

HYPERDÉFORMATION D'ALLIAGES DE Cu ET D'Al PAR ECAE

T. Baudin

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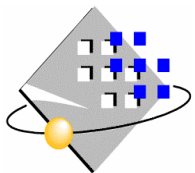
P.L. Reydet, P. Barbé

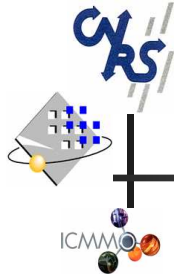
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Pourquoi l'hyperdéformation ?

Élaborer des matériaux **massifs** à grains submicroniques voire nanométriques



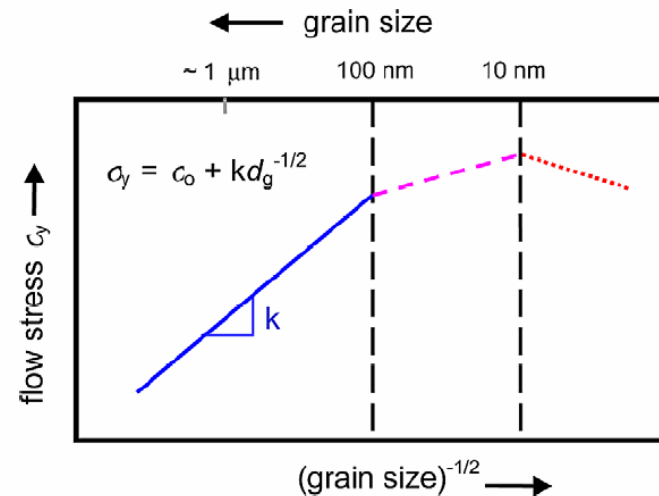
Améliorer les propriétés mécaniques (loi de Hall et Petch)

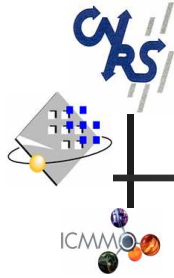
$$\sigma_e = \sigma_0 + kd^{-1/2}$$

La limite d'élasticité augmente lorsque la taille des grains diminue



On cherche donc à fabriquer des **microstructures à grains fins** (par la maîtrise des conditions de coulée, du laminage contrôlé, ...).



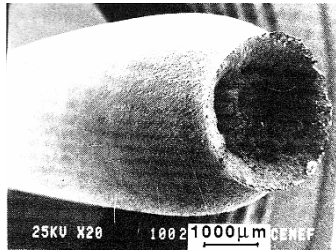


Pourquoi l'hyperdéformation ?

Élaborer des matériaux **massifs** à grains submicroniques voire nanométriques

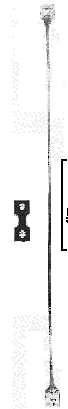


Obtenir des propriétés superplastiques à basse température

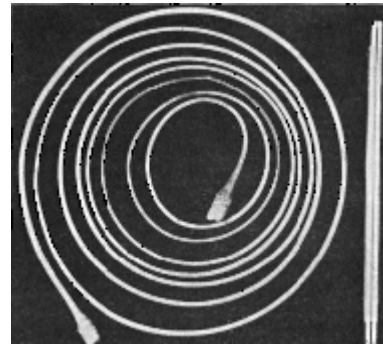


Plasticité

Allongement : 20%

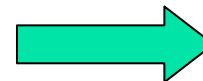


Traction à haute température

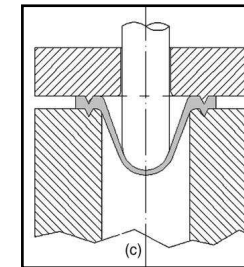


Superplasticité

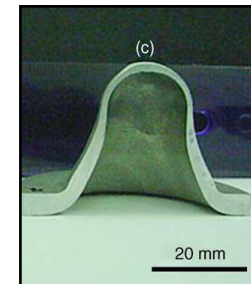
Allongement : 1000%

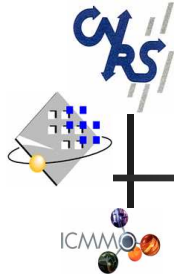


Emboutissabilité



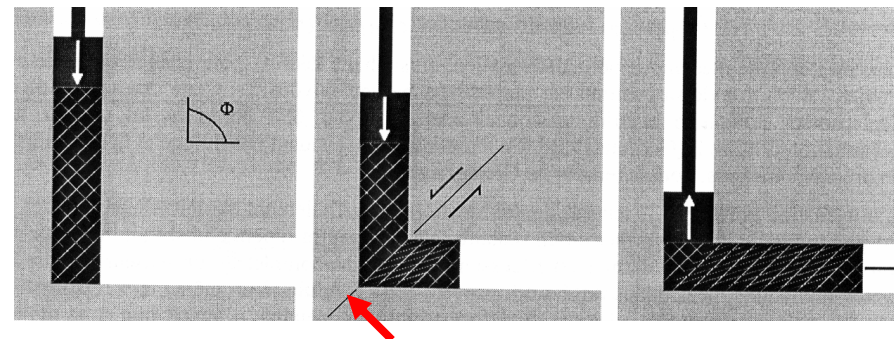
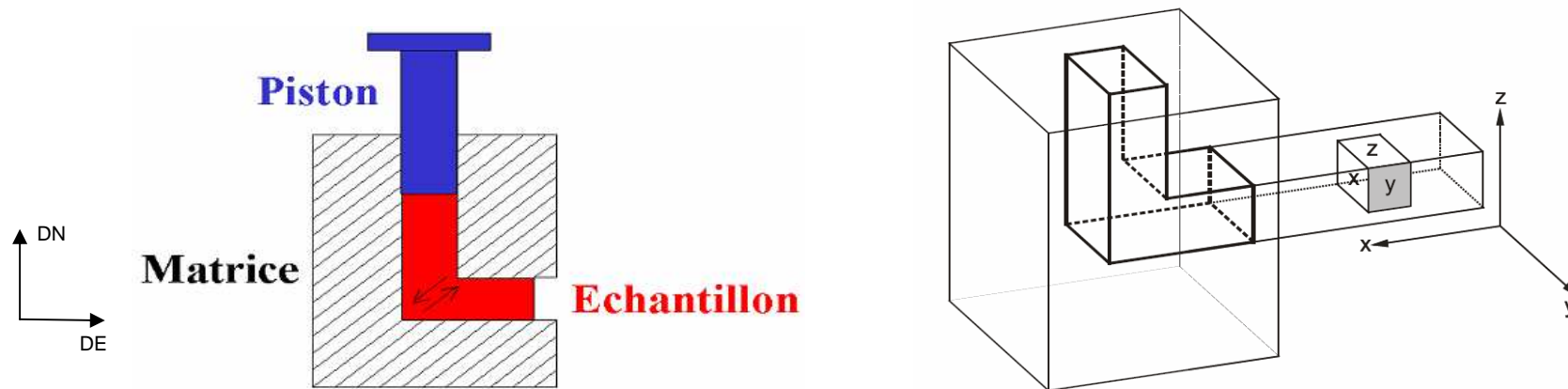
(Dutta *et al.*, 2005)



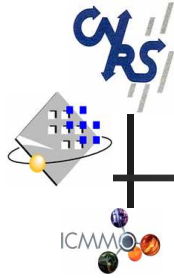


Comment hyperdéformer ?

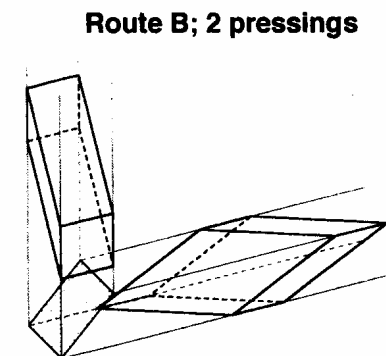
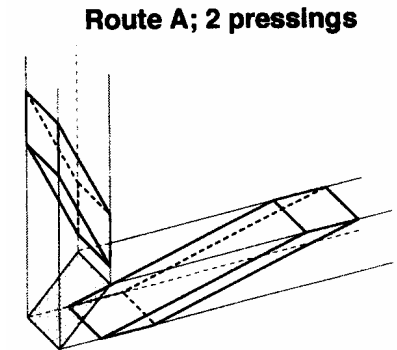
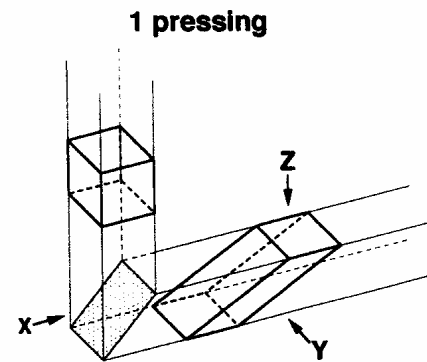
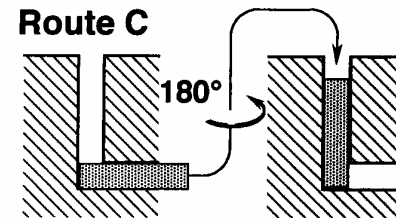
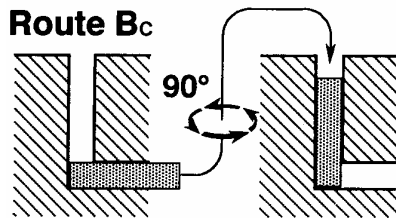
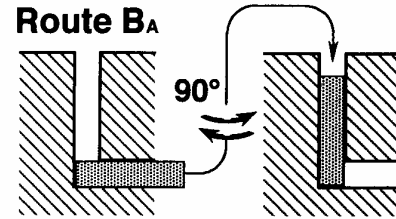
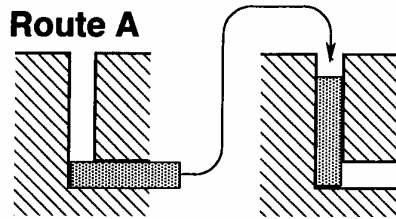
- Un moyen très utilisé : ECAE (Equal Channel Angular Extrusion).

