

Microstructure et propriétés mécaniques des composites Cu/C fabriqués par voie semi-liquide

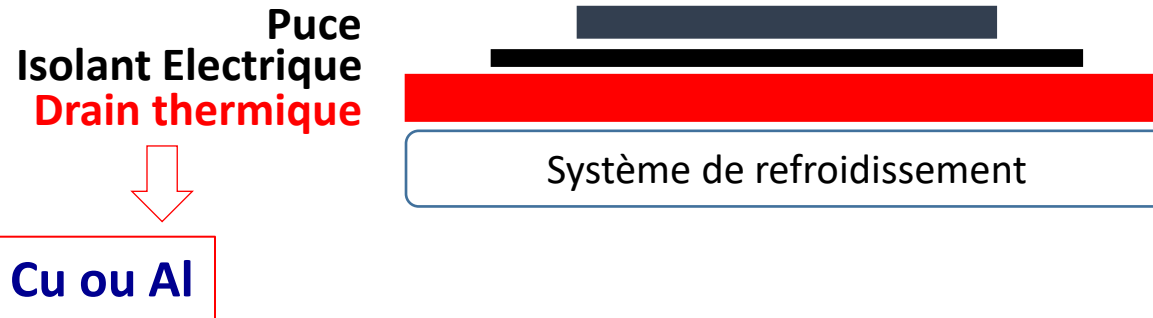
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Contexte : optimisation des **drains thermiques** des composés électroniques



Cu ou Al : CTE **élevé** ($17 \cdot 10^{-6} \text{ K}^{-1}$)

- **Contraintes thermomécaniques** aux interfaces électriques avec l'isolant thermique (céramique)
- **Rupture** du montage

⇒ **Composites à Matrice Métallique**
aux propriétés thermo-mécanique adaptables

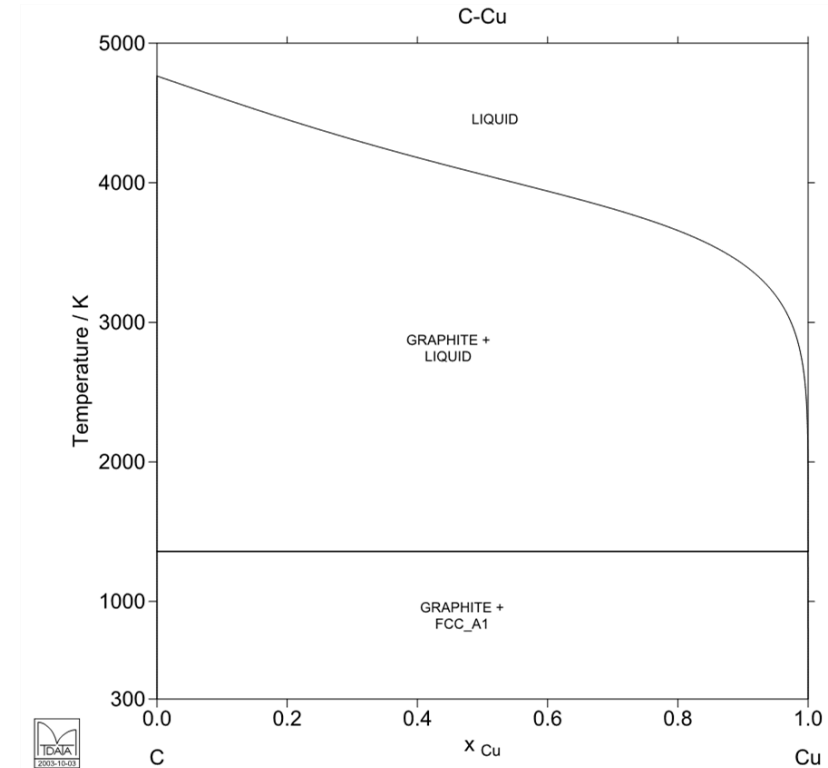
Systeme Cu/C : non réactif

=> interfaces non réactives

Interface

=> Transfert des propriétés physiques

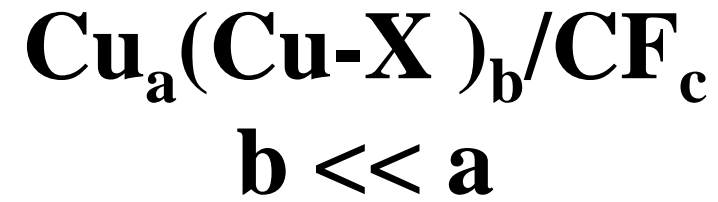
- Utilisation d'alliage de Cu
 - ⇒ ou solution solide ou intermétalliques CuX
 - ⇒ ou formation de carbures dans la matrice XC
- Fonctionnalisation in-situ des renforts C par une couche de carbure



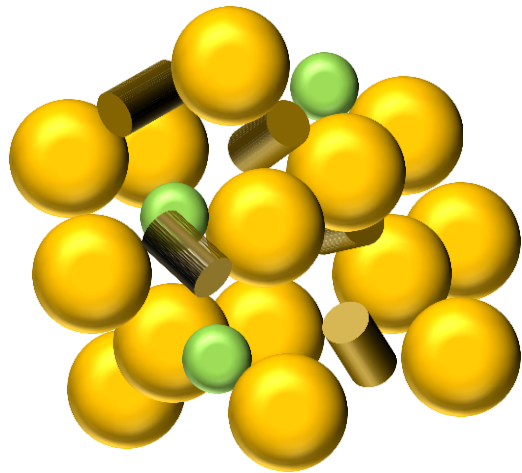
⇒ Voie semi-liquide



Voie semi-liquide

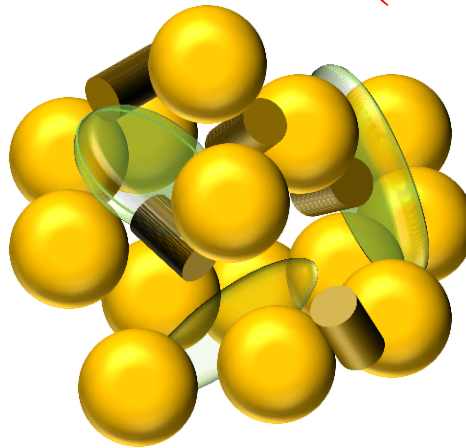


$$T_{\text{fusion}(\text{Cu-X})} < T_{\text{sintering}} < T_{\text{fusion}(\text{Cu})}$$



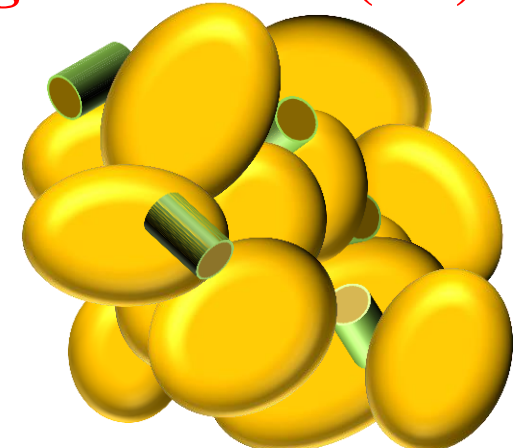
Powder mixture prior
to sintering

High T°
and P



Cu-X liquid phase during
sintering

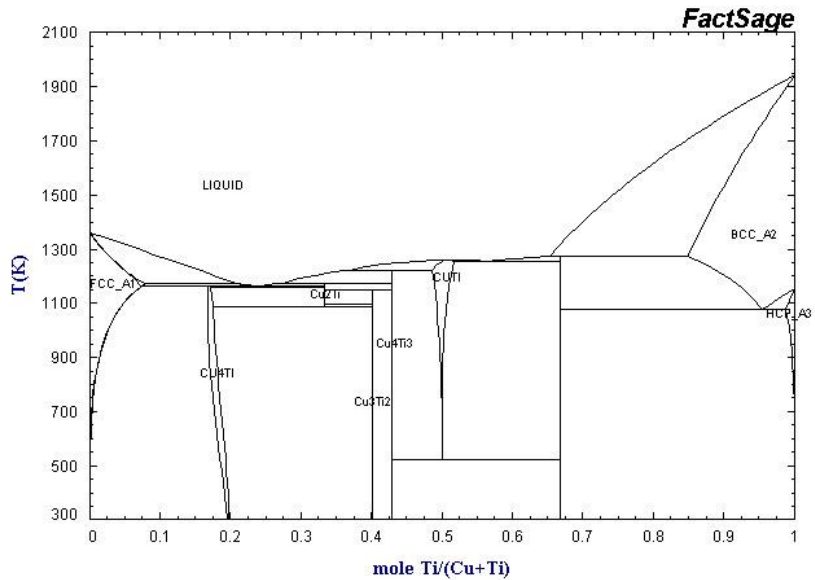
End of sintering



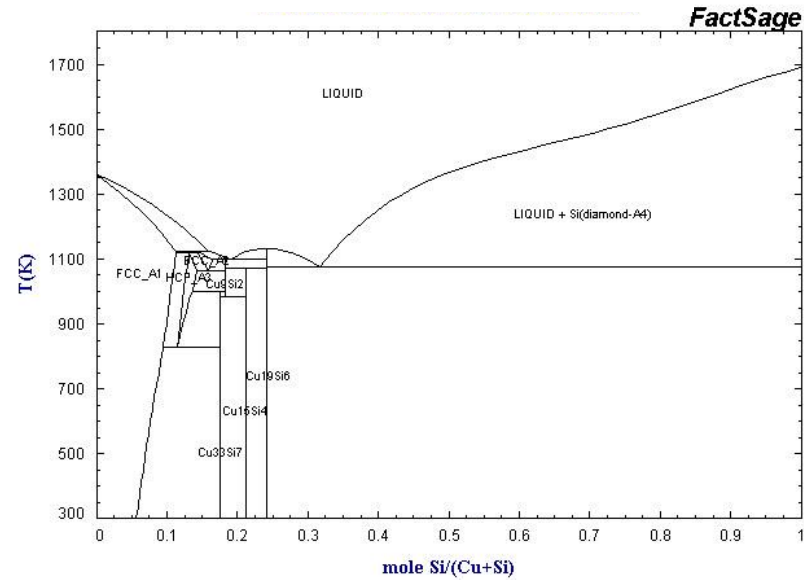
Creation of interphase +
solidification of Cu matrix

Systèmes possibles

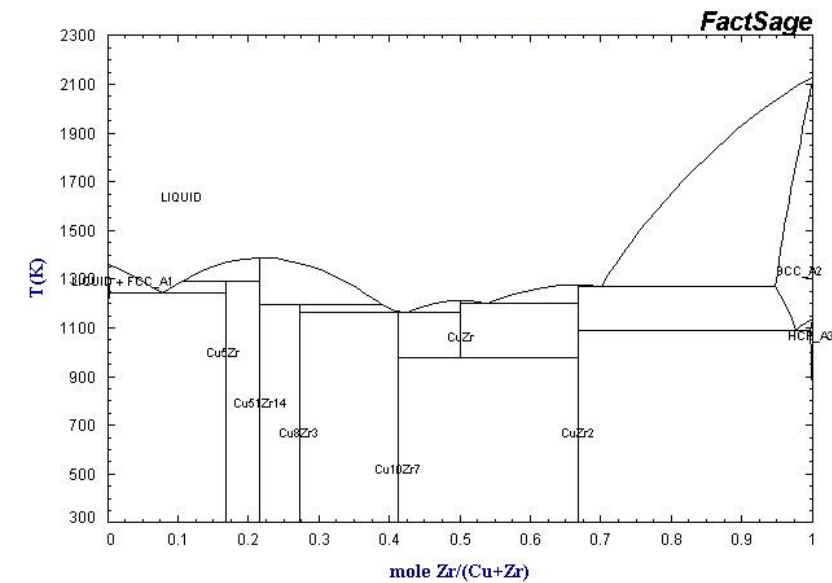
Cu-Ti



Cu-Si



Cu-Zr



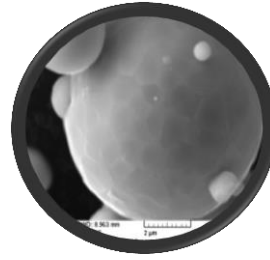
- Formation de carbures XC
- Eutectique (composition + température)
- Taille des particules

$$\text{Cu}_{73}\text{Ti}_{27} - T_{\text{eutectique}} = 884^{\circ}\text{C}$$



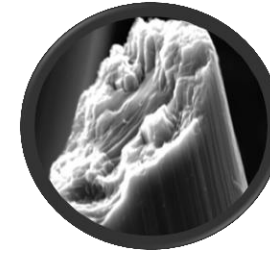
Copper (Cu)
 $\alpha = 16.7 \times 10^{-6}/\text{K}$
 $k = 400 \text{ W/m.K}$

+



**Copper-Titanium
(Cu-Ti)**
 22 %at in Ti

+



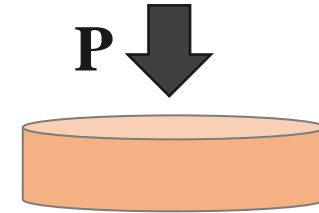
Carbon fiber (CF)
 $\alpha = -1 \times 10^{-6}/\text{K}$
 $k = 550 \text{ W/m.K}$



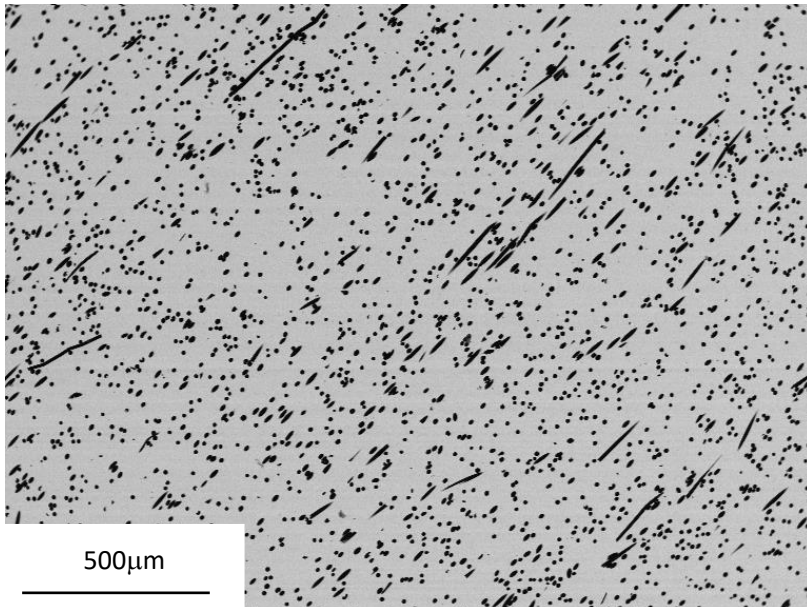
$$b \ll a$$

$$884^\circ\text{C} < 950^\circ\text{C} < 1083^\circ\text{C}$$

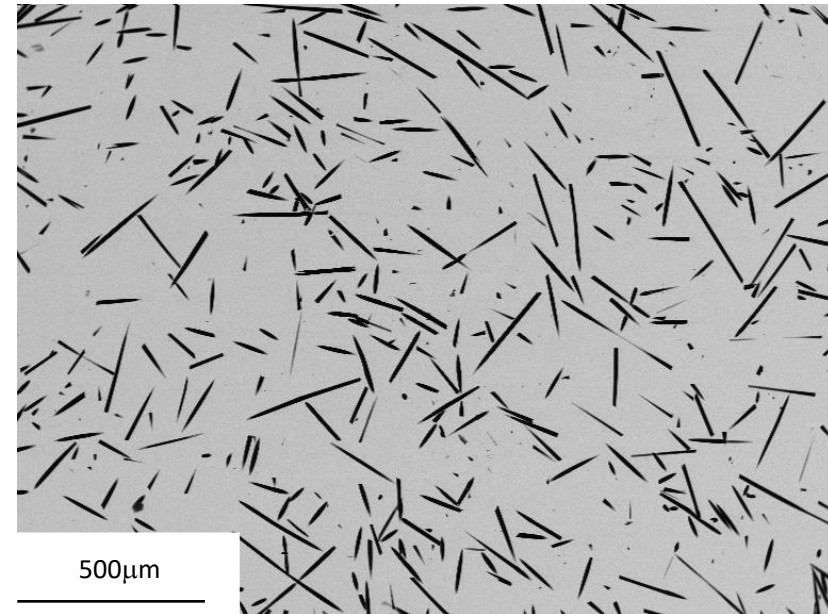
Conditions de densification :
40 MPa / 950 °C / 30 min / sous vide



