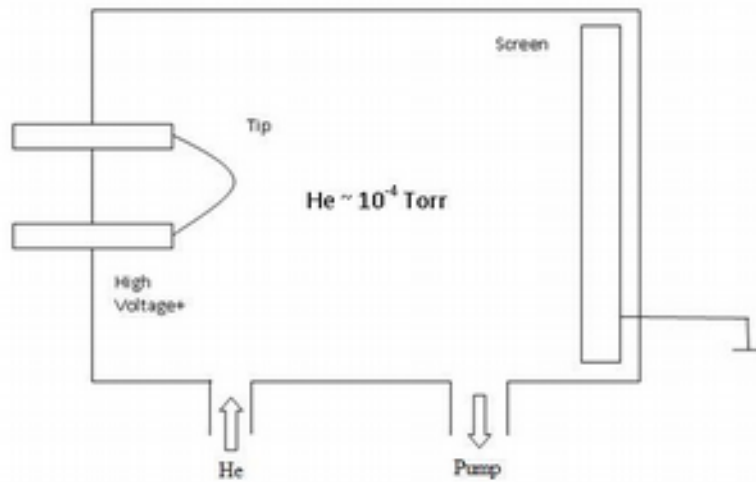
**Selective
dissolution**



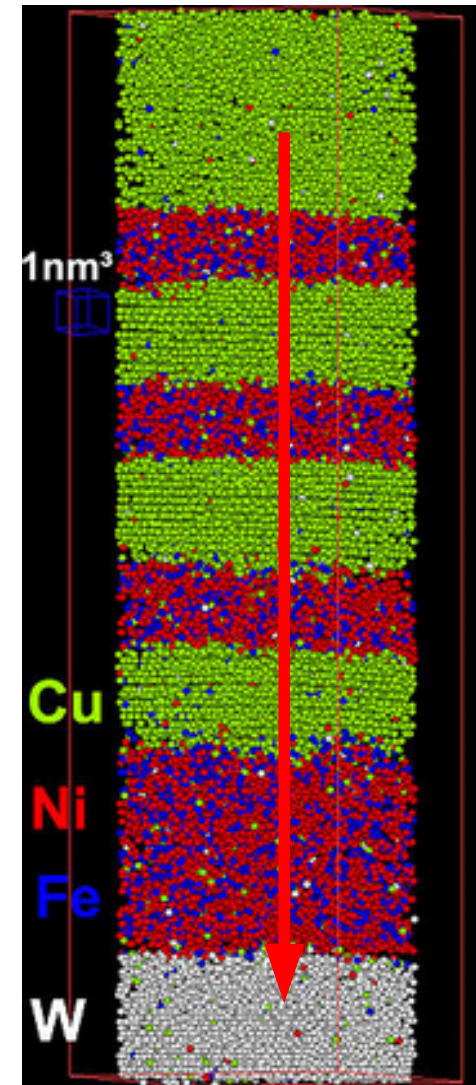
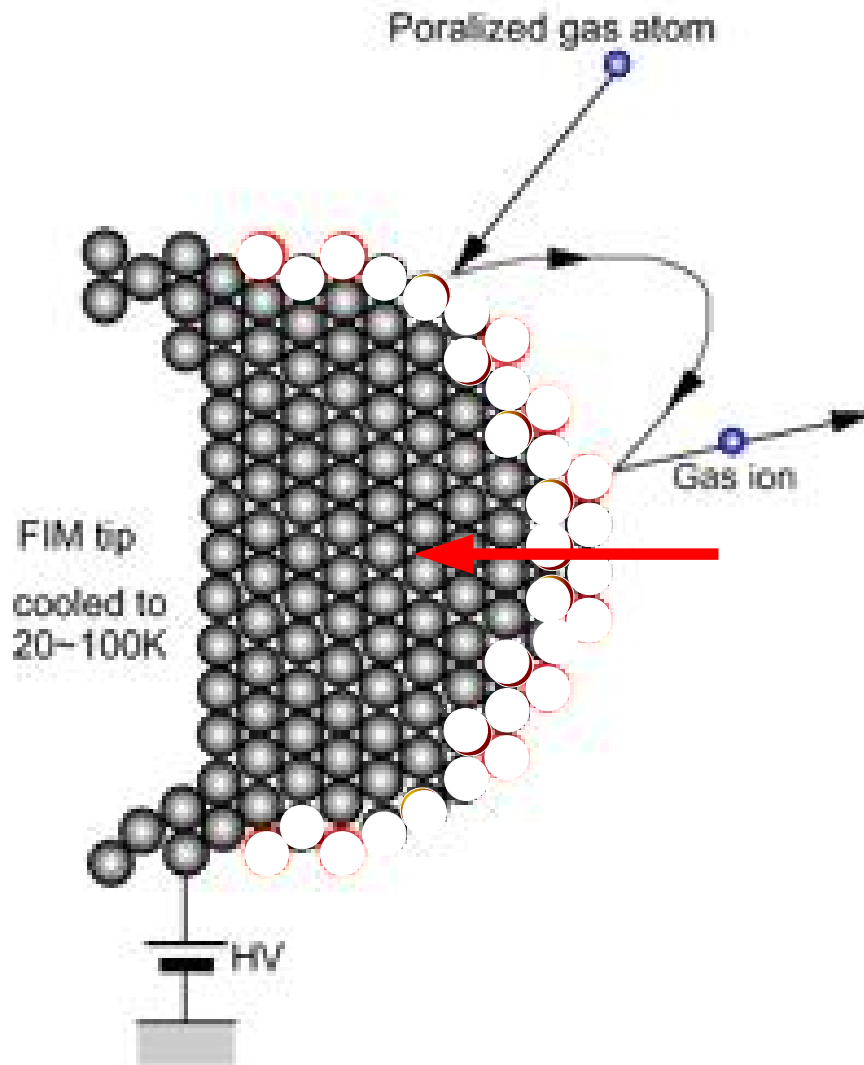
+ Imaging
ex situ : OM,
SEM
or in situ : SEM,
ion, atome
probing



Enlever des couches (polir) à l'échelle **atomique** Microscopie ionique



Polissage ionique : Sonde Atomique Tomographique



Bilan

- Une vue 3D de l'intérieur de l'échantillon
- A différentes échelles (y compris atomique)
- Mais
 - Destructif
 - Ne permet pas de suivre une évolution sous chargement

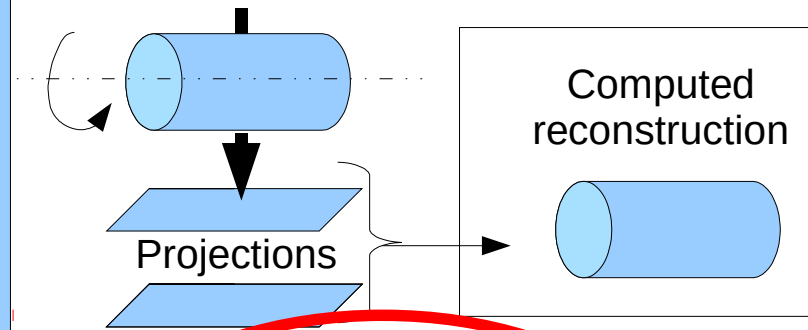
Imagerie 3D non destructive

Radiation qui pénètre, interagit et ressort en quantité suffisante

Méthodes NON DESTRUCTIVES (permettent les suivis in situ)

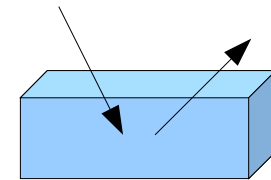
Non destructive methods

Transmission + rotation :
electrons or X rays



**Reflexion, emission or
scattering**

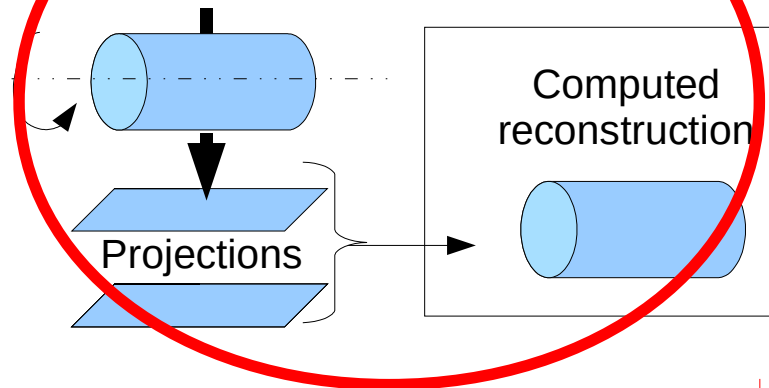
Acoustic waves, magnetic
field, X rays



Techniques en Transmission / Rotation

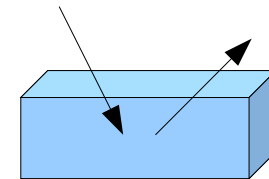
Non destructive methods

Transmission + rotation :
electrons or X rays



Reflexion, emission or scattering

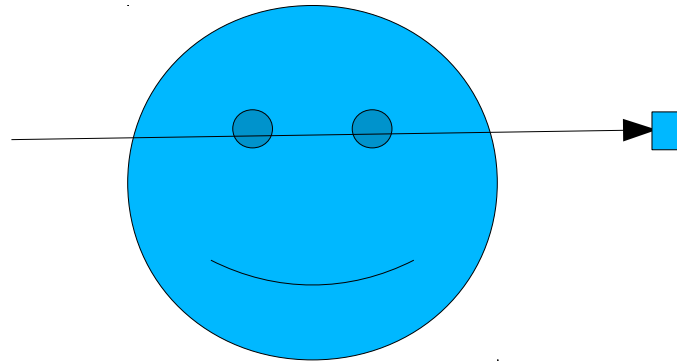
Acoustic waves, magnetic field, X rays



Tomographie par projection/rotation (+reconstruction)

- Combine l'information de PLUSIEURS radiographies pour reconstruire la carte 3D de la valeur de μ

Vue du dessus :

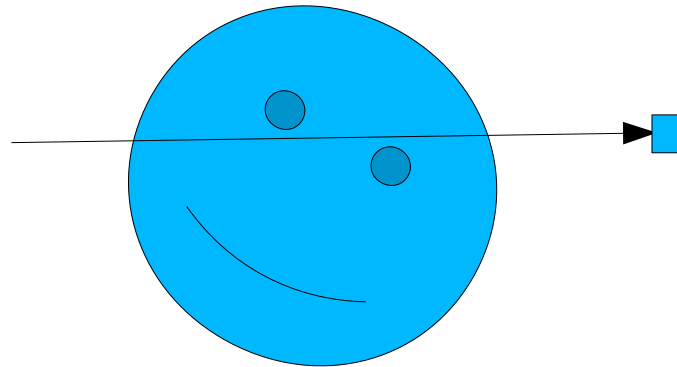


En radio, on mesure l'intégrale de μ
Ce qu'on souhaite c'est recalculer la valeur de μ le long du trajet

Tomographie par projection/rotation (+reconstruction)

- Combine l'information de PLUSIEURS radiographies pour reconstruire la carte 3D de la valeur de μ

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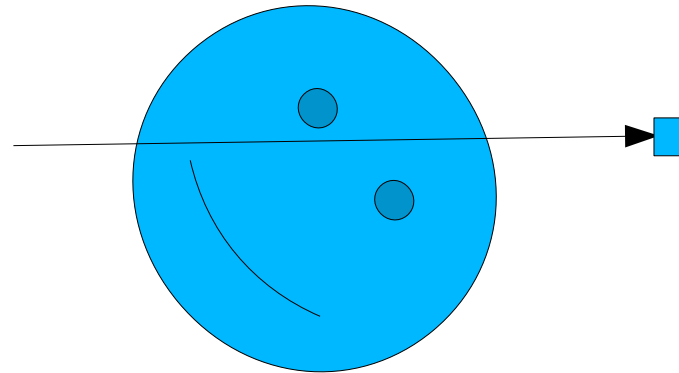


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Tomographie par projection/rotation (+reconstruction)

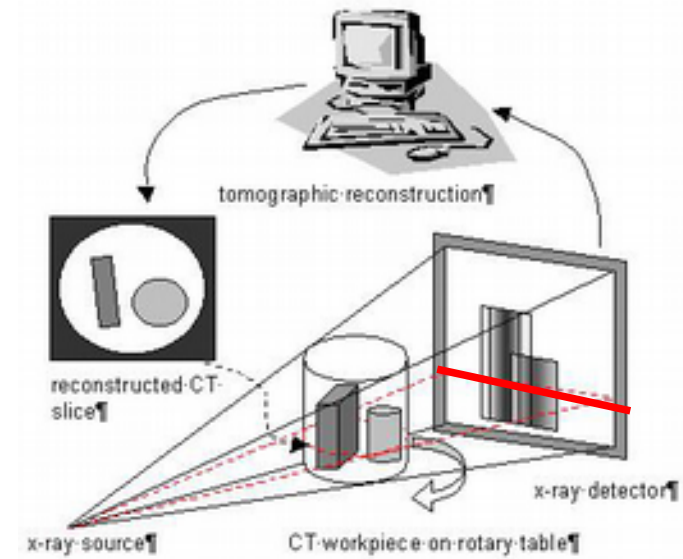
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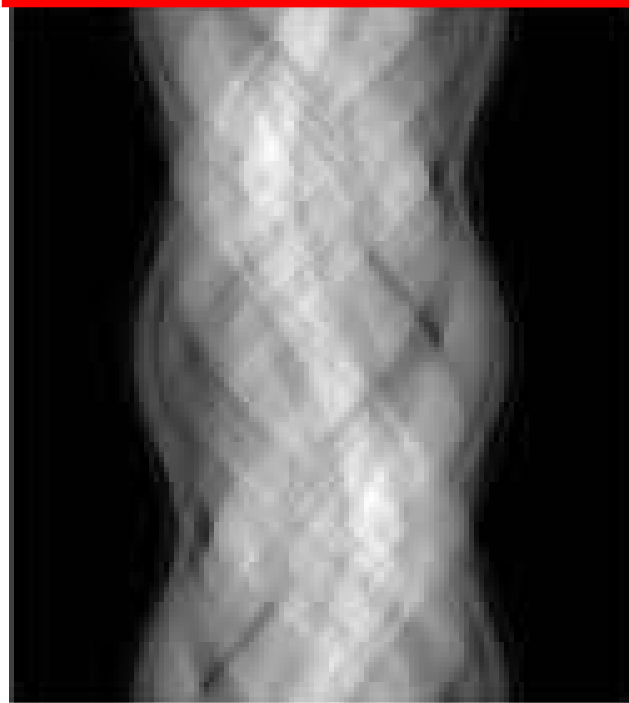


En radio, on mesure l'intégrale de μ
Ce qu'on souhaite c'est recalculer la valeur de μ le long du trajet

Il y a une étape informatisée (reconstruction)

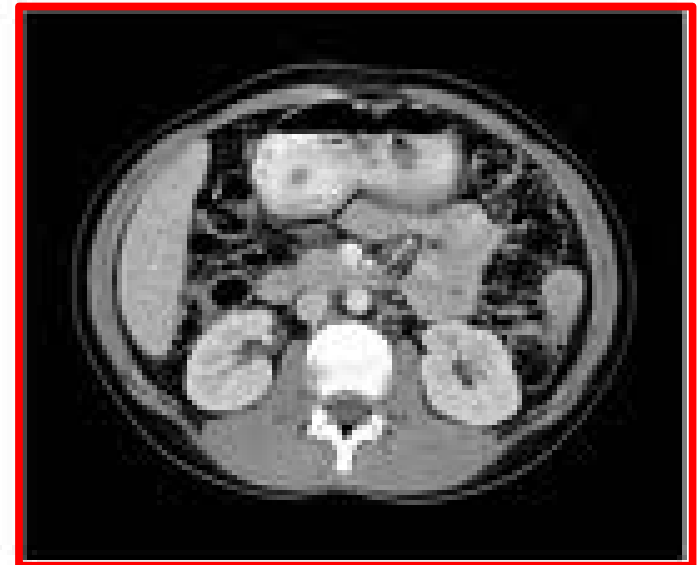


Sinogram



angle

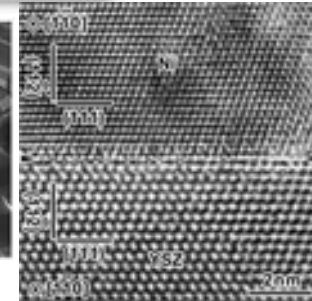
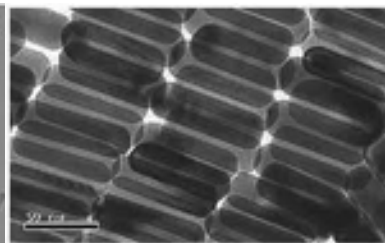
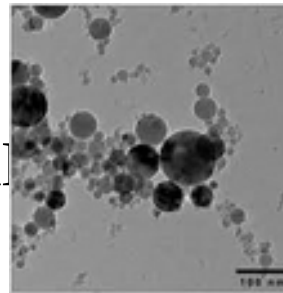
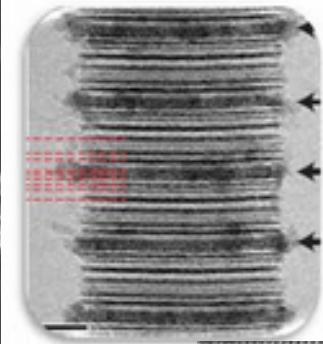
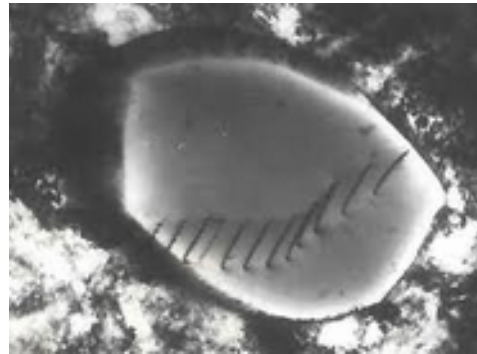
Reconstruct



The result is a 2D map of μ

Avec des électrons

- Microscopie électronique en transmission
- Quelques problèmes :
 - Absorption
 - Il faut des échantillons minces
 - Diffraction
 - On peut utiliser l'HAA
 - Ou l'imagerie en perte d'énergie (EELS)
 - Angles qui manquent
- Cf P. Midgeley, T. Epicier



Neutrons

- Pénètre, interagit, peu absorbé
- Diffraction
- Imagerie : radio/tomo
- Mais faible flux des sources
- Basse résolution, mauvais détecteurs
- **Très utile pour les matériaux très absorbants**

P. Vontobel et al. / Physica B 385–386 (2006) 475–480

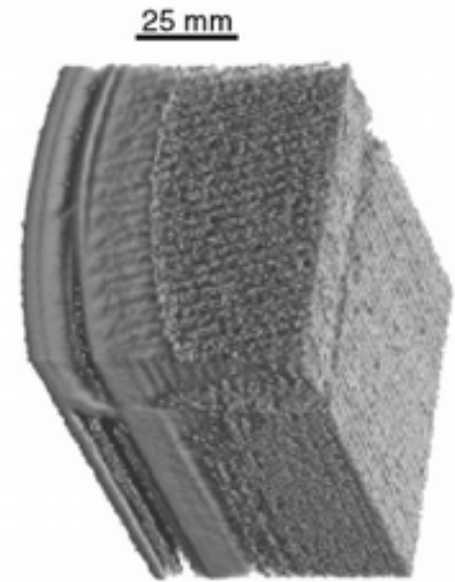
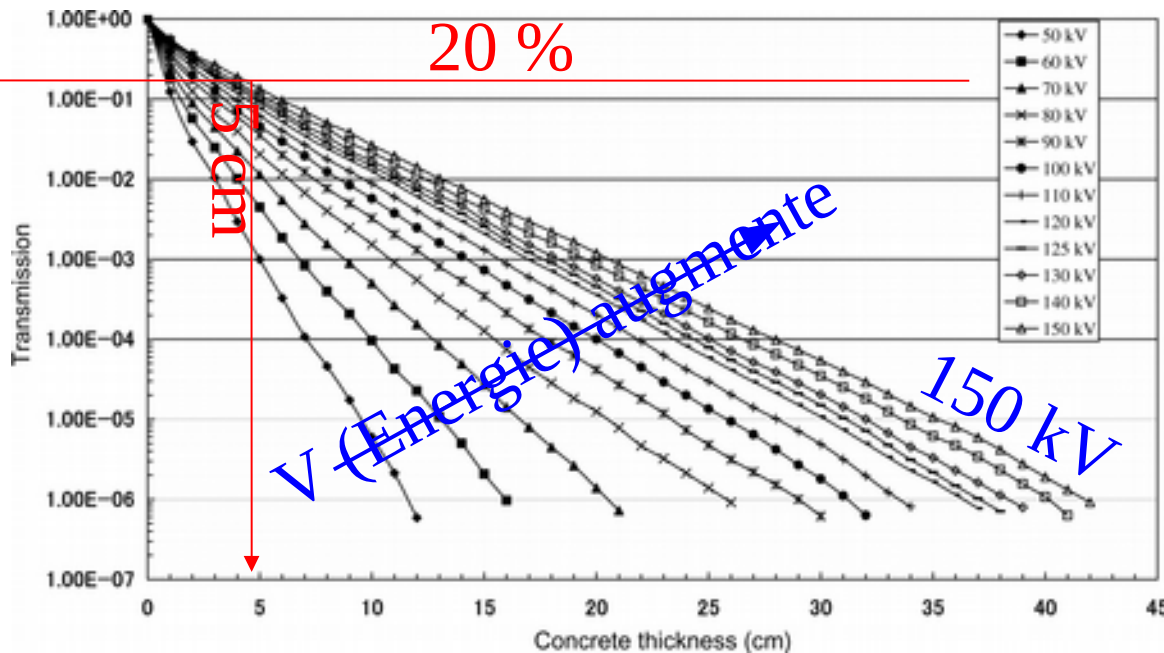


Fig. 6. Section of soot filter from diesel engine.

Projet NEXT Grenoble

Imagerie aux rayons X

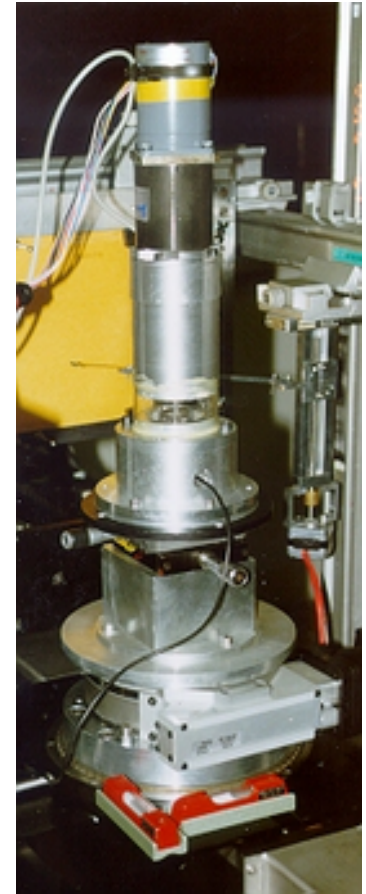
- Limité en termes de résolution (moins bien que le MEB... 10 nm actuellement)
- Mais on peut traverser des échantillons épais
 - Transmission à travers des échantillons opaques



- Accès à de l'information profenant du volume du matériau
- Intéressant particulièrement pour :
 - L'étude de l'endommagement (effets de surface)
 - Les matériaux à microstructure complexe (mousses, laines, etc)...

In Situ / Ex situ

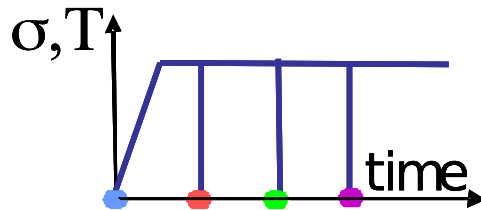
- In situ : observation en même temps que sollicitation
 - Nécessite des machines spéciales
 - MEB in situ
 - Tomographie in situ (rotation de 180° sans masquer le faisceau)
 - Idéal pour interpréter
 - Mais échantillons petits ...
- Ex situ :
 - Le même échantillon (en surface)
 - En volume : destructif : différents échantillons



Plusieurs façon d'étudier l'effet d'une sollicitation

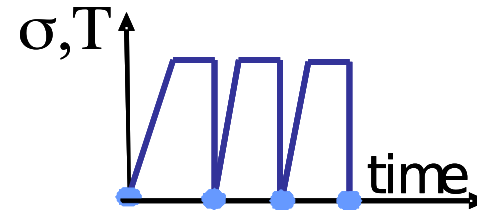
Quelle que soit la méthode d'observation

Post mortem



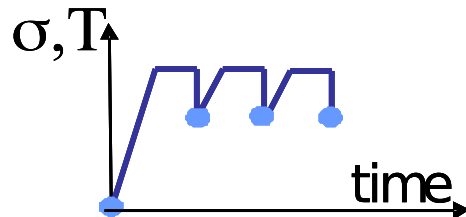
Several samples
Tomography at RT

Ex situ



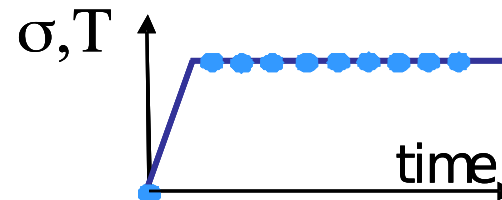
One sample
Treatment out of the tomograph
Tomography at RT