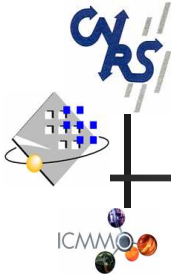


Plan de cisaillement

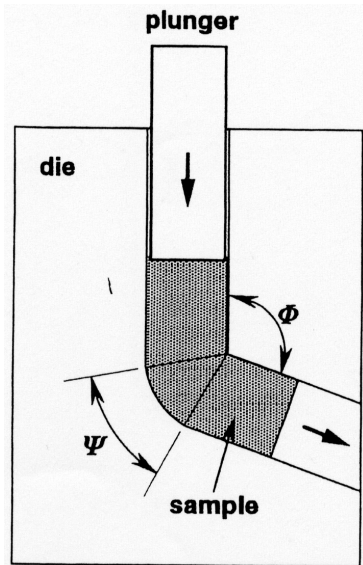


Différents chemins de déformation

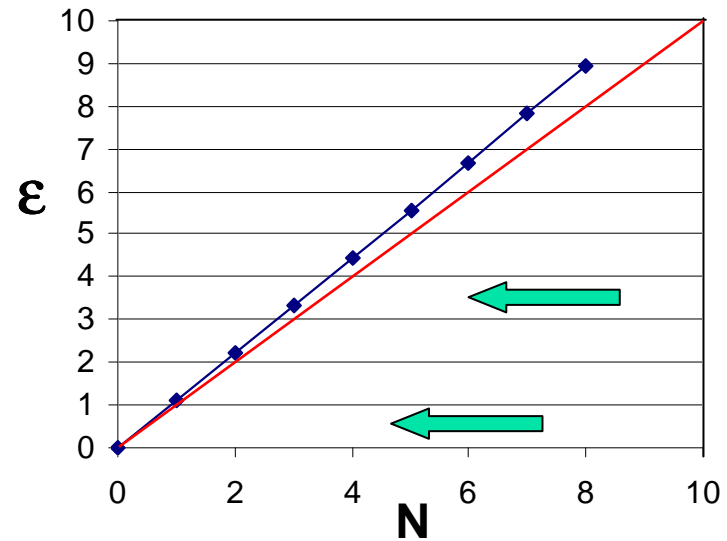




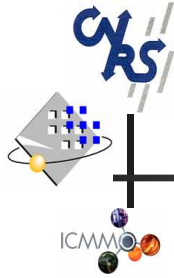
Quelles déformations ?



Dans le cas où : $\phi = 92^\circ$ et $\psi = 0^\circ$

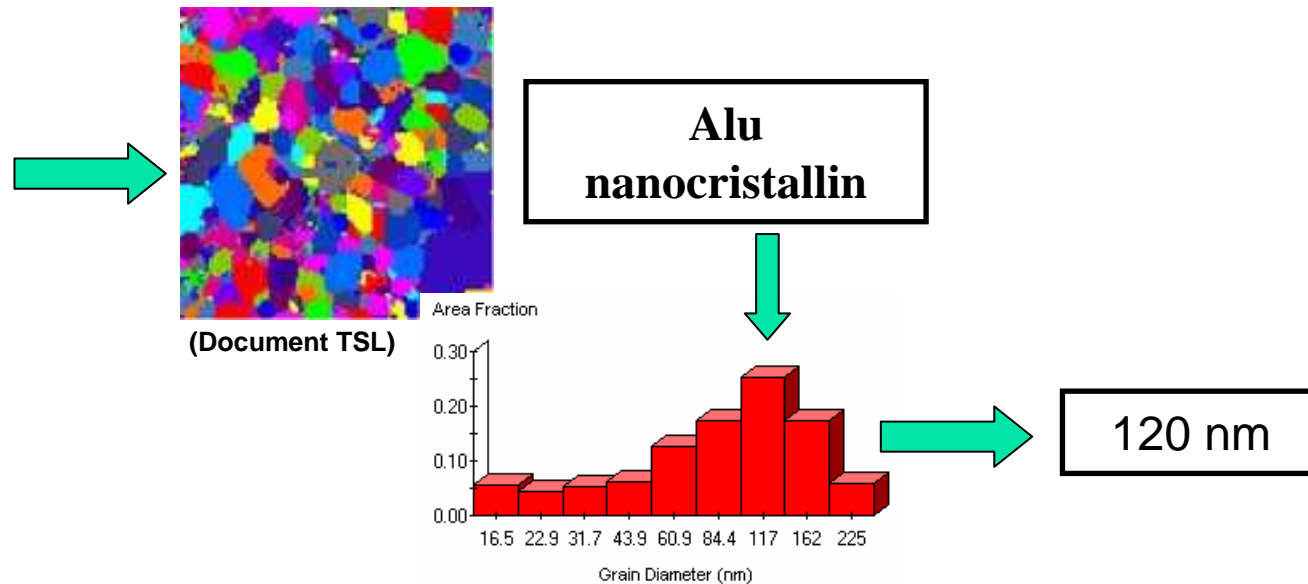


| N | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|------|------|------|------|------|------|------|------|
| ε | 0 | 1,12 | 2,23 | 3,35 | 4,46 | 5,58 | 6,69 | 7,81 | 8,92 |

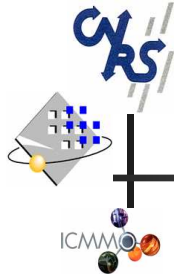


Quelques résultats

- 1. Formation des microstructures de déformation



- 2. Stabilité en température : minimiser la croissance de grains et donc les baisses de propriétés mécaniques acquises grâce à l'obtention d'une structure submicronique.



1. Formation des microstructures de déformation

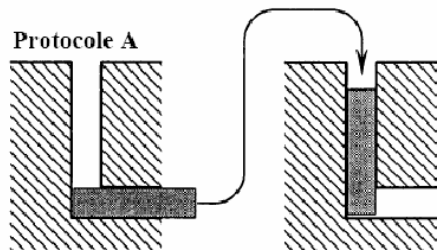
MATERIAUX

- **Aluminium** de faible pureté 99,1%
- État initial : $d = 85 \mu\text{m}$

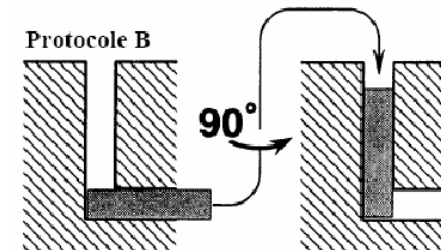
- **Cuivre** de pureté commerciale
- État initial : $d = 40 \mu\text{m}$

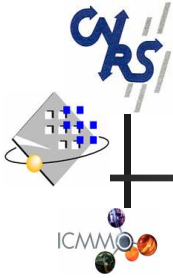
HYPERDEFORMATION PAR ECAE

- Échantillons : $12 \times 12 \times 50 \text{ mm}^3$
- Matrice ECAE ($\alpha = 90^\circ$) – $N=5$



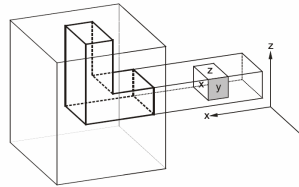
- Échantillons : $12 \times 12 \times 80 \text{ mm}^3$
- Matrice ECAE ($\alpha = 92^\circ$) – $N=8$



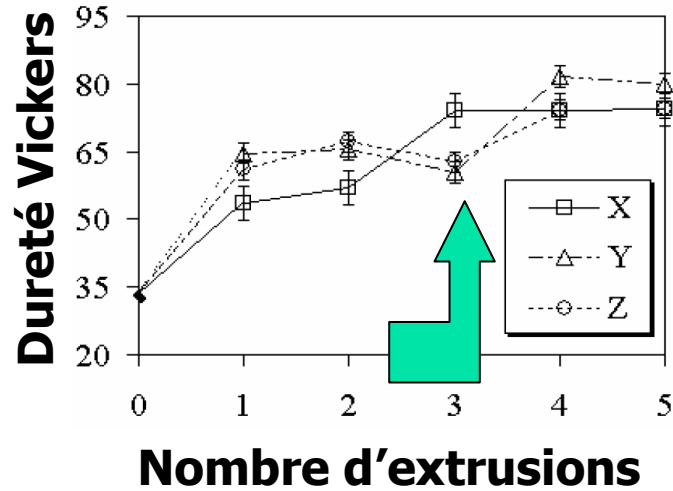


1. Formation des microstructures de déformation

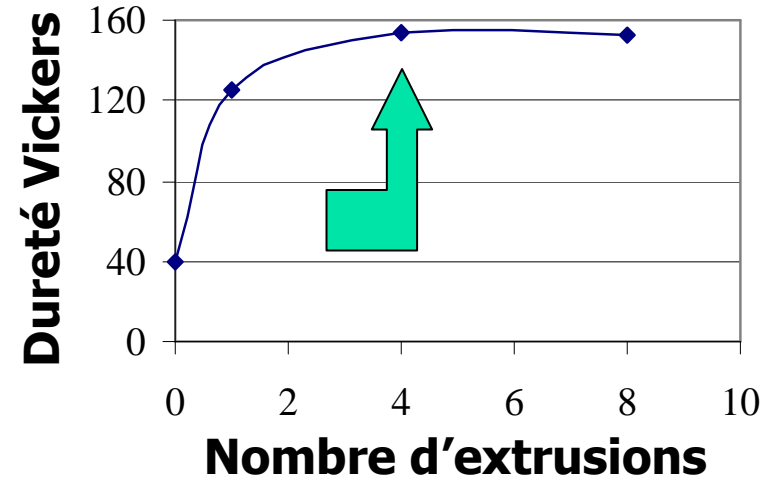
Aluminium



Cuivre

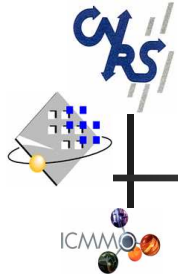


Saturation vers une valeur proche de 80 HV



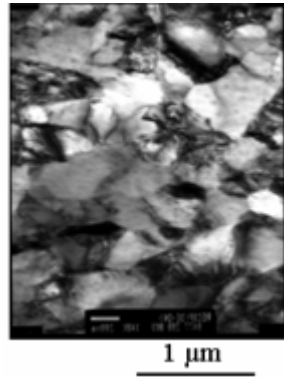
Saturation vers une valeur proche de 160 HV