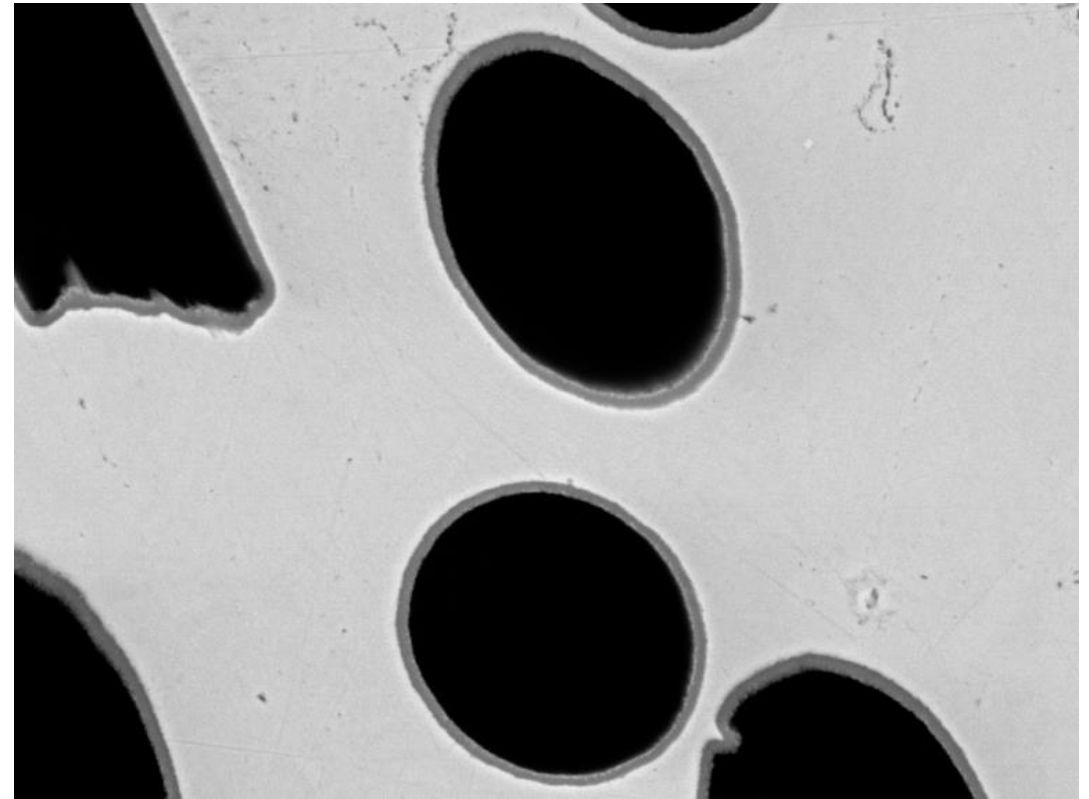
// à l'axe de compression



⊥ à l'axe de compression



$\text{Cu}(\text{CuTi})_x/\text{FC}$ 20%



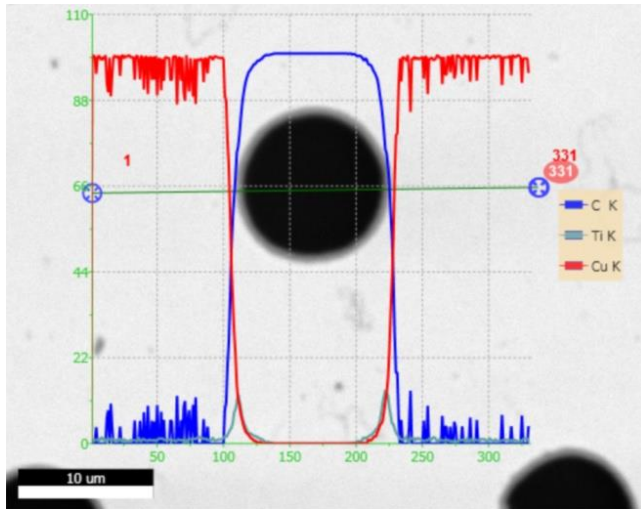
=> Formation in-situ d'une **interphase** entre Cu et FC

CF volume fraction (vol%)	Relative density (%)		Liquid phase content (vol%)
	No Cu-Ti addition	Cu-Ti addition	
10	98.6	99.6	2
20	98.9	100	4
30	96.3	99.0	4
40	95.8	99.4	4
50	95.4	97.6	8
60	94.1	95.7	8

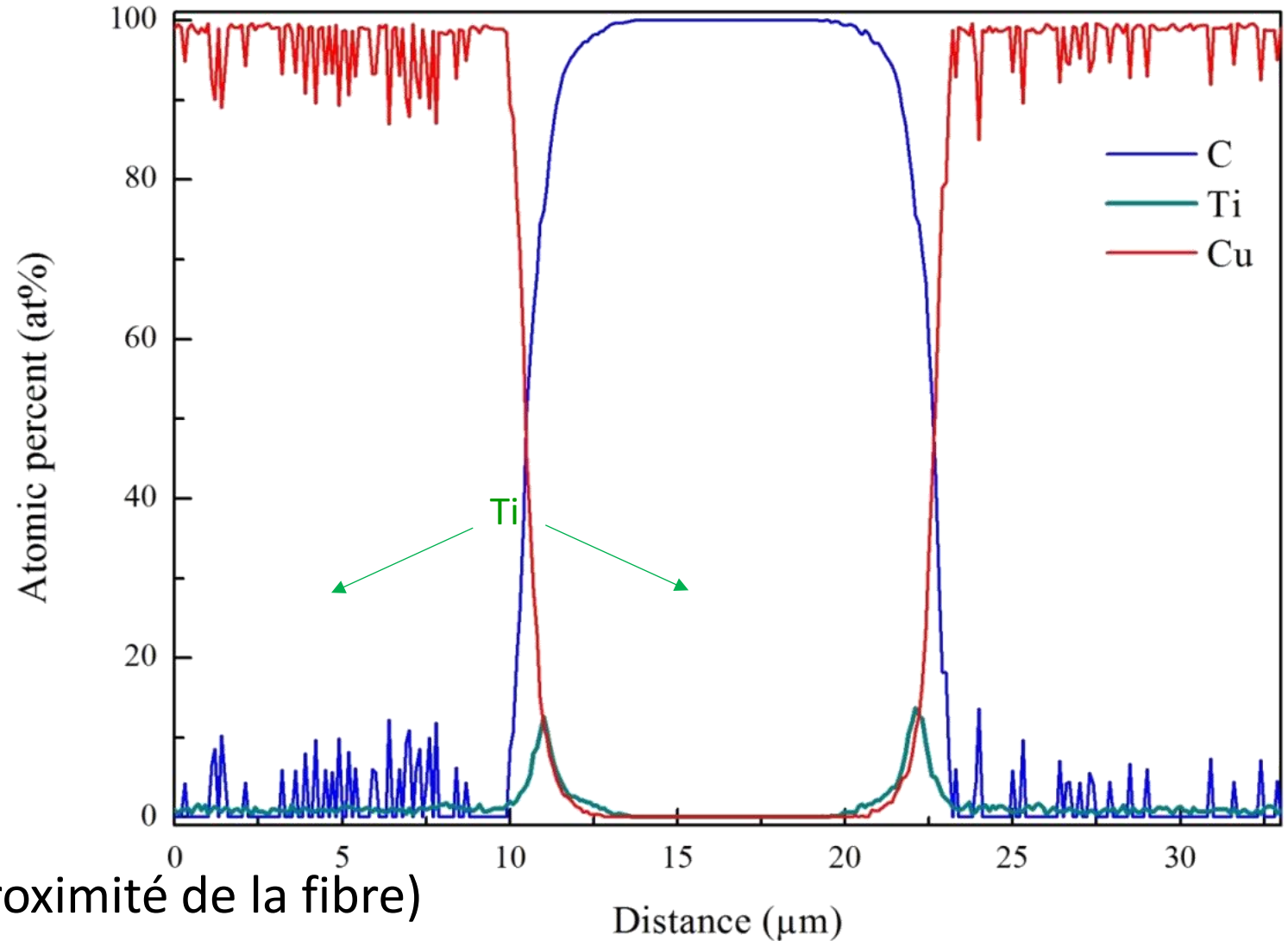
Densité **avec** Cu-Ti > Densité **sans** Cu-Ti

=> Remplissage des pores par la phase liquide

$\text{Cu}(\text{CuTi})_x/\text{FC}$ 20%

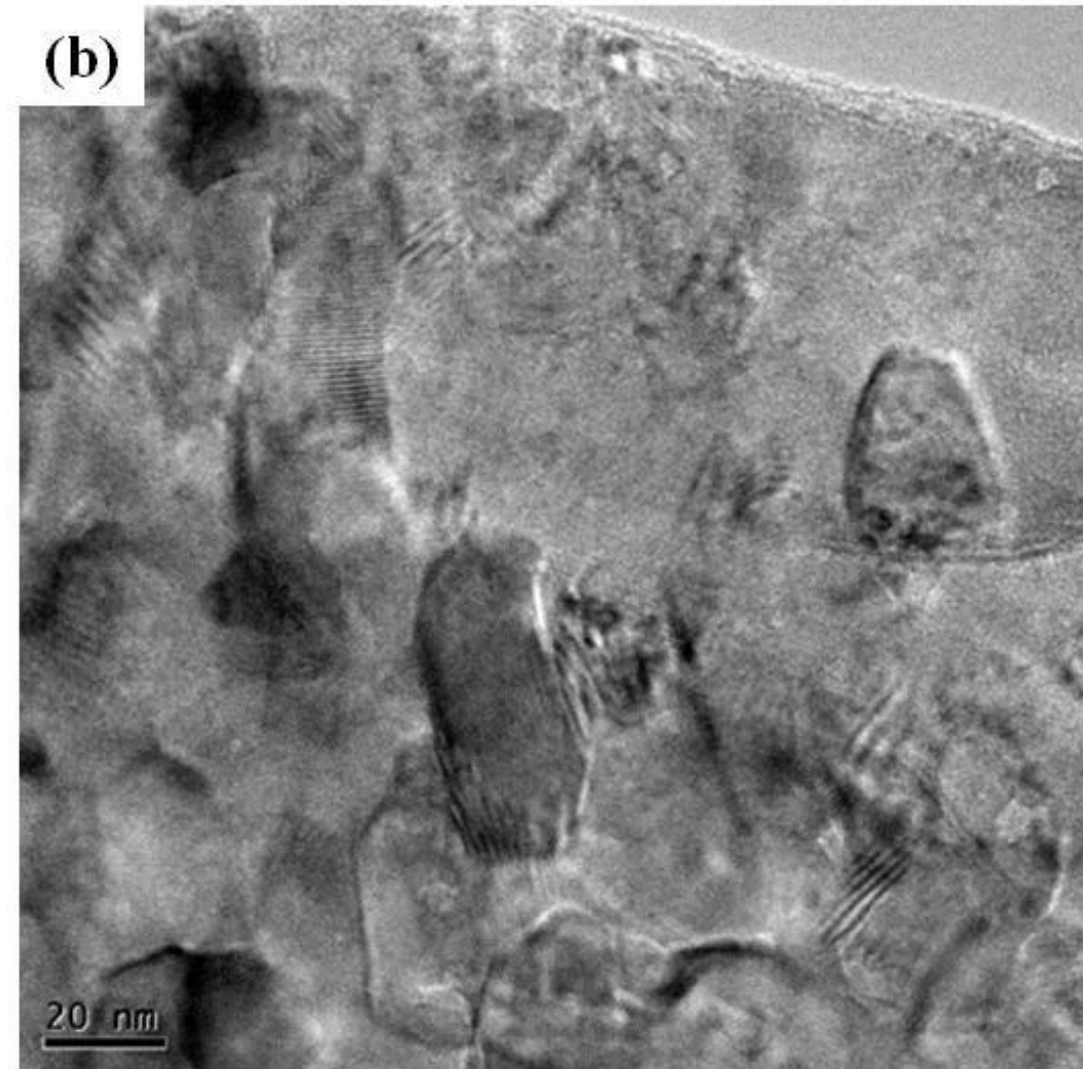
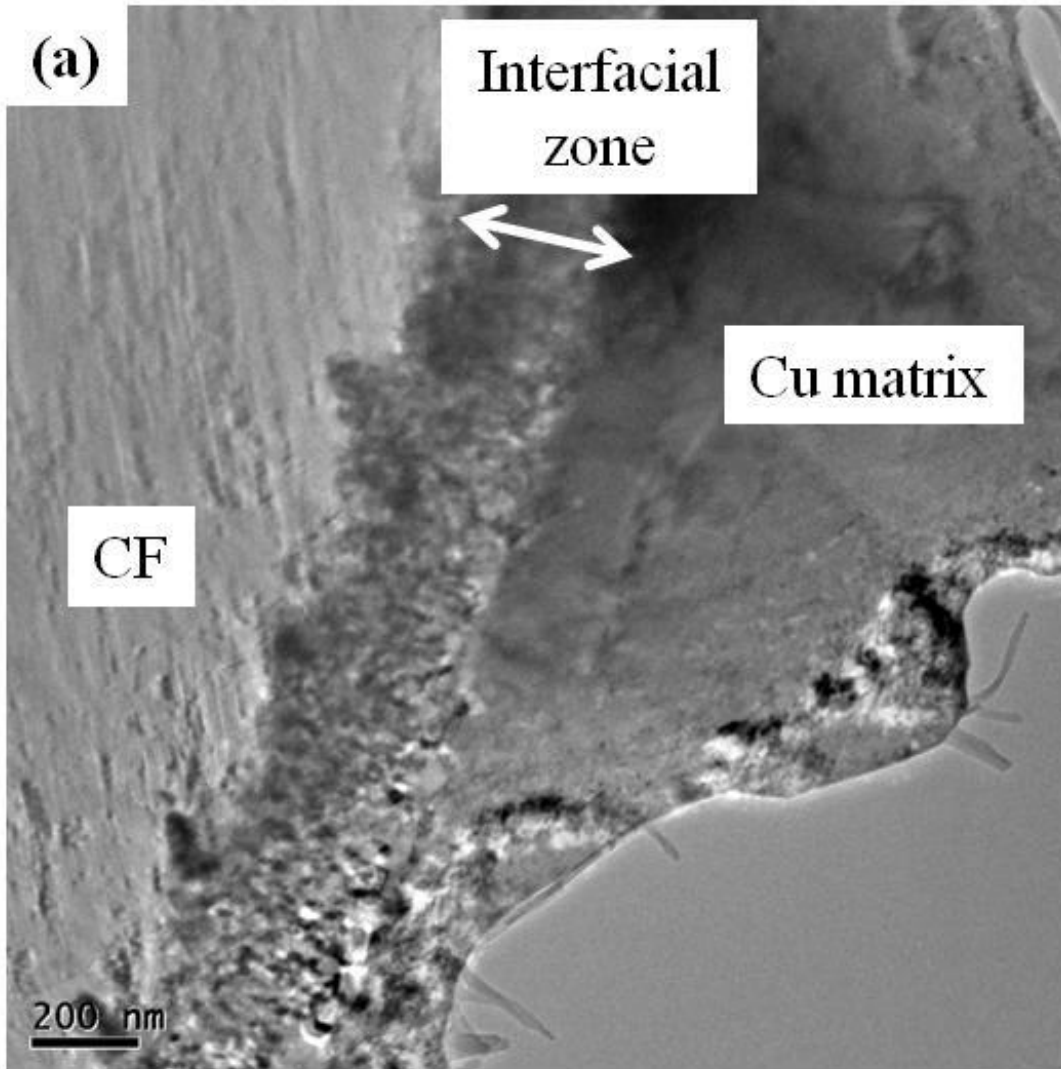