Interrupted in situ



One sample
Treatment carried out
on the tomograph

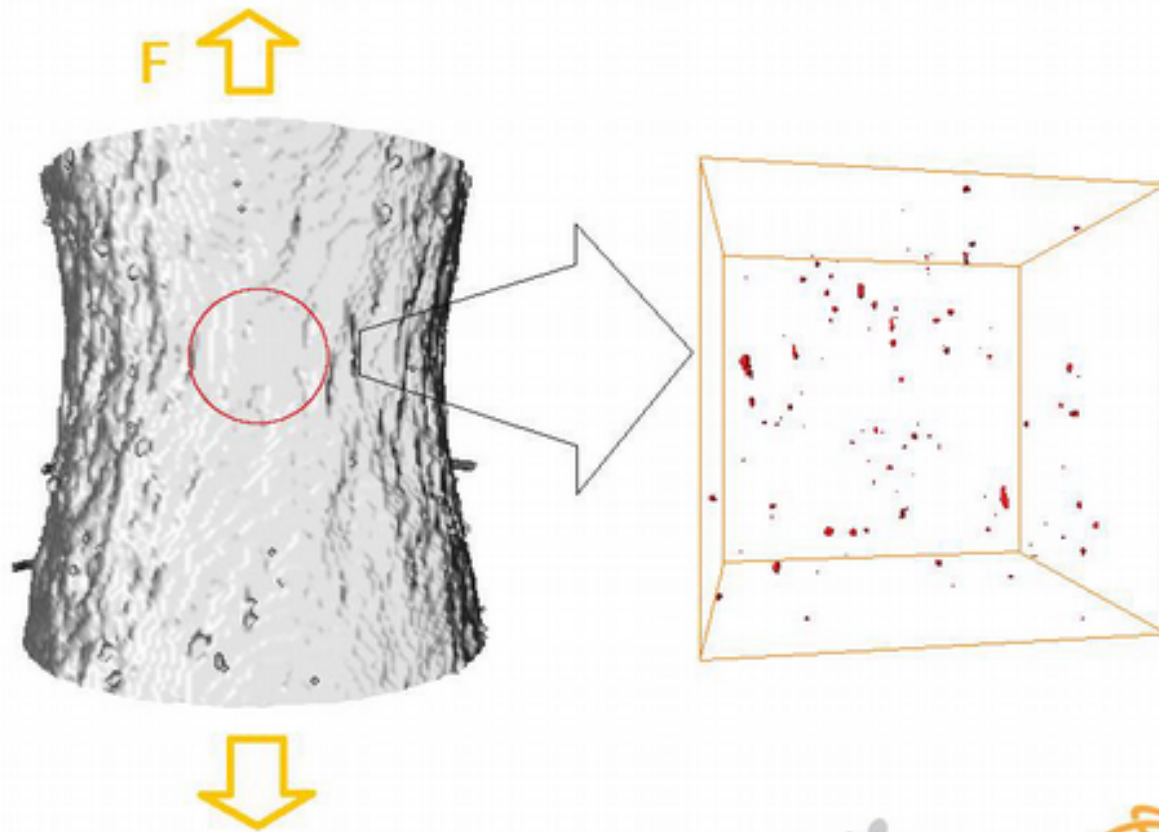
Continuous in situ



One sample
Treatment carried out
on the tomograph
No interruption

Résultat d'un test de traction in situ

Ferrite



Essais in situ en tomographie RX

Un tomographe



ID15 fast acquisition
ID22 Very high
resolution

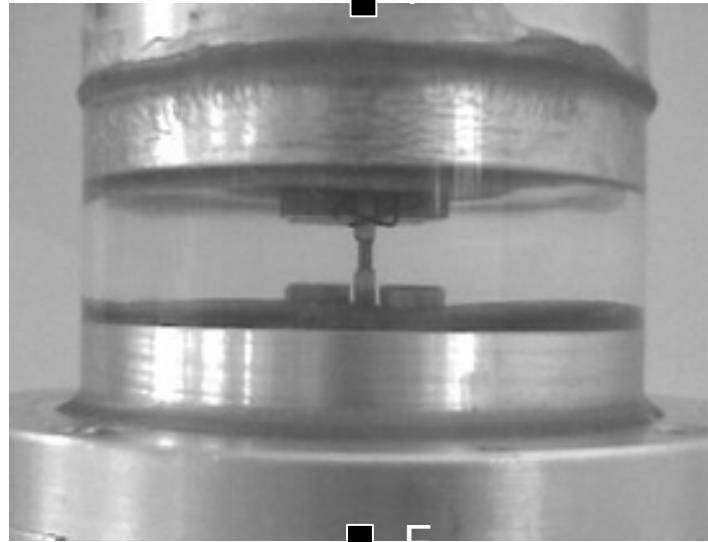
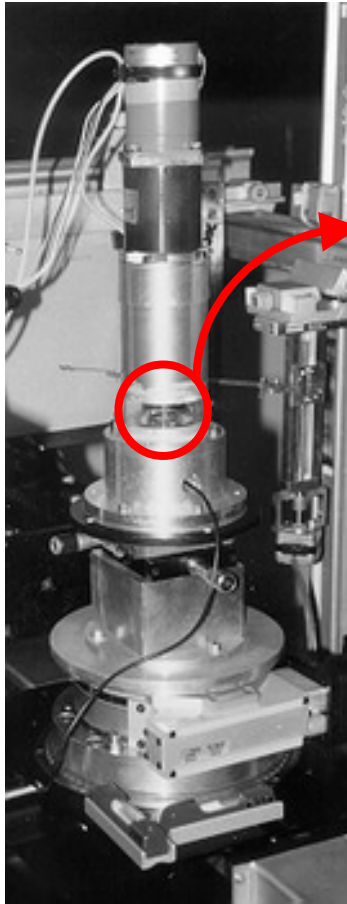
APS
BNL
Berkeley

Une machine de sollicitation

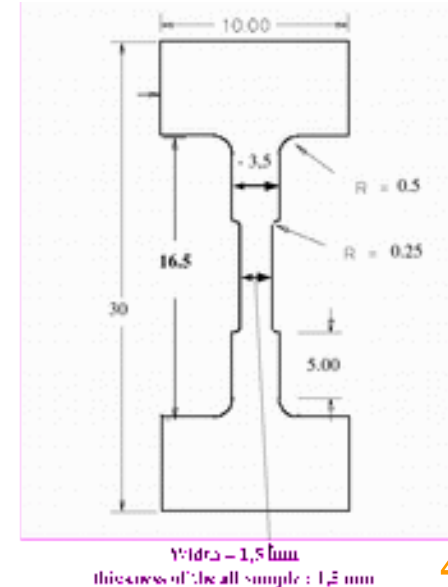
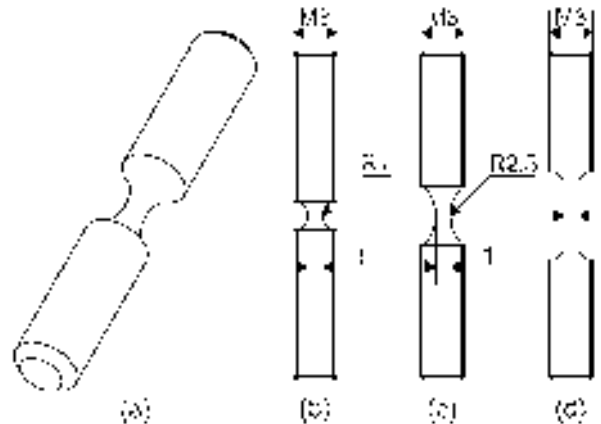
- Tension, compression

Buffière et al. Acta Mater 1998

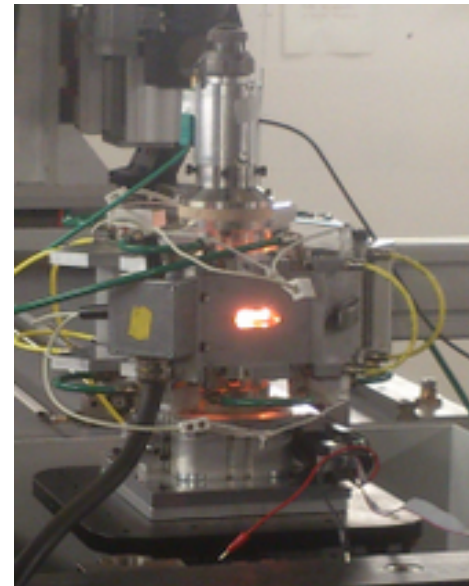
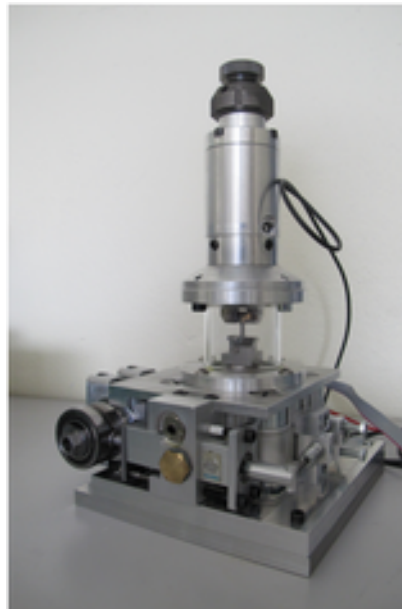
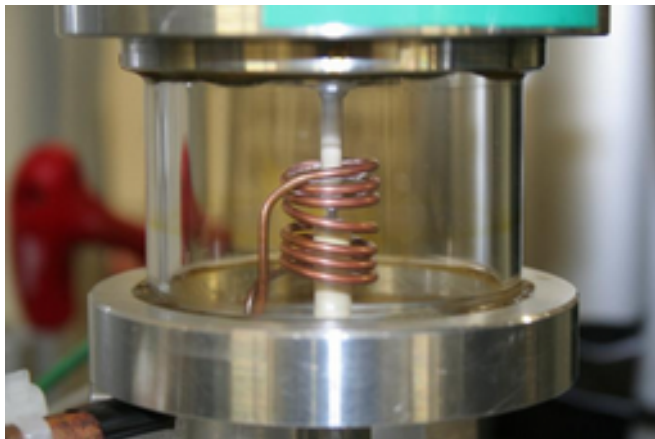
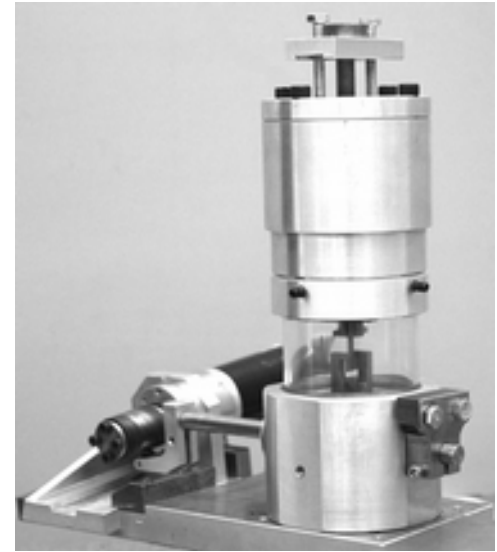
Buffière et al Exp Mech 2009



- Stepping motor
- Reductor
- F and disp recorded
- $10^{-5} - 1$ mm/s
- Several Force sensors :
50 – 5000 N
- Grips adapted for
different geometries

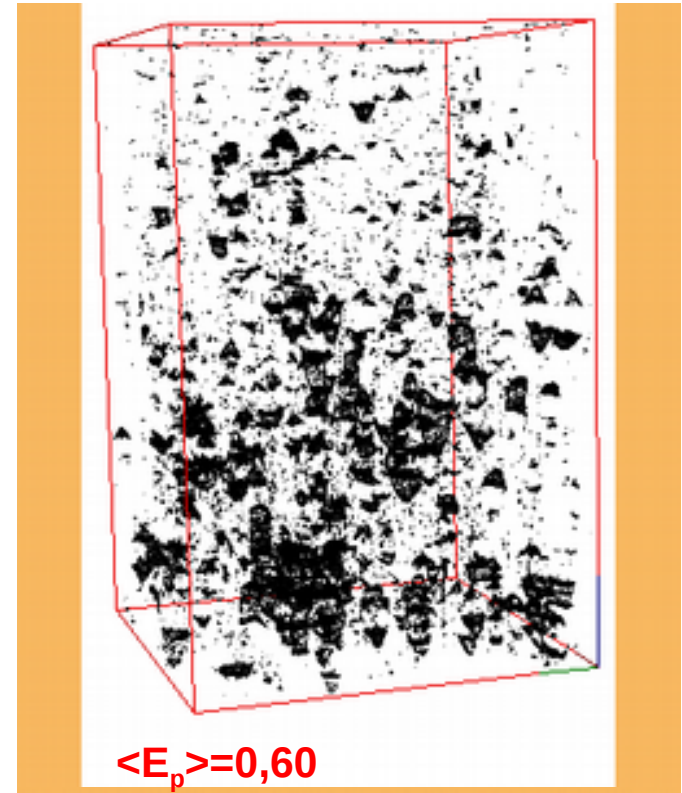
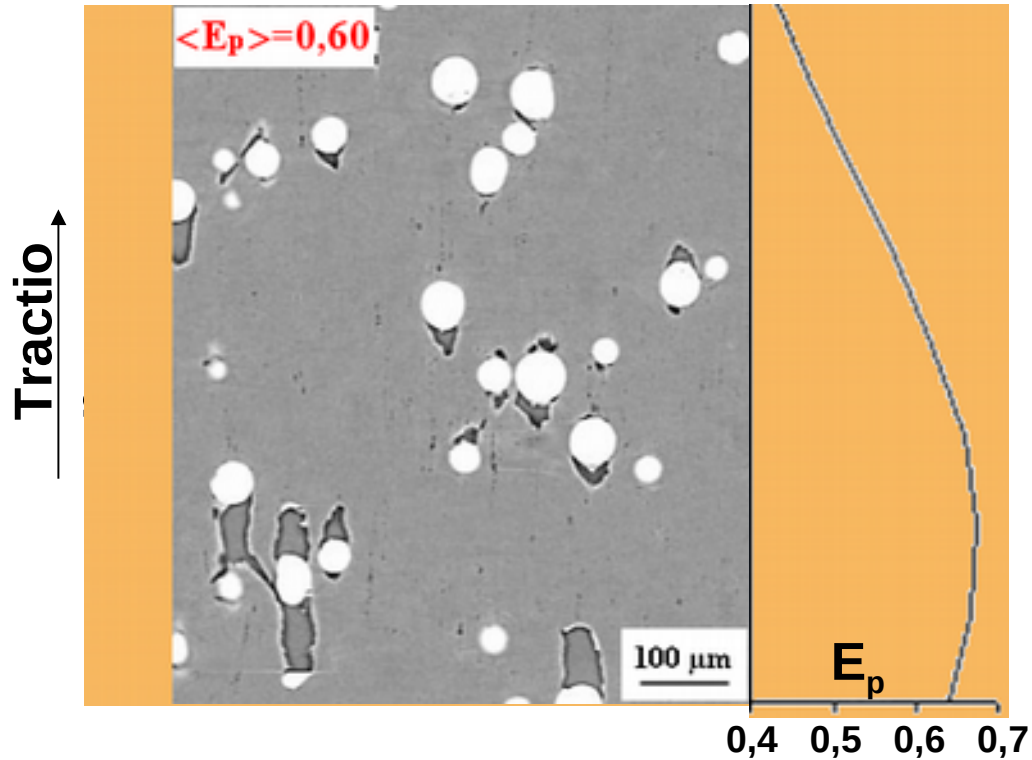


Ou plusieurs



Systemes matrice molle

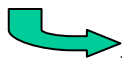
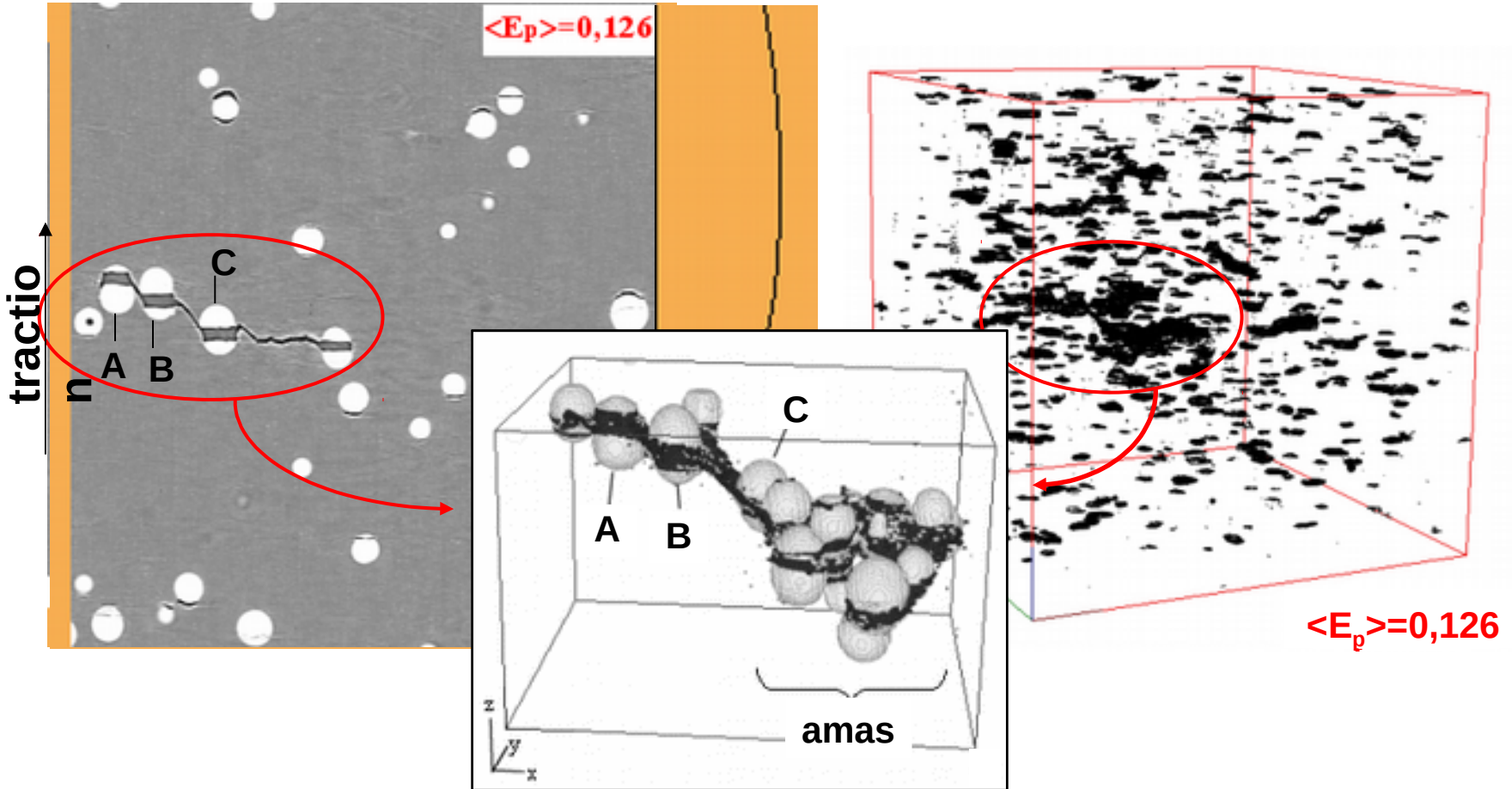
Exemple qualitatif : Al + 4% ZS



Mode d'amorçage préférentiel : DECOHESION par TRACTION

- **Systemes matrice dure**

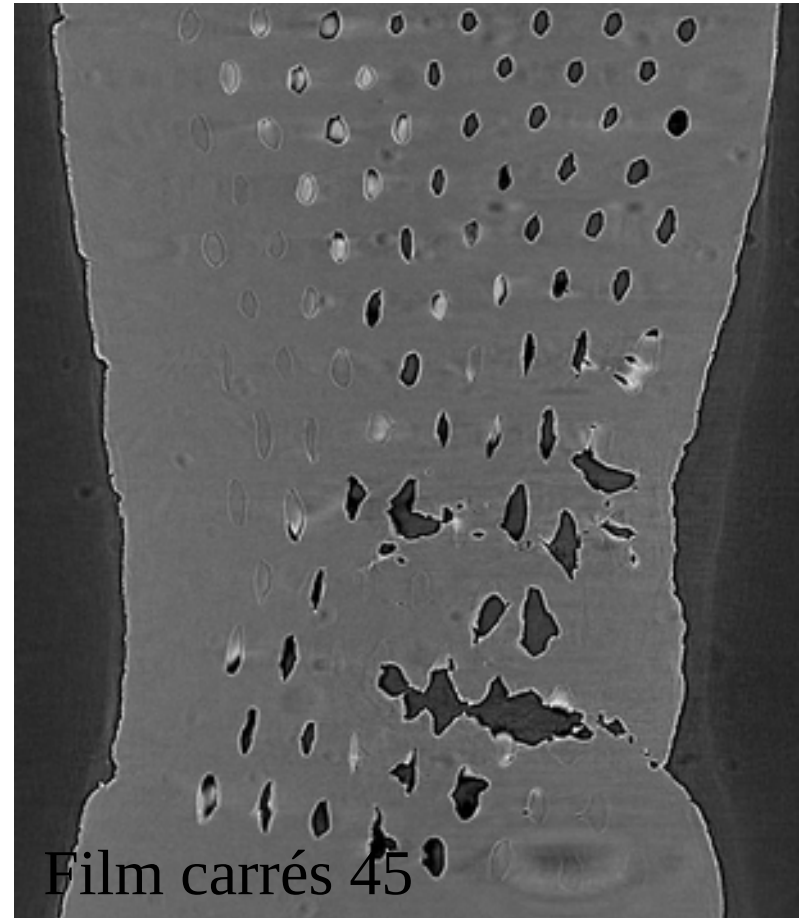
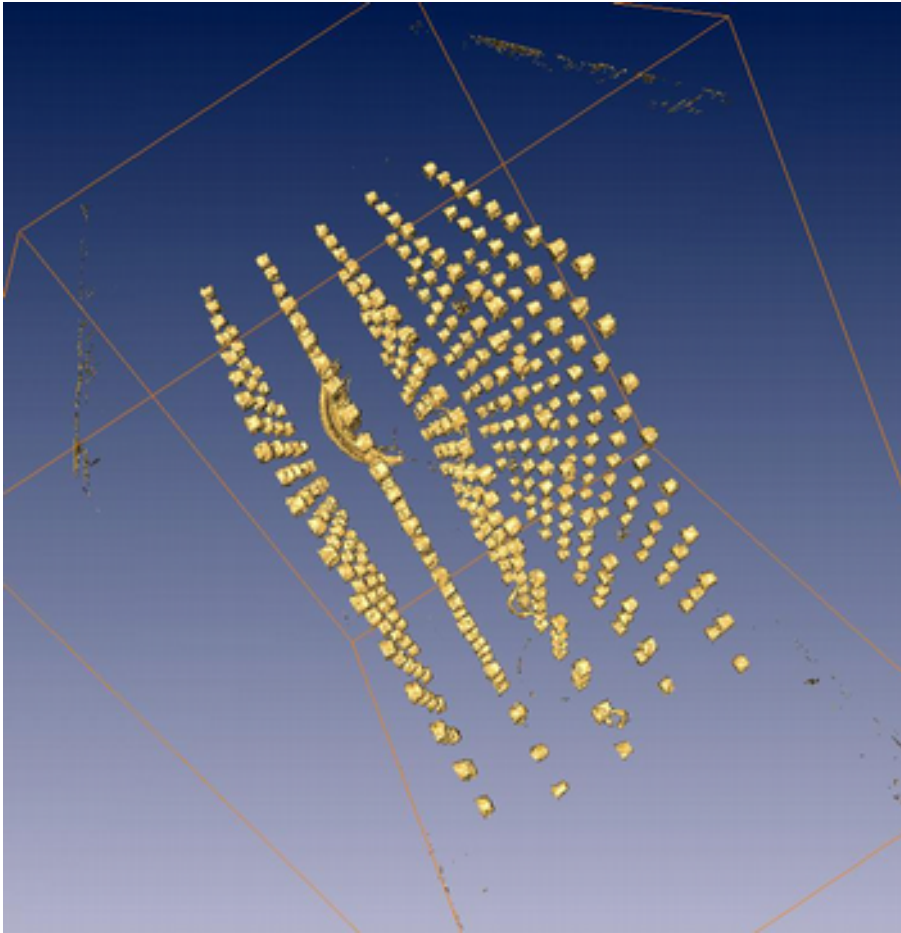
exemple qualitatif : Al2124(T6) + 4%ZS



Mode d'amorçage préférentiel : RUPTURE particules mode I

Weck *et al* sur la coalescence

Trous contrôlés :



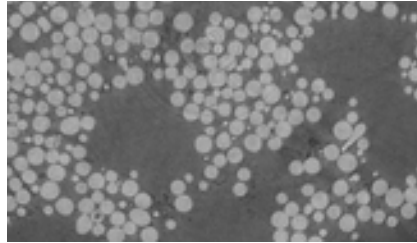
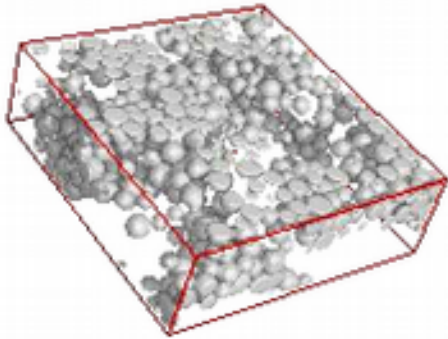
○
Film carrés 0°
Film aléatoire

Quantification de l'endommagement ductile

A mesurer pour l'endommagement

- Mesure de f :

Mesures directes sur images 2D, voire 1D ou 0D



- $f_{0D} = f_{1D} = f_{2D} = f_{3D}$

- A condition que le nombre d'échantillons soit grand

- N

- Taille, forme

- Si forme simple (disque, ellipse)

- Taille 3D = $A * \text{Taille 2D}$ [A=f(forme), sphère : $4/\pi$]

- Si forme complexe (coalescence) il faut l'info 3D 54

Materials Steels, Ti and Al Alloys

Acta Materialia 61 (2013) 6821–6829

Experimental investigation of void coalescence in a dual phase steel using X-ray tomography

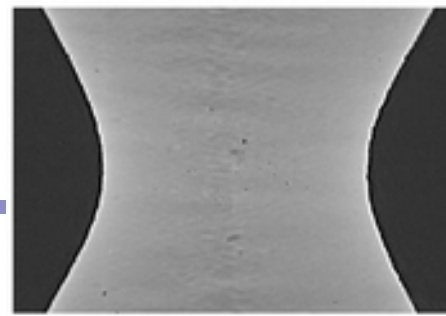
C. Landron^{a,b,1}, O. Bouaziz^{c,d}, E. Maire^{a,b,*}, J. Adrien^{a,b}

Engineering Fracture Mechanics 78 (2011) 2679–2690

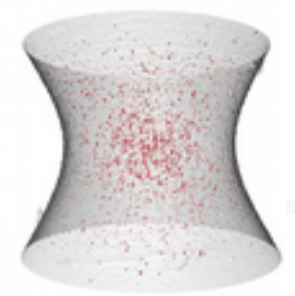
Damage quantification in aluminium alloys using in situ tensile tests in X-ray tomography

Eric Maire^{a,*}, Suxia Zhou^b, Jerome Adrien^b, Marco Dimichiel^c

Investigated steels



(a)



(b)