Thèse A. Korchef (2004)

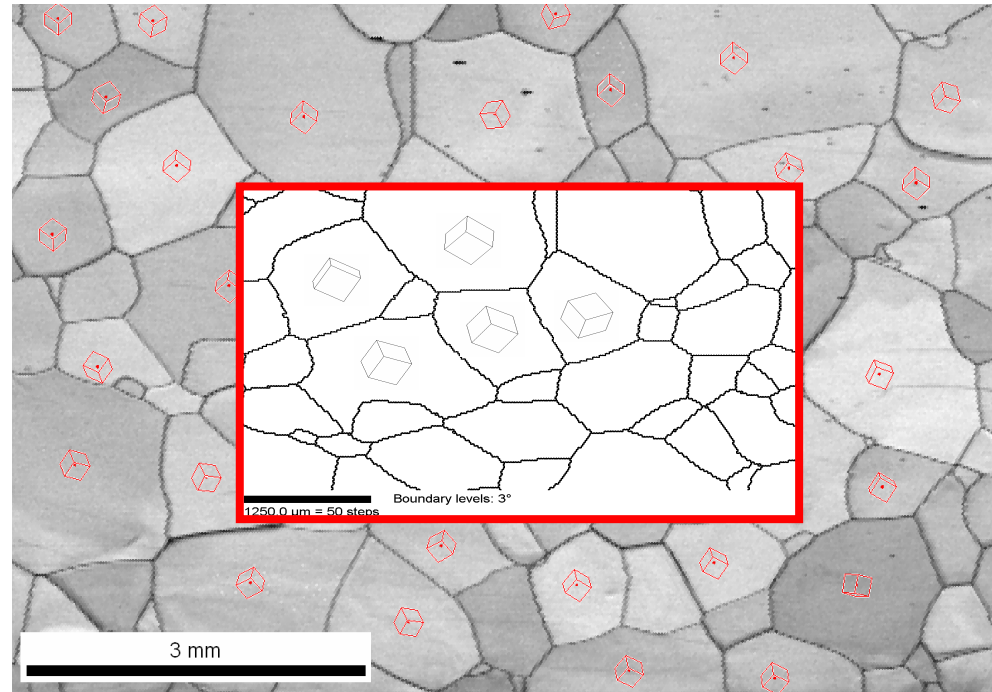
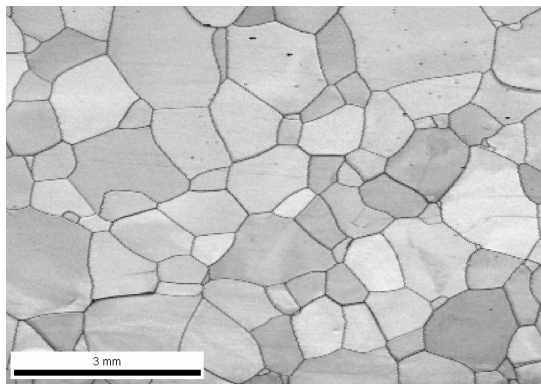


1. Formation des microstructures de déformation

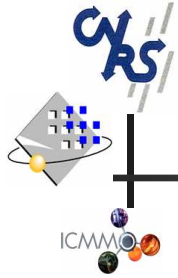
MET



MEB

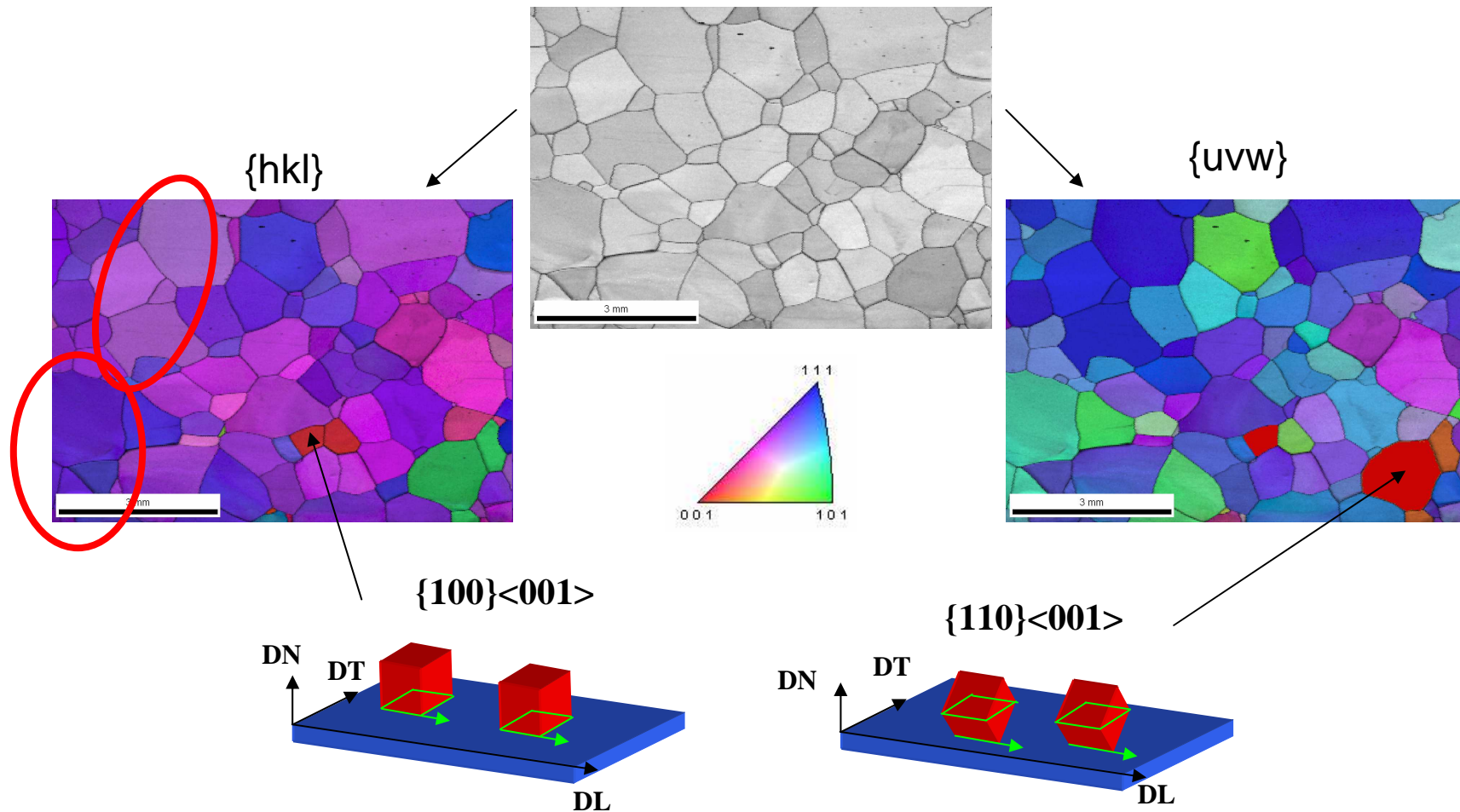


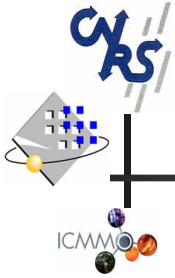
→ Corrélation entre la texture et la microstructure



1. Formation des microstructures de déformation

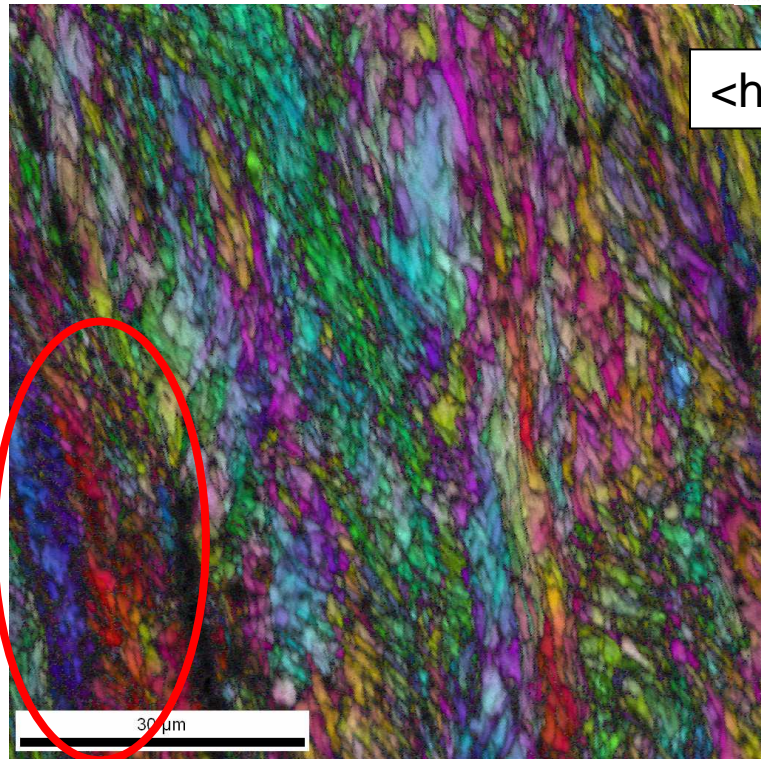
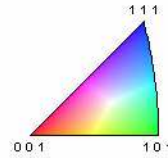
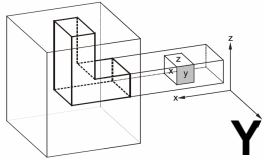
MET ou MEB/EBSD