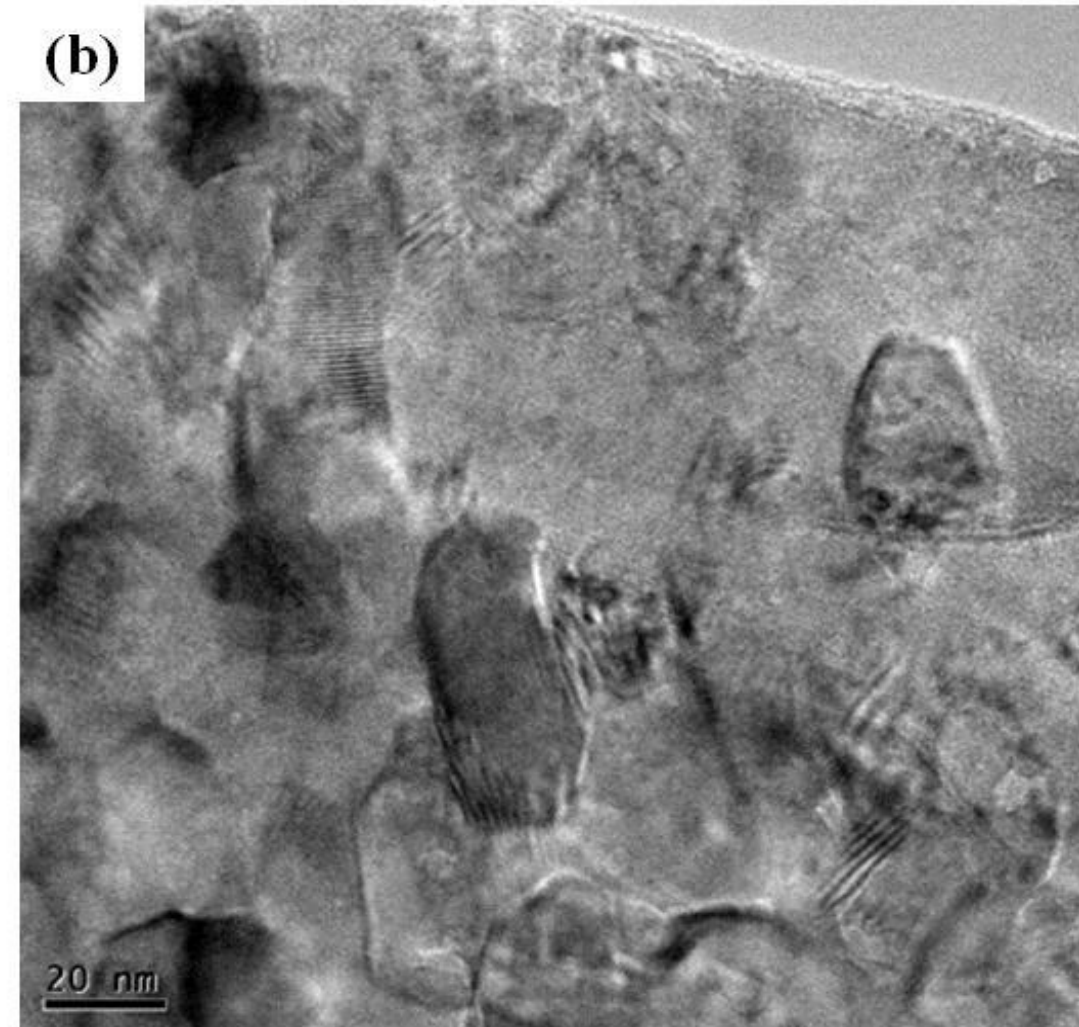
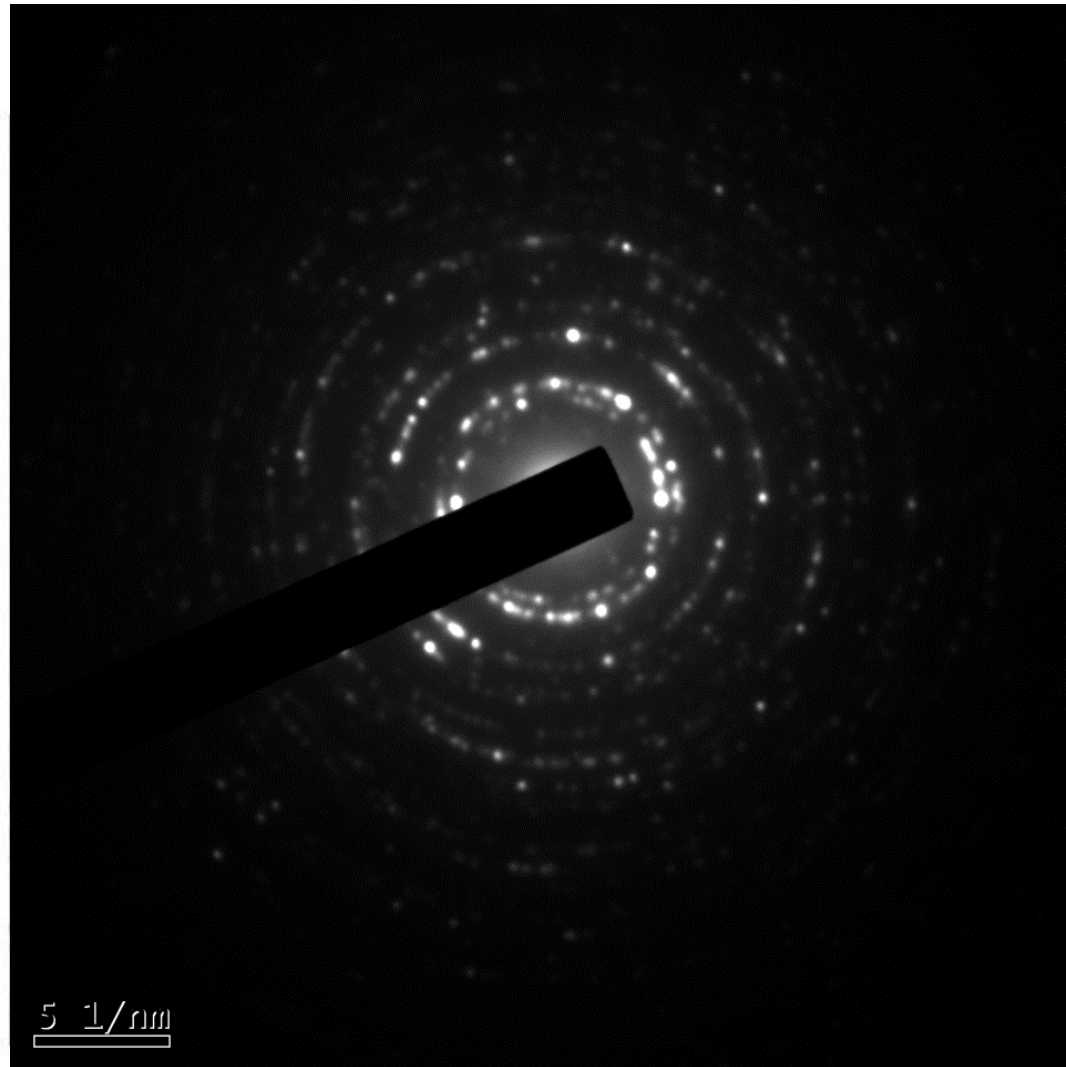
Analyse EDS



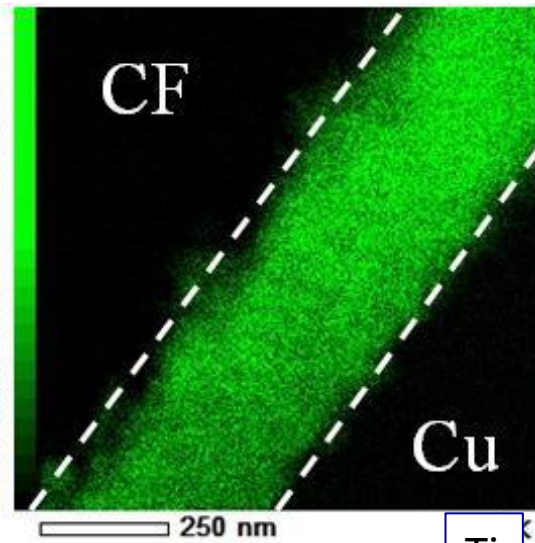
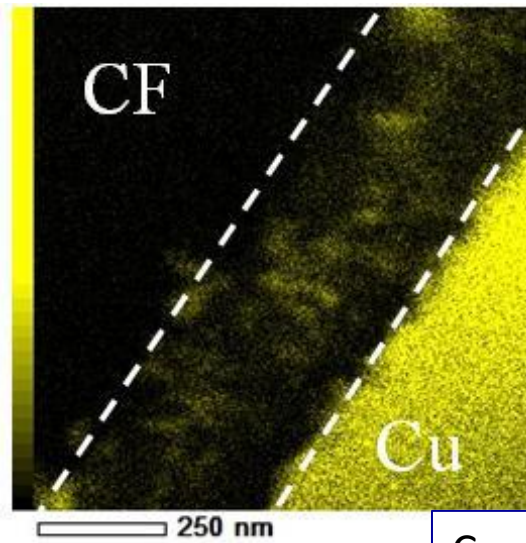
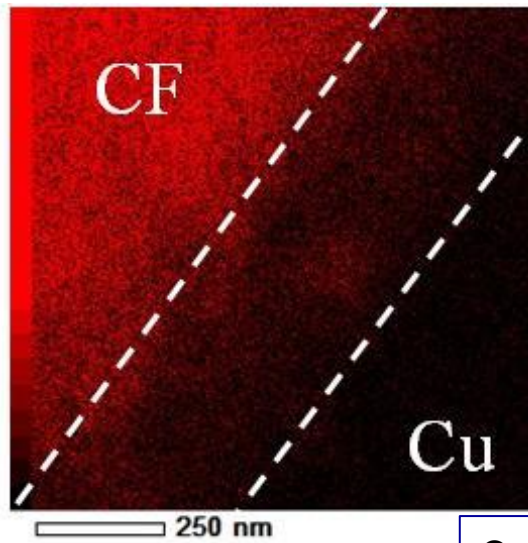
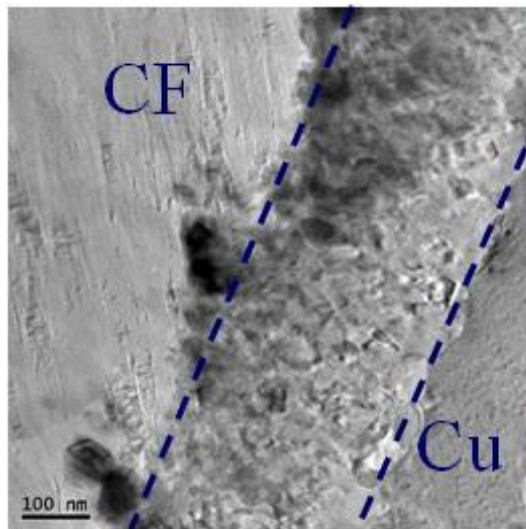
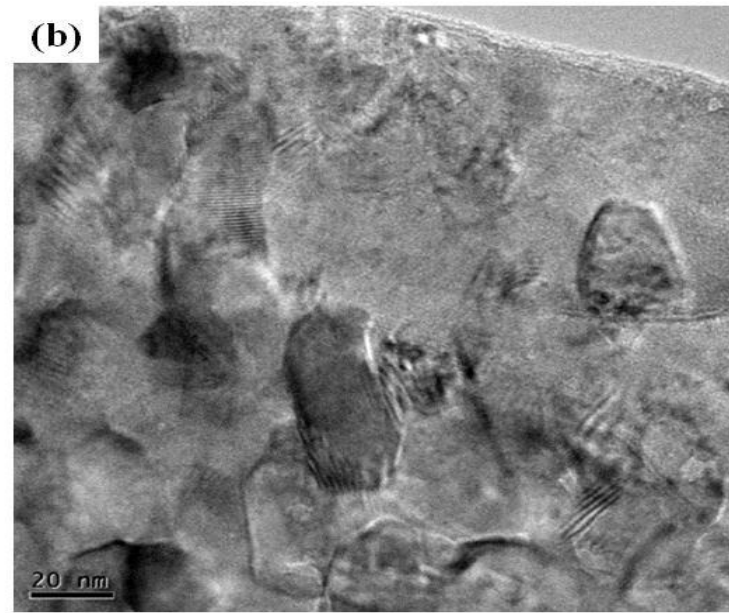
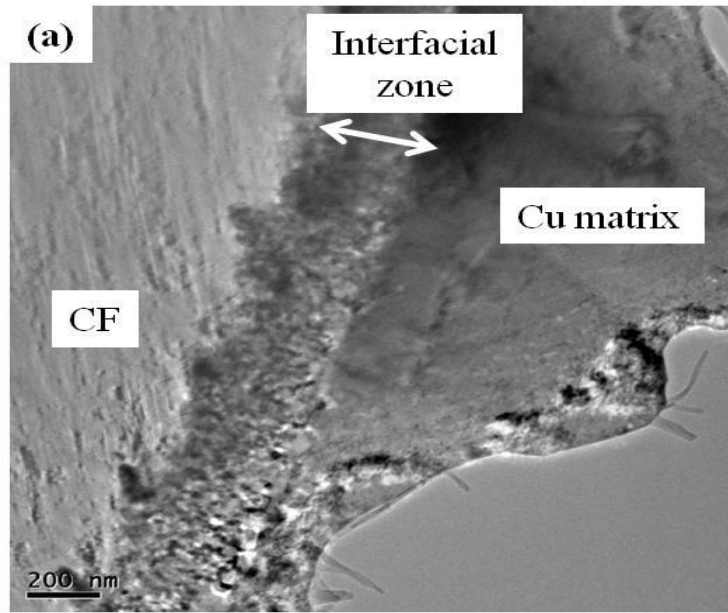
- Interphase riche en **Ti**
- Pas de Ti dans la matrice (à proximité de la fibre)

Analyse MET





Structure polycristalline TiC – Nanograins facetés.



Conductivité thermique « dans le plan »

Fricke model :

$$K_C = K_m \left[\frac{K_r + (n - 1)K_m - (n - 1)V_f(K_m - K_r)}{K_r + (n - 1)K_m + V_f(K_m - K_r)} \right]$$

K_C : Thermal conductivity of composite

K_m : Thermal conductivity of matrix (Cu)

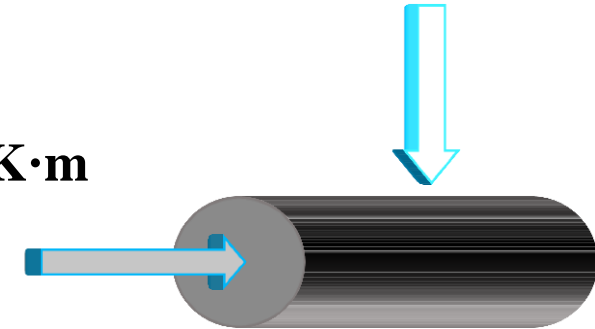
K_r : Thermal conductivity of reinforcement (CF)

V_f : Volume fraction of reinforcement

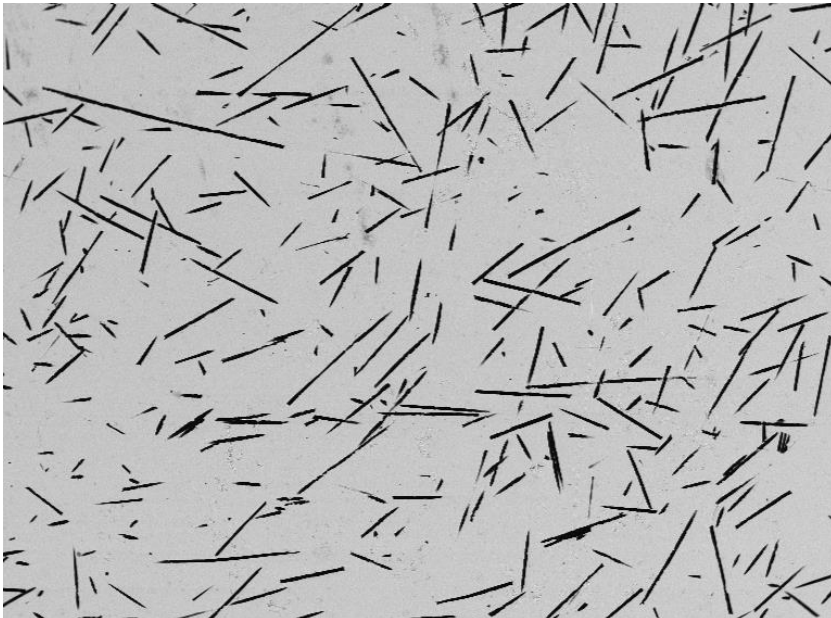
n : Shape factor of reinforcement

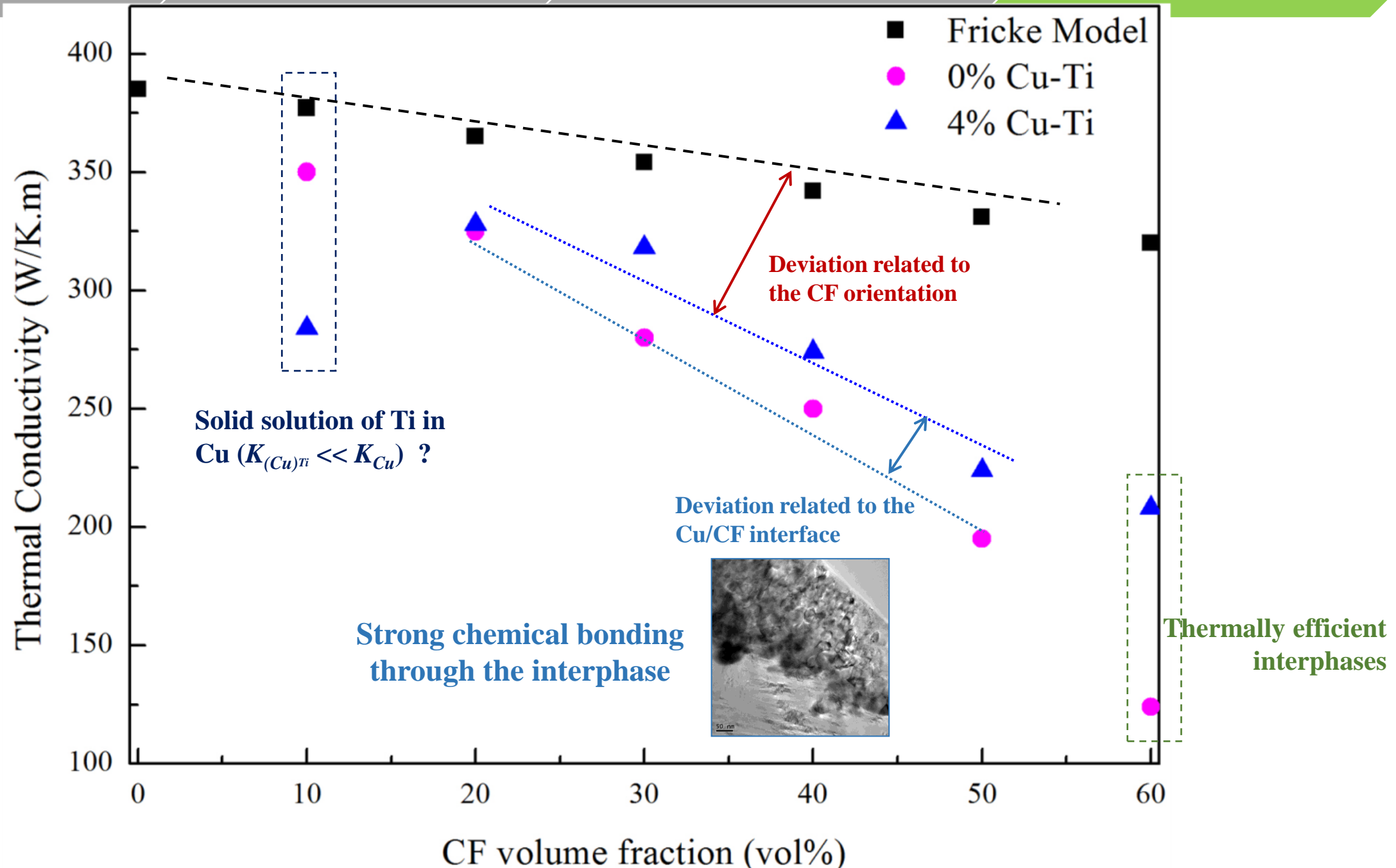
$$K_{CF\perp} = [5-10] \text{ W/K}\cdot\text{m}$$