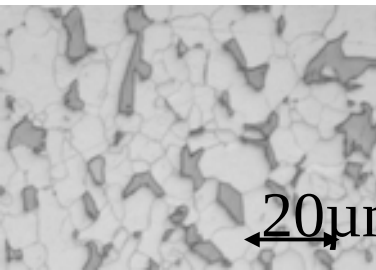
DP11

DP11T
T=400°C, t=30min

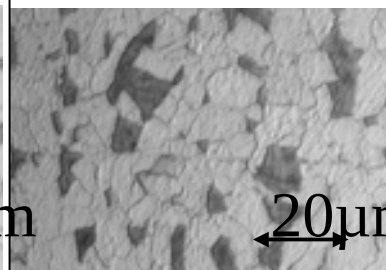
DP62

Ferrite

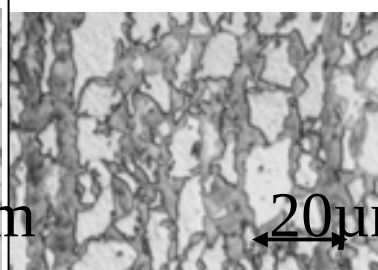
Martensite



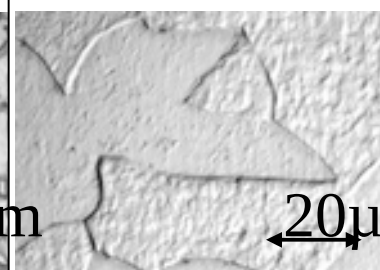
20μm



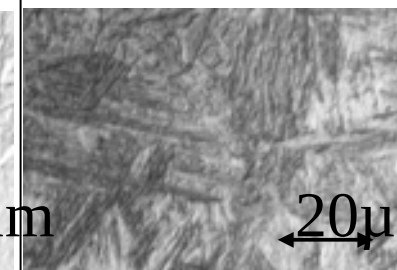
20μm



20μm



20μm



20μm

180 HV

180 HV 165 HV

315 HV

150 HV

330 HV

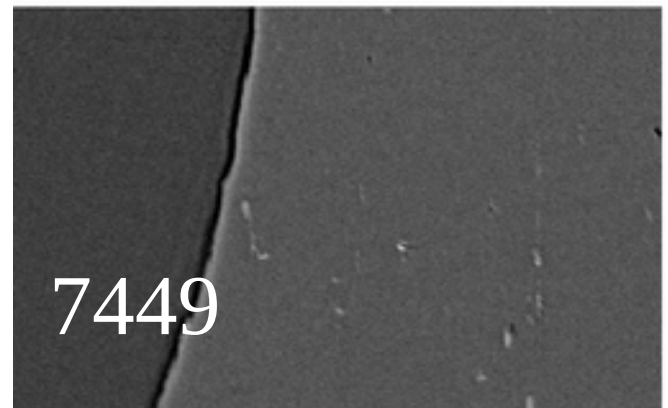
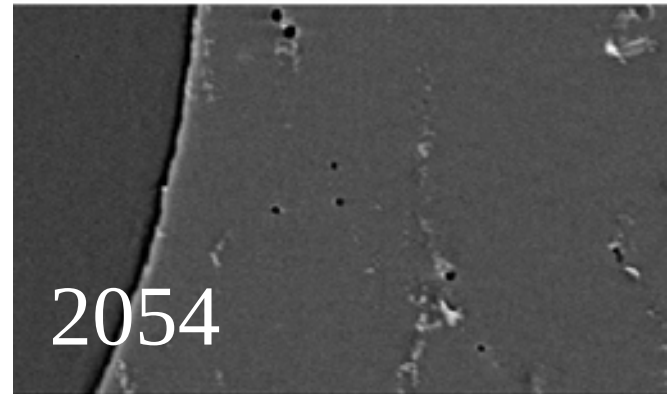
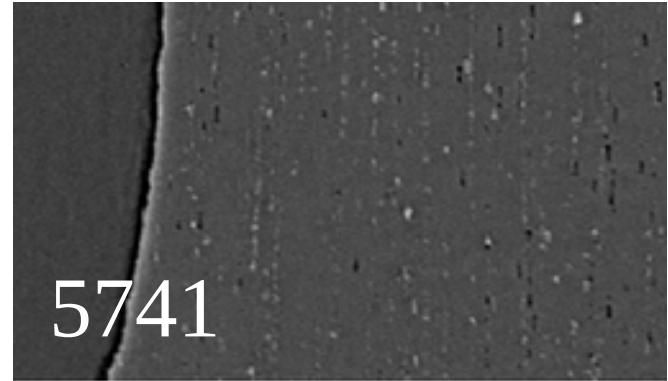
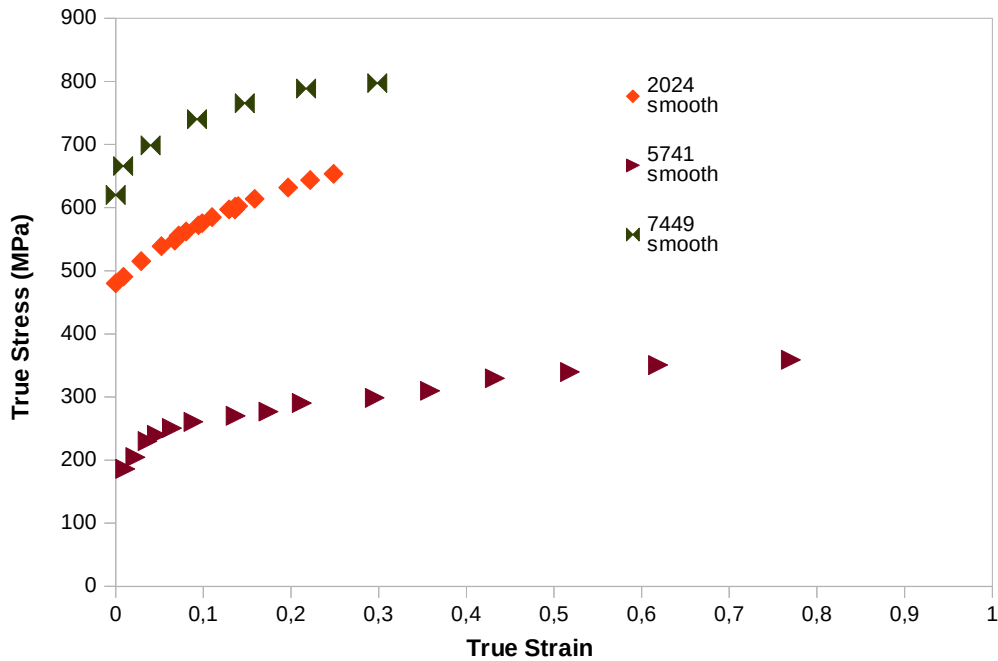
Volume fraction of martensite $F_M = 11\%$

Carbon content in martensite $C_M = 0.73\%$

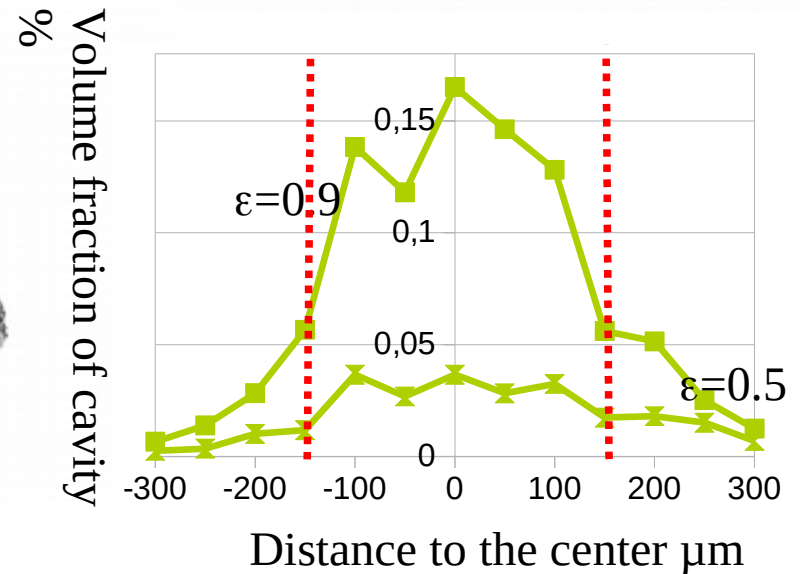
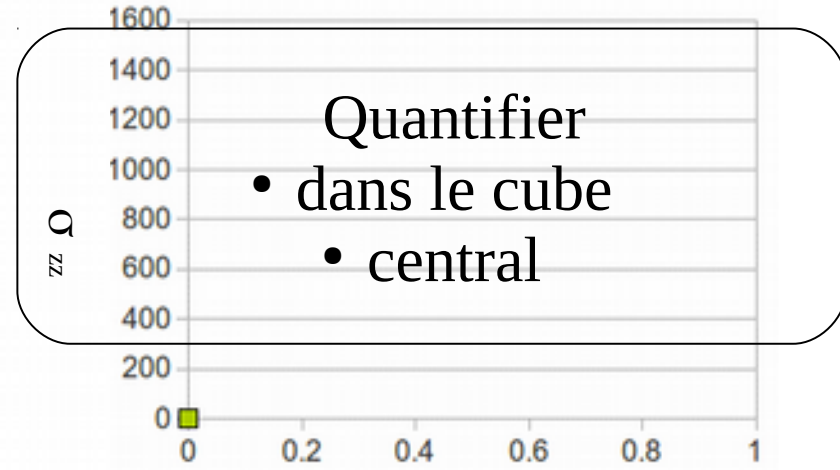
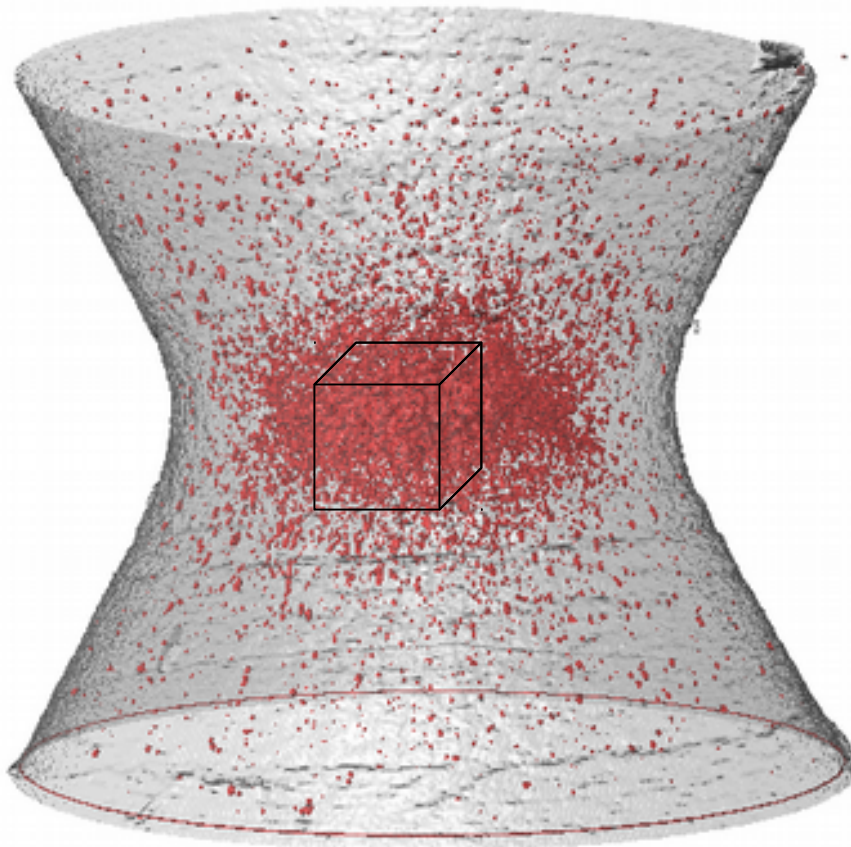
$C_M = 0.1\%$

Martensite hardness = 415 HV 830 HV 530 HV

Al Alloys



Deux choses : chgt de forme + endo

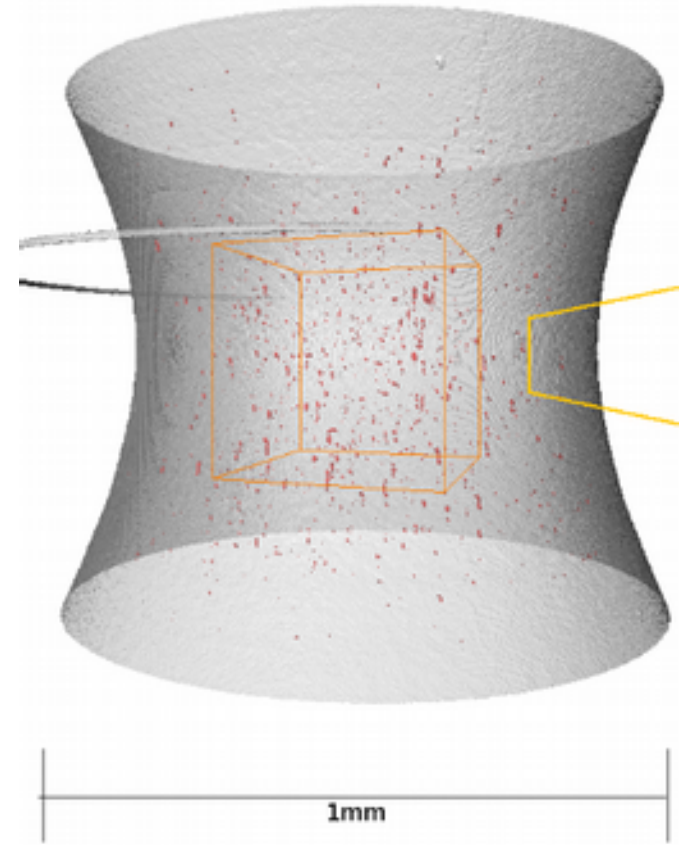
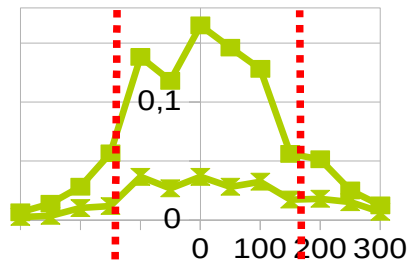


Quelques mesures macroscopiques préalables

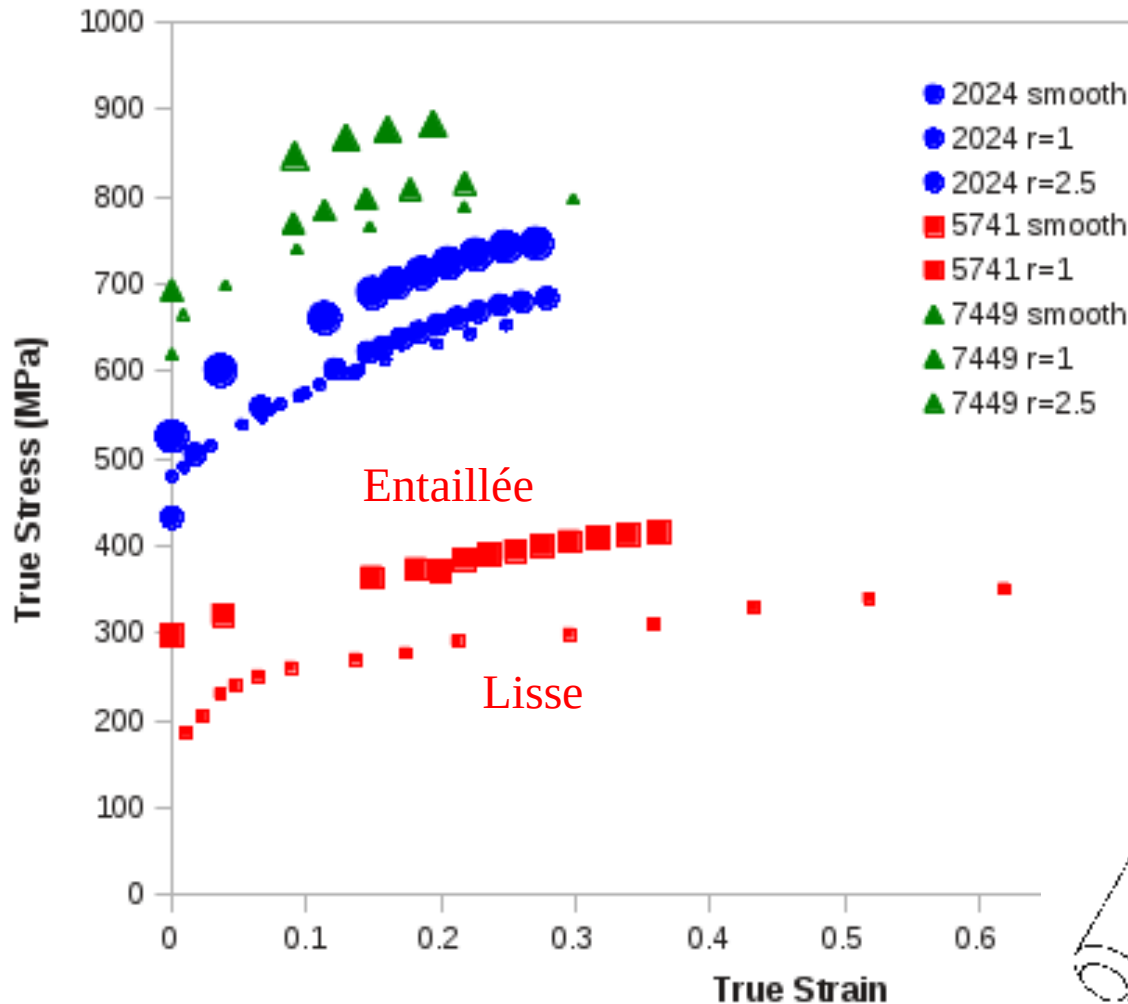
$$\varepsilon = \frac{S(z)}{S_0} - 1$$
$$\sigma = F/S$$

T =Bridgeman :

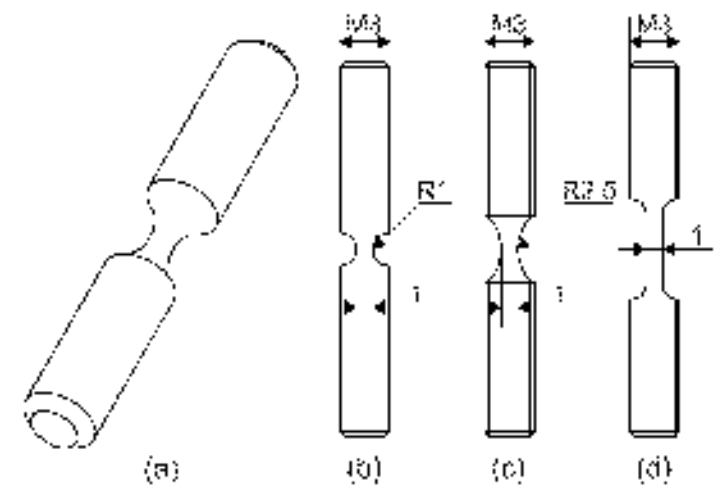
$$T = \frac{1}{3} + \sqrt{2} \ln \left(1 + \frac{r_{Section}}{2 R_{Notch}} \right)$$



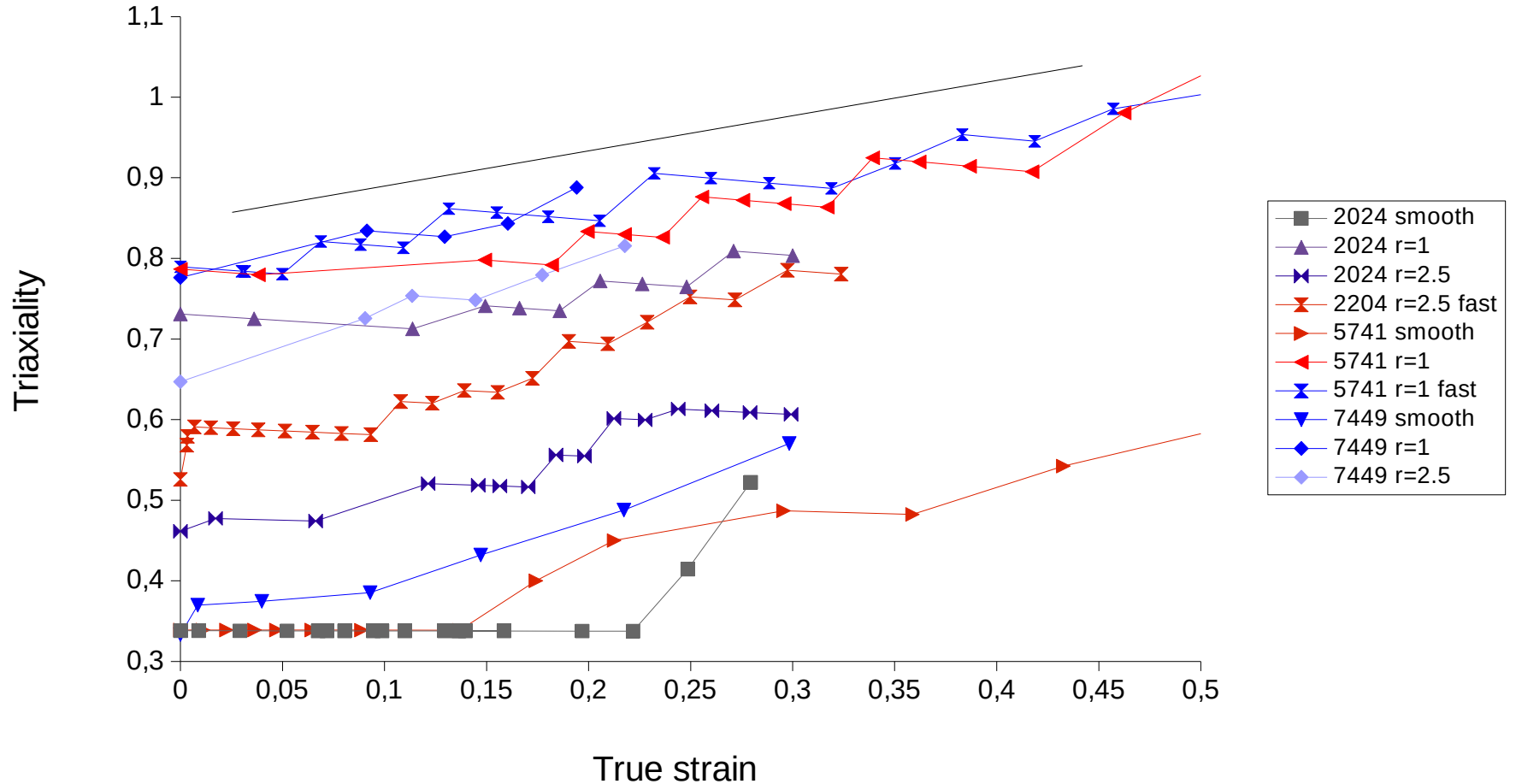
Mesure des courbes de traction



Échantillons entaillés :



Triaxialité



Material	Notch radius (mm)	σ_0 (MPa)	n	Strain to failure	T_0	s_t
5754	smooth	370	0.15	0.95	0.33	0.1
	1	500		0.55	0.44	
2024	smooth	730	0.1	0.3	0.33	
	2.5	750		0.31	0.37	
	1	840		0.3	0.44	
7449	smooth	860	0.06	0.3	0.33	
	2.5	900		0.22	0.37	
	1	980		0.19	0.44	

$$\sigma = \sigma_0 A \varepsilon^n$$

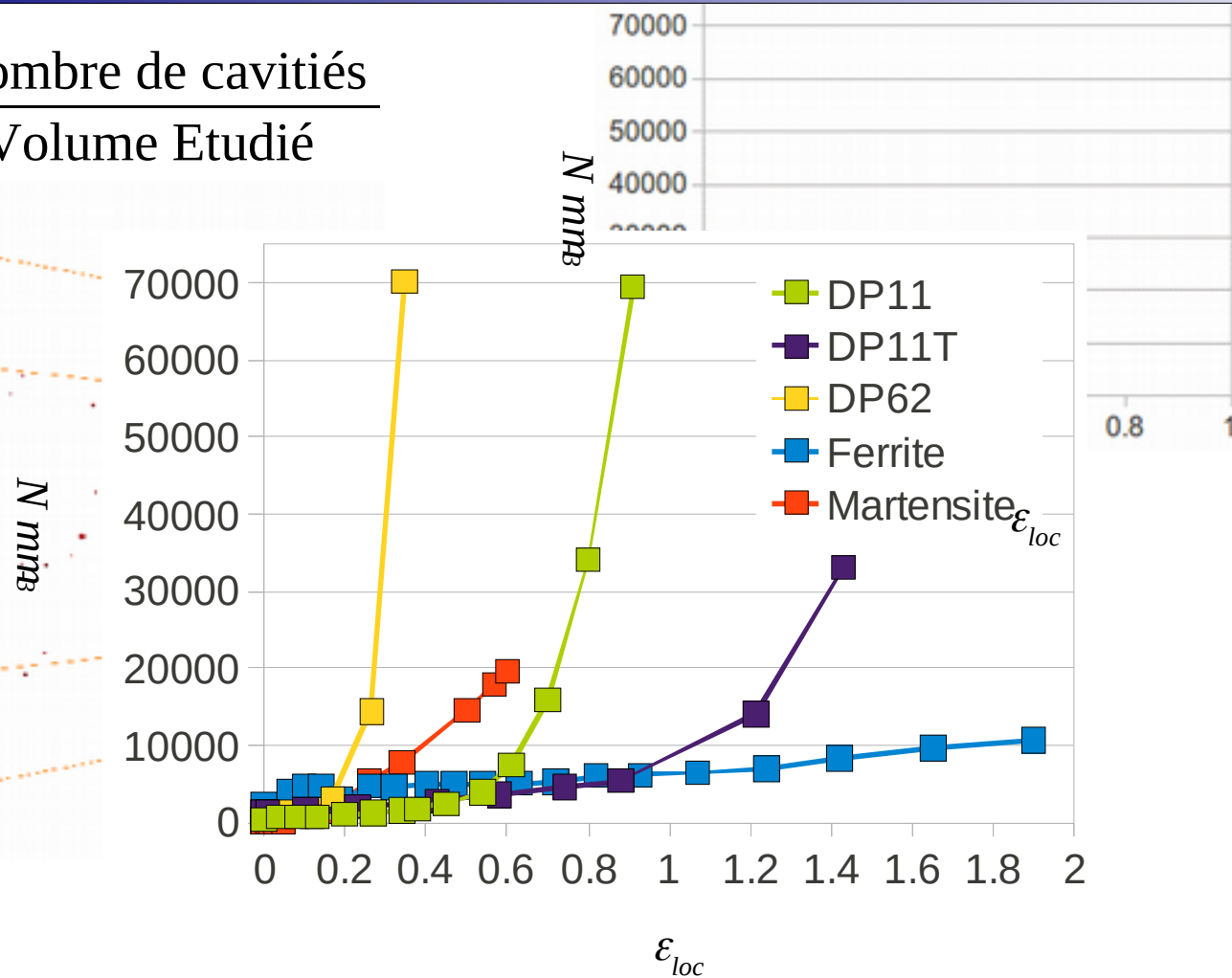
$$T = T_0 s_t \varepsilon$$

Amorçage

- Compter N (mm^3)

Quantification de l'amorçage

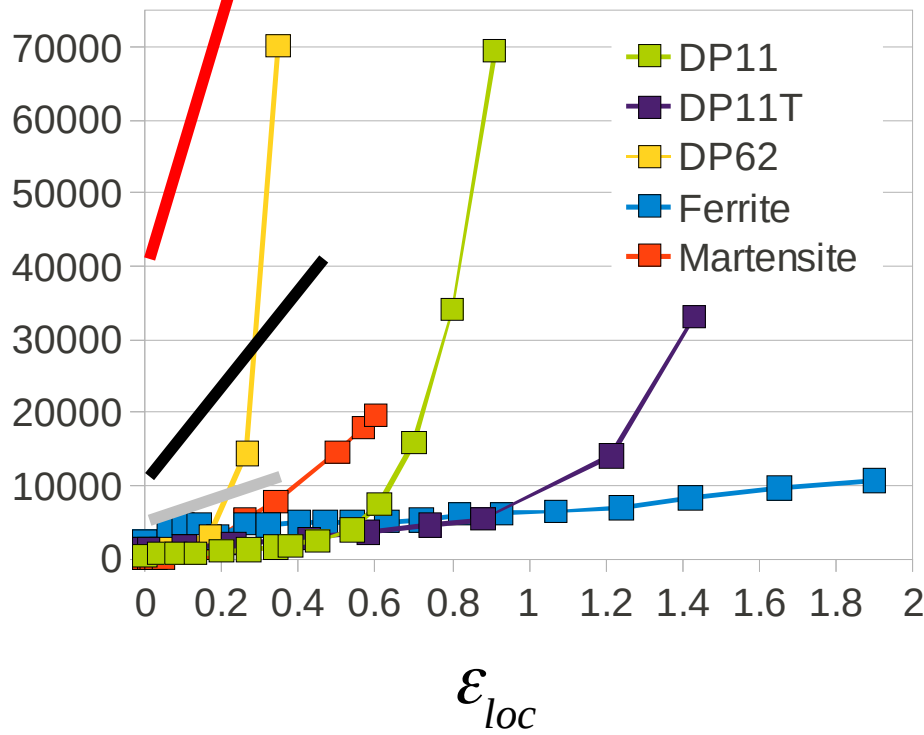
$$N = \frac{\text{nombre de cavités}}{\text{Volume Etudié}}$$



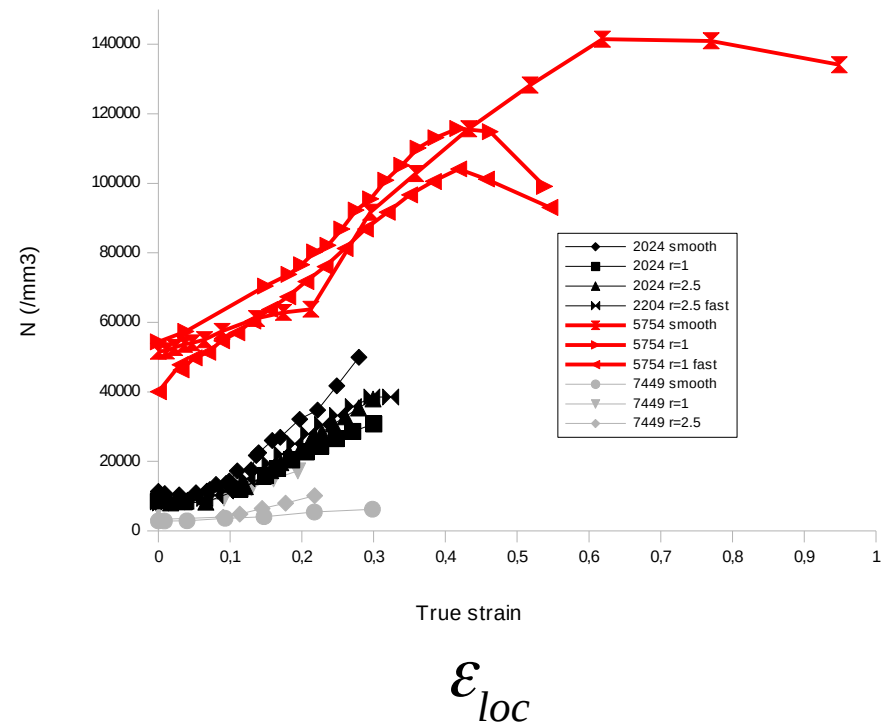
Quantification de l'amorçage

$$N = \frac{\text{number of cavities}}{\text{studied volume}}$$

Steels



Al alloys

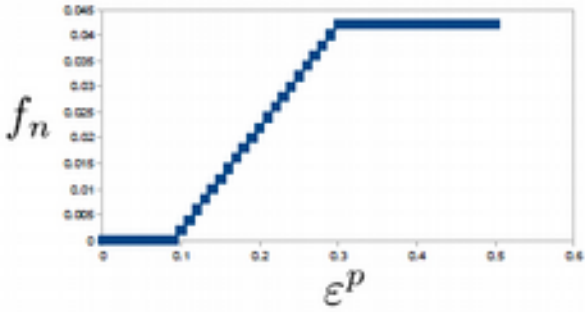
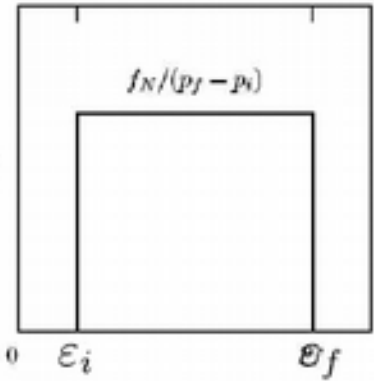