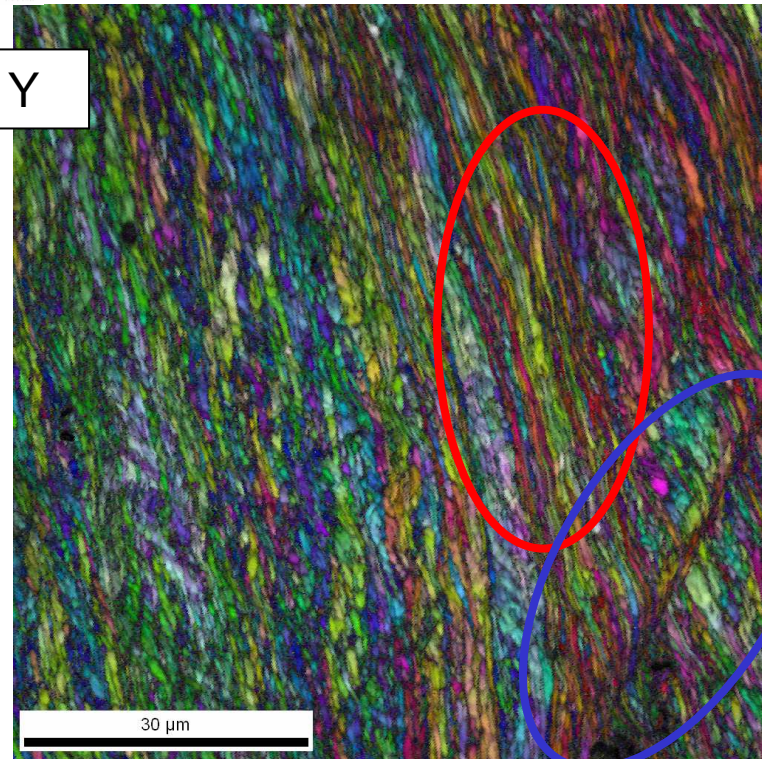


1. Formation des microstructures de déformation

ECAE – Aluminium (FEG/EBSD – MSSMat, ECP)



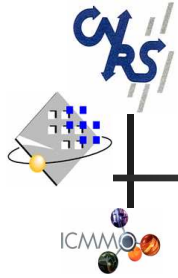
N = 2



N = 4

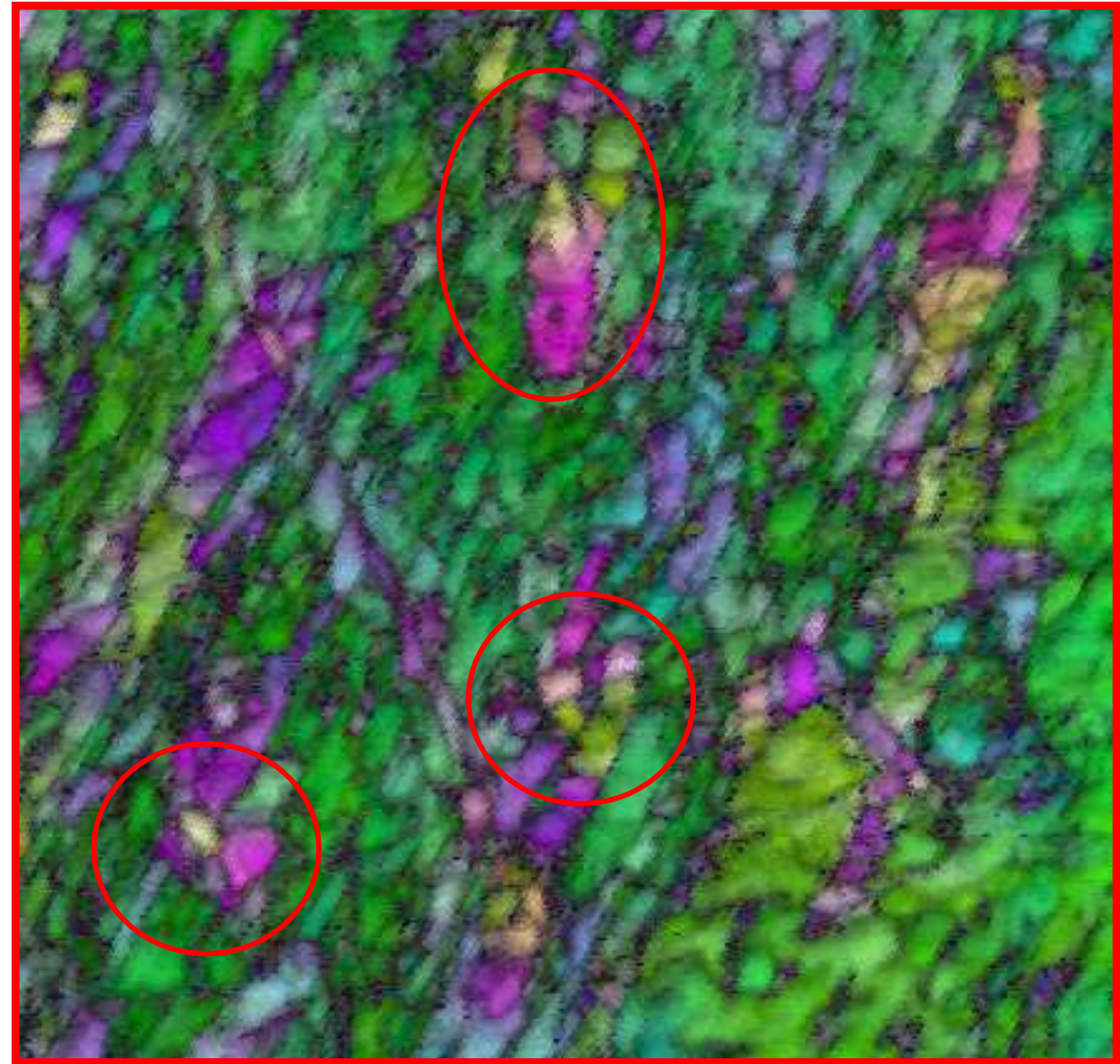
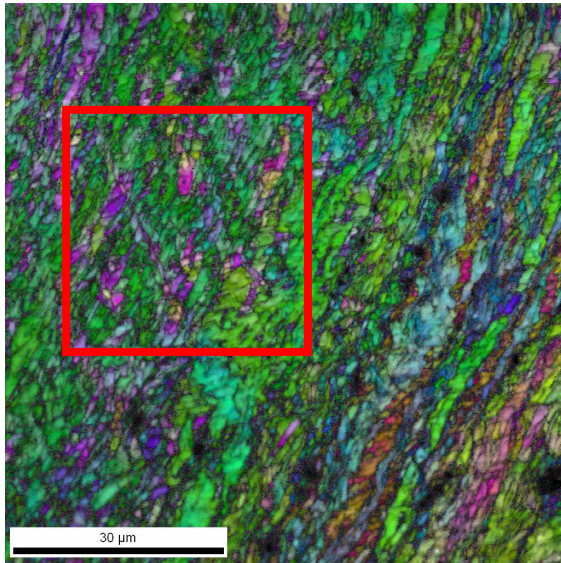
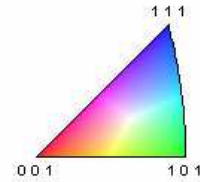
Affinement de la microstructure

Bande de cisaillement

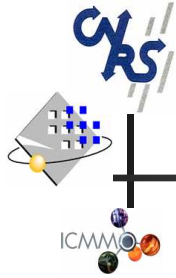


1. Formation des microstructures de déformation

N = 3

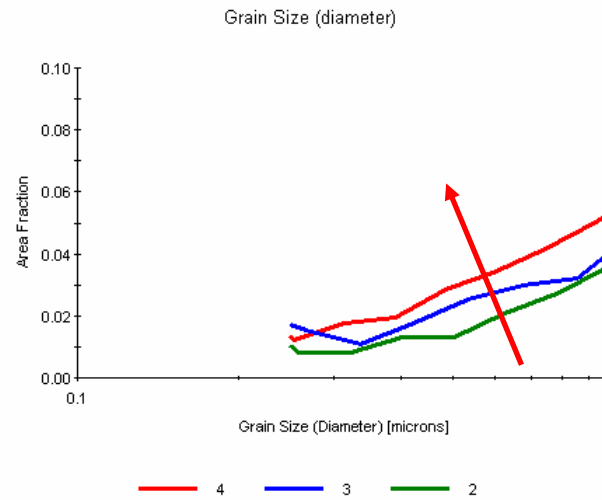
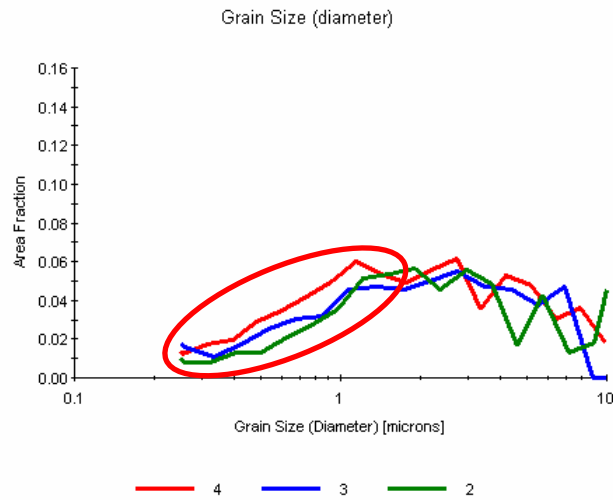


Apparition de petits grains

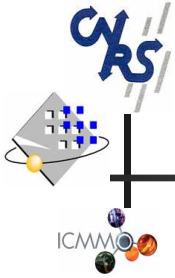


1. Formation des microstructures de déformation

Distribution de la taille de grains Peu de variation !