$$K_{CF//} = 550 \text{ W/K}\cdot\text{m}$$

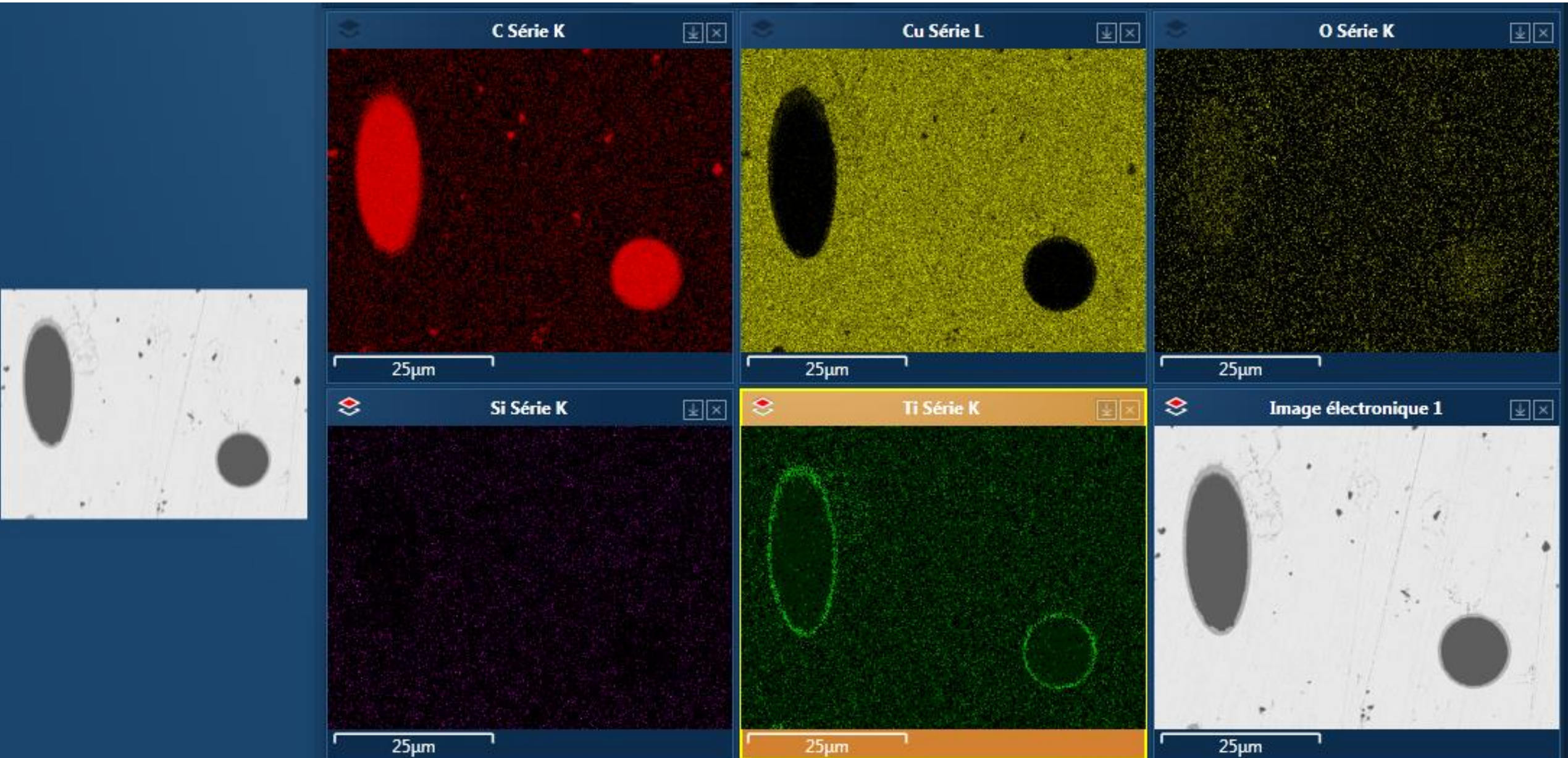


$$K_{CF\text{average}} = 278 \text{ W/K}\cdot\text{m}$$

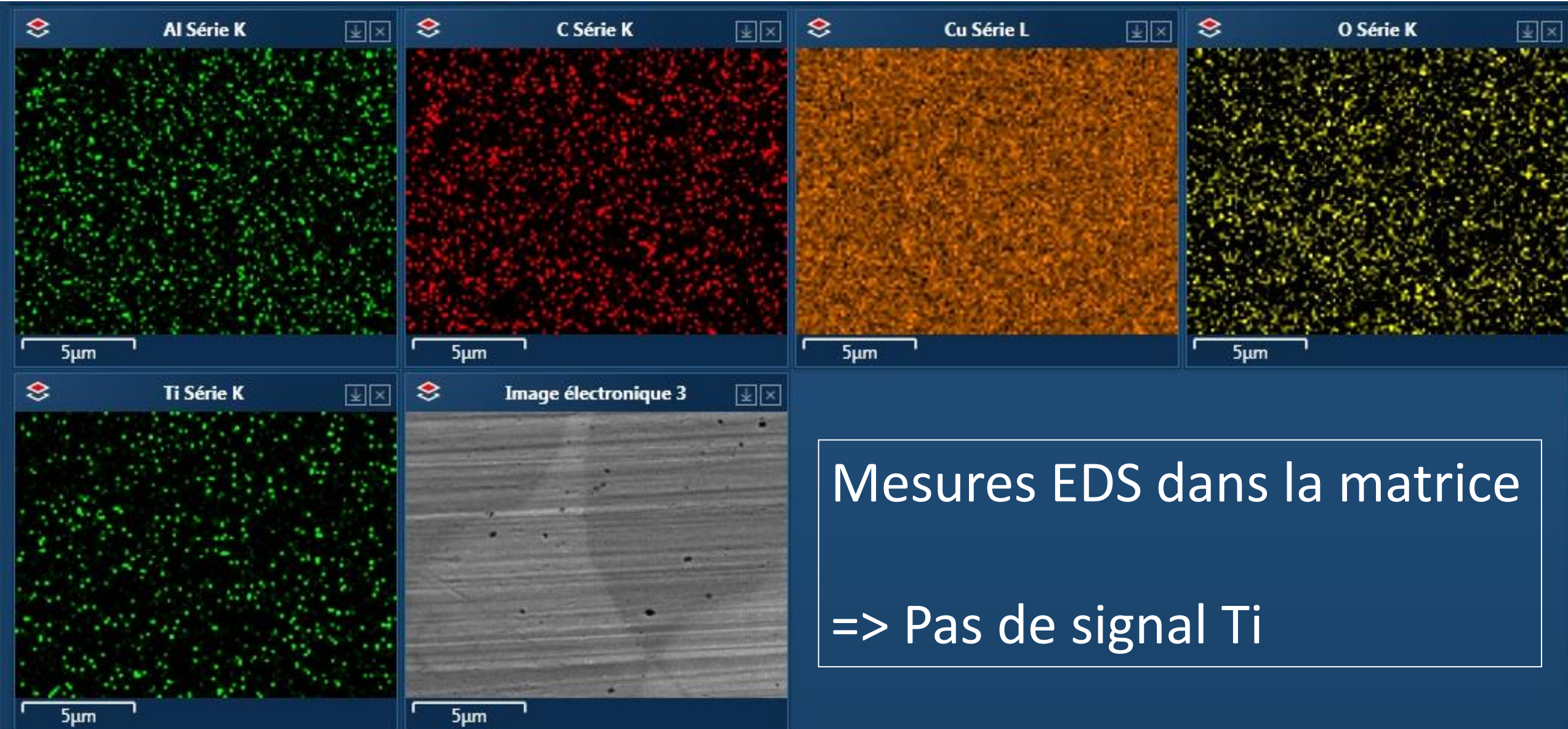




Cu/CuTi/CF10% solution solide ?

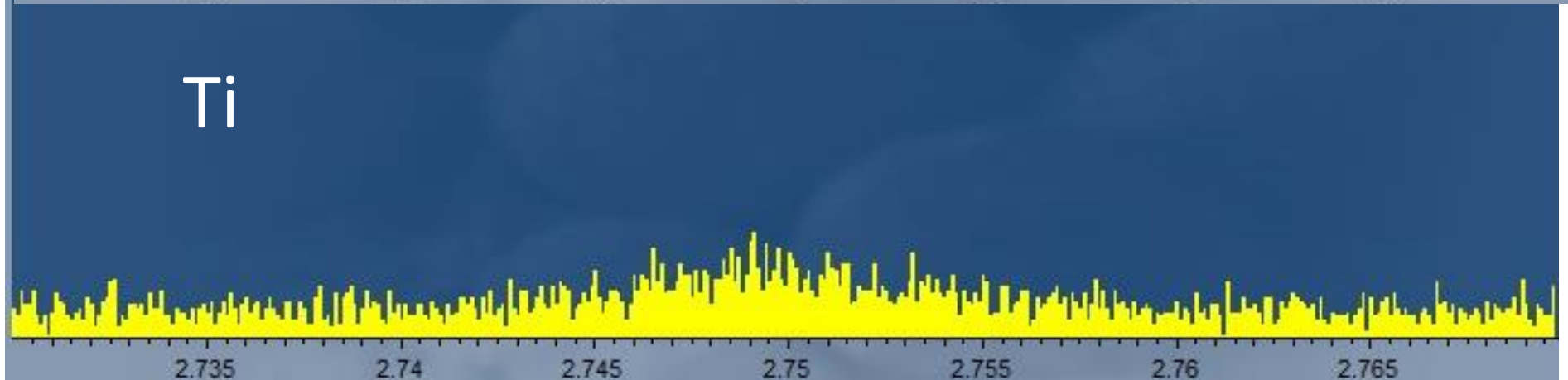
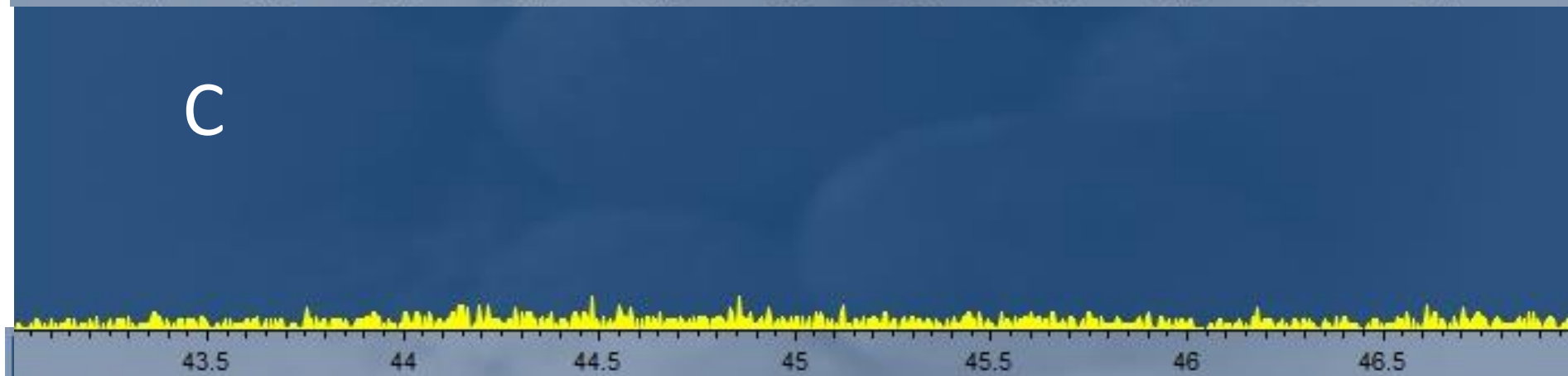
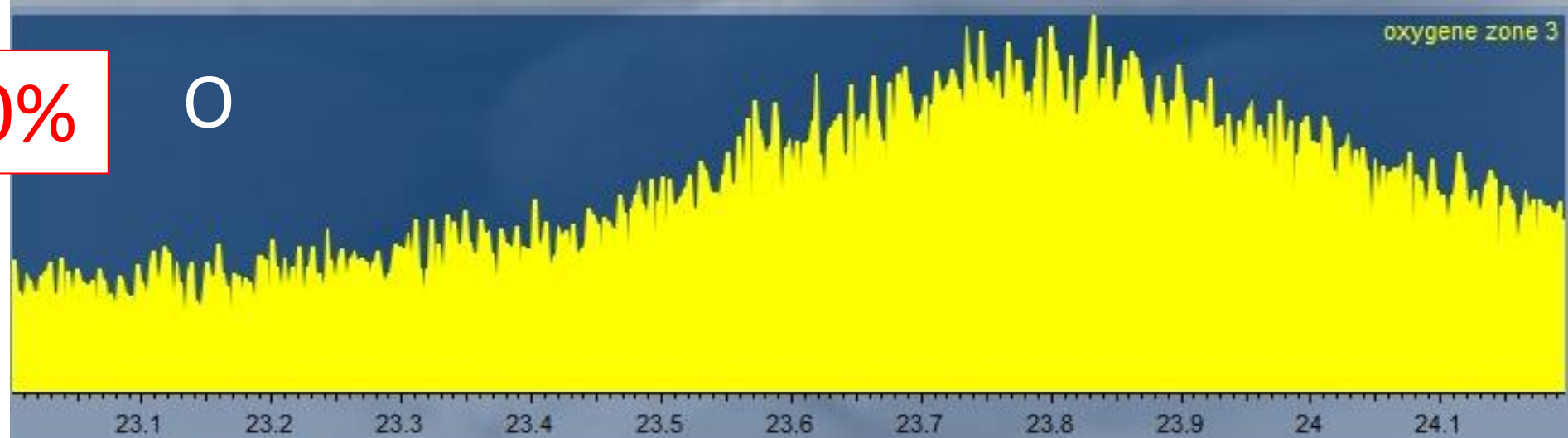


Cu/CuTi/CF10% solution solide ?