Utilisé pour alimenter des critères Beremin

$$\dot{f}_n = A_n \dot{\epsilon}^P$$

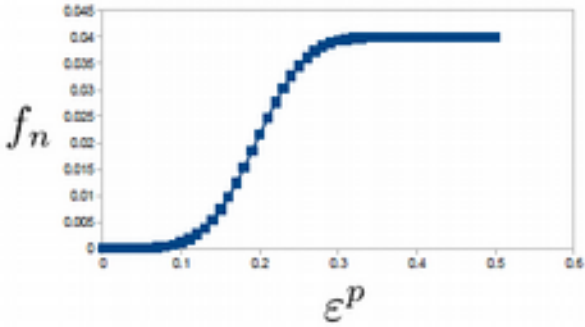
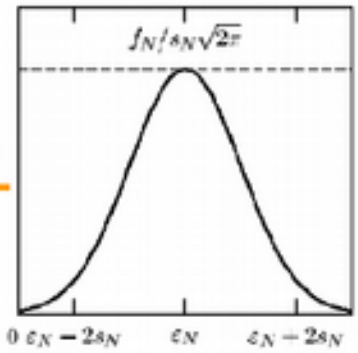
$$A_n = \frac{f_N}{\epsilon_f - \epsilon_i}$$

(Zhang et al, 2000; Besson et al, 2000)



$$A_n = \frac{f_N}{s_N \sqrt{2\pi}} \exp \left[\frac{-1}{2} \left(\frac{\epsilon^P - \epsilon_N}{s_N} \right)^2 \right]$$

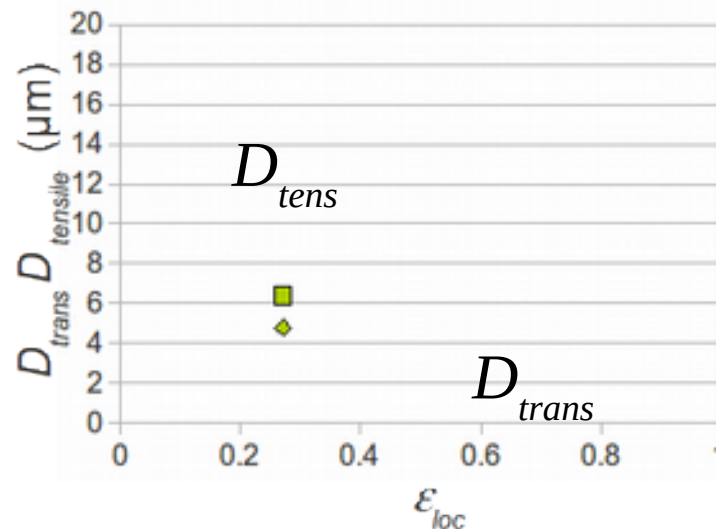
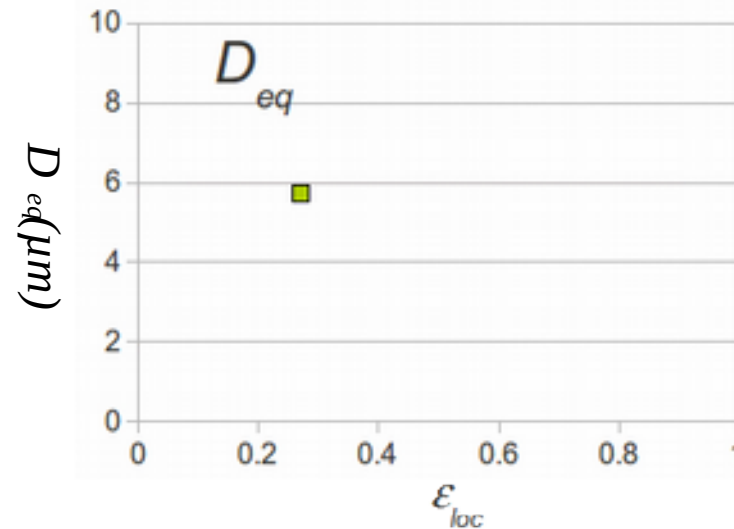
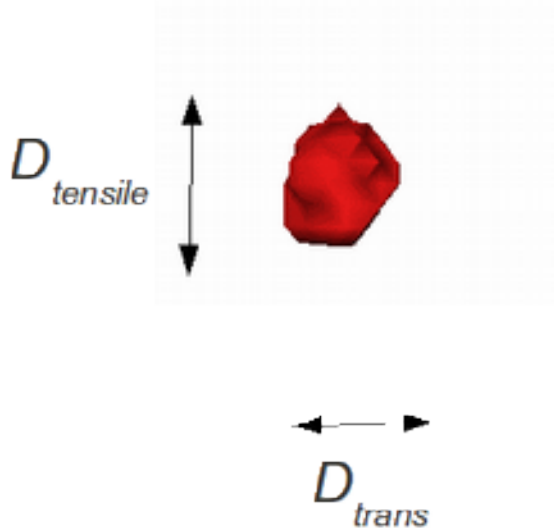
(Chu and Needleman, 1980)



Croissance (quantification)

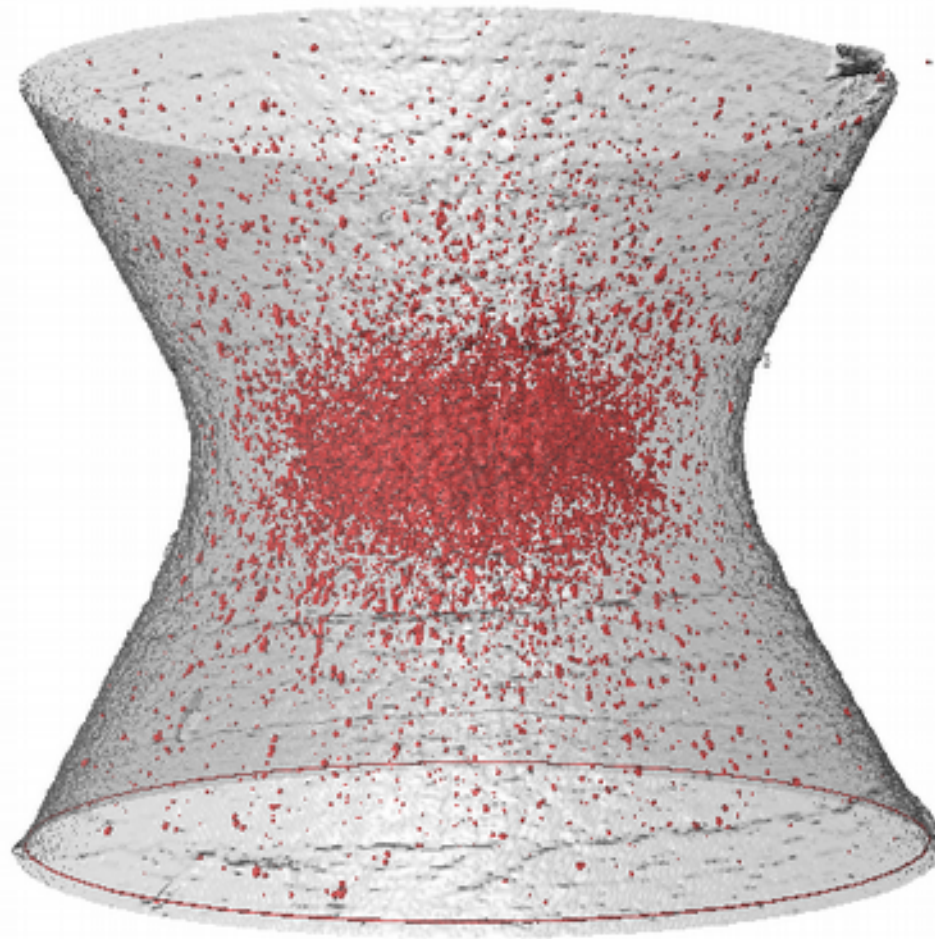
➤ Augmentation de volume : D_{eq} (cavité sphérique)

➤ Changement de forme : D_{tens} et D_{trans}



$$W = \frac{D_{tensile}}{D_{trans}}$$

Très difficile de suivre les cavités



Hypothèse : les plus grosses sont toujours les mêmes

Void growth model identification

Growth of isolated and spherical voids in a perfectly plastic matrix [*Rice and Tracey J. Mech. Phys. Sol. 1969*]

$$\frac{dR}{R} = \alpha_{RT} \exp\left(\frac{3}{2}T\right) d\varepsilon$$

$$\alpha_{RT} = 0.272$$

Later revisited by Huang to better take T into account

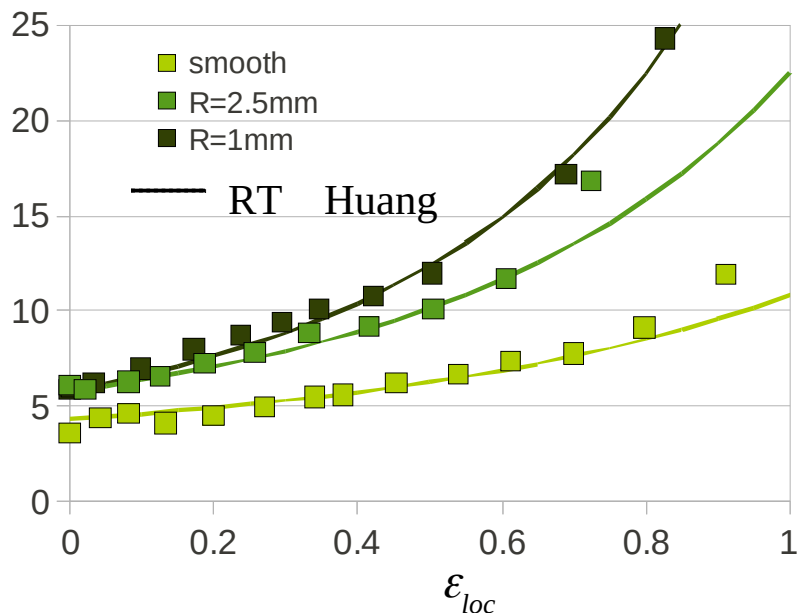
[*Huang J. Appl. Mech. 1991*]

$$\frac{dR}{R} = \alpha_{Huang} T^{0.25} \exp\left(\frac{3}{2}T\right) d\varepsilon \text{ for } T \leq 1$$

$$\frac{dR}{R} = \alpha_{Huang} \exp\left(\frac{3}{2}T\right) d\varepsilon \text{ for } T > 1$$

$$\alpha_{Huang} = 0.427$$

D_{eq}(μm) - 20 largest voids

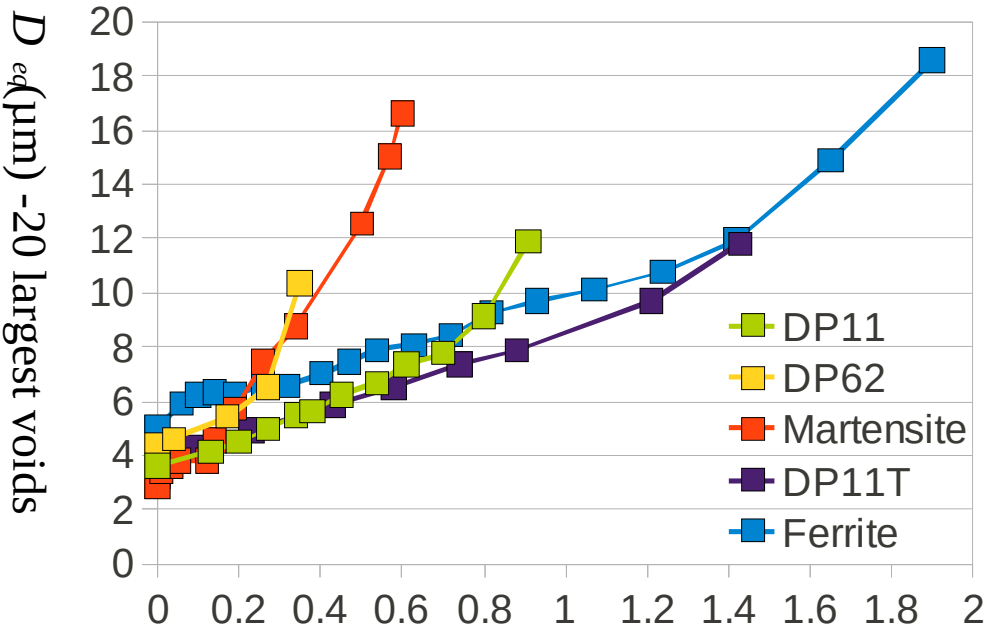


Specimens	α_{RT}	α_{Huang}
Smooth	0.47	0.55
R=2.5mm	0.50	0.55
R=1mm	0.52	0.55

Landron et al. Acta Mater. 2011

Modélisation croissance

$$\frac{dR}{R} = \alpha_{Huang} T^{0.25} \exp\left(\frac{3}{2}T\right) d\varepsilon$$



Samples	α_{Huang}
DP11	0.55
DP11T	0.45
DP62	1.2
Ferrite	0.22
Martensite	1.6

Effects of the matrix around growing voids

Void growth modeling for AAlloys

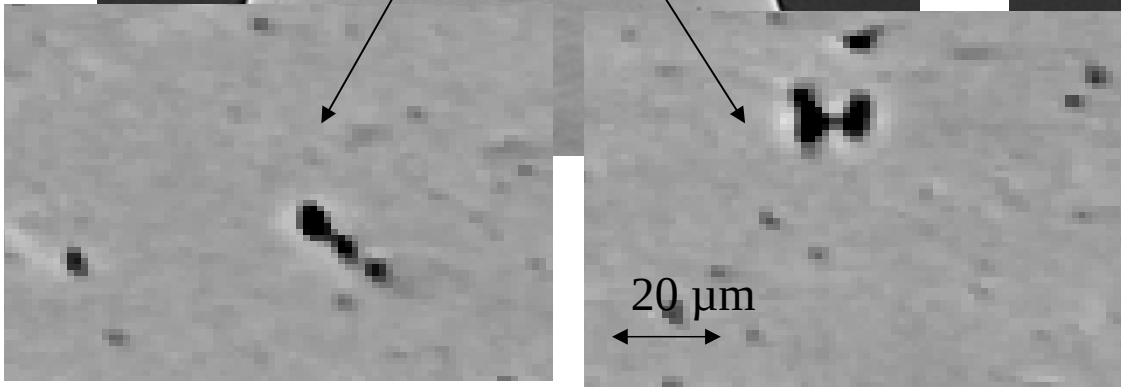
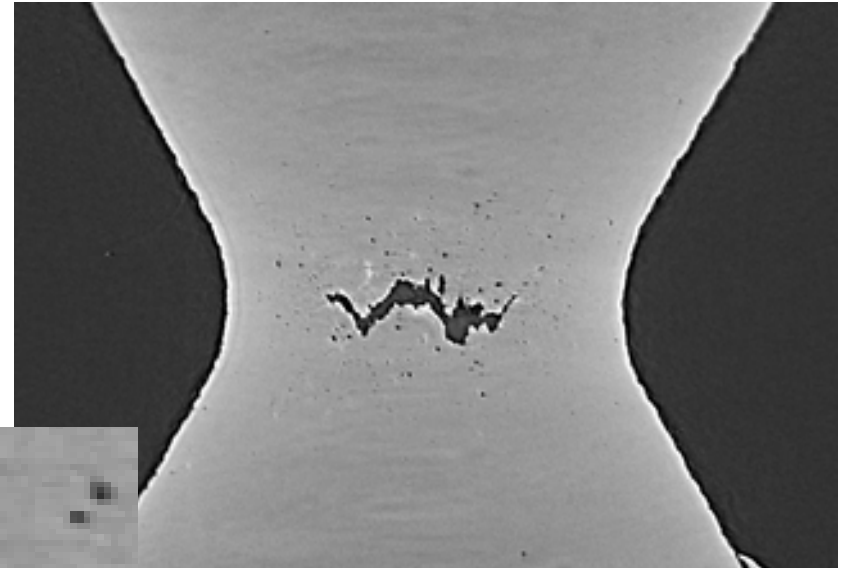
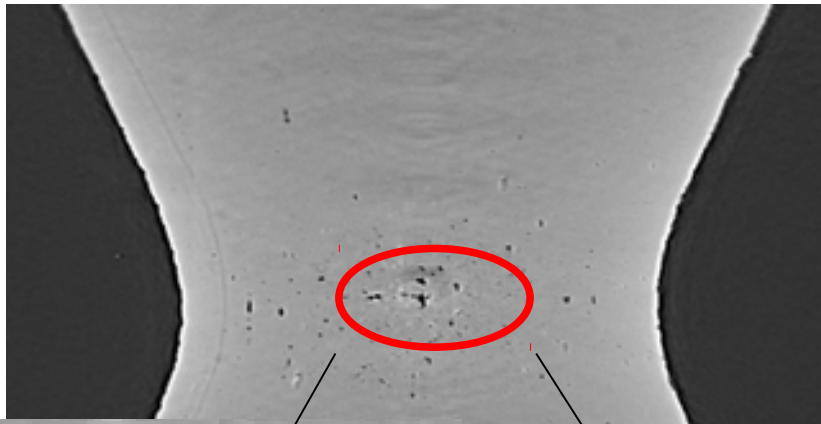
Material	Notch radius (mm)	Initiation rate (x1000 /mm ³ /strain)	α (Huang)
5754	smooth	72	0.35
	1	166	
2024	smooth	111	0.55
	2.5	94	
	1	69	
7449	smooth	8	0.8
	2.5	30	
	1	55	

Steel samples	α_{Huang}
DP11	0.55
DP11T	0.45
DP62	1.2
Ferrite	0.22
Martensite	1.6

3. Observation of void coalescence (steels)

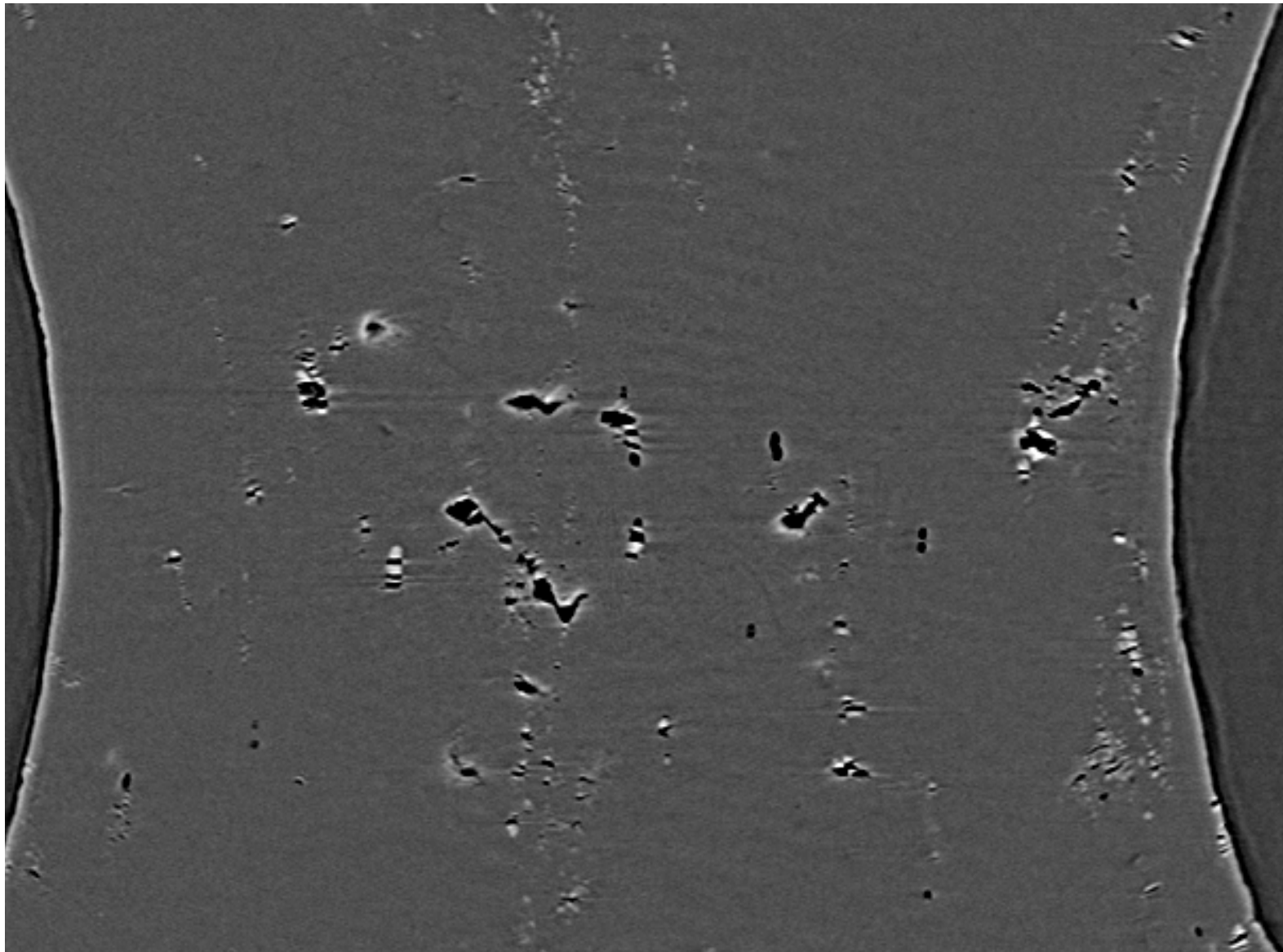
① Local events

② Macroscopic coalescence



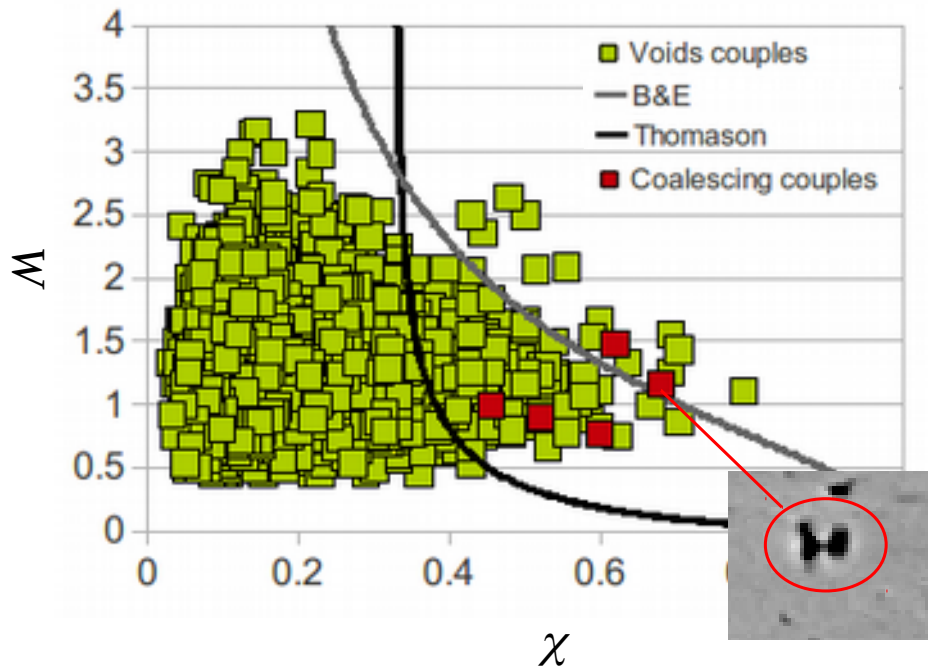
Shear localization

Necking of the internal ligament



Local approach

- Observation of dynamic coalescence
- Mainly because of the distribution of the distance between cavities



W and χ calculated from the dimensions of the two cavities and from the distance between the two cavities

Brown & Embury

$$\chi \sqrt{1+W^2} = 1$$

Thomason

$$\frac{\sigma_{ZZ}}{\sigma_y^{loc}} = (1-\chi^2) \left[0.1 \left(\frac{1-\chi}{\chi W} \right)^2 + 1.24 \frac{1}{\sqrt{\chi}} \right]$$

- ✓ Thomason's criterion

Tracking de cavités



Available online at www.sciencedirect.com

ScienceDirect

Acta Materialia 63 (2014) 130–139



Acta MATERIALIA

www.elsevier.com/locate/actamat

Heterogenous void growth revealed by in situ 3-D X-ray
microtomography using automatic cavity tracking

L. Lecarme^a, E. Maire^c, A. Kumar K.C.^b, C. De Vleeschouwer^b, L. Jacques^b, A. Simar^{a,*},
T. Pardoen^{a,*}

^a *Institute of Mechanics, Materials and Civil Engineering, Université catholique de Louvain, B-1348 Louvain-la-Neuve, Belgium*

^b *Institute of Information and Communication Technologies, Electronics and Applied Mathematics, Université catholique de Louvain, B-1348 Louvain-la-Neuve, Belgium*

^c *MATEIS UMR5510, INSA-Lyon, F-69621 Villeurbanne, France*

Received 20 July 2013; accepted 9 October 2013

Available online 13 November 2013

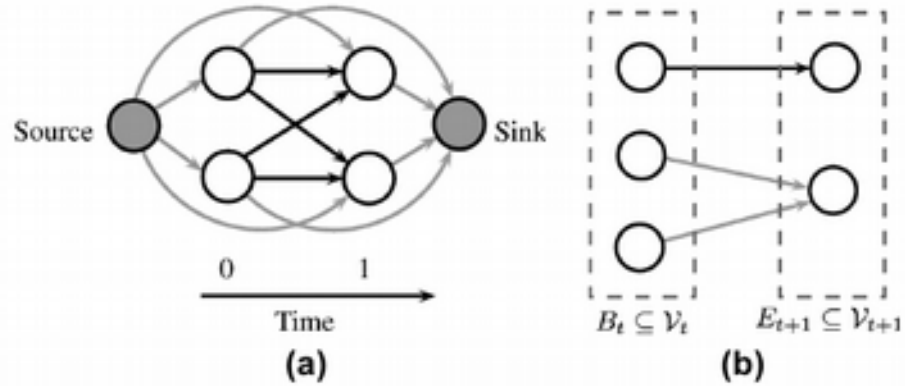
Tracking = linking detections based on positions and appearances

Amit Kumar K.C., and al., "Aggregation of Local Shortest Paths for Multiple Object Tracking with Noisy/Missing Appearance Features", Asian Conference on Computer Vision (ACCV), 2012.