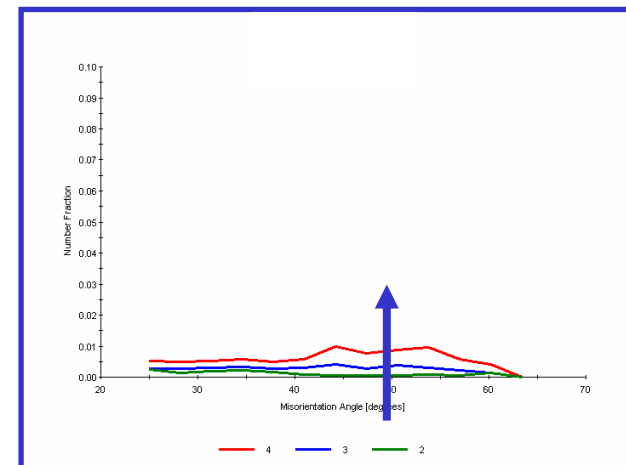
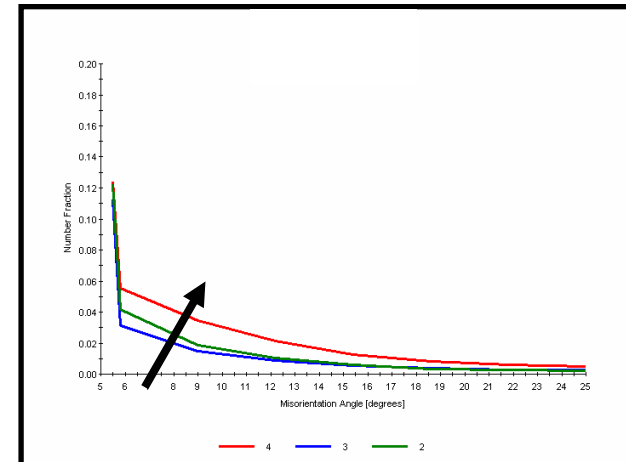
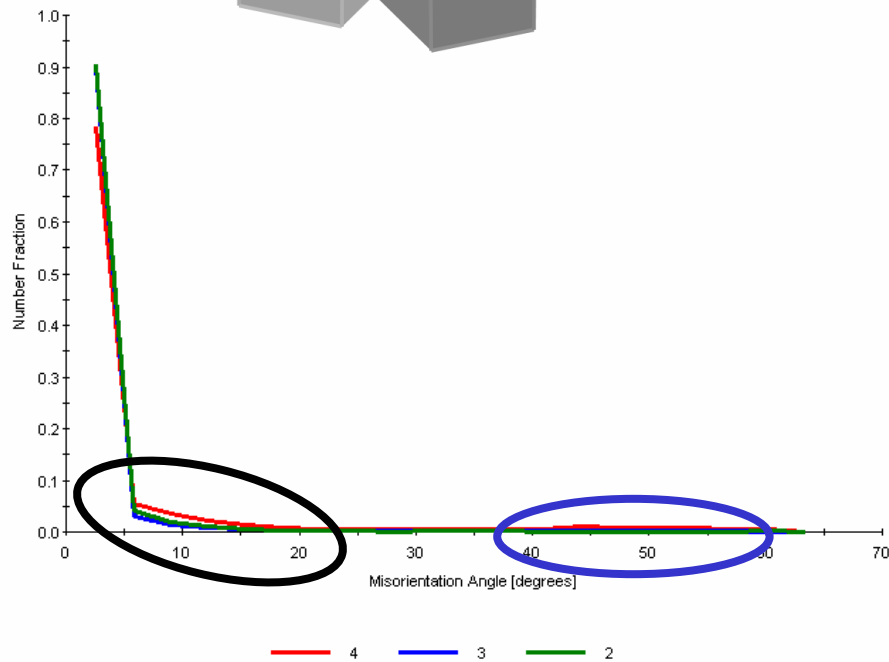
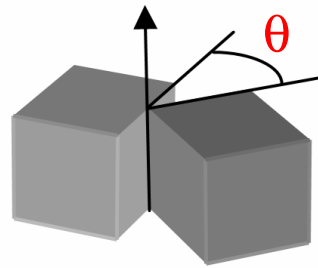


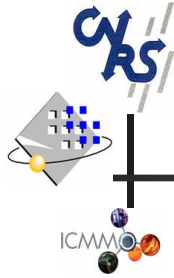
Augmentation du nombre
de petits grains



1. Formation des microstructures de déformation

Distribution de la désorientation θ entre « grains »
Peu de variation !

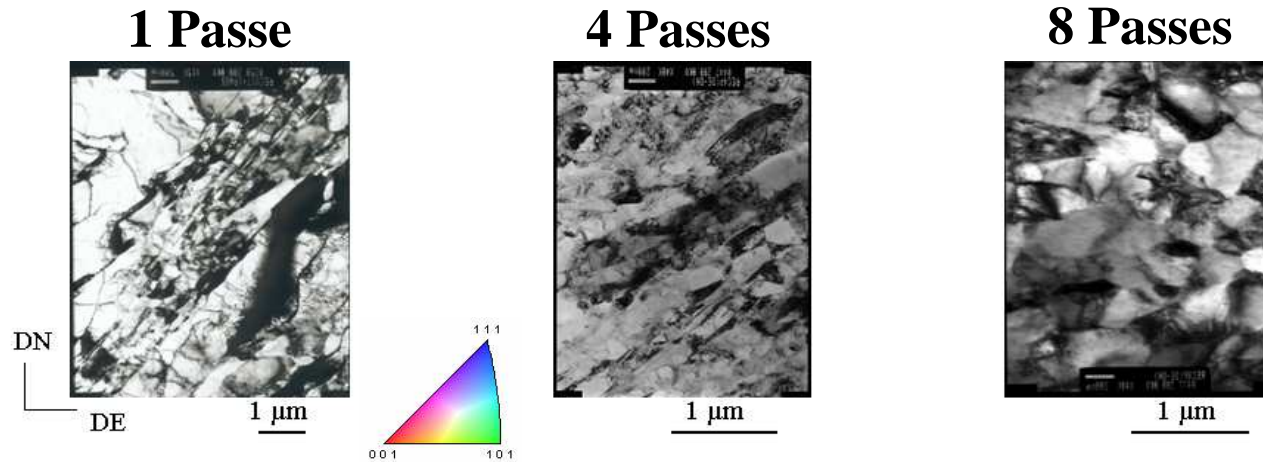




1. Formation des microstructures de déformation

ECAE - Cuivre

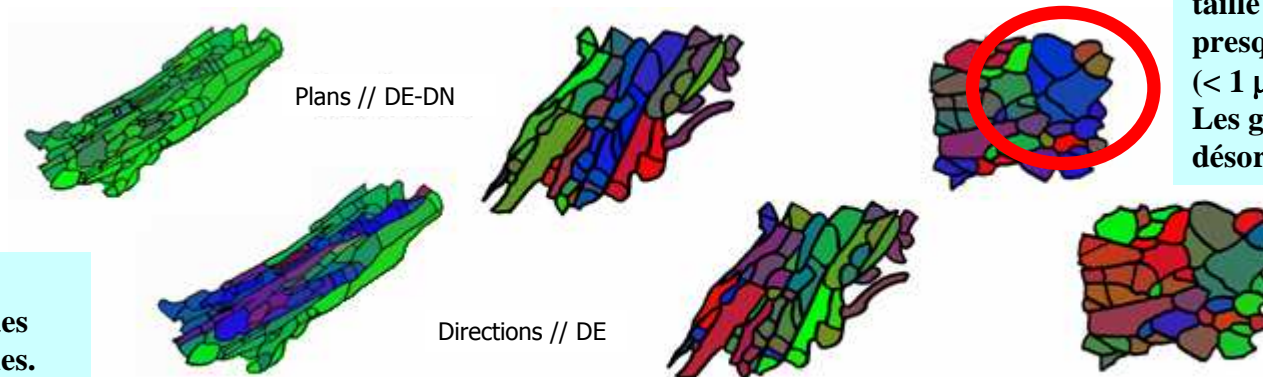
MET

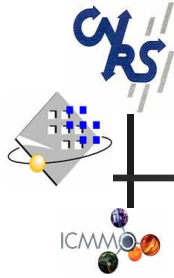


**Formation de nouvelles bandes.
Formation de grains équiaxes dans les anciennes bandes.**

Entre 4 et 8 passes la taille des grains reste presque constante (< 1 μm). Les grains sont plus désorientés.