Cu/CuTi/CF10%

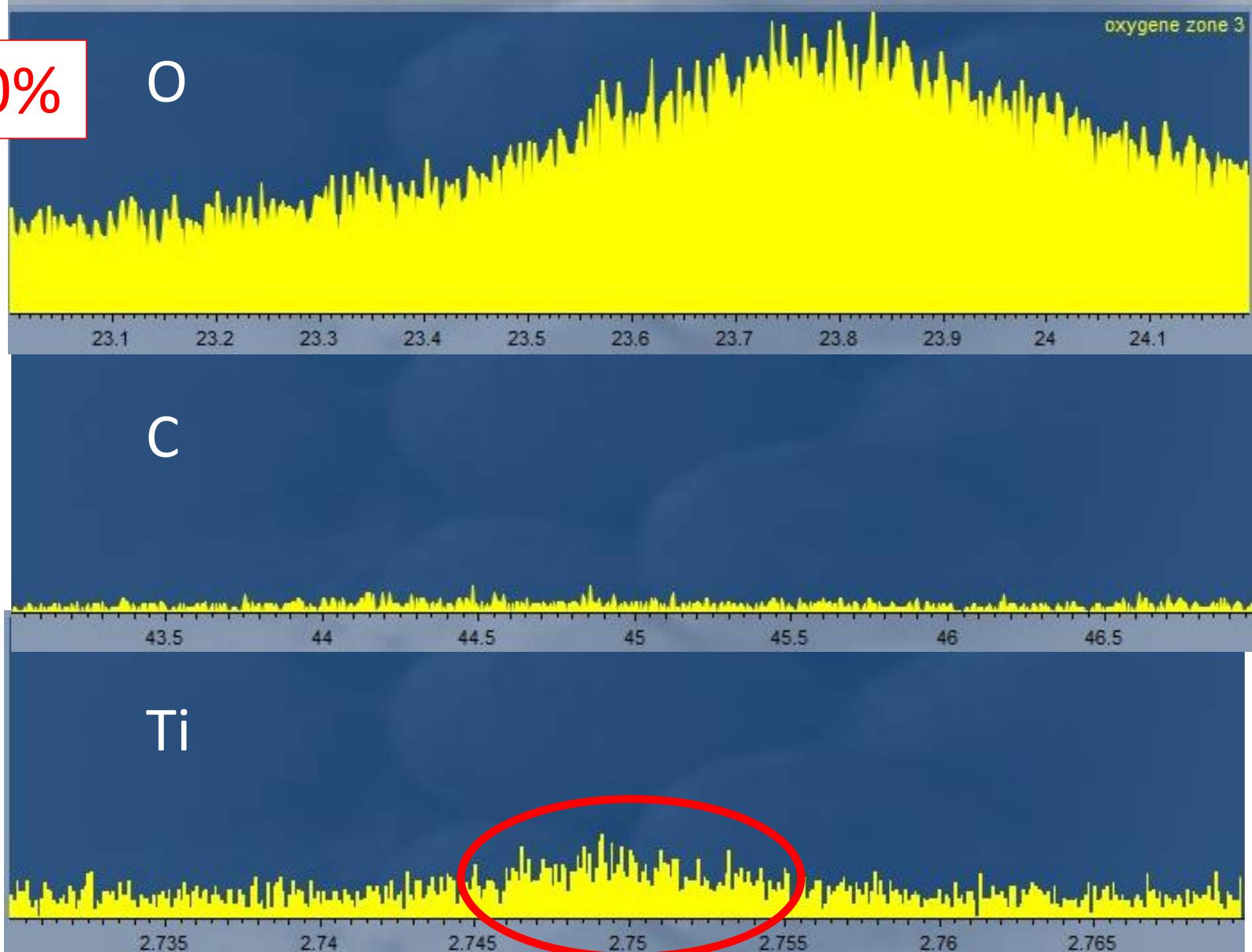
Mesures WDS



Cu/CuTi/CF10%

Mesures WDS

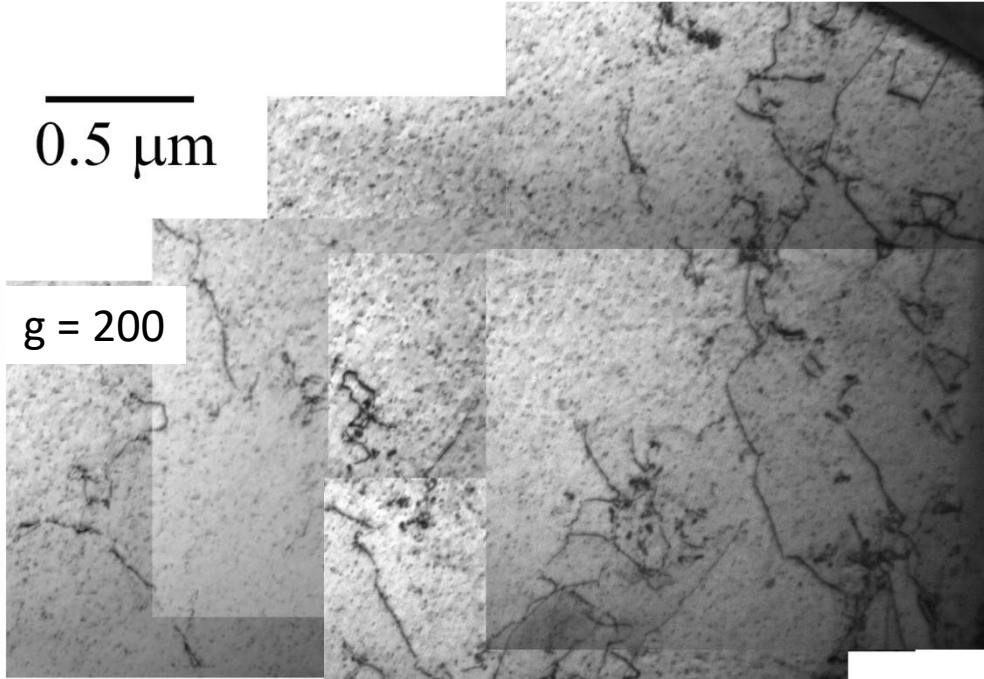
=> Ti détecté



Cu/CuTi/CF10% solution solide ?

0.5 μm

g = 200



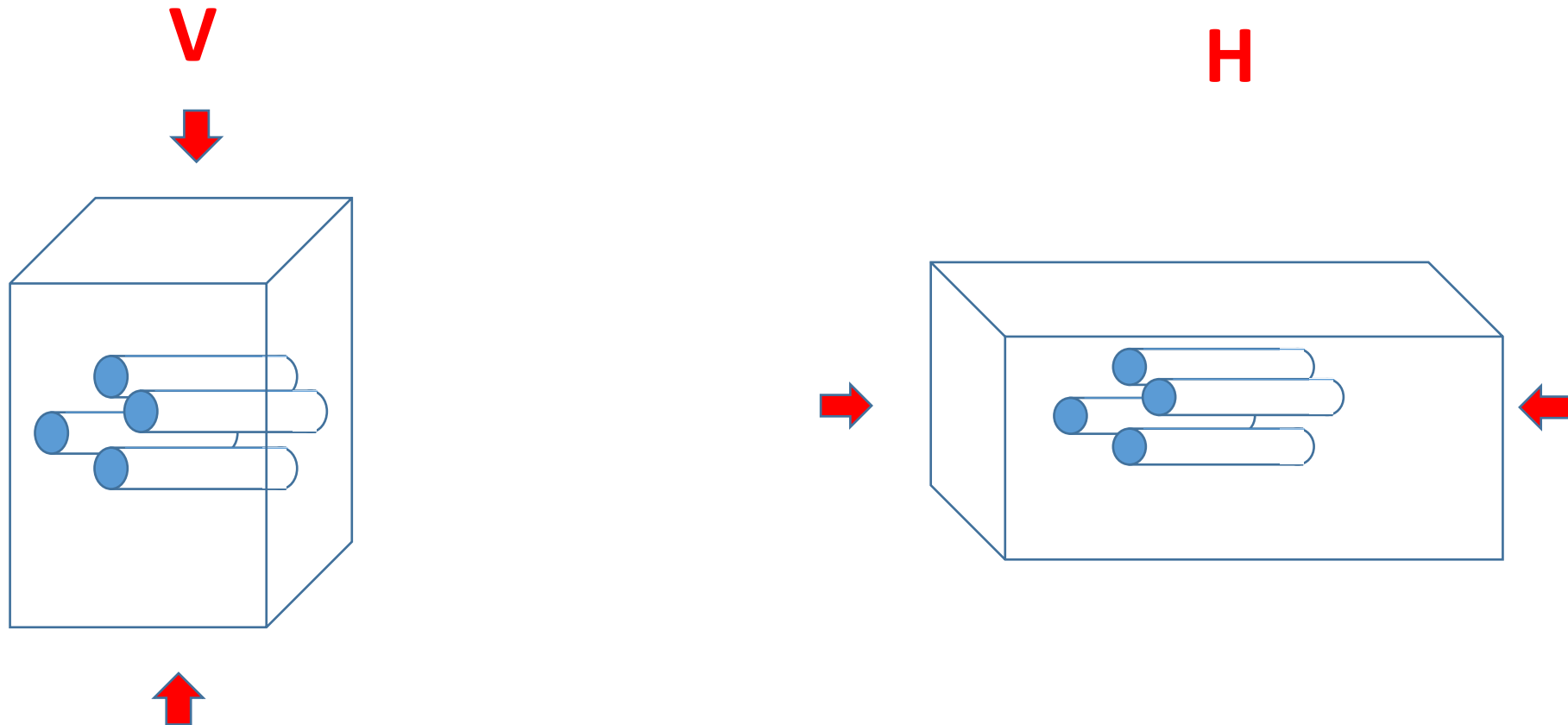
MET dans matrice

⇒ Dislocations épinglées ?

⇒ **À venir : nanoindentation**

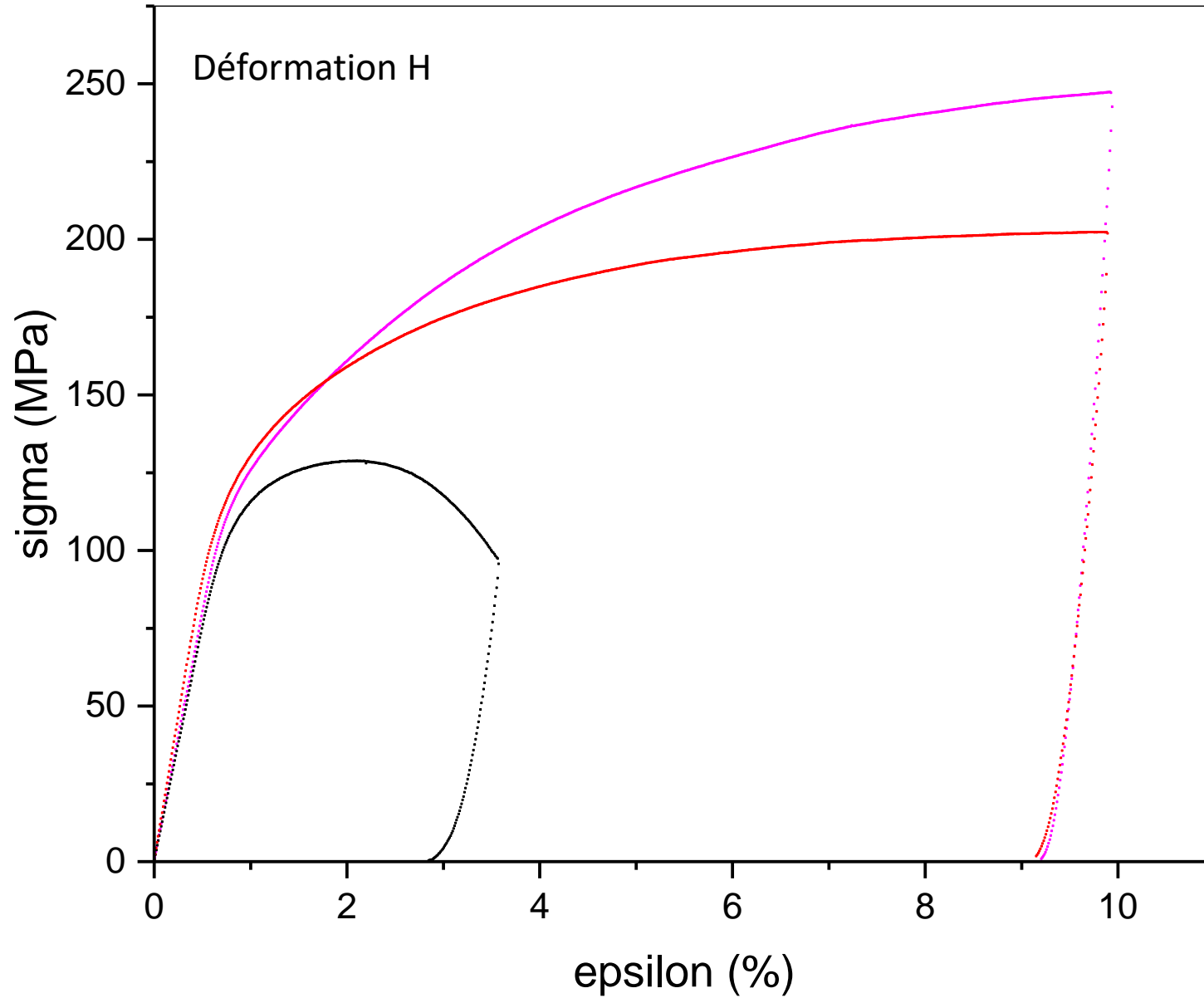
Propriétés Mécaniques

- Déformation par compression à vitesse imposée,
- Différentes directions



Propriétés Mécaniques

- Déformation par compression à vitesse imposée,
- Différentes directions **H** et **V**
- Différentes compositions : **10%**, **20%**, **40%** **avec et sans Ti**