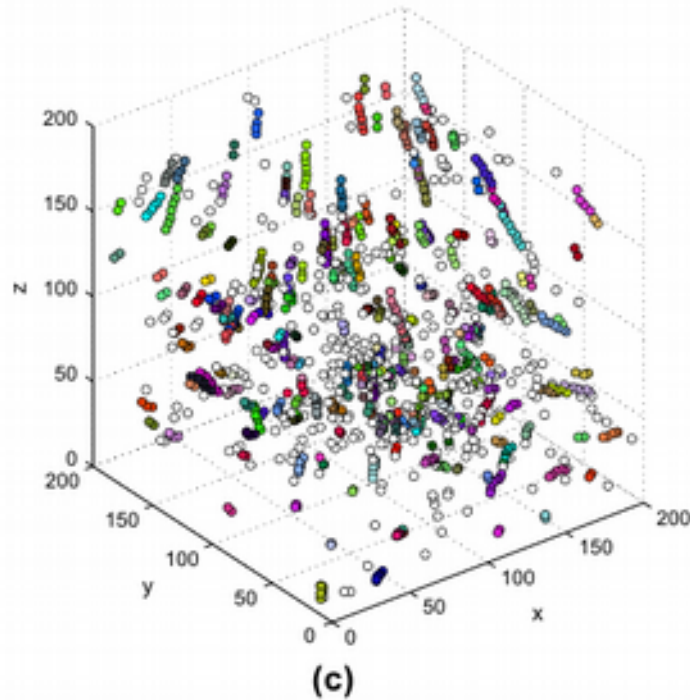
Amit Kumar K.C. and C. De Vleeschouwer. Discriminative label propagation for multi-object tracking with sporadic appearance features, ICCV 2013.



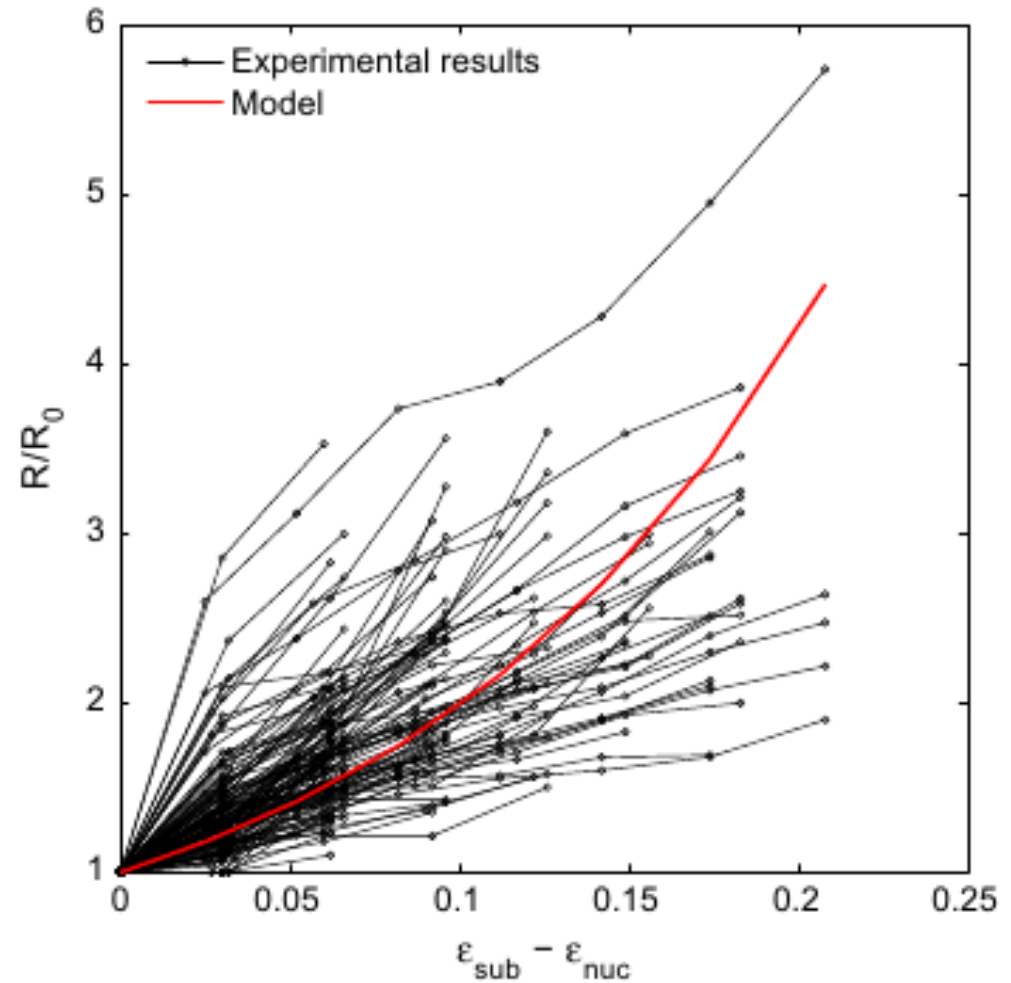
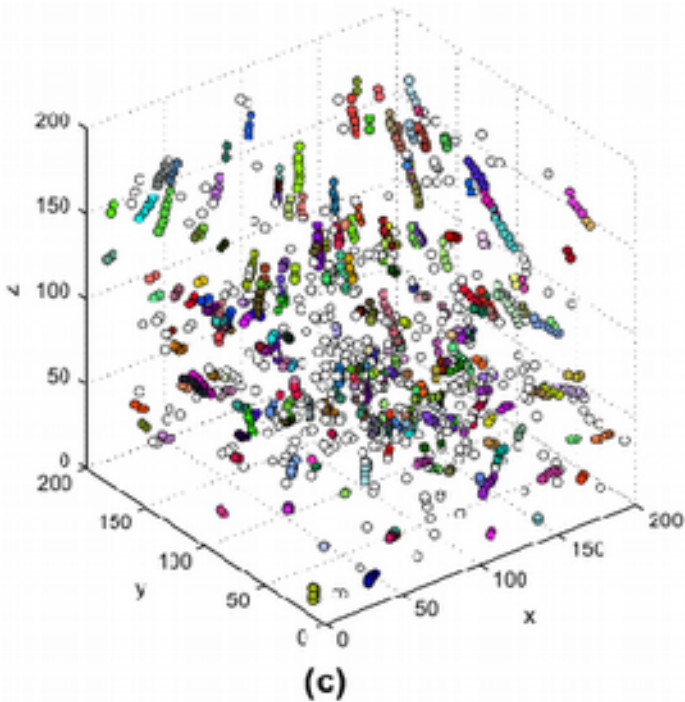
Key results: tracking



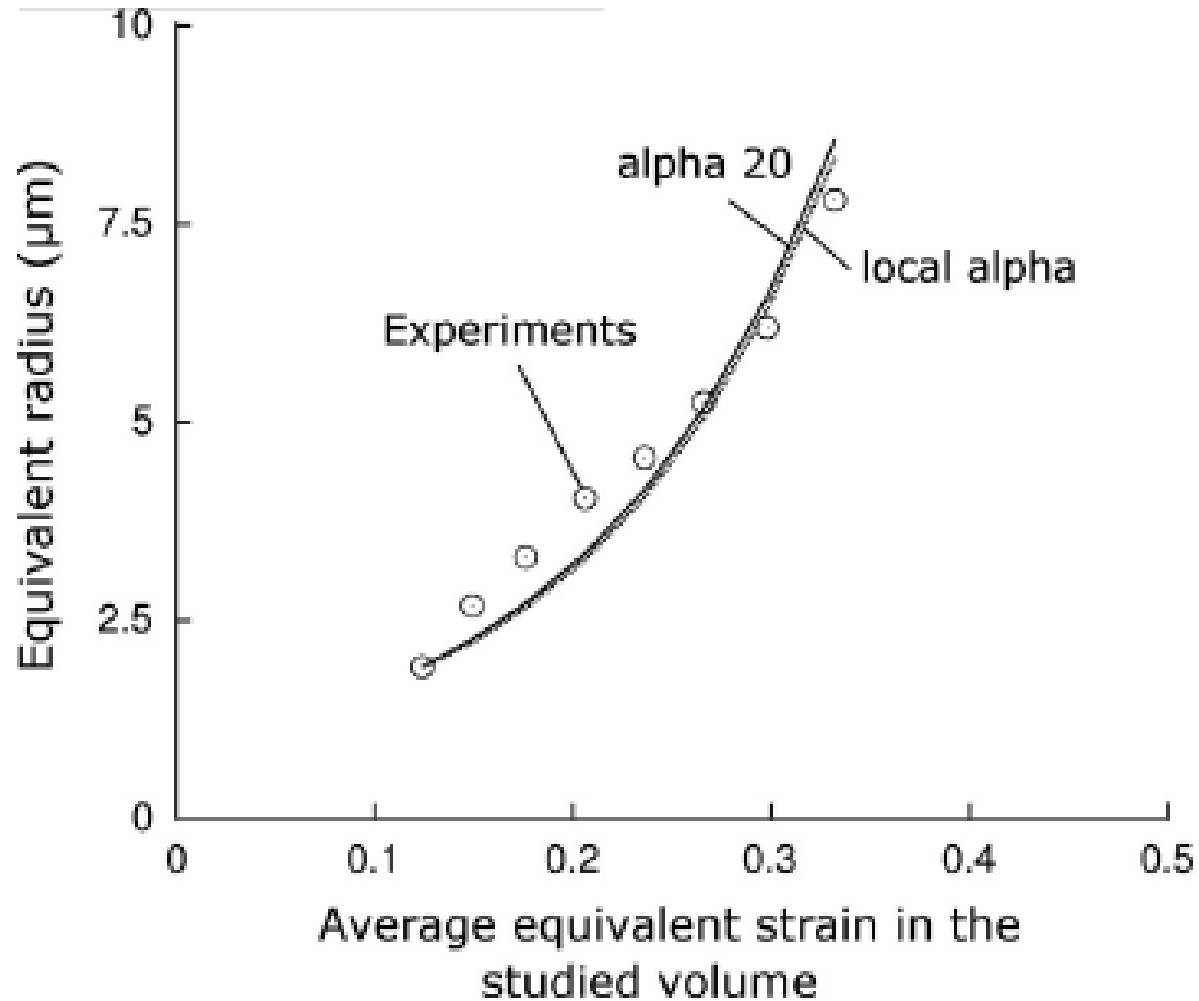
TA6V



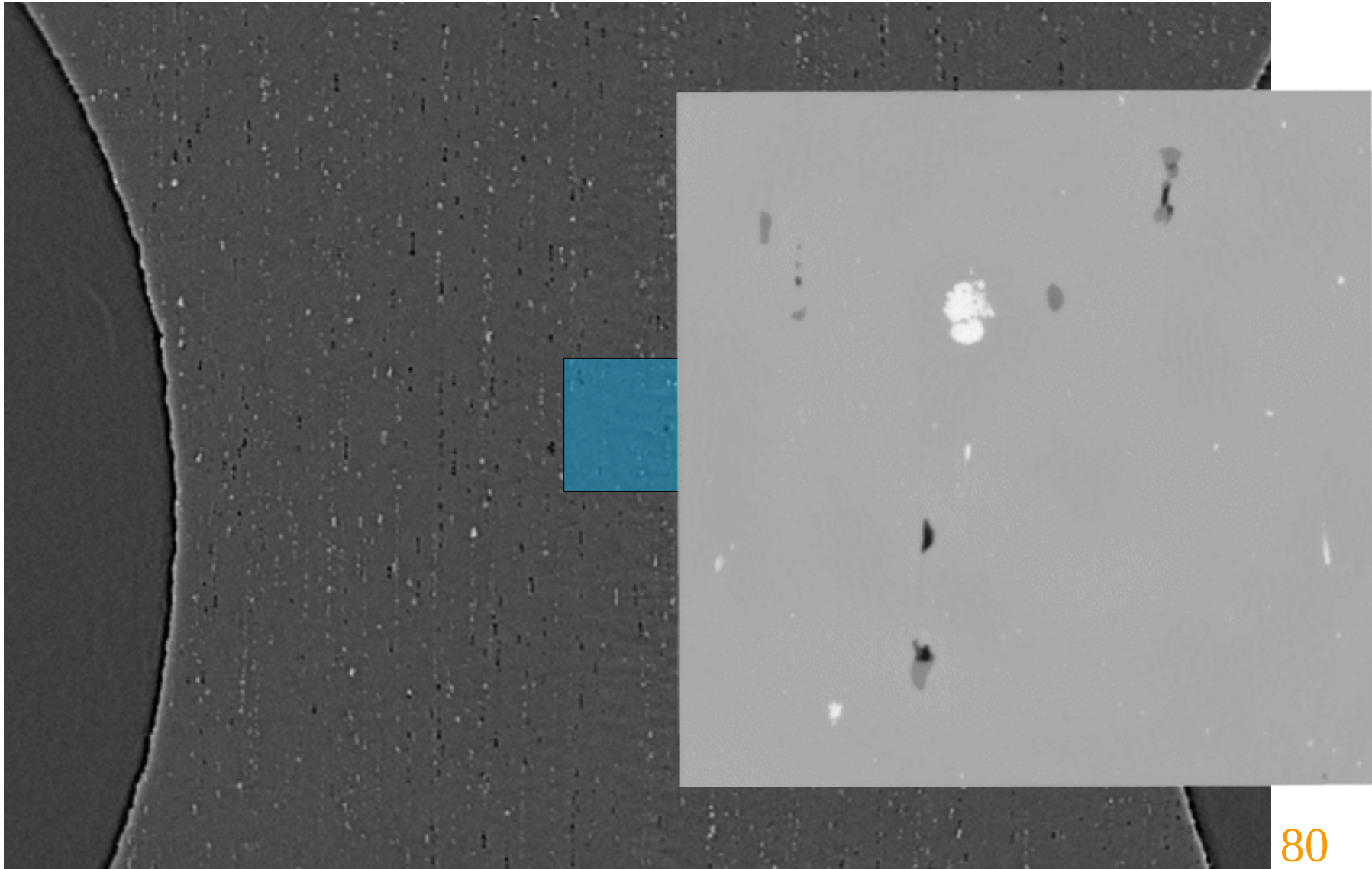
Mesure de la vitesse de croissance de chacune des cavités



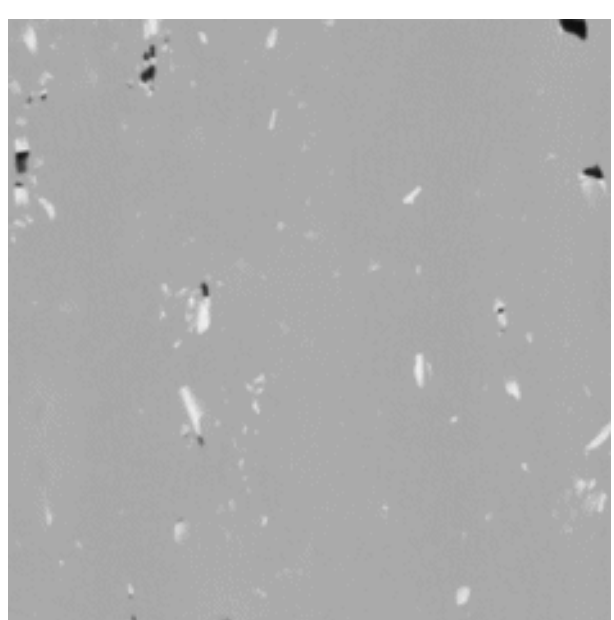
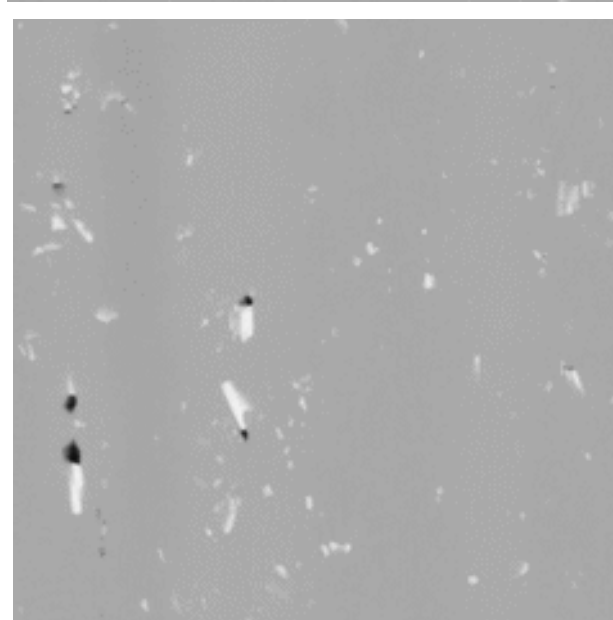
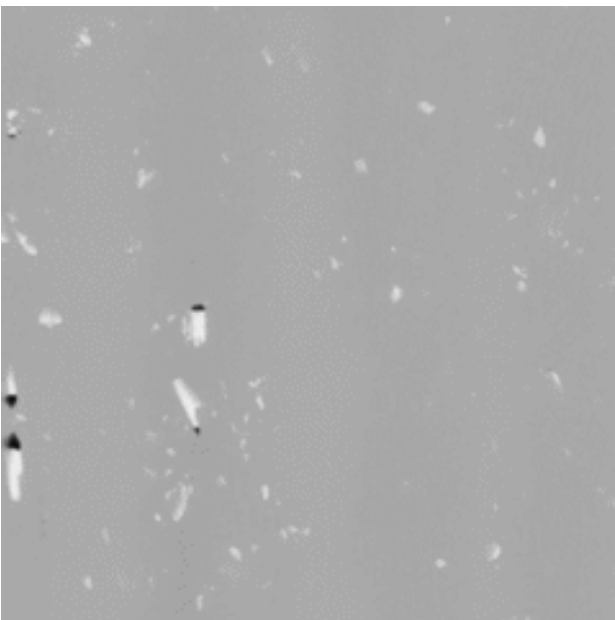
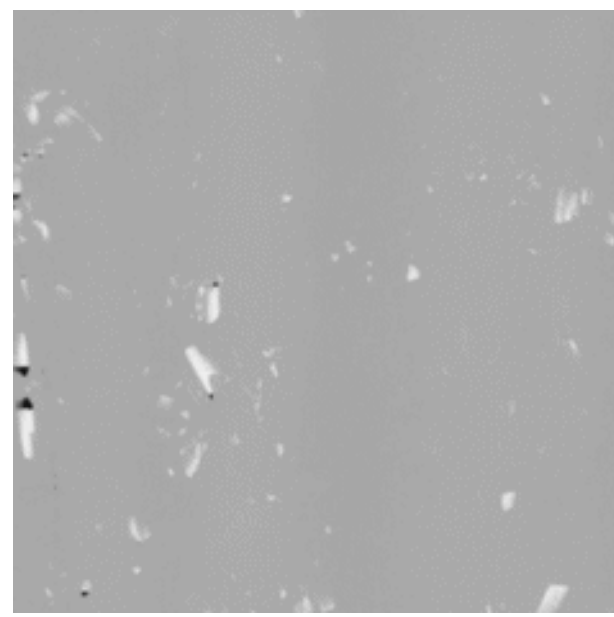
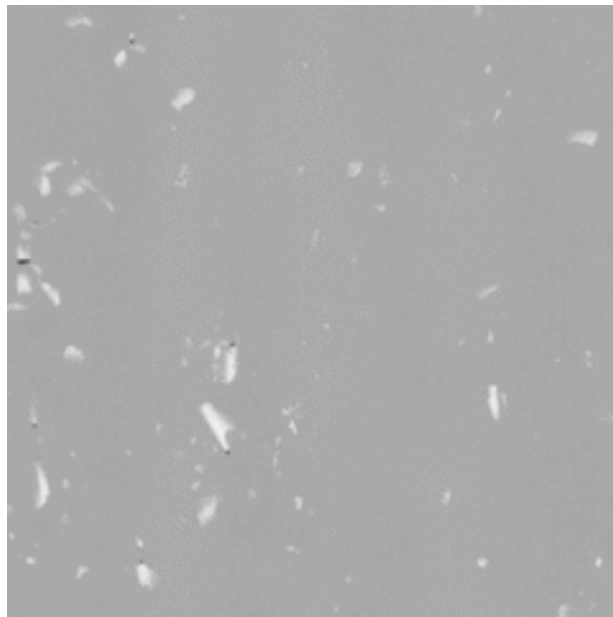
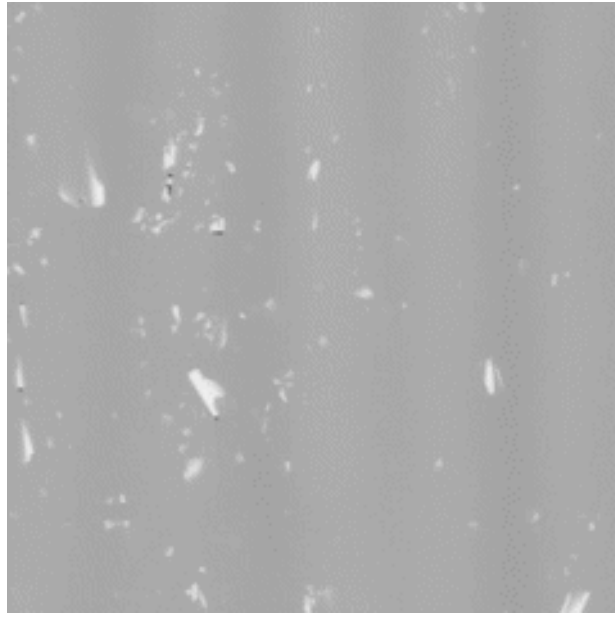
Vitesse moyenne OK



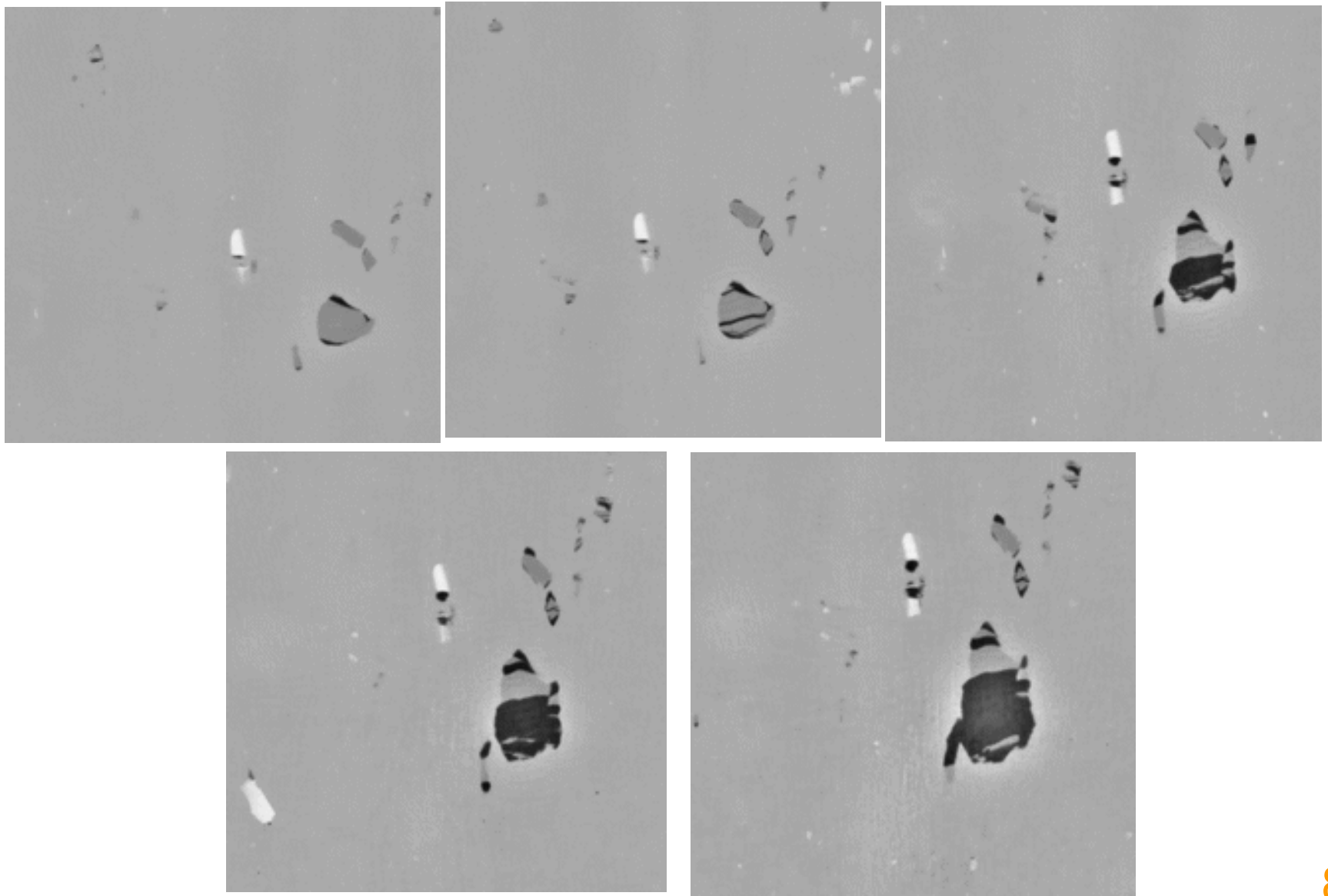
Higher magnification ID22 (now 16B)



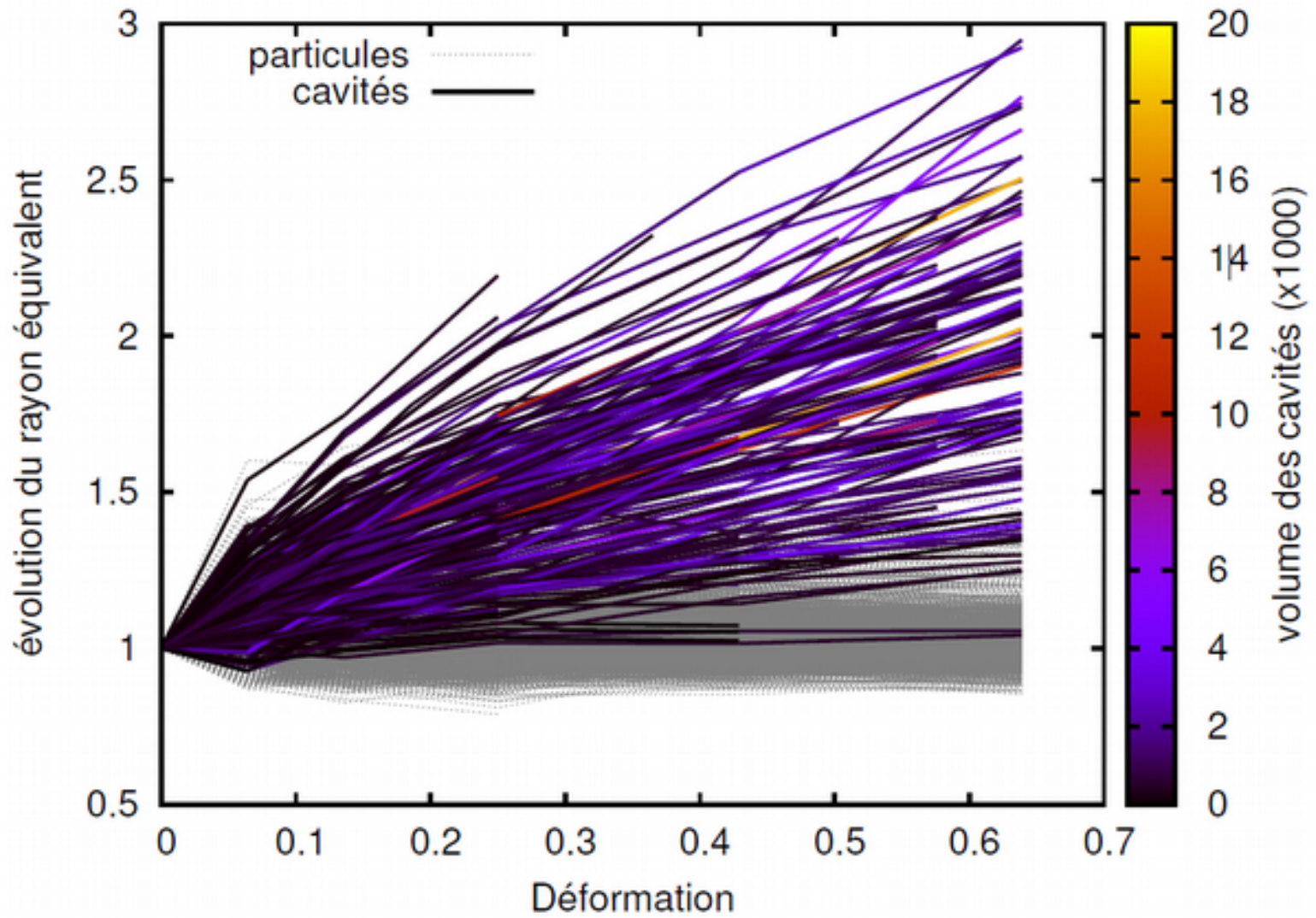
1200



5182



Key result



Un modèle pour tout intégrer de manière simple

Acta Materialia 103 (2016) 558–572



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Full length article

Characterization and micromechanical modelling of microstructural heterogeneity effects on ductile fracture of 6xxx aluminium alloys