**Grains cisailés.
Formation de bandes constituées de cellules.**



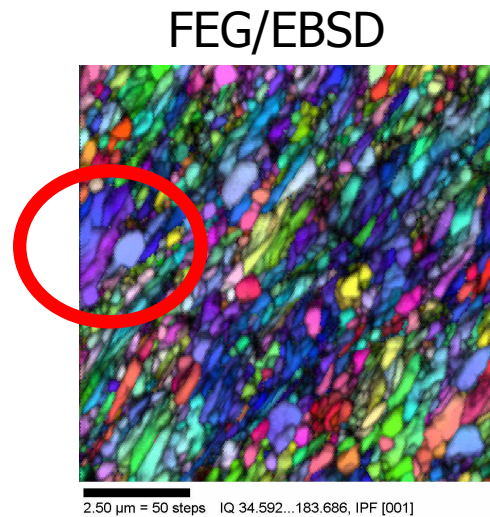
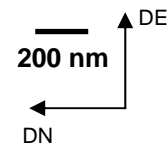
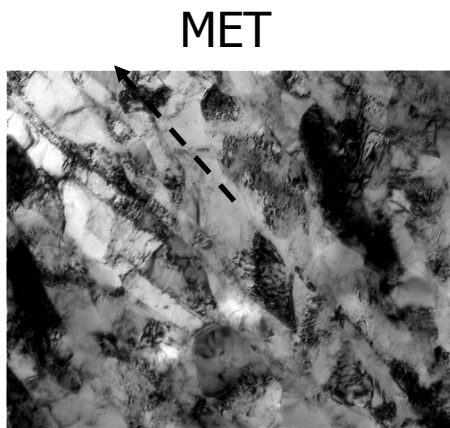


1. Formation des microstructures de déformation

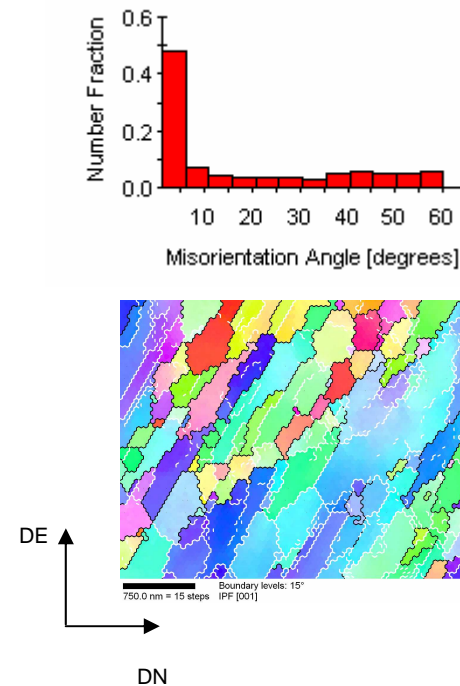
MICROSTRUCTURE APRES 8 PASSES

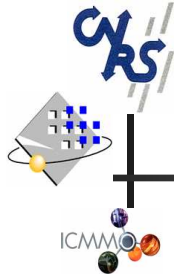
La microstructure à petits grains n'est pas obtenue malgré la saturation de la dureté.

1. Amas de petits grains de même orientation
2. Persistance de bandes allongées



(MSSMat, ECP)



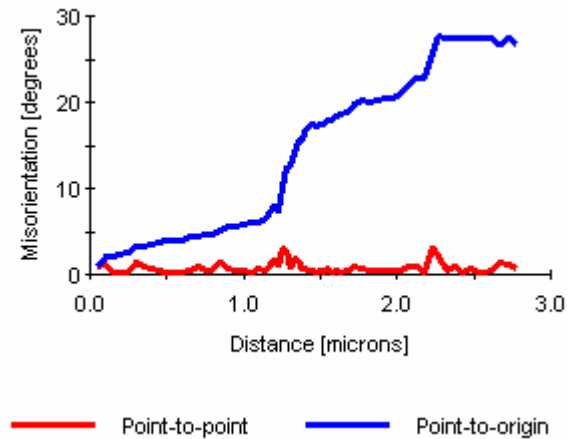
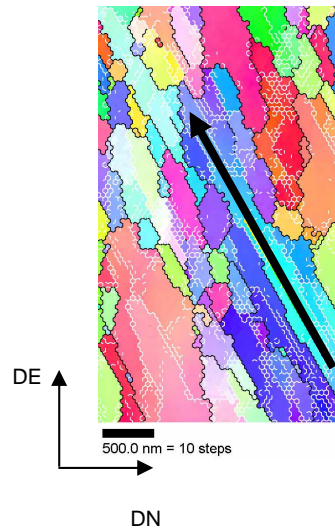


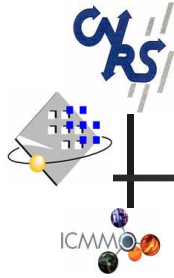
1. Formation des microstructures de déformation

MICROSTRUCTURE APRES 8 PASSES

1. Amas de petits grains de même orientation
2. **Persistence de bandes allongées (suite)**

FEG/EBSD



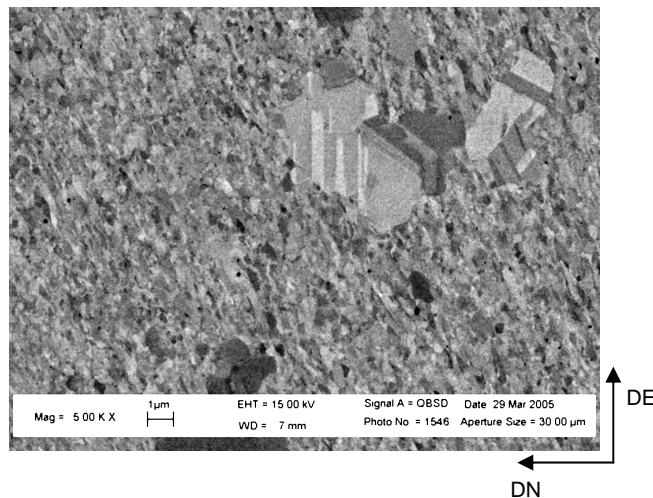


1. Formation des microstructures de déformation

MICROSTRUCTURE APRES 8 PASSES

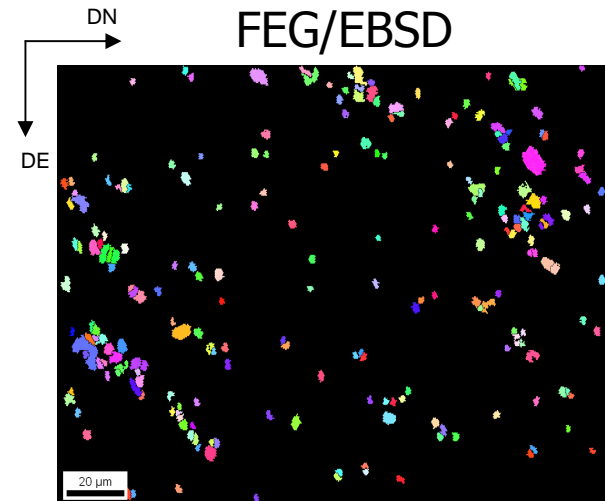
1. Amas de petits grains de même orientation
2. Persistance de bandes allongées
3. Présence de grains « recristallisés dynamiquement »

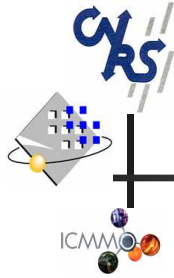
MEB



Échauffement
durant
l'extrusion

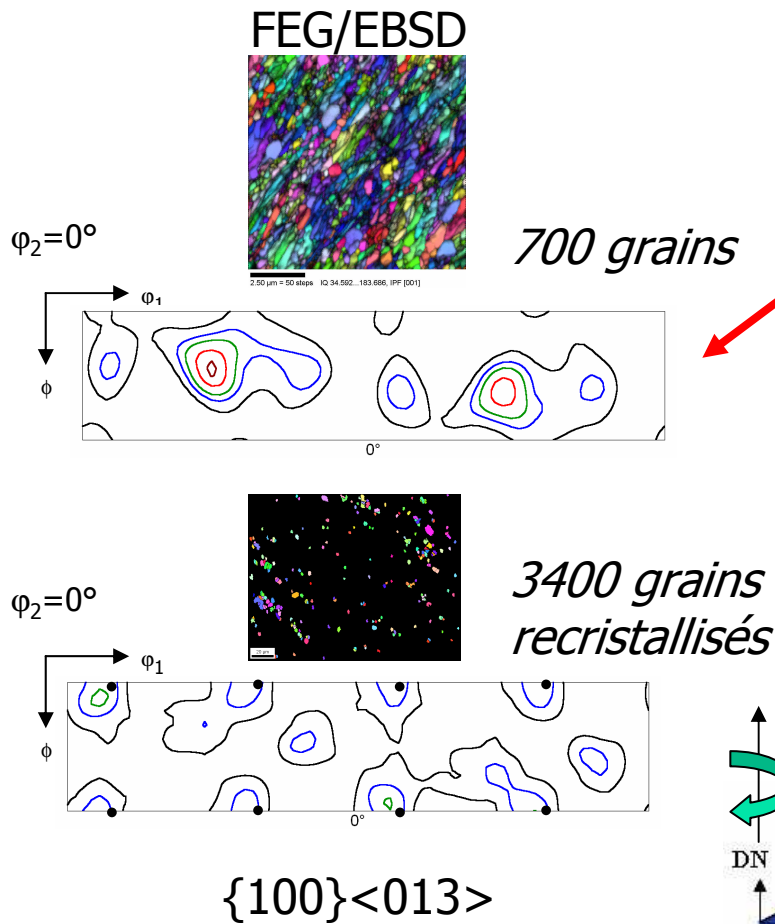
FEG/EBSD



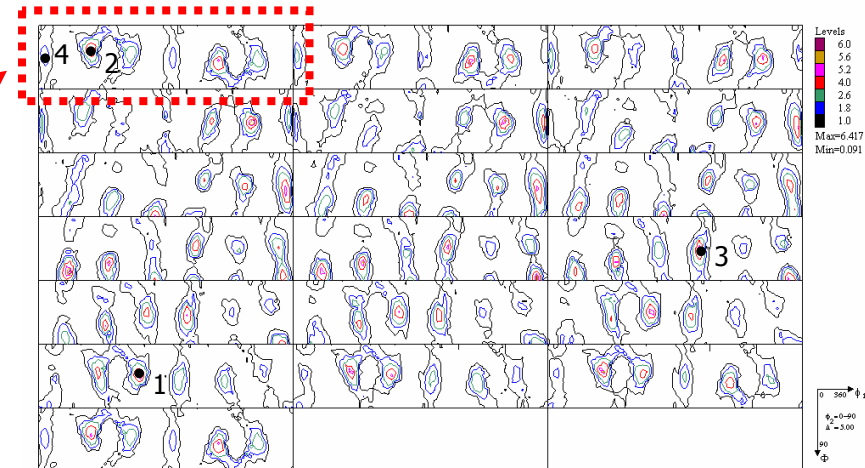


1. Formation des microstructures de déformation

TEXTURE APRES 8 PASSES

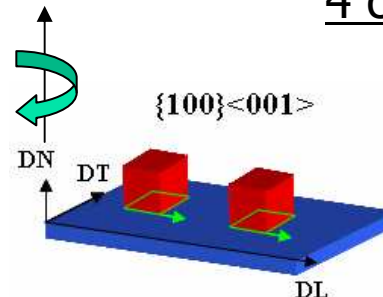


Diffraction des neutrons



4 composantes principales

1. $\{101\}\langle -111 \rangle$
2. $\{-101\}\langle 3-13 \rangle$
3. $\{323\}\langle -16-3 \rangle$
4. $\{011\}\langle 8-11 \rangle$