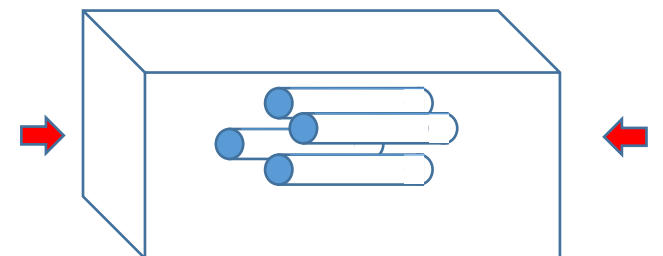


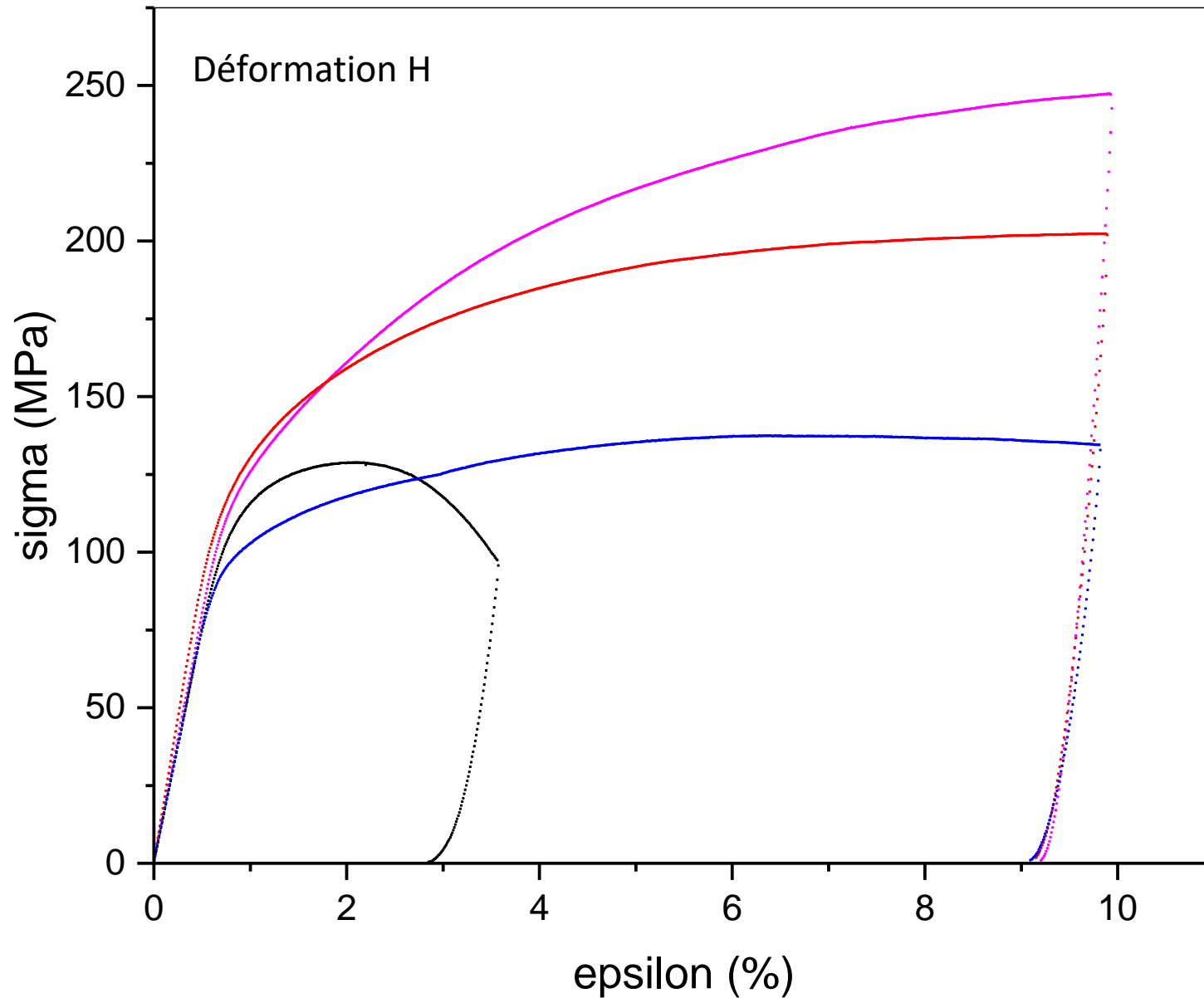
Cu/CuTi/CF10%

Cu/CuTi/CF20%

Cu/CuTi/CF40%

Déformation H





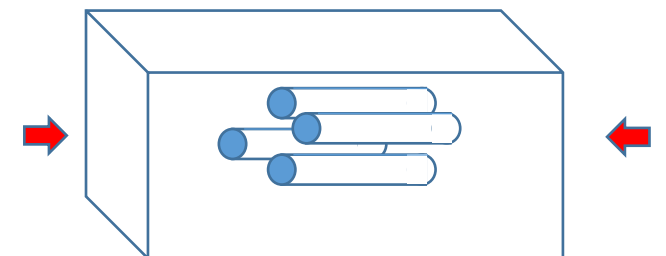
Cu/CuTi/CF10%

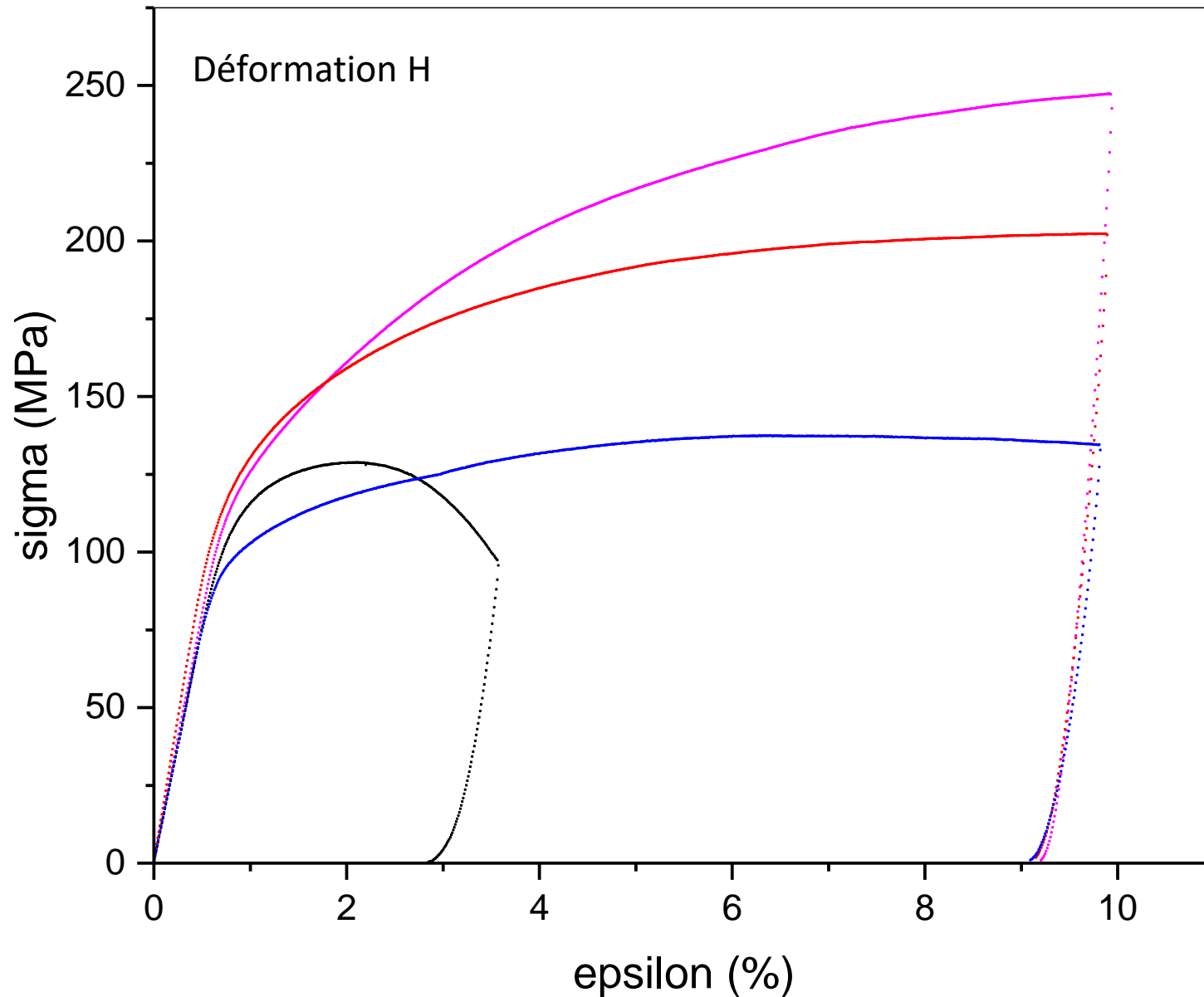
Cu/CuTi/CF20%

Cu/CF40%

Cu/CuTi/CF40%

Déformation H





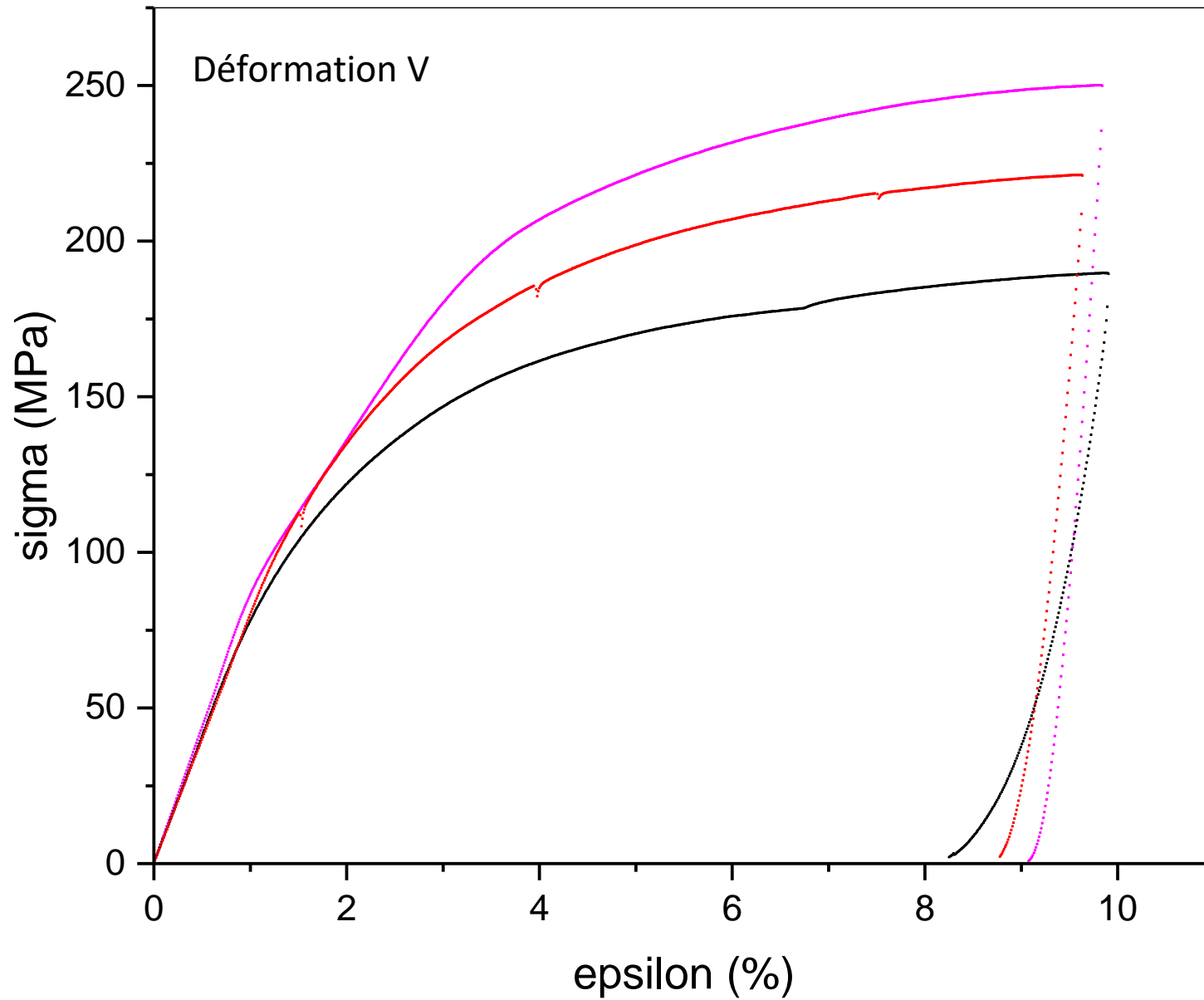
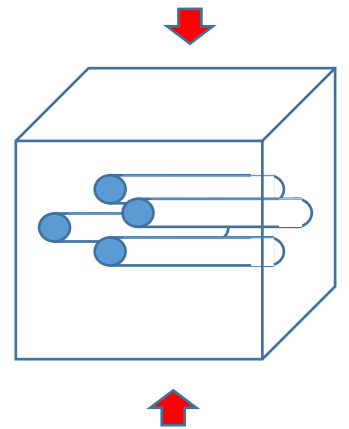
Cu/CuTi/CF10%

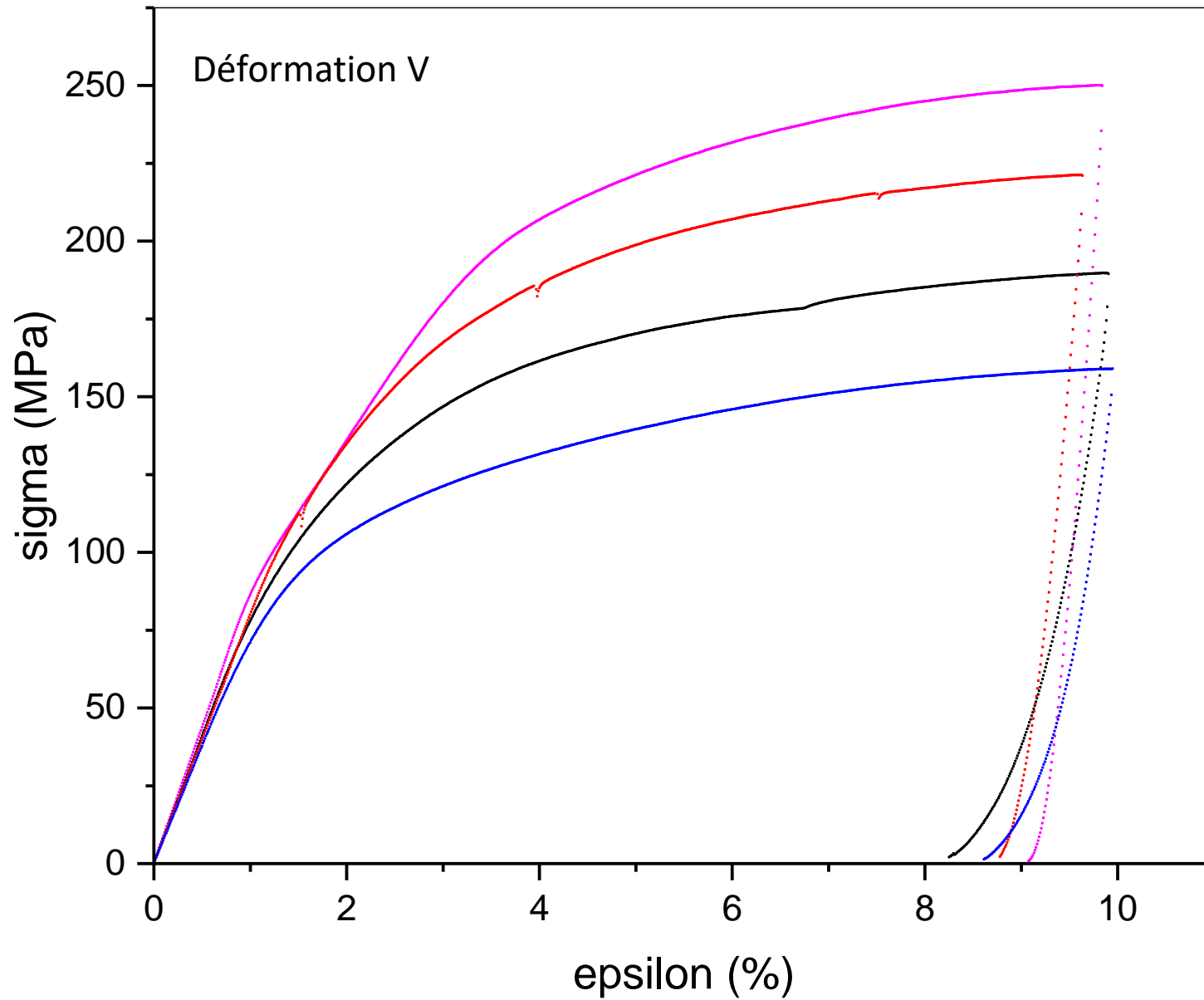
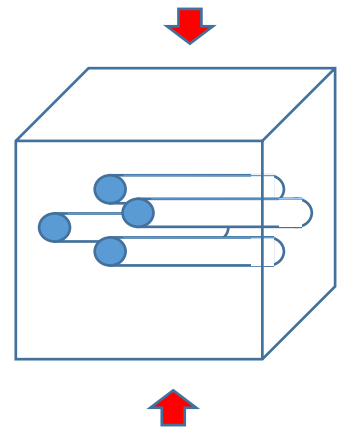
Cu/CuTi/CF20%

Cu/CF40%

Cu/CuTi/CF40%

=> Rôle des interphases
(TiC) dans
Cu/CuTi/CF40%

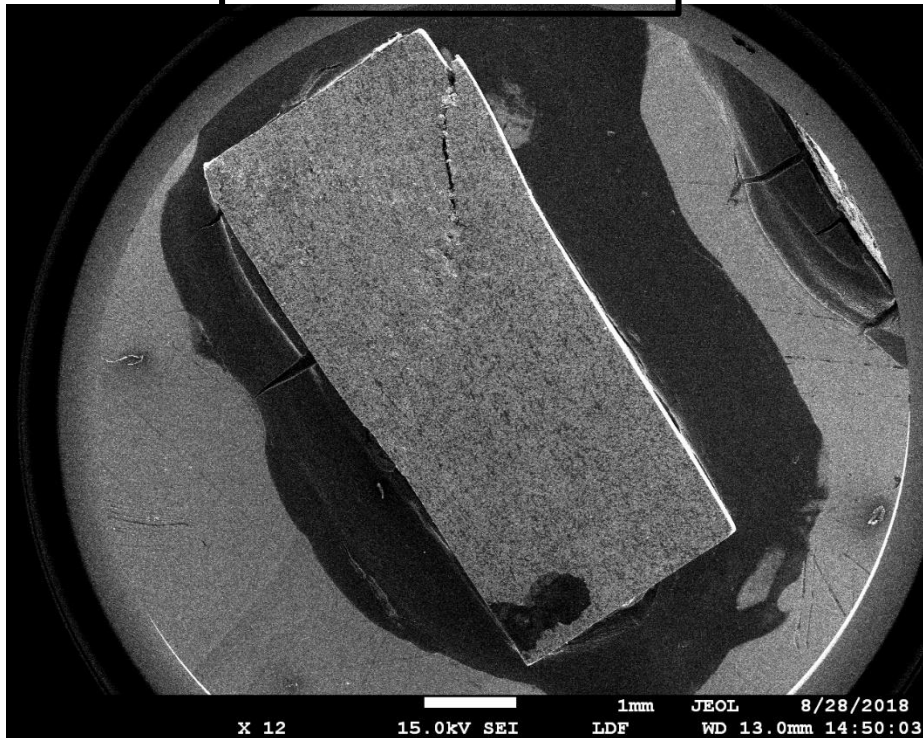
**Cu/CuTi/CF10%****Cu/CuTi/CF20%****Cu/CuTi/CF40%**