F. Hannard ^{a,*}, T. Pardoen ^a, E. Maire ^b, C. Le Bourlot ^b, R. Mokso ^c, A. Simar ^a

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^b MATEIS UMR5510, INSA-Lyon, F-69621 Villeurbanne, France

^c Swiss Light Source, Paul Scherrer Institute, Villigen, 5232, Switzerland



Un modèle pour tout intégrer de manière simple



ELSEVIER

Full length

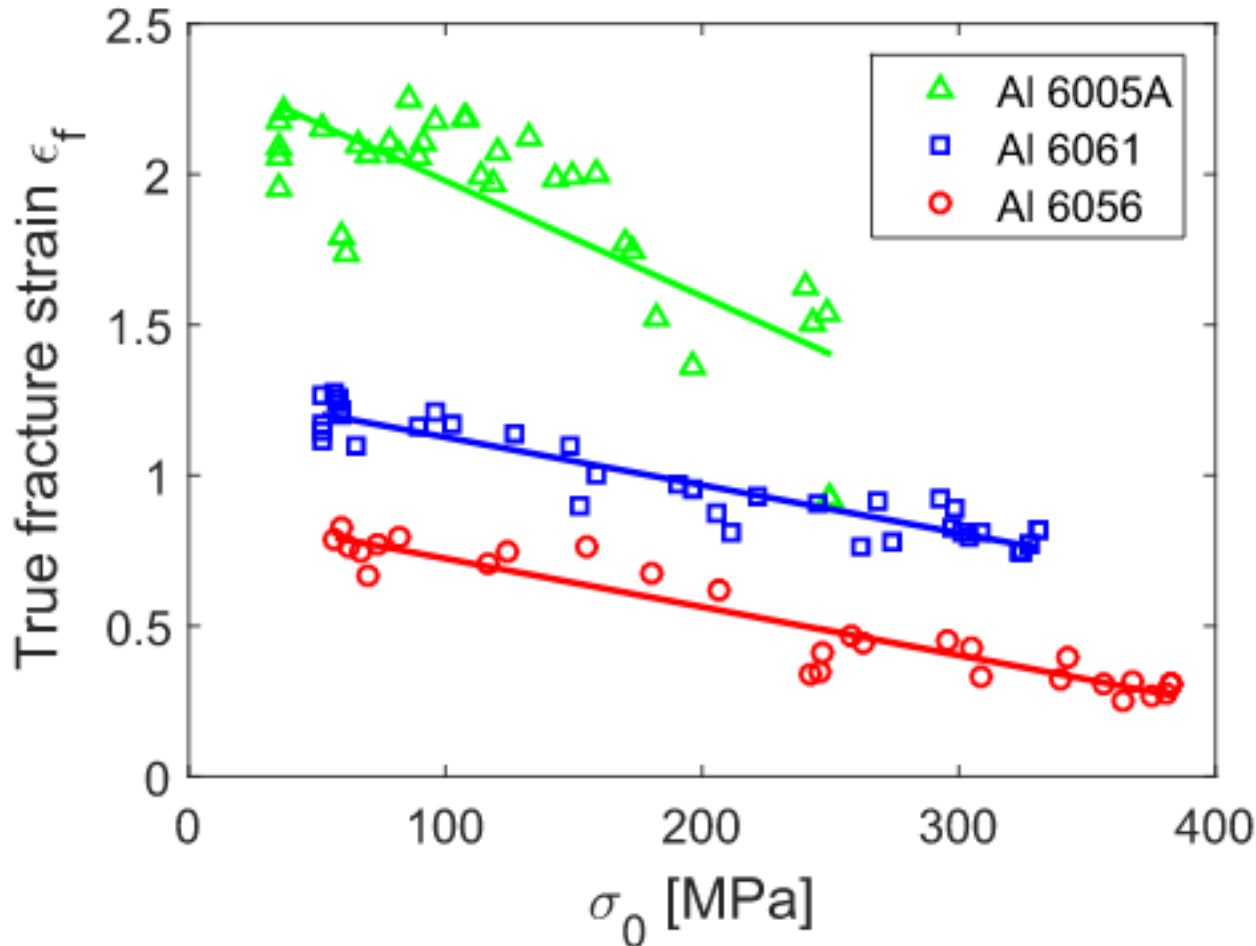
Characterization
heterogeneous

F. Hann

^a Institute of

^b MATEIS UM

^c Swiss Light



Synopsis du modèle

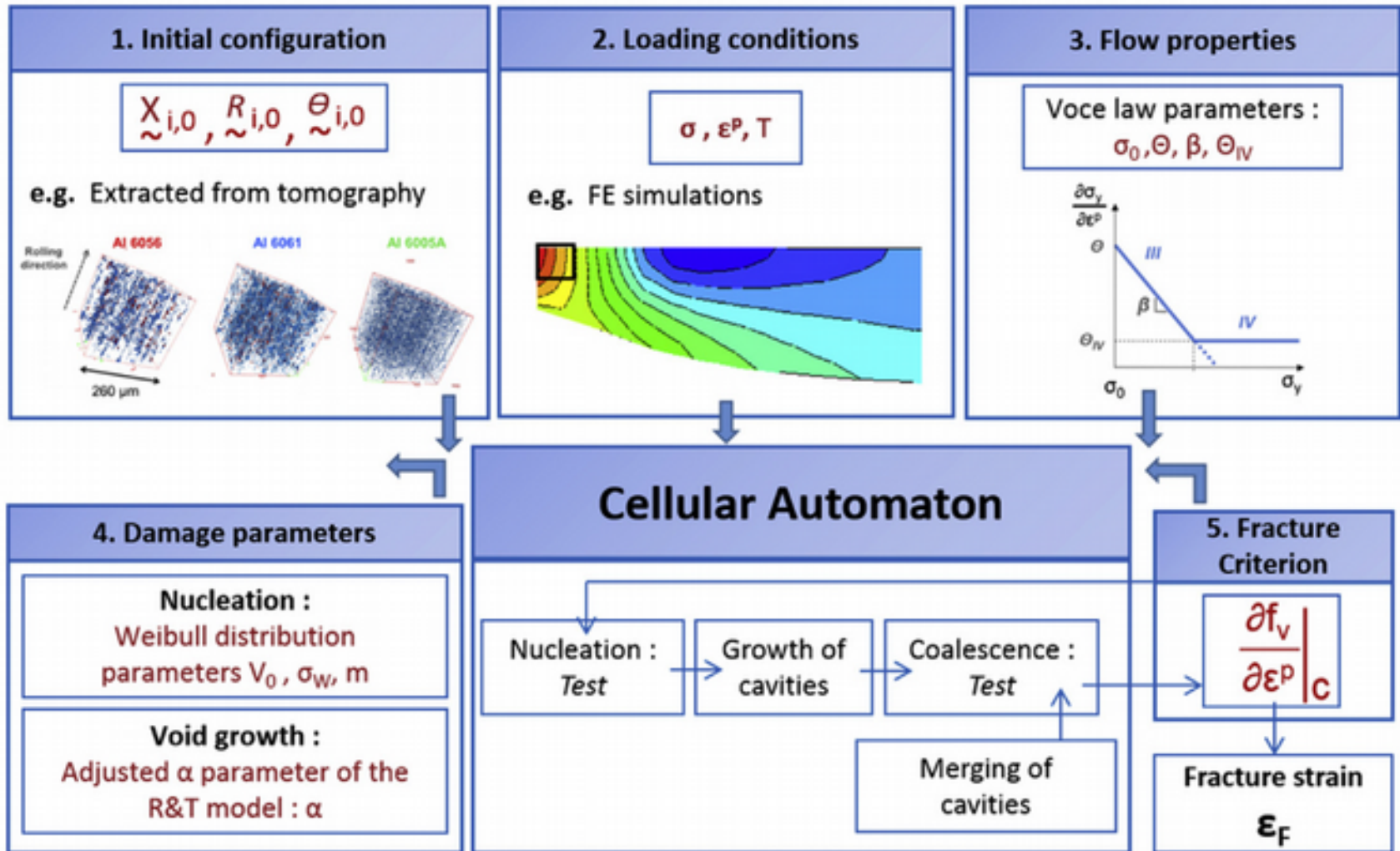


Fig. 4. Overview of the modelling strategy.

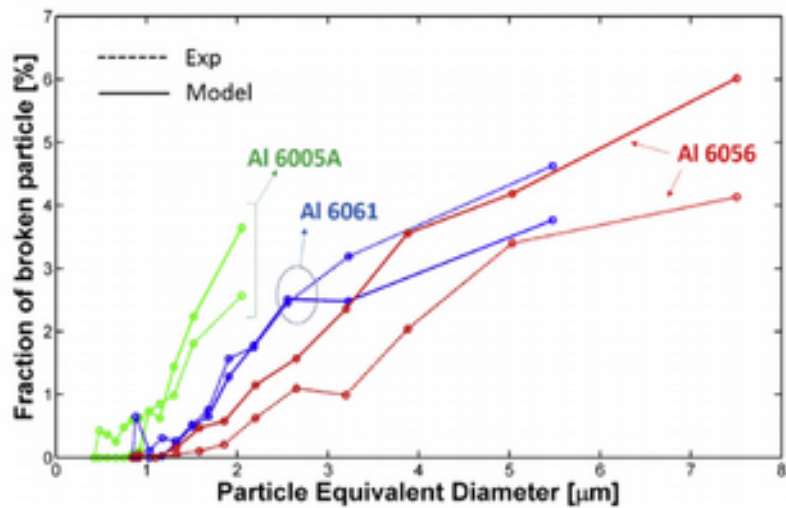
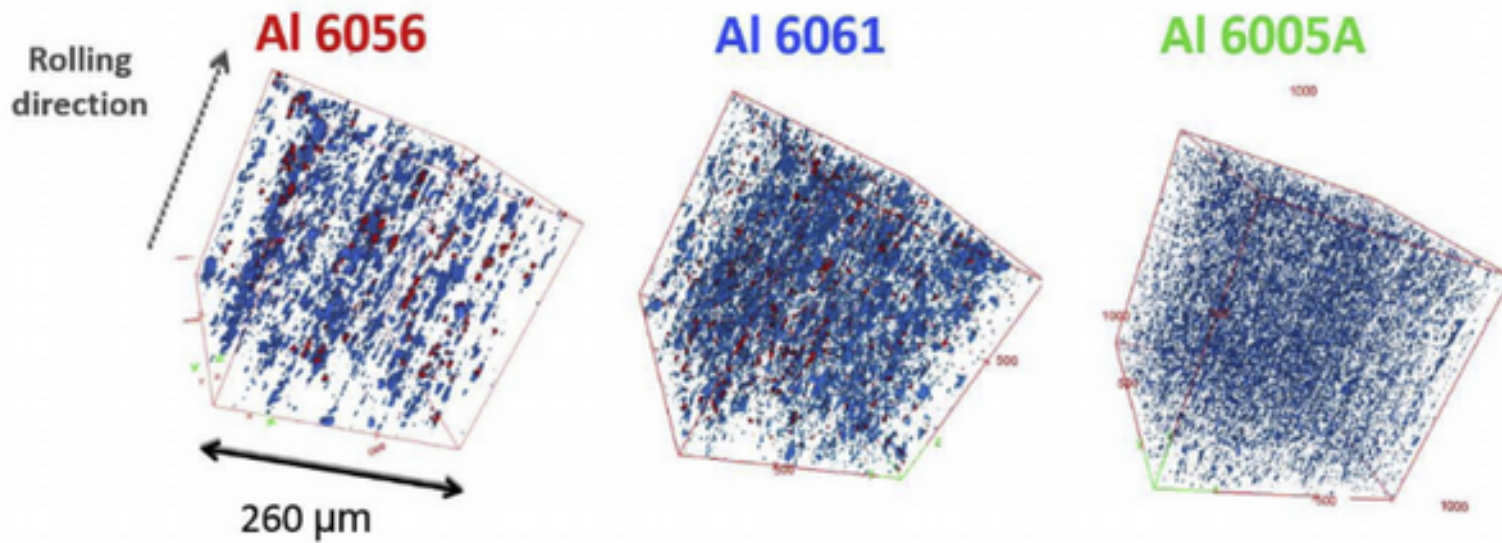
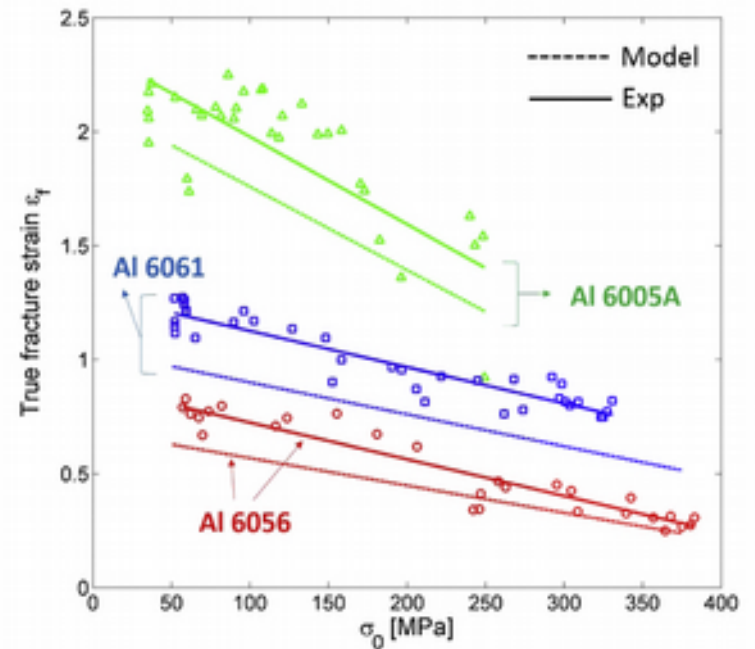
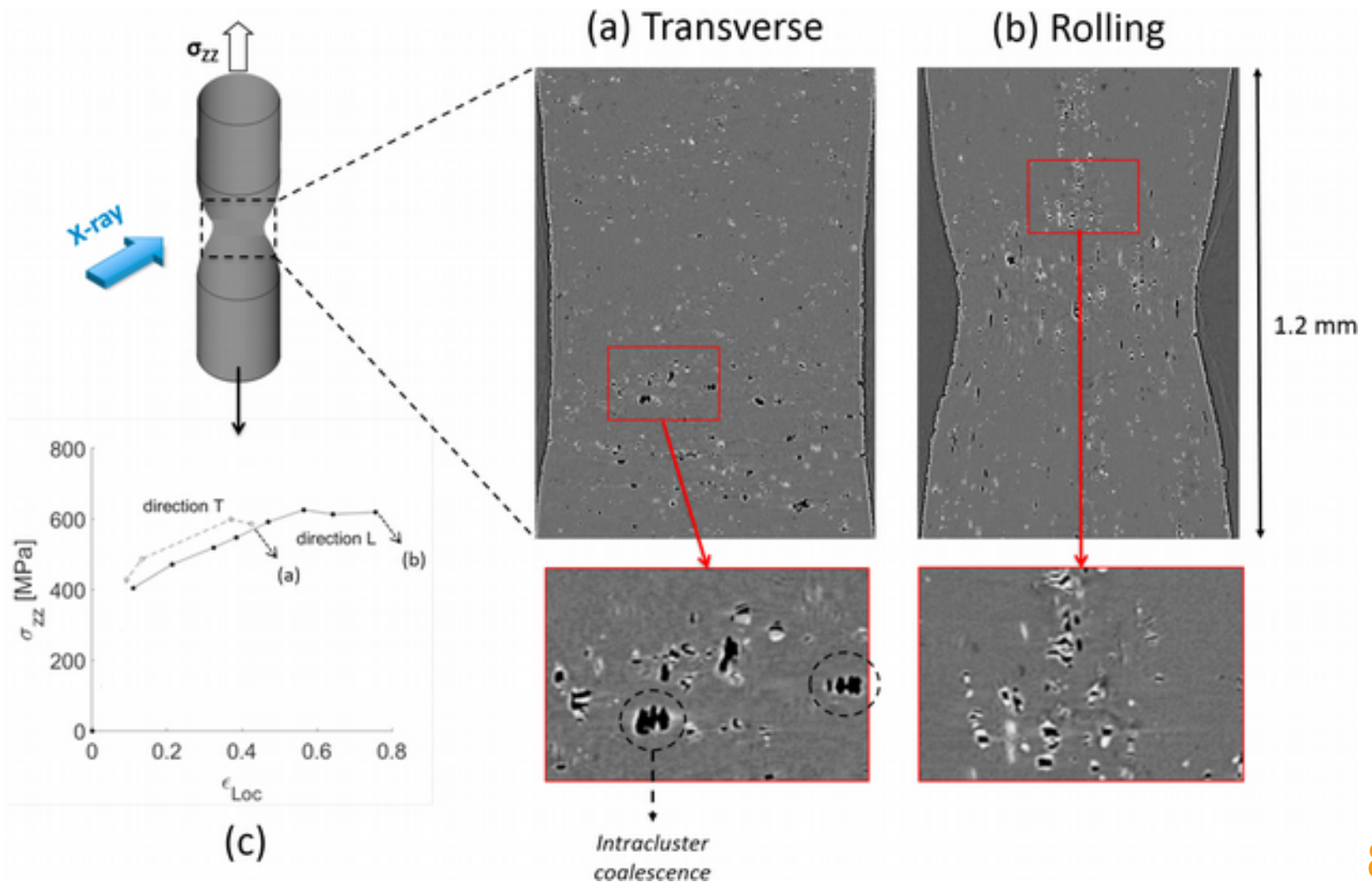


Fig. 7. Comparison between the experimental and modelled (best identification) fraction of broken particles as a function of the particles equivalent diameter in the three alloys for all heat treatment conditions.



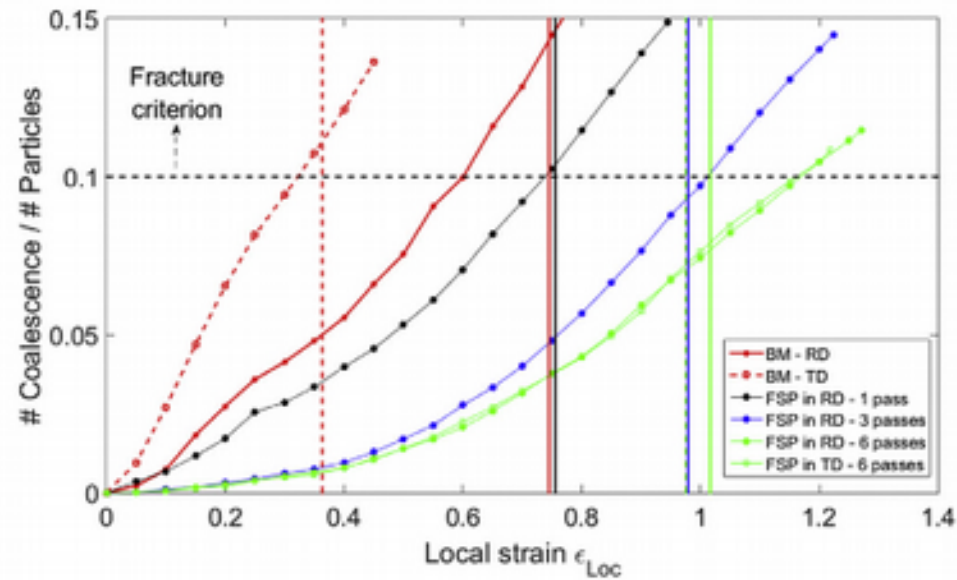
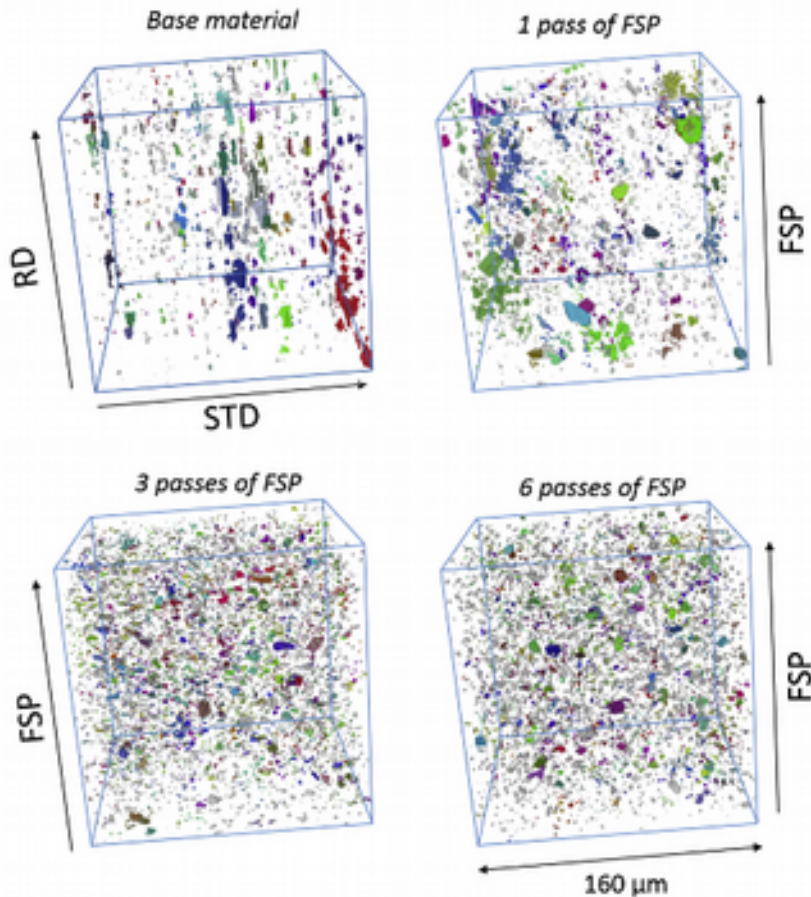
Sens long / sens travers



Full length article

Ductilization of aluminium alloy 6056 by friction stir processing

F. Hannard ^{a,*}, S. Castin ^a, E. Maire ^b, R. Mokso ^{c,d}, T. Pardoen ^a, A. Simar ^a



Laminographie



Available online at www.sciencedirect.com

ScienceDirect

Acta Materialia 69 (2014) 78–91



Acta MATERIALIA

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In situ 3-D observation of early strain localization during failure of thin Al alloy (2198) sheet

Thilo F. Morgeneyer^{a,*}, Thibault Taillandier-Thomas^{a,b}, Lukas Helfen^{c,d}, Tilo Baumbach^c, Ian Sinclair^e, Stéphane Roux^b, François Hild^b

^a *Mines ParisTech, Centre des Matériaux, CNRS UMR 7633, BP 87, F-91003 Evry Cedex, France*

^b *LMT-Cachan, ENS Cachan/CNRS/PRES UniverSud Paris, 61 avenue du Président Wilson, F-94235 Cachan Cedex, France*

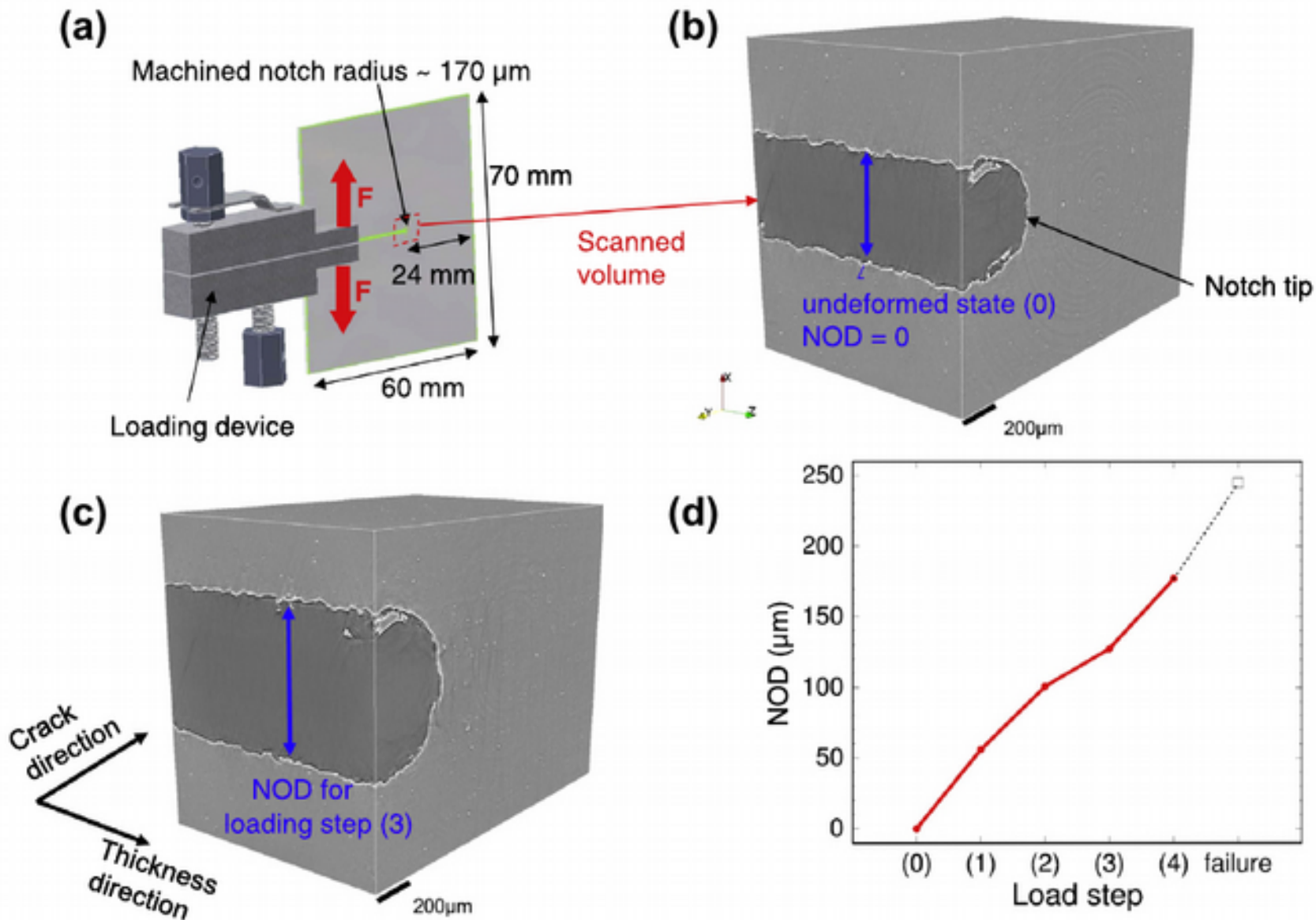
^c *ANKA Institute for Photon Science and Synchrotron Radiation, Karlsruhe Institute of Technology (KIT), D-76131 Karlsruhe, Germany*