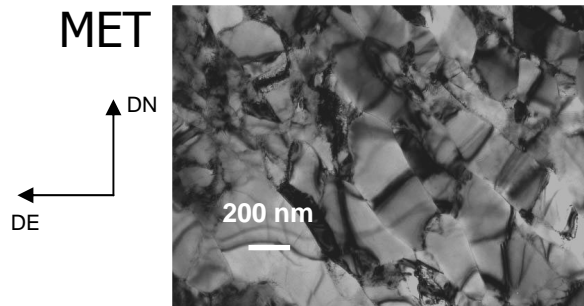
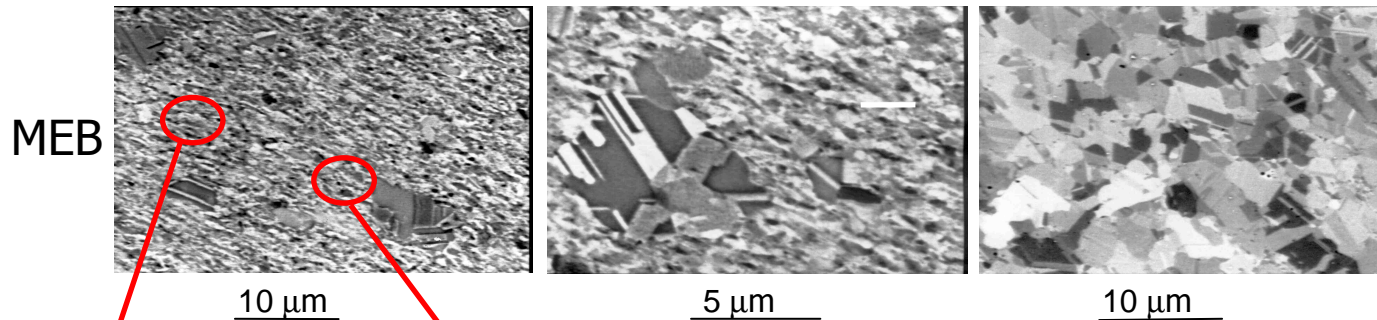


2. Stabilité en température de la microstructure du cuivre (Recuit en bain d'huile à 200°C)

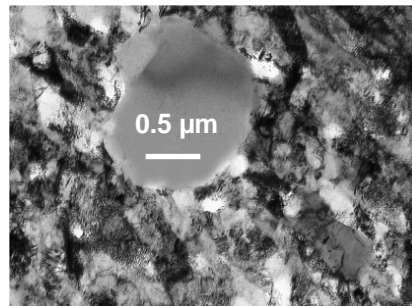
MICROSTRUCTURE APRES 8 PASSES + RECUIT

30 secondes

210 secondes

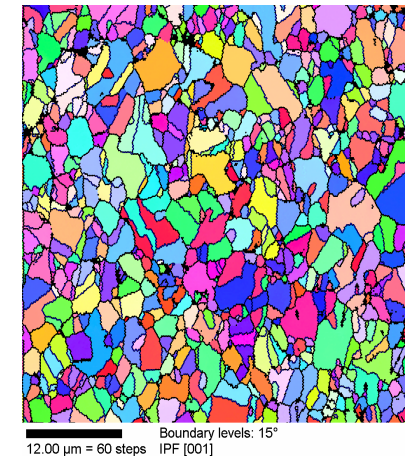


Cellules allongées restaurées

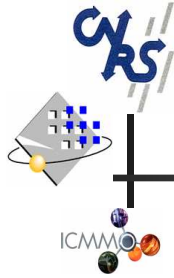


Grain recrystallisé
Recristallisation statique ou dynamique ?

Recristallisation complète

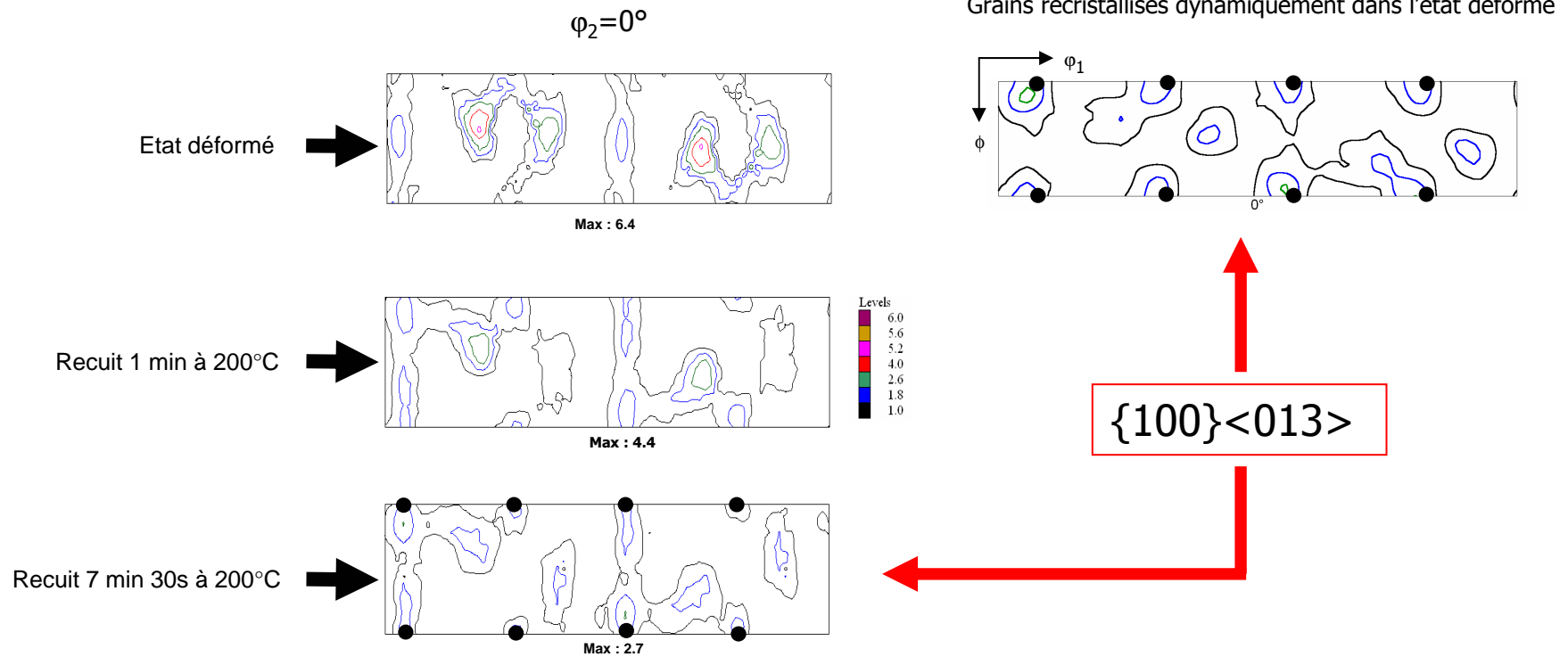


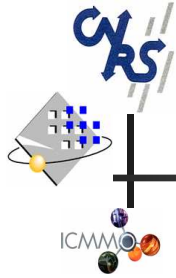
MEB/EBSD



2. Stabilité en température de la microstructure du cuivre (Recuit en bain d'huile à 200°C)

TEXTURE APRES 8 PASSES + RECUIT





Conclusion

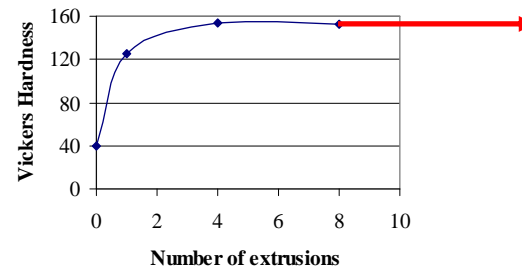
1. Hyperdéformation

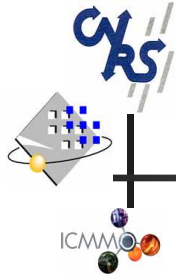
Après **5** passes d'extrusion pour l'aluminium et **8** pour le cuivre, la **structure** attendue de petits grains de taille sub-micronique, **n'est pas atteinte malgré la constance de la dureté** :

Intérêt de la
corrélation

Texture/micro-
structure

- **Zones déformées** constituées de bandes lamellaires possédant des cellules de dislocations plus ou moins restaurées.
- **Amas de sous-grains** de même orientation qui peuvent jouer le rôle de gros grains (abaissement des propriétés mécaniques).
- Pour le cuivre, présence de **grains restaurés et/ou recristallisés** dynamiquement.