**Cu/CuTi/CF10%****Cu/CuTi/CF20%****Cu/CuTi/CF40%****Cu/CF40%**

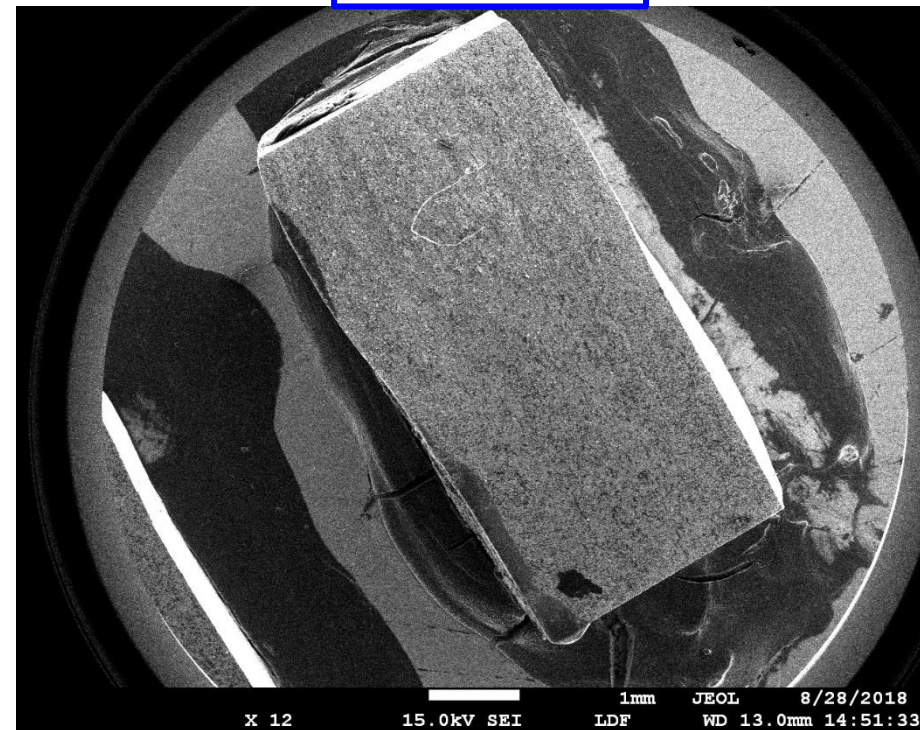
Observation après déformation

- **Cu/CuTi/CF40%** et **Cu/CF40%** après déformation H

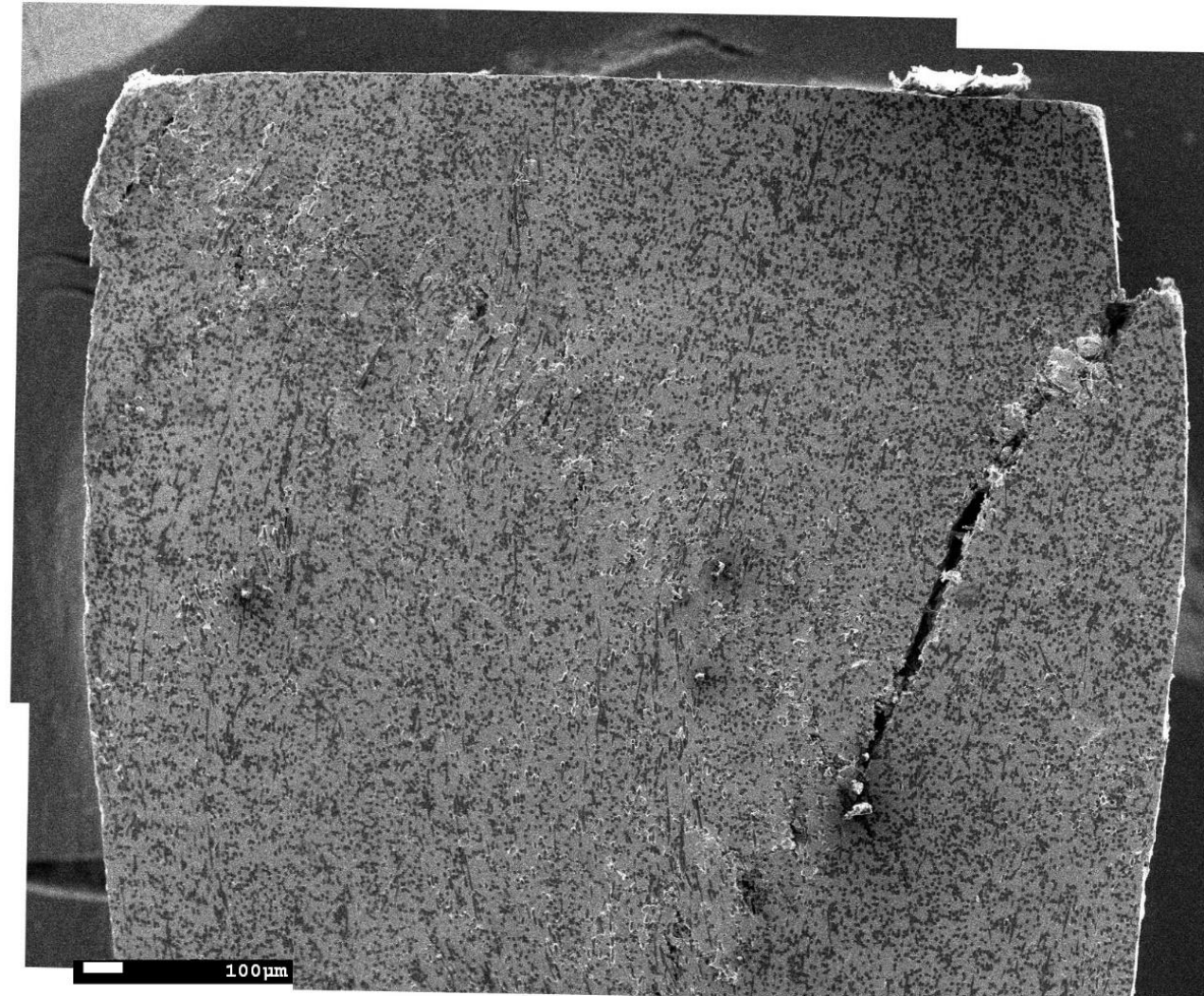
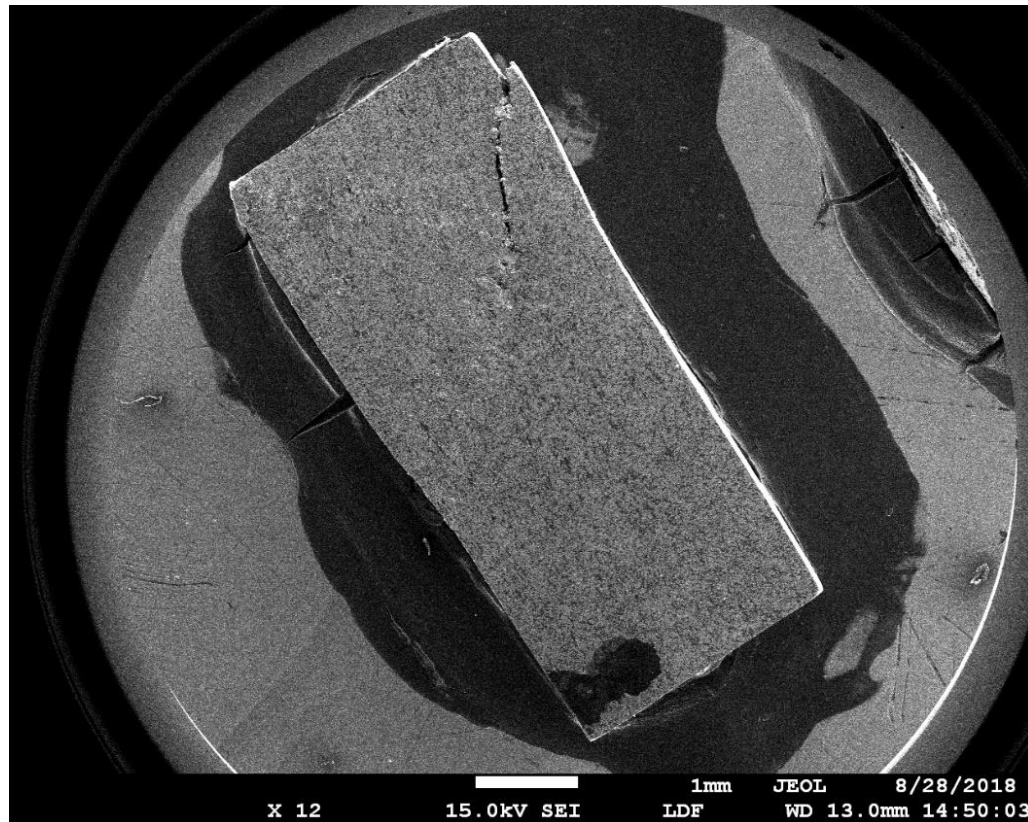
Cu/CuTi/CF40%