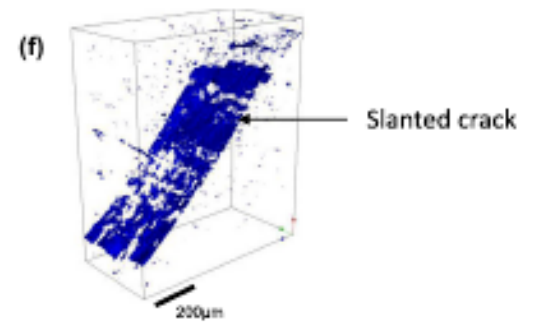
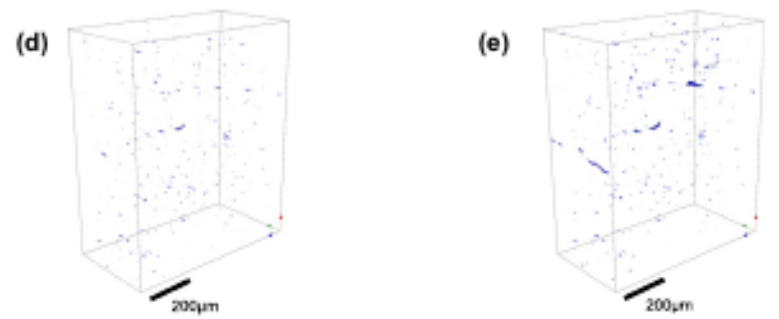
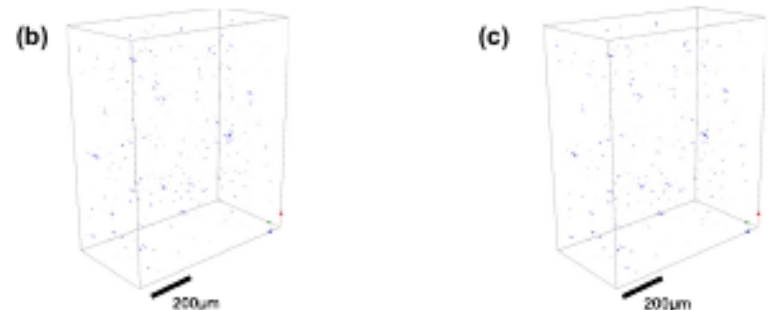
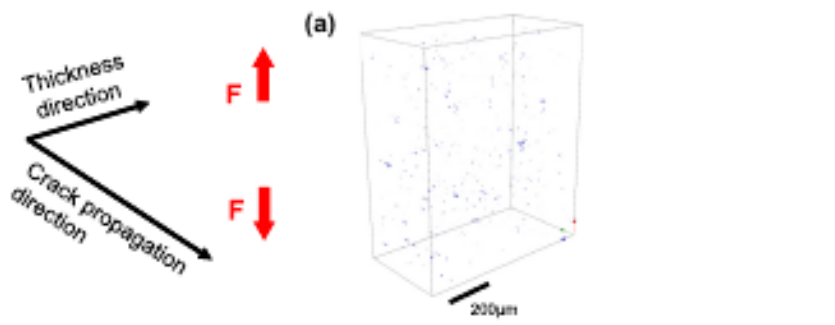
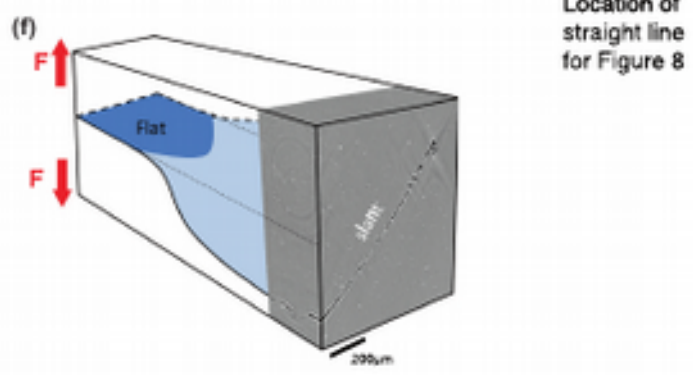
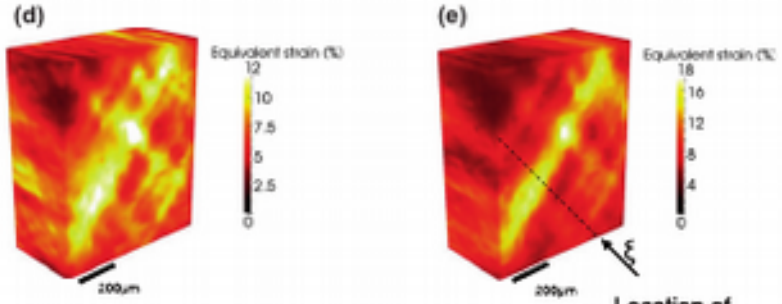
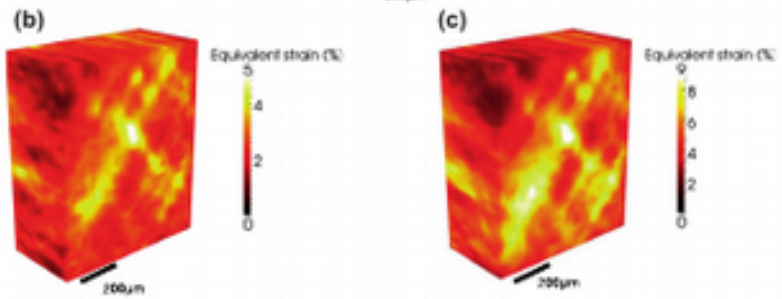
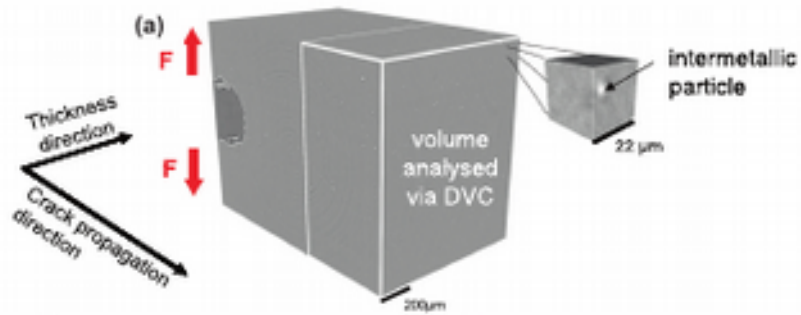
^d *European Synchrotron Radiation Facility (ESRF), BP 220, F-38043 Grenoble Cedex, France*

^e *μVIS X-ray Imaging Centre, Faculty of Engineering and the Environment, Southampton University, Southampton SO17 1BJ, UK*

Received 3 September 2013; received in revised form 16 January 2014; accepted 17 January 2014

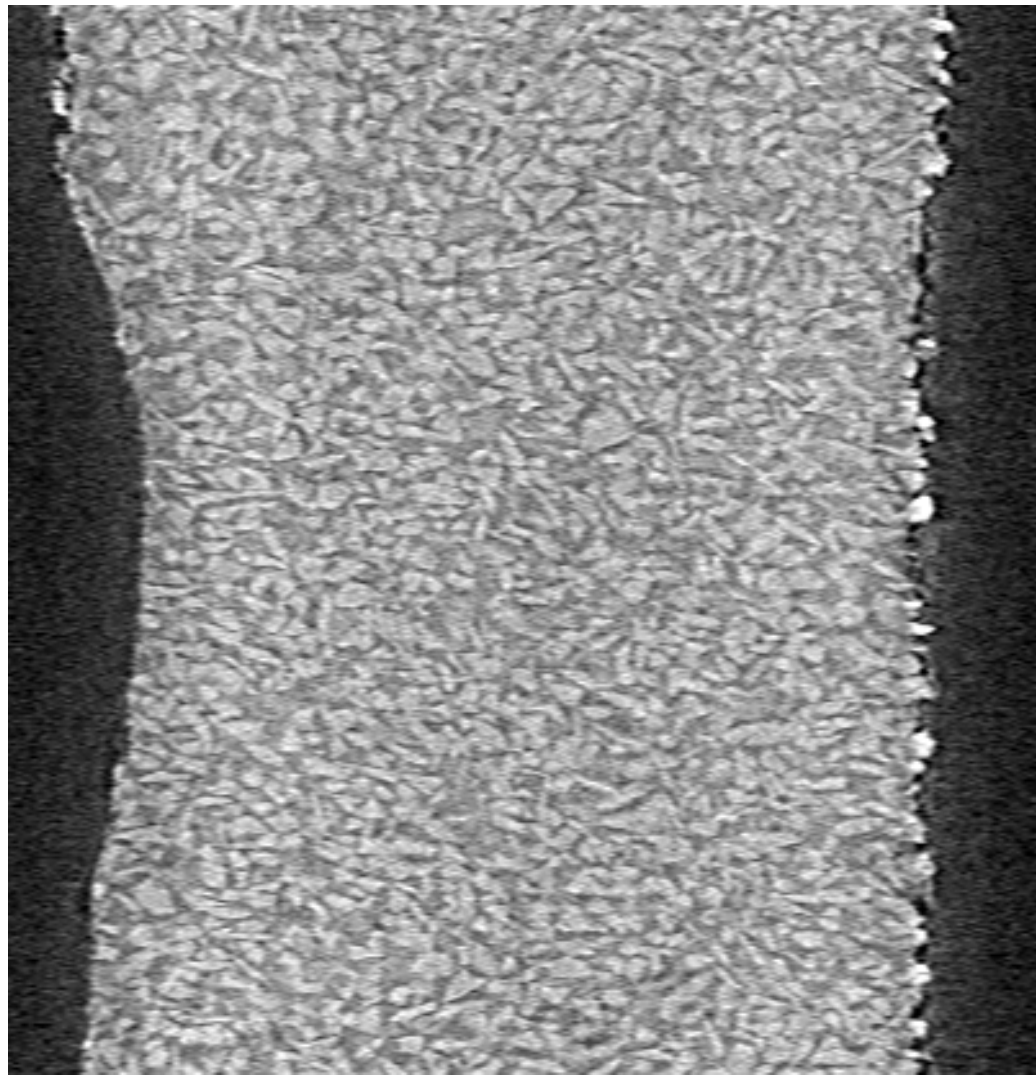
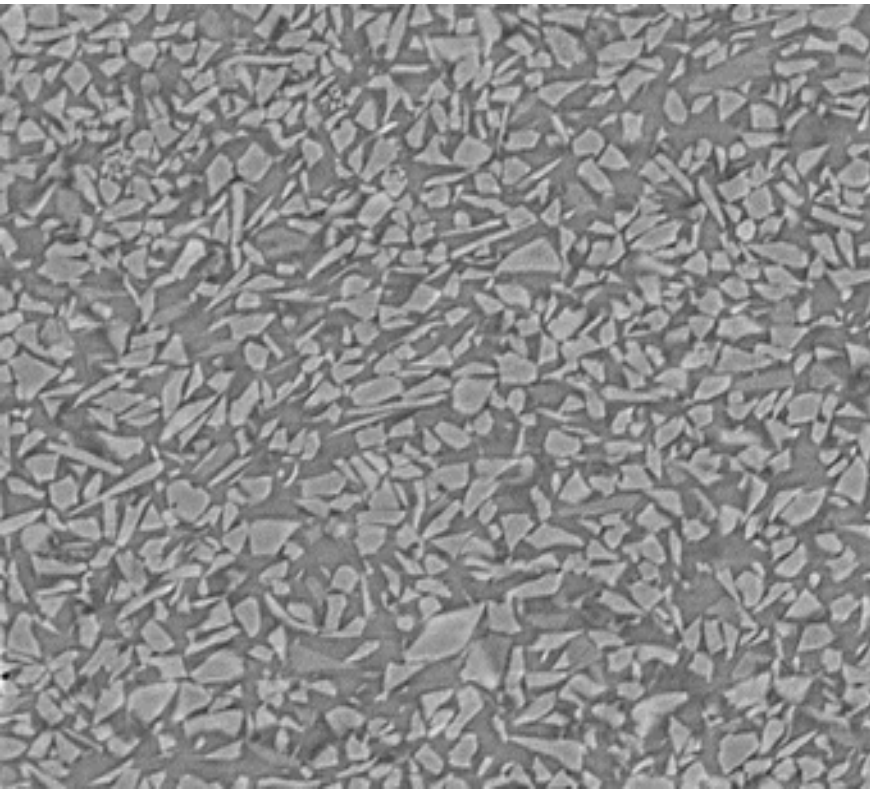
Available online 25 February 2014



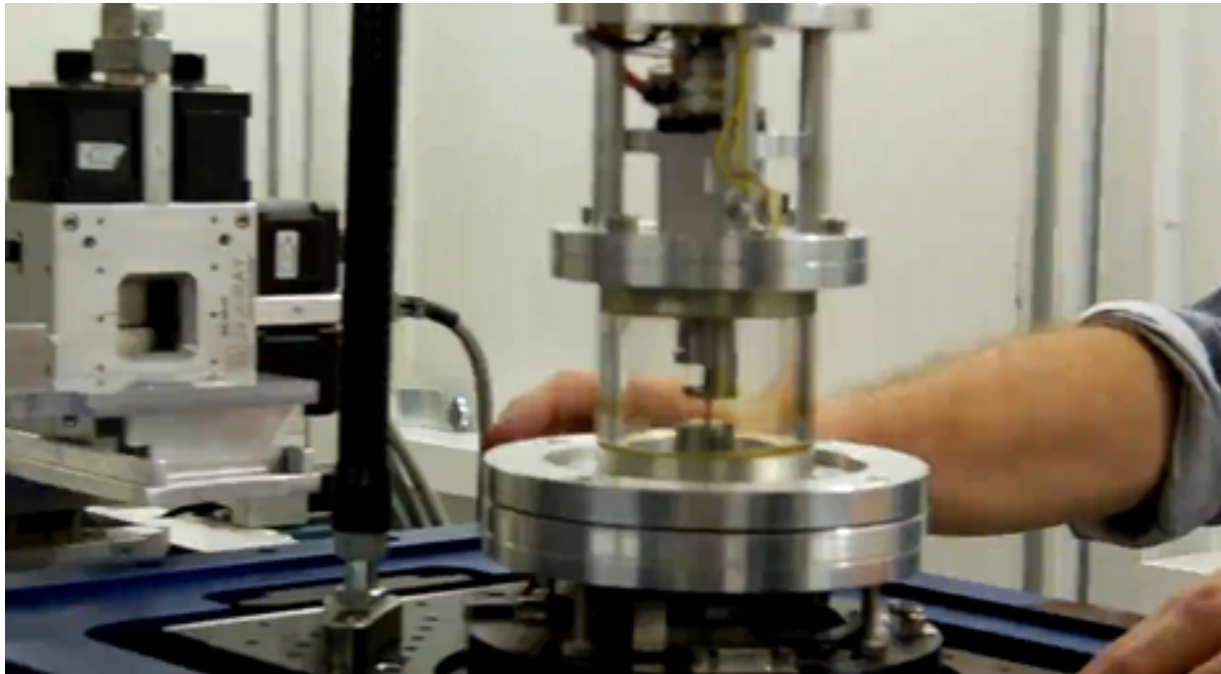


Autres exemples :

- Matériaux denses
 - Polymères (semi-cristallins, crazing...) exposé de Nicolas Saintier
 - Composites (Céramiques, polymères)
- Cellulaires architecturés
 - Mousses
 - Plâtre
 - Traction ou compression

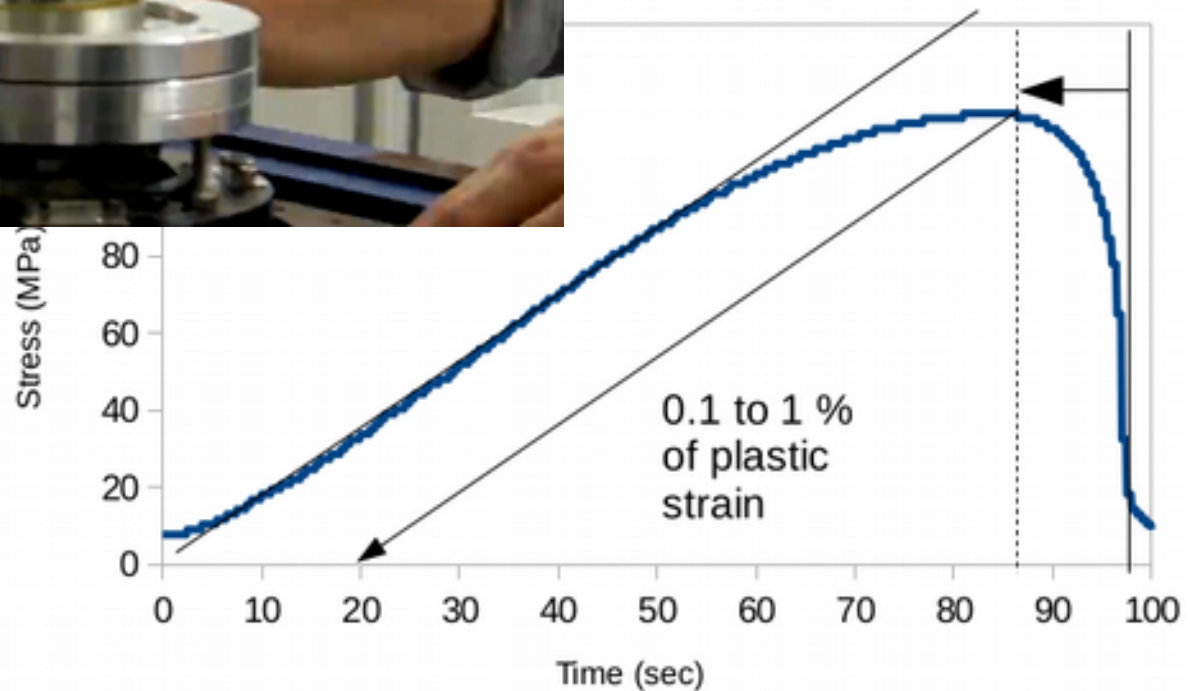


3 : Rupture - Fast tomo

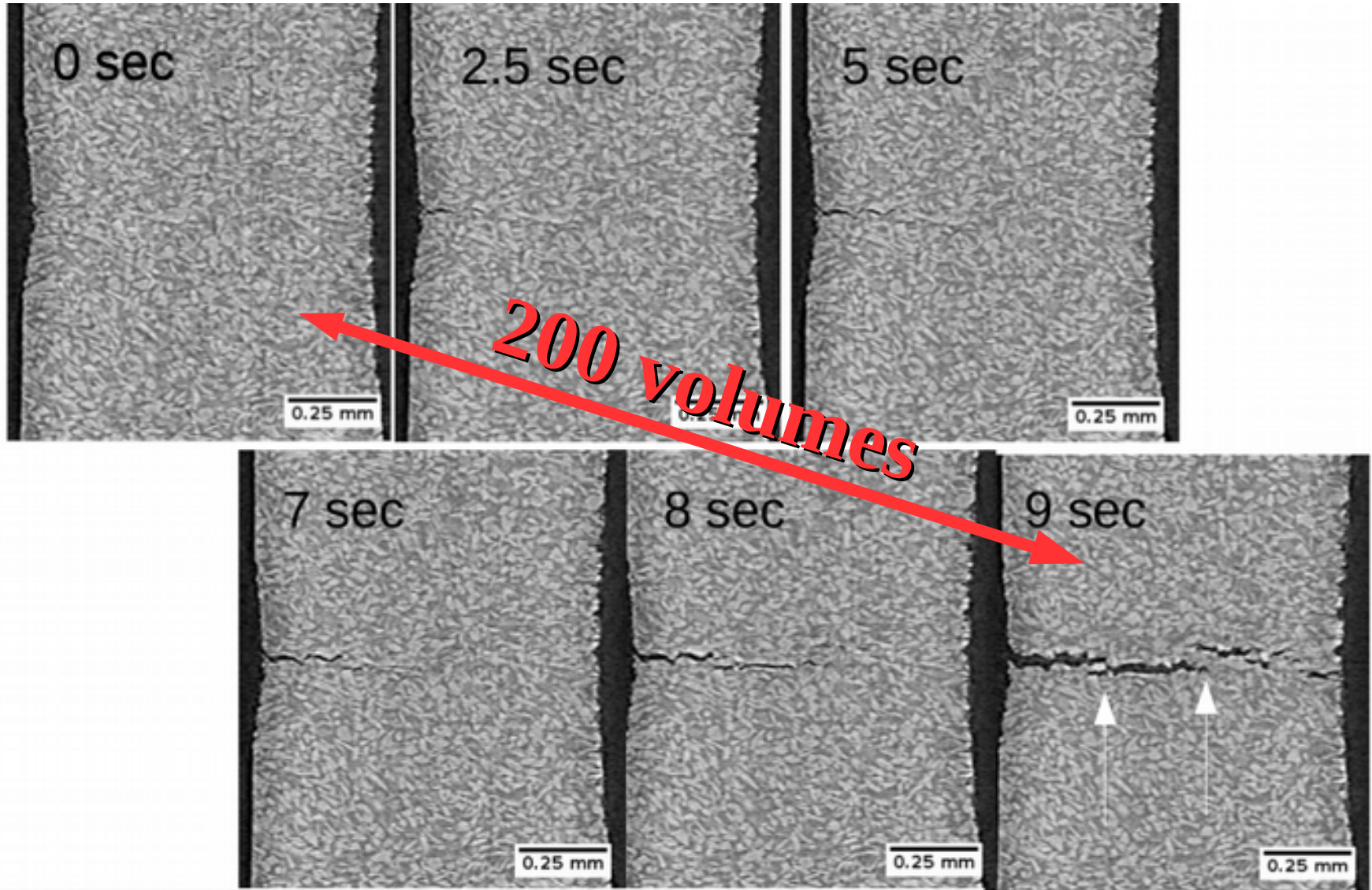


- Rotation : 10Hz
- Acquisition : >10kHz
- 20 volumes/s
- 12s d'acquisition (cyclique buffer)

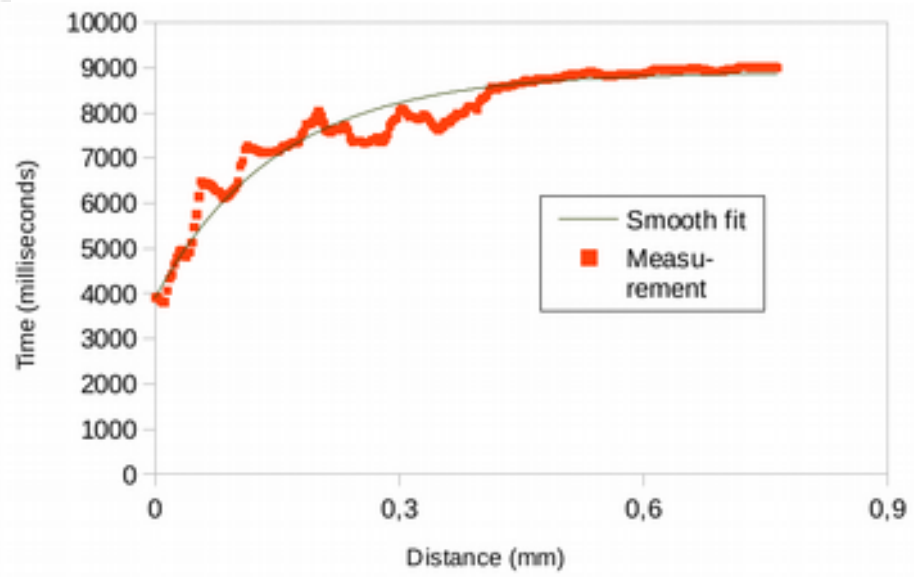
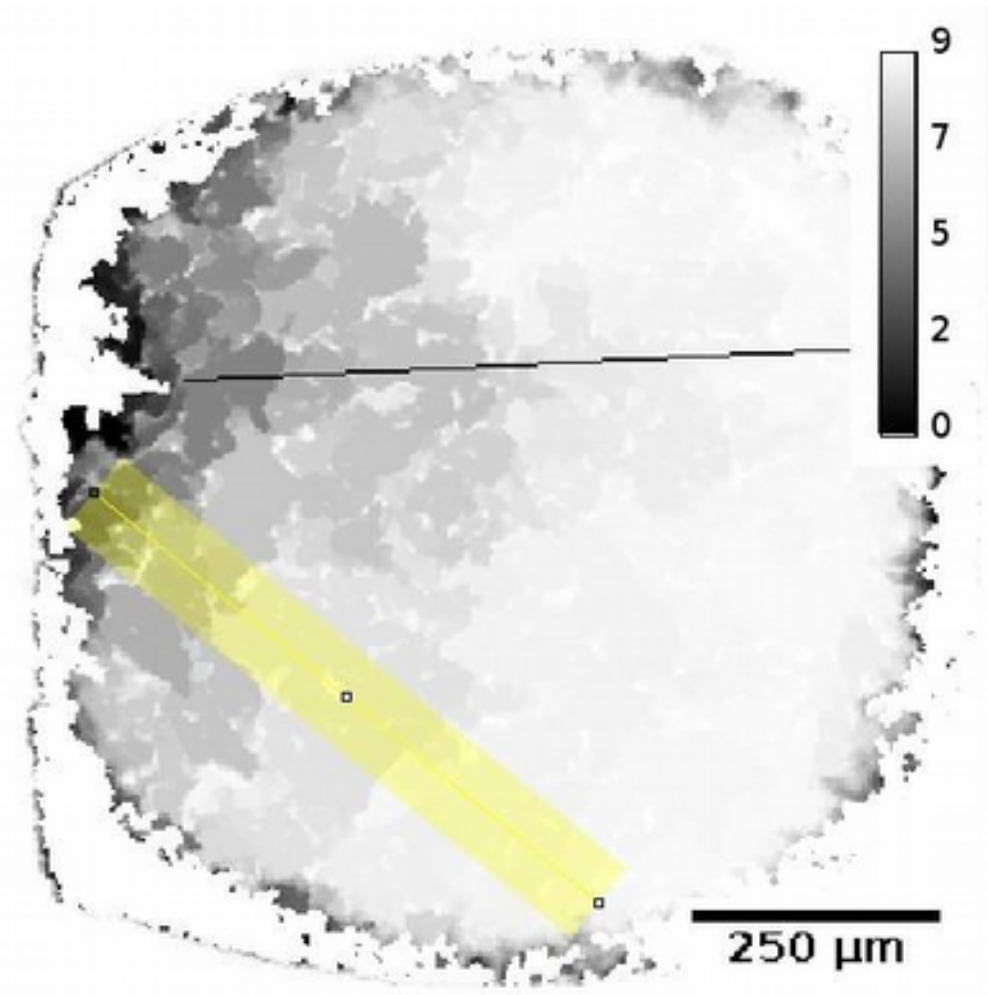
> SLS, TomCat
 > traction in situ INSA-MATEIS



3 : Rupture - Fast tomo



3 : Rupture - Fast tomo



> 20 Hz X-ray tomography during an in situ tensile test, E. Maire · C. Le Bourlot · J. Adrien · A. Mortensen · R. Mokso, IJF

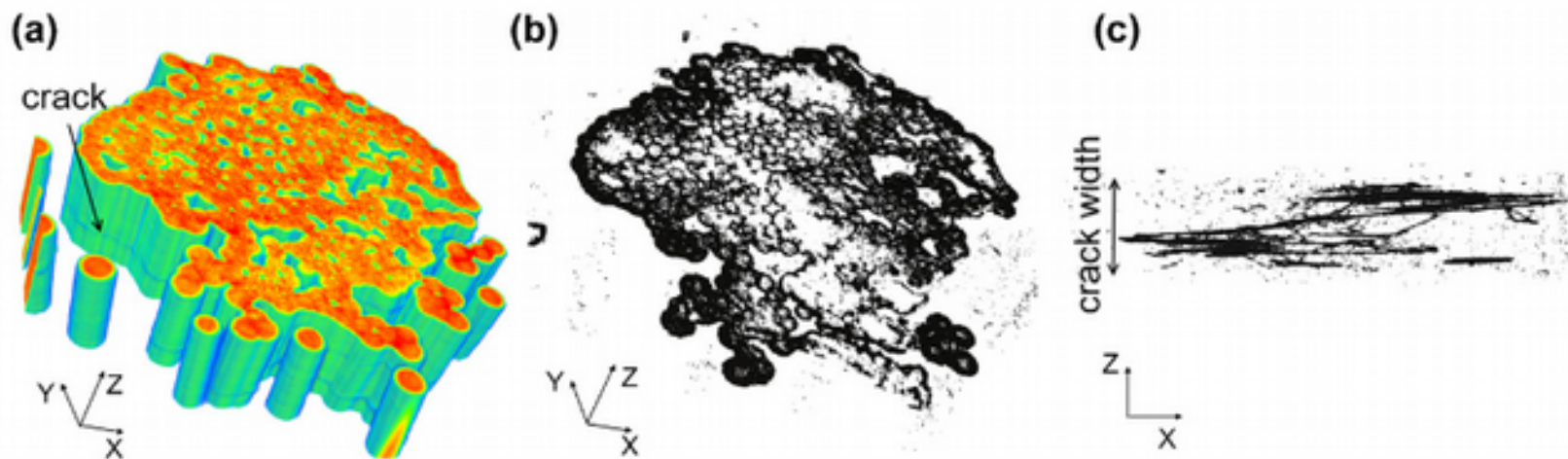


Fig. 3. (a) Sub-volume containing a matrix crack; (b–c) detected matrix crack from two different angles of view.