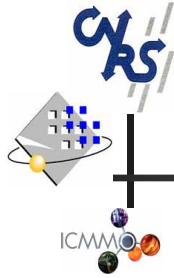


Conclusion

2. Stabilité en température du cuivre

Après complète recristallisation :

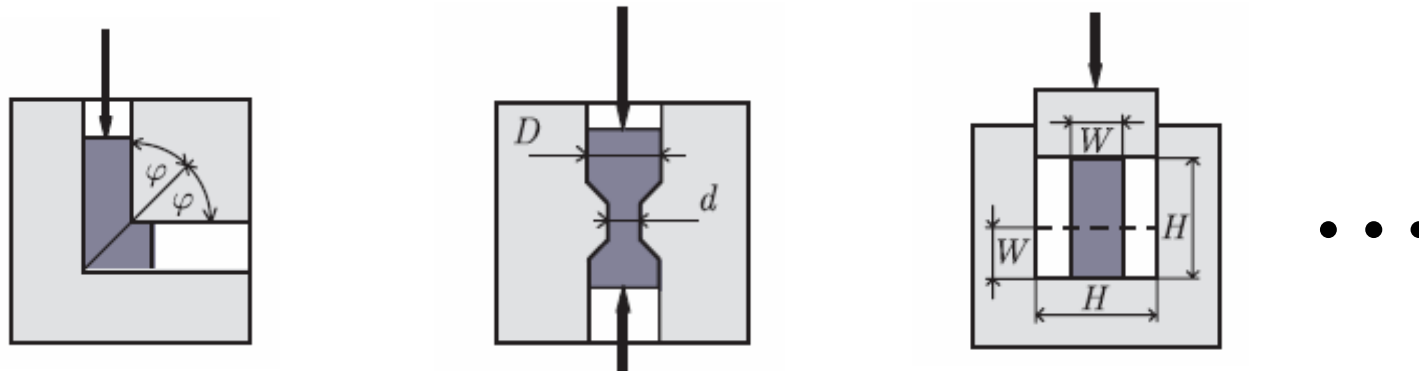
- La texture finale $\{100\}\langle 013\rangle$ n'est que faiblement accusée :
 - La croissance de grains d'orientation aléatoire est également possible.
 - Le *maclage* génère de nouvelles orientations qui contribuent au développement de la partie isotrope de la texture.
- Malgré les hétérogénéités microstructurales trouvées à l'état déformé :
 - La microstructure, après complète recristallisation, possède une *taille de grains relativement faible* ($< 3-4 \mu\text{m}$)
 - *Aucun phénomène de croissance normale ou anormale n'a été mis en évidence.*



Conclusion

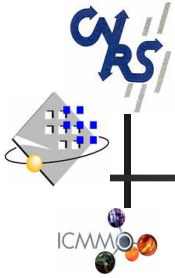
3. Avenir de l'ECAE ?

- Petites pièces (sinon forces de pression très importantes)



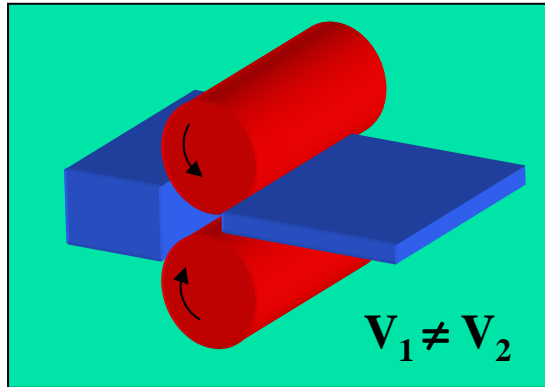
BULLETIN OF THE POLISH ACADEMY OF SCIENCES
TECHNICAL SCIENCES
Vol. 53, No. 4, 2005
L. OLEJNIK and A. ROSOCHOWSKI

- Procédé non continu

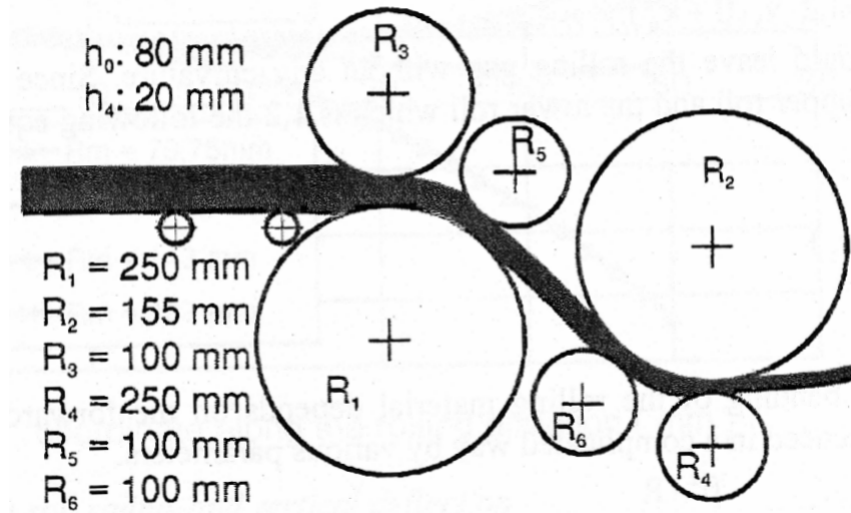
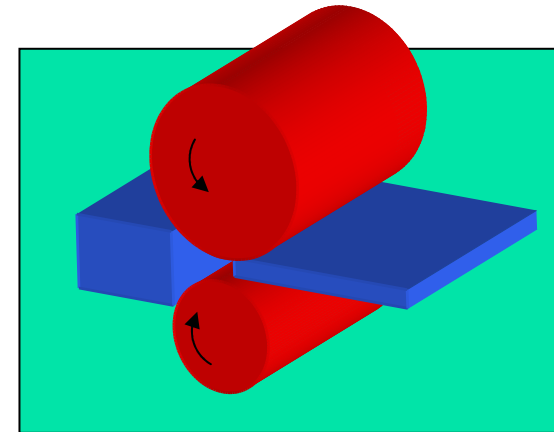


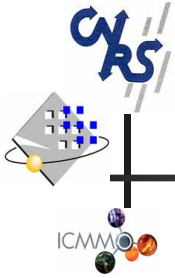
Conclusion

Procédés continus



Laminage asymétrique

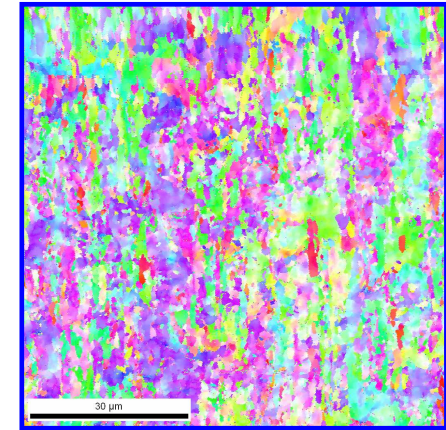
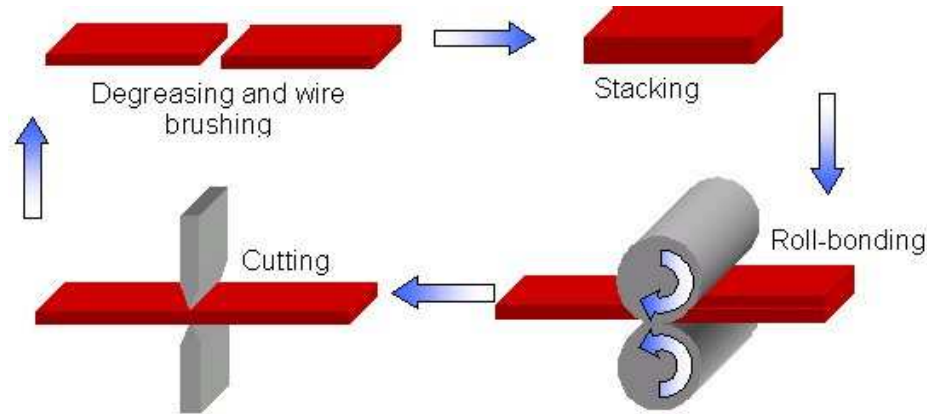




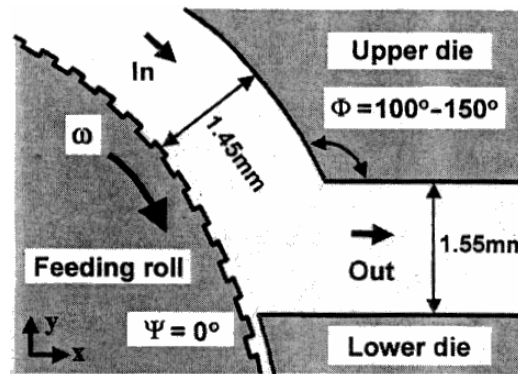
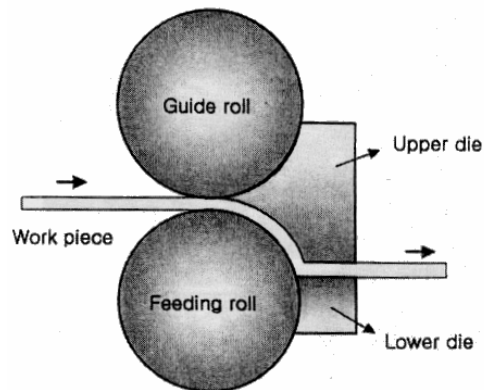
Conclusion

Procédés continus

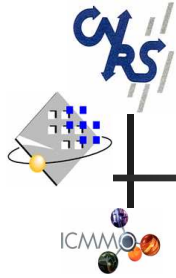
Multi-colaminage



Schematic diagram of the ARB process



Laminage + ECAE



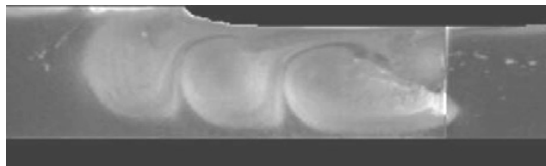
Conclusion

Autres procédés

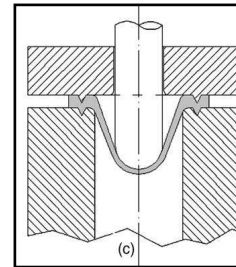
FSW Friction Stir Welding



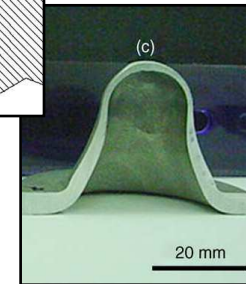
FSP Friction Stir Processing



Superplasticité pour mise en forme ultérieure



(Dutta *et al.*, 2005)



Superplasticité sélective

(Wang and Mishra, 2006)