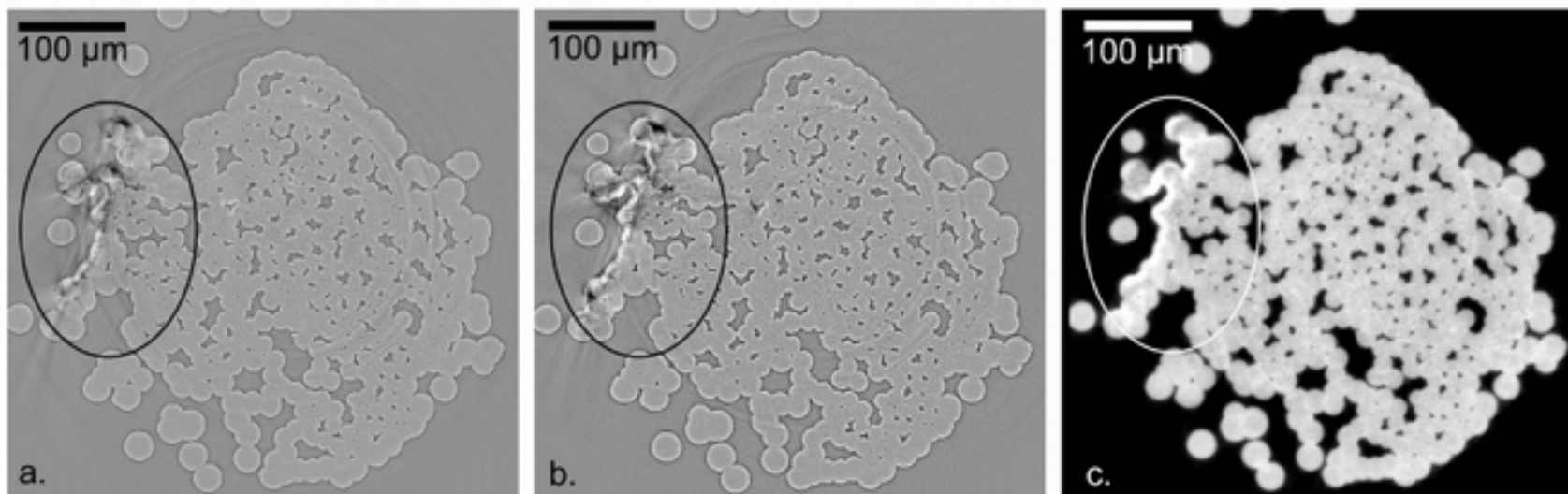
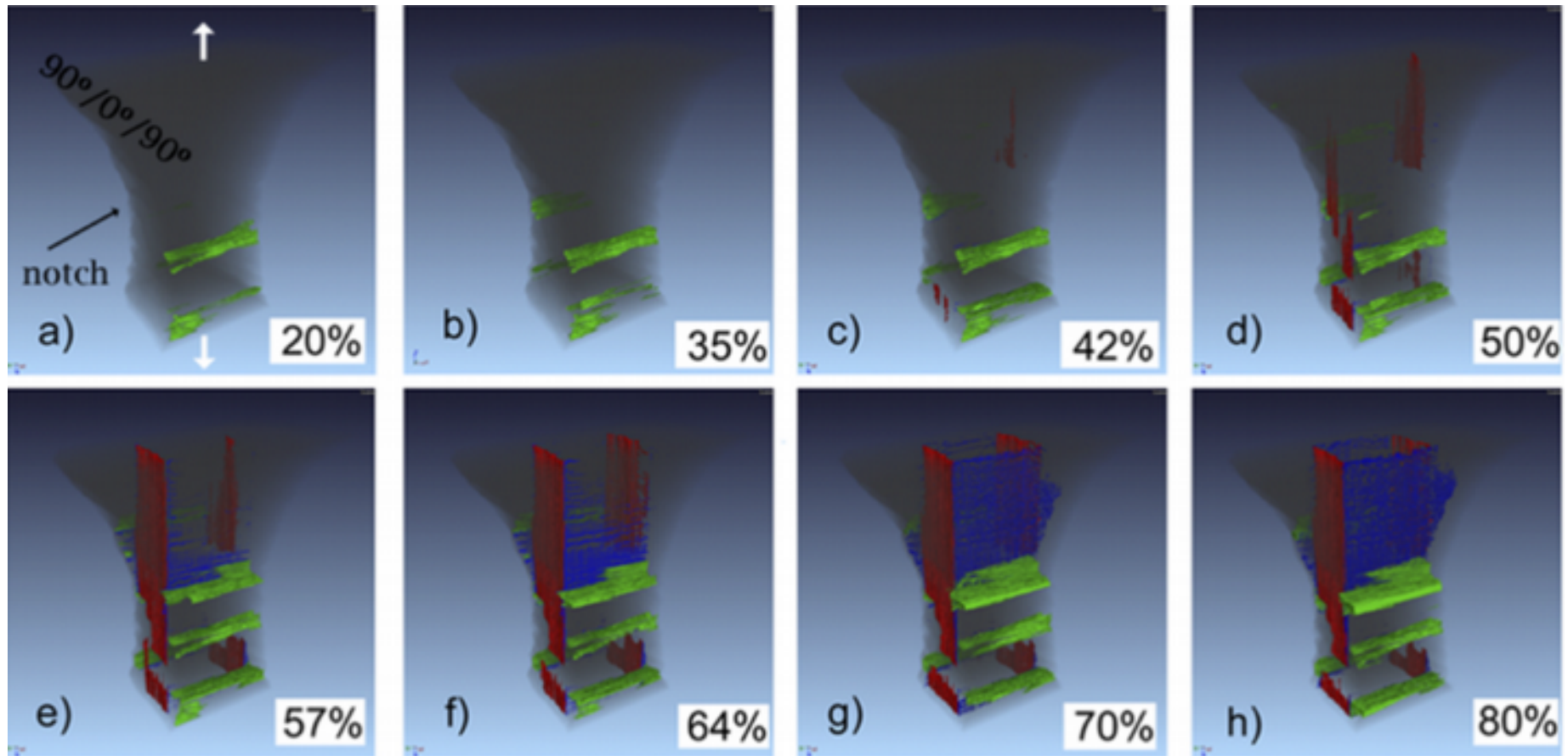


Fig. 4. Reconstruction of a transverse slice in absorption contrast (first two distances) and holotomographic mode within a matrix crack.

► To cite this version:

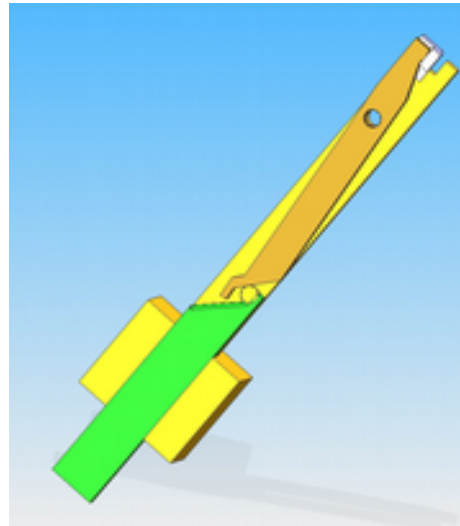
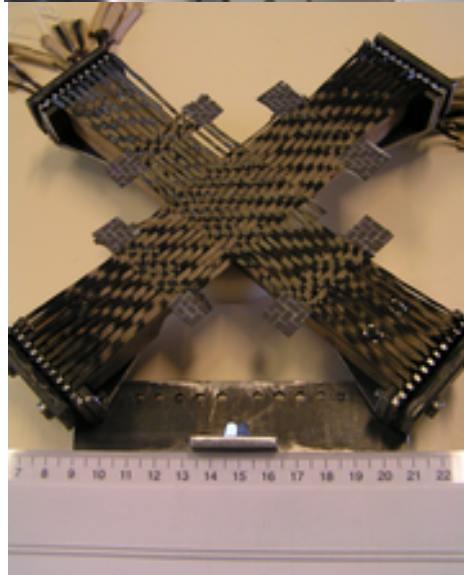
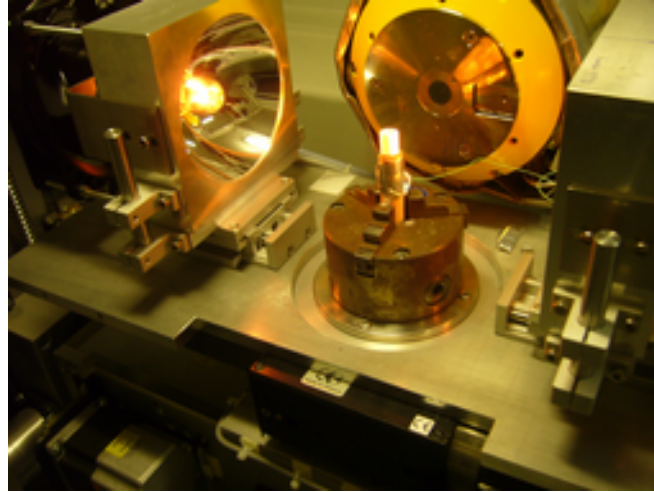
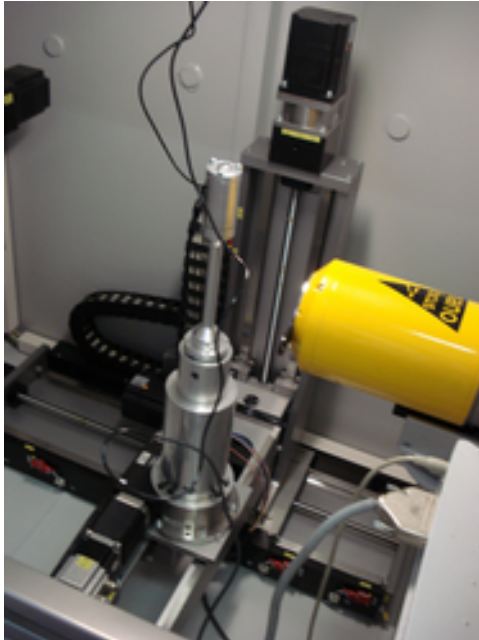
A.E. Scott, M. Mavrogordato, P. Wright, I. Sinclair, S.M. Spearing. Fibre Fracture Measurement in Carbon-Epoxy Laminates using High Resolution Computed Tomography. Composites Science and Technology, Elsevier, 2011, 71 (12), pp.1471. <10.1016/j.compscitech.2011.06.004>. <hal-00786584>

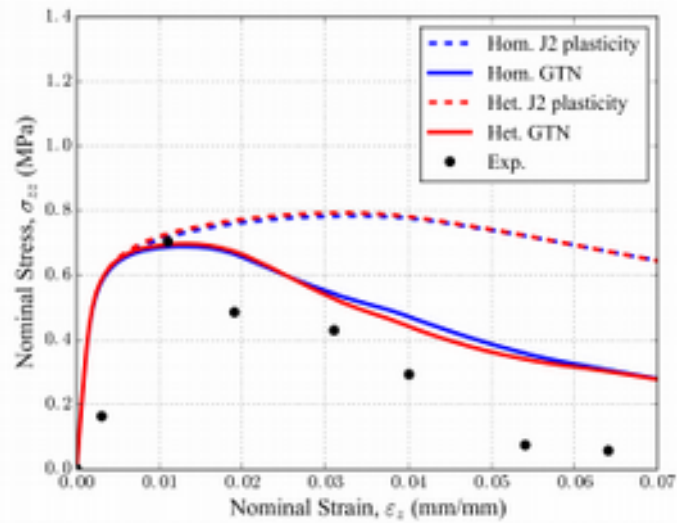
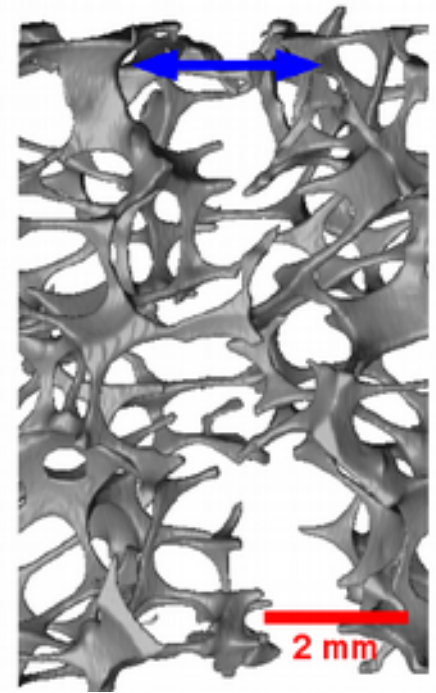
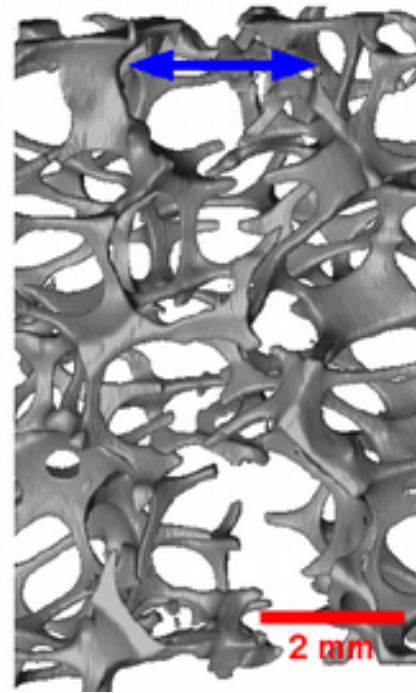
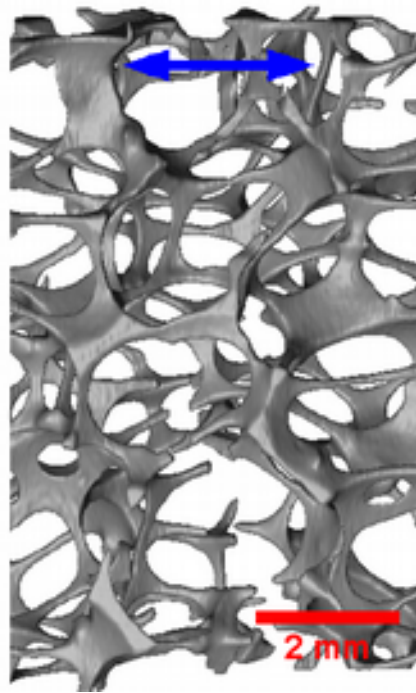
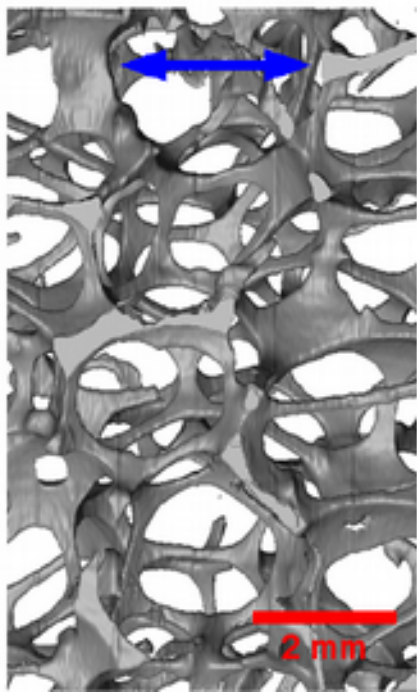


Transverse Ply Cracks 0° Splits Delaminations

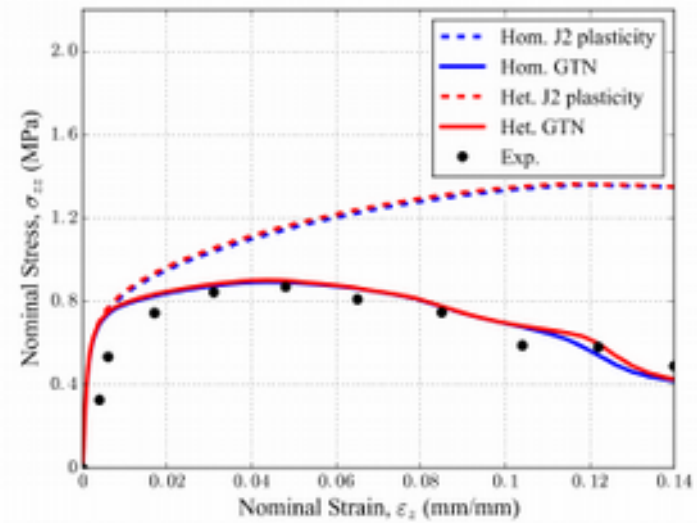
% of final failure load

Tomographe de laboratoire

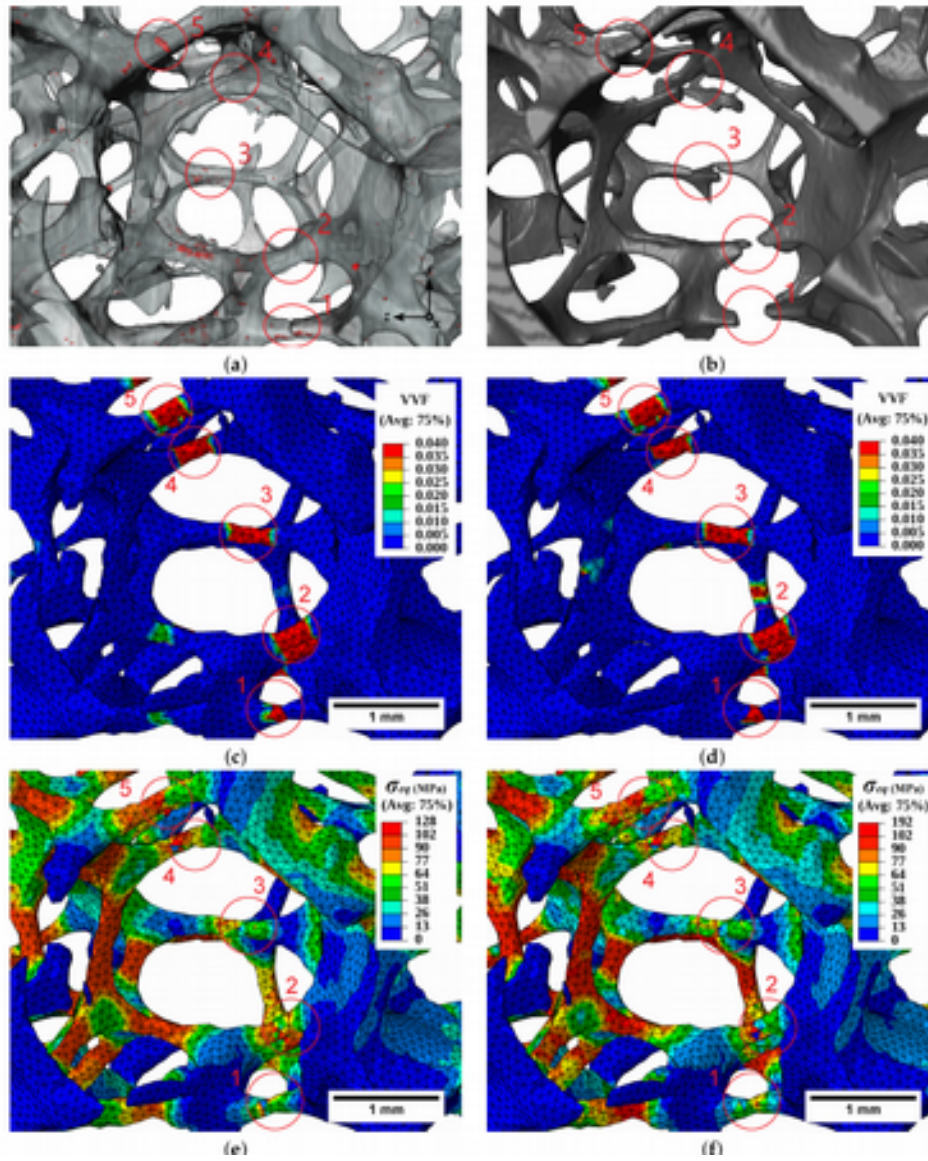




(a)



(b)



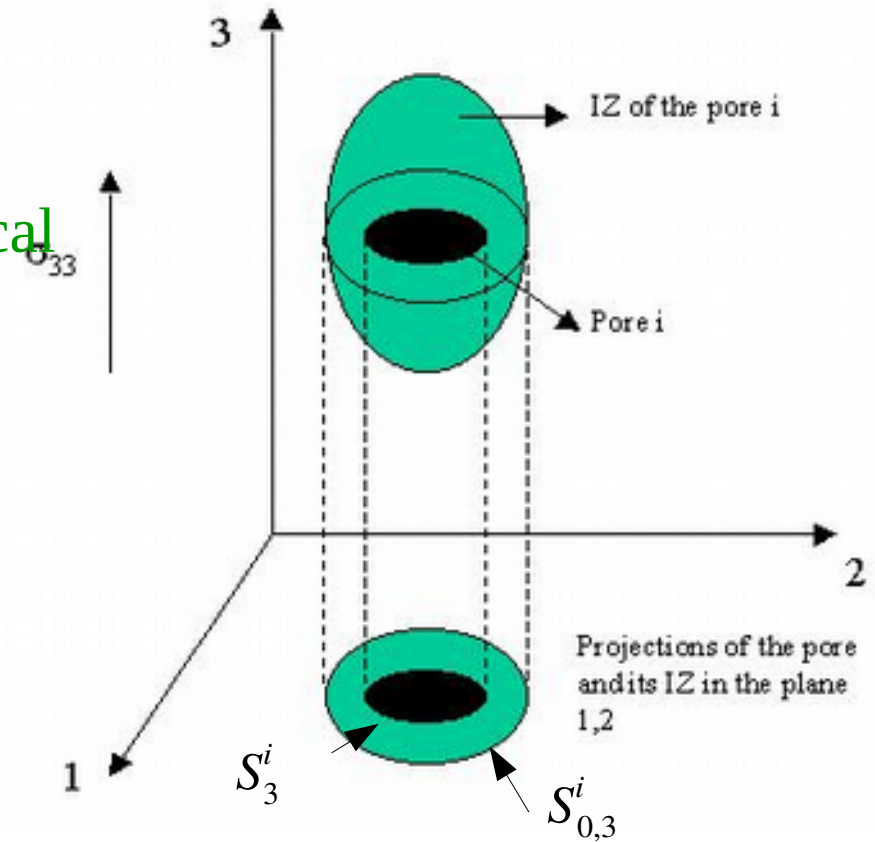


Autres acteurs

- MatéIS : J Adrien, C Le Bourlot, S Dancette, X Boulnat, J Lachambre, JY Buffiere, C Landron
- O Bouaziz, F Hannard, A Simar, T Pardoën, T Balan, O Cazacu, T Morgeneyer, H Proudhon, A Bouterf, F Hild, S Roux, M Bornert, L3SR, SIMAP
- H Toda, P Withers, I Sinclair

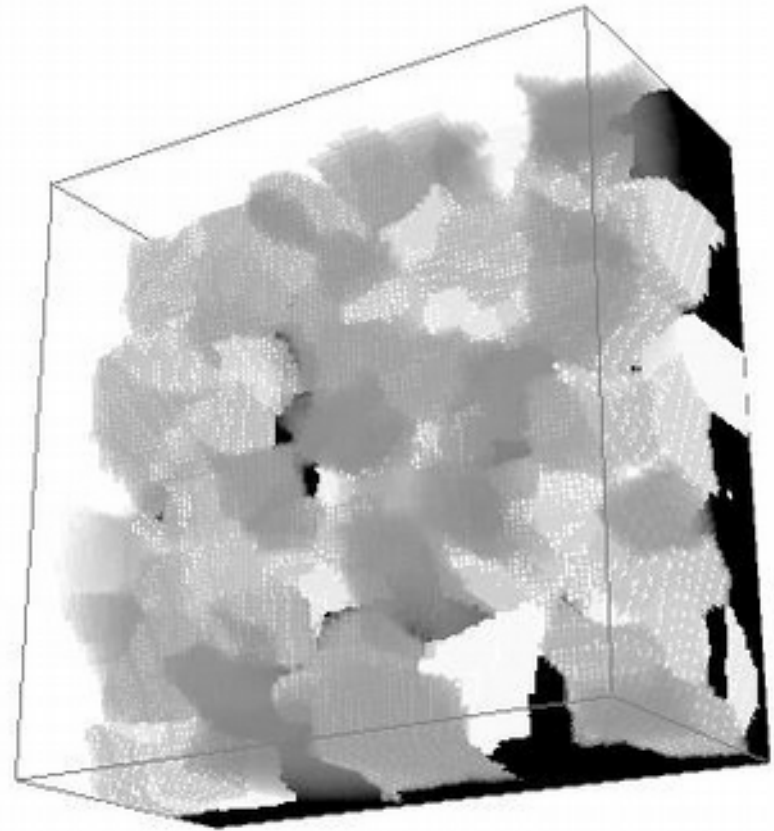
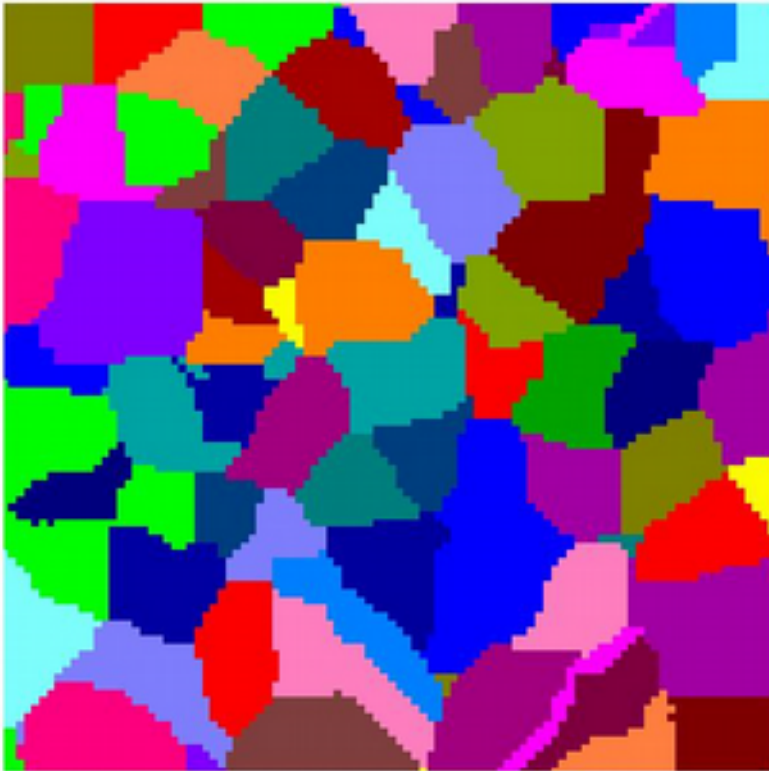
Mesure du paramètre d'endommagement d à partir des images

- Comment mesurer D à partir d'une image ?
- Mesure de f_{2D} (fraction surface) dans des sections perpendiculaires ?
 - Ne marche pas car f a toujours la même valeur (propriété stéréologique)
 - Donc il faut faire un calcul local de surface projetées S_D et S_0 de $D=(S_D/S_0)$ pour chacun des trous
 - Nécessite le calcul de la zone d'influence du pore



Zone d'influence

- Voronoï
- SKIZ



Gurson model ?

- Thuillier, Maire *et al.*
- Habrakem, Maire *et al.*
- Bouchard, Maire *et al.*
 - Cazacu, Maire *et al.*
- Pardoën, Maire *et al.*