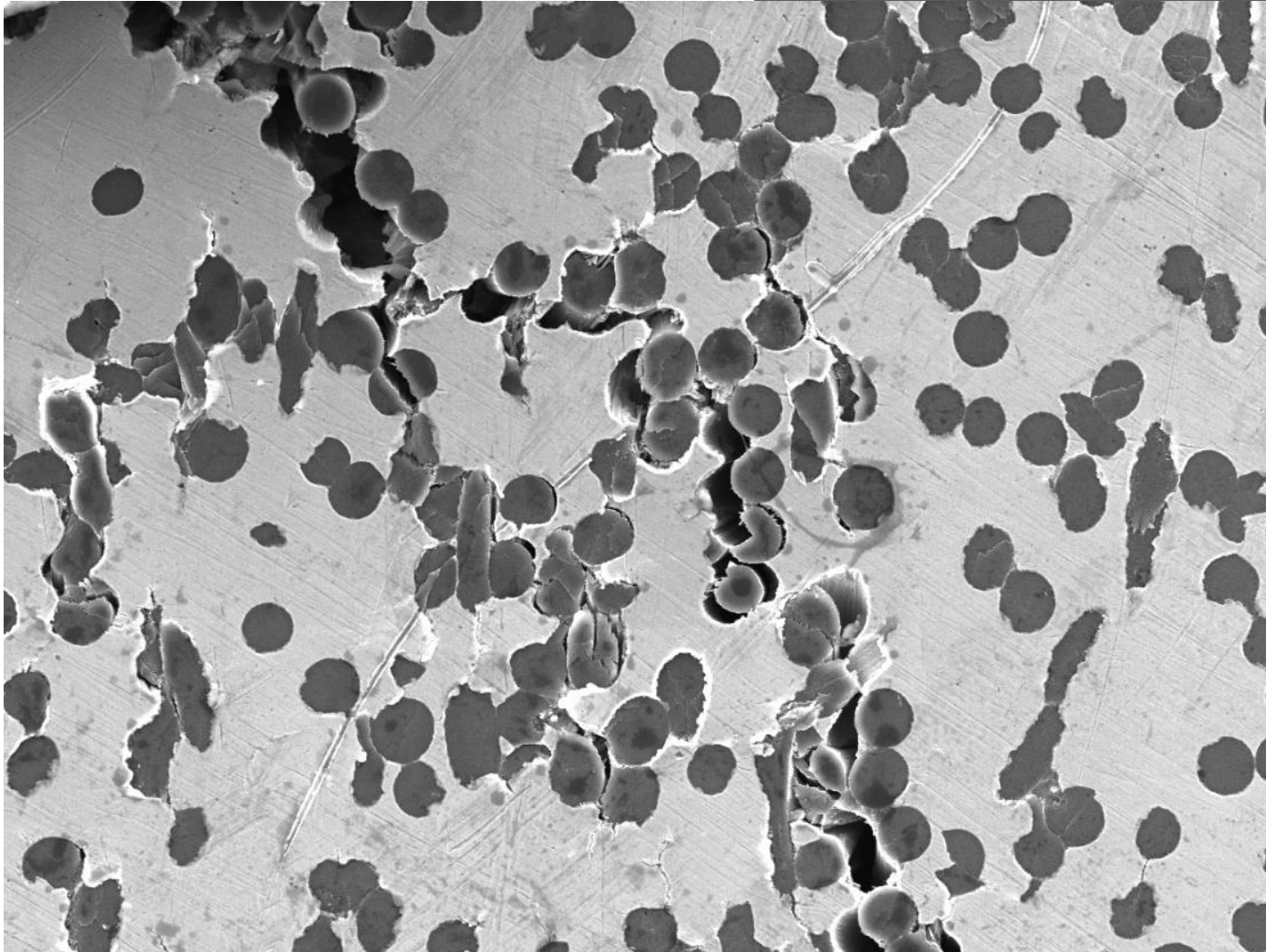
Cu/CF40%



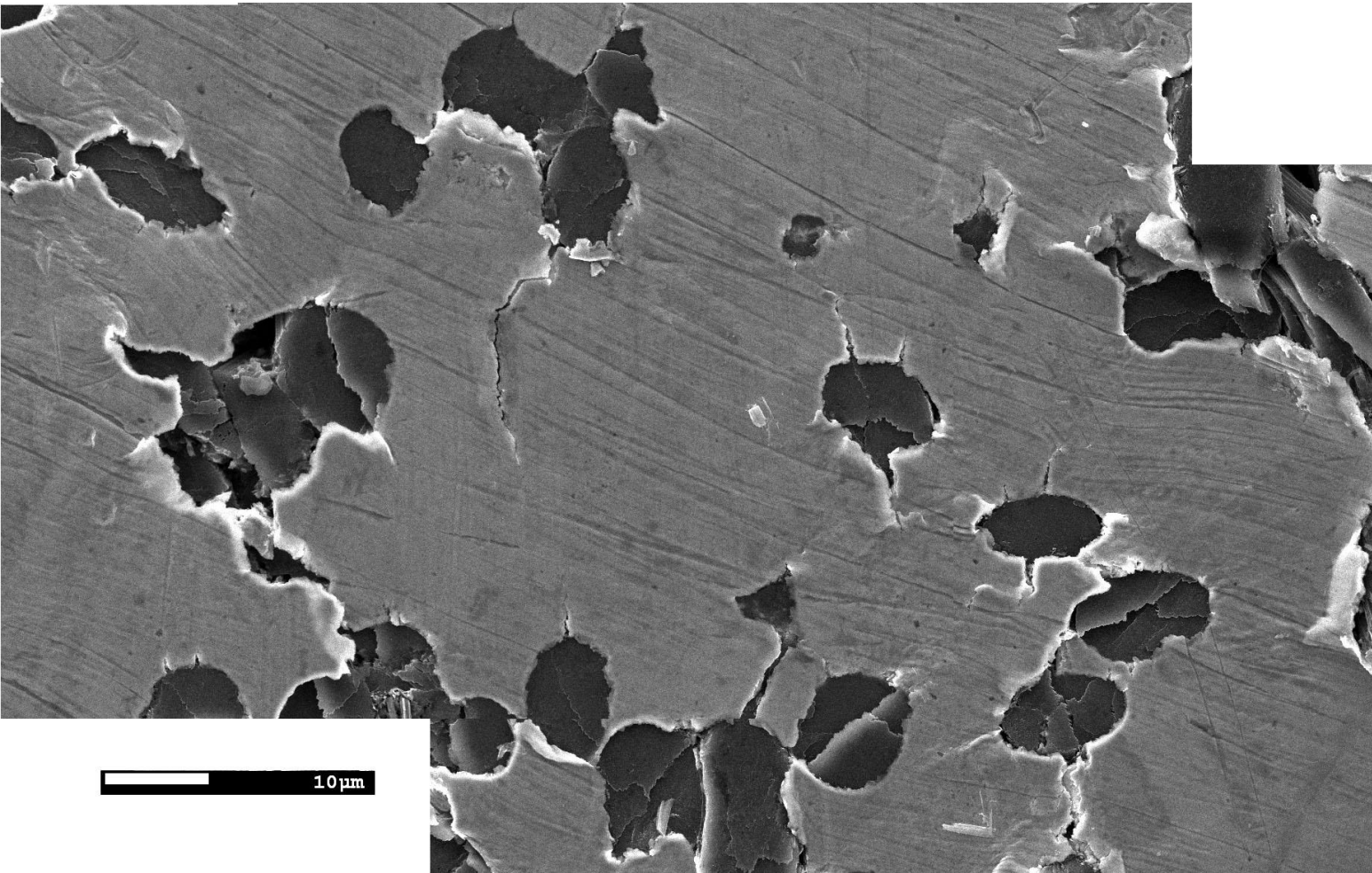
Cu/CuTi/CF40%



Cu/CuTi/CF40%

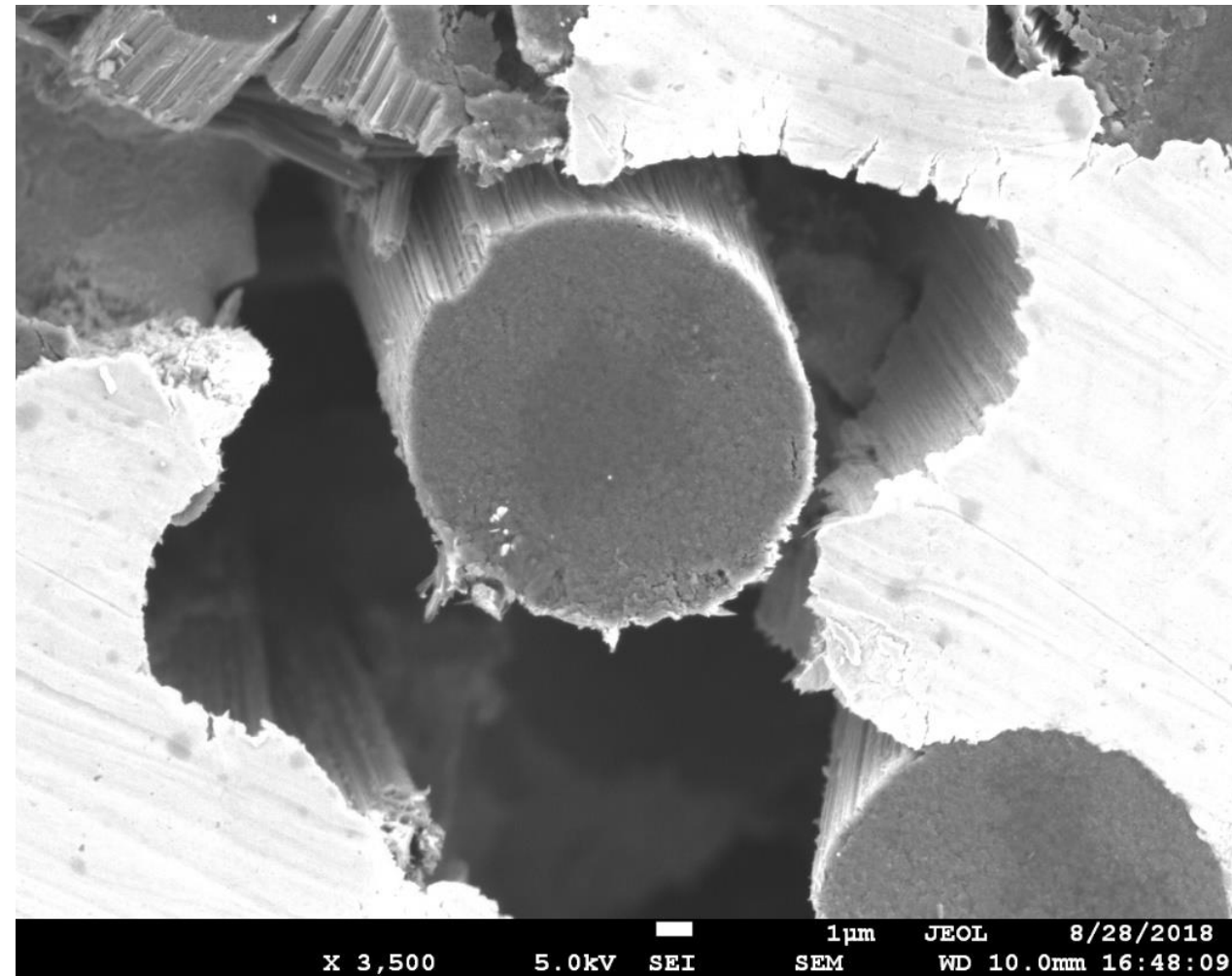
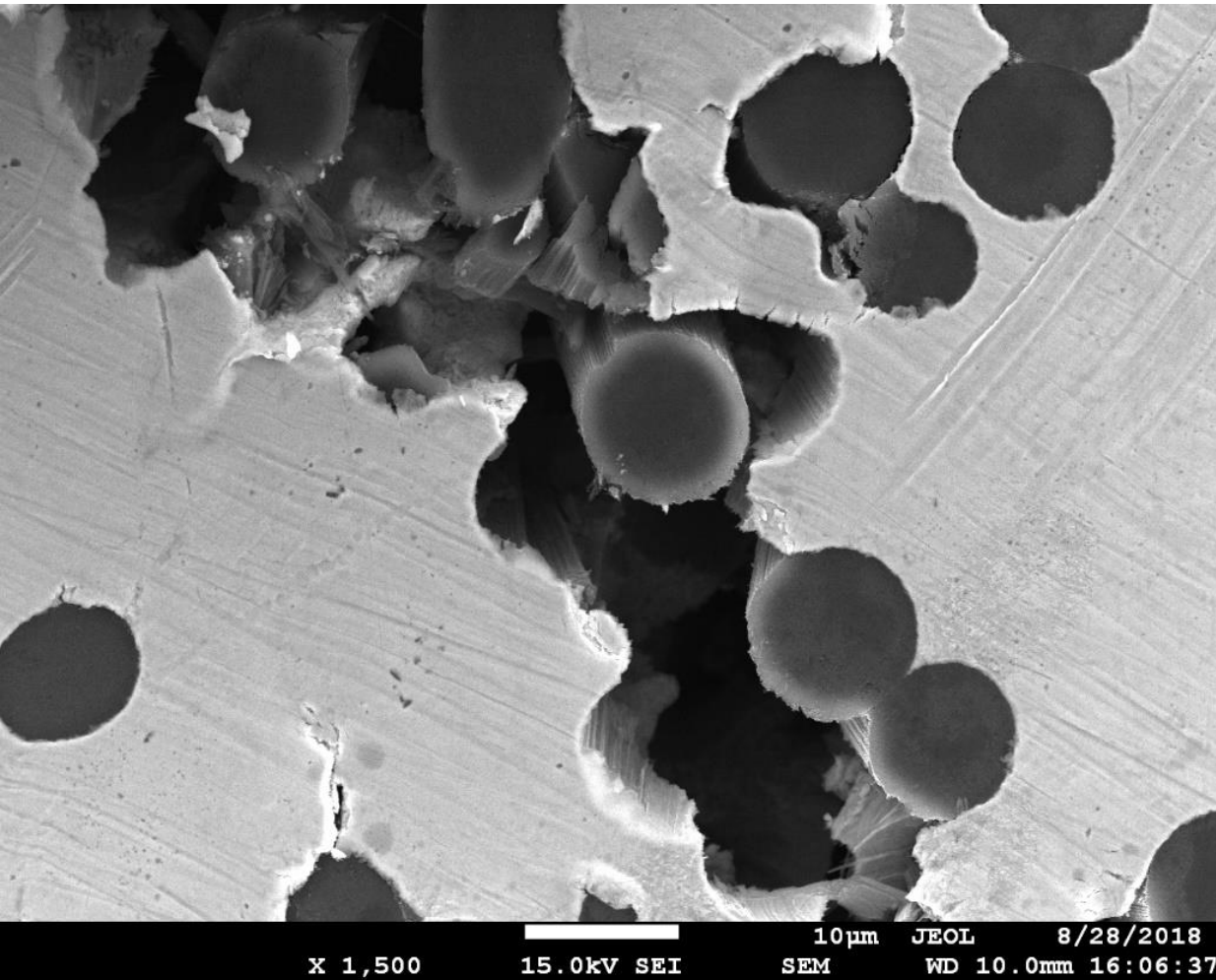


- Décohésion matrice/fibres
- Propagation de la fissure

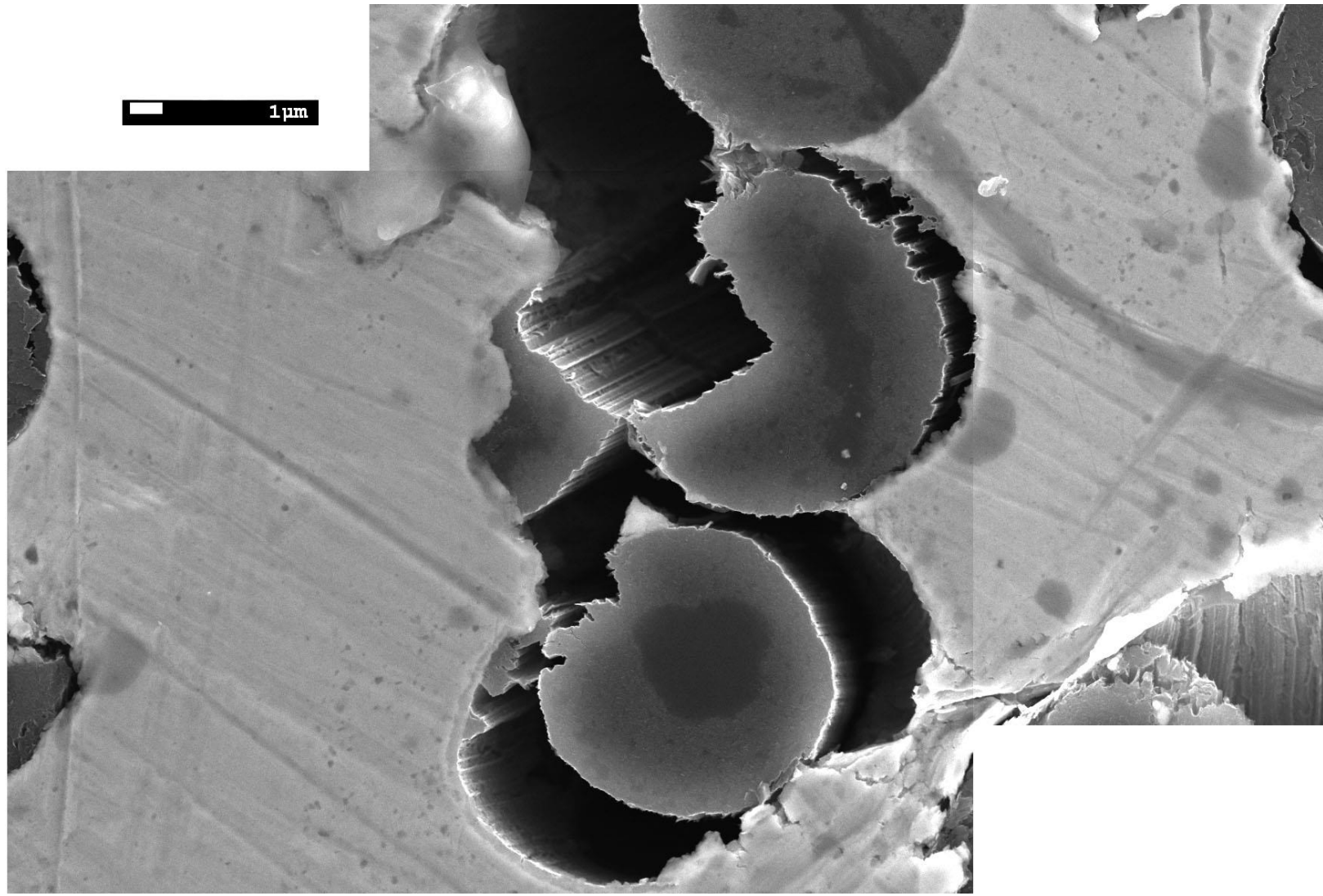
Cu/CuTi/CF40%

- Décohésion matrice/fibres
- Propagation de la fissure

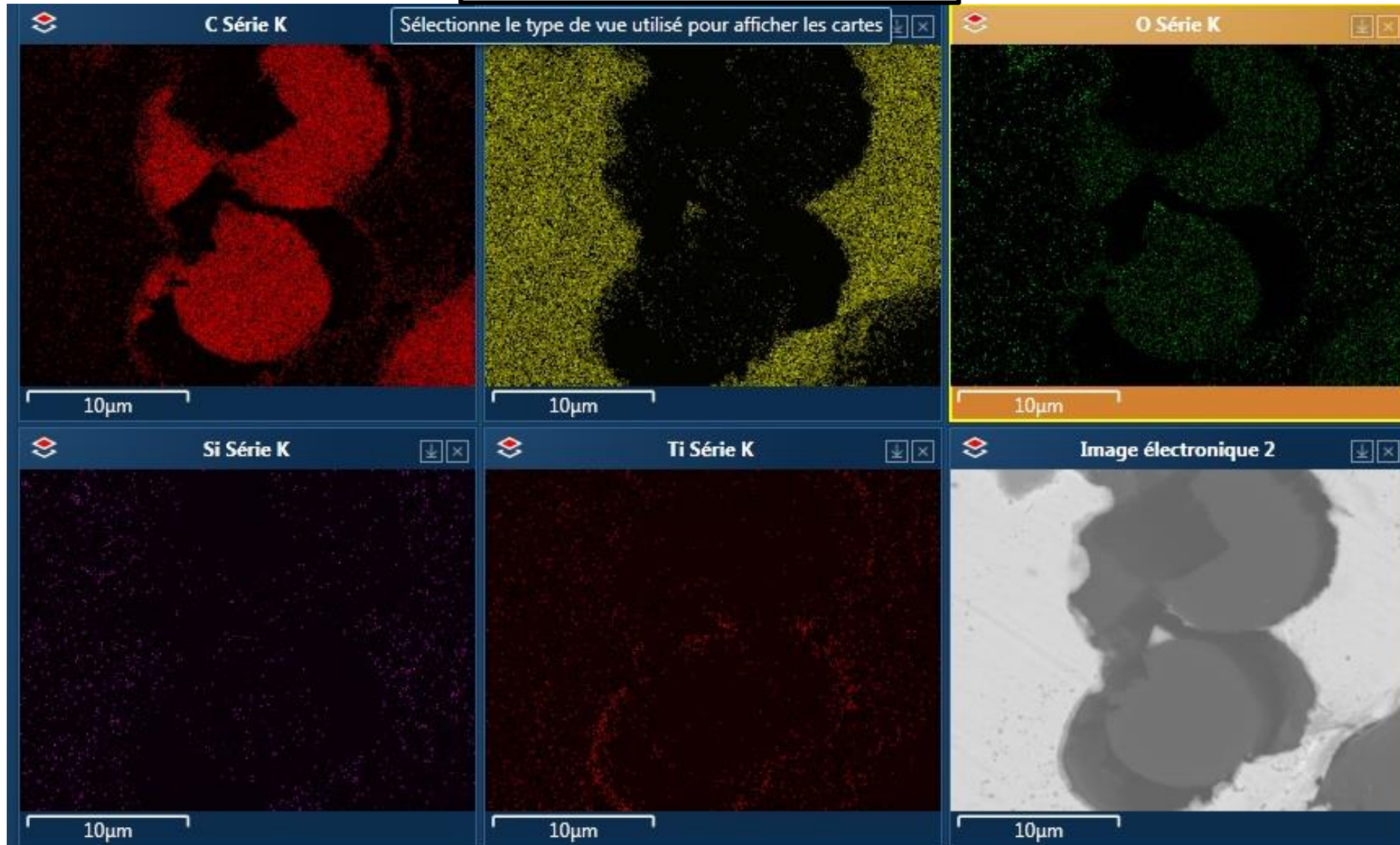
Cu/CuTi/CF40%



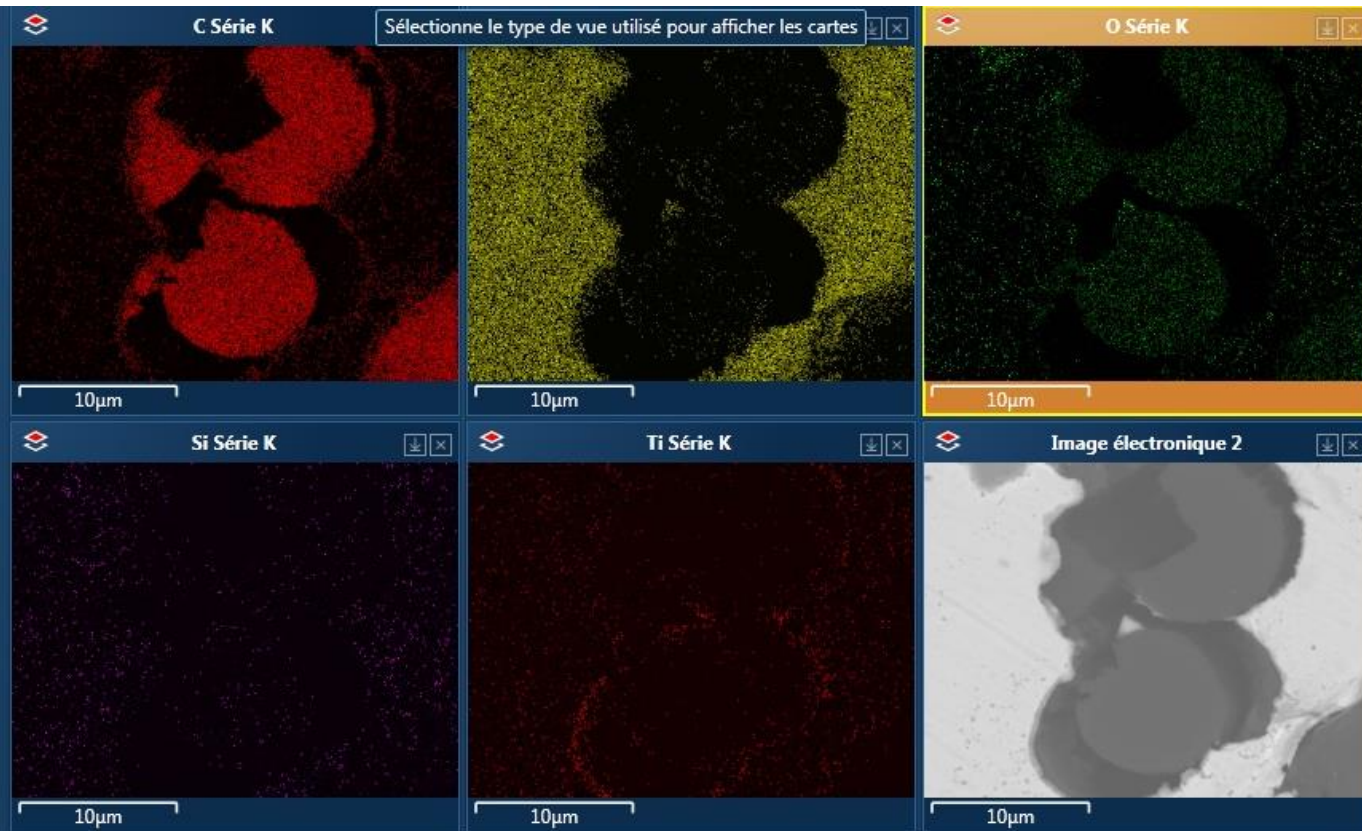
Cu/CuTi/CF40%



Cu/CuTi/CF40%



Cu/CuTi/CF40%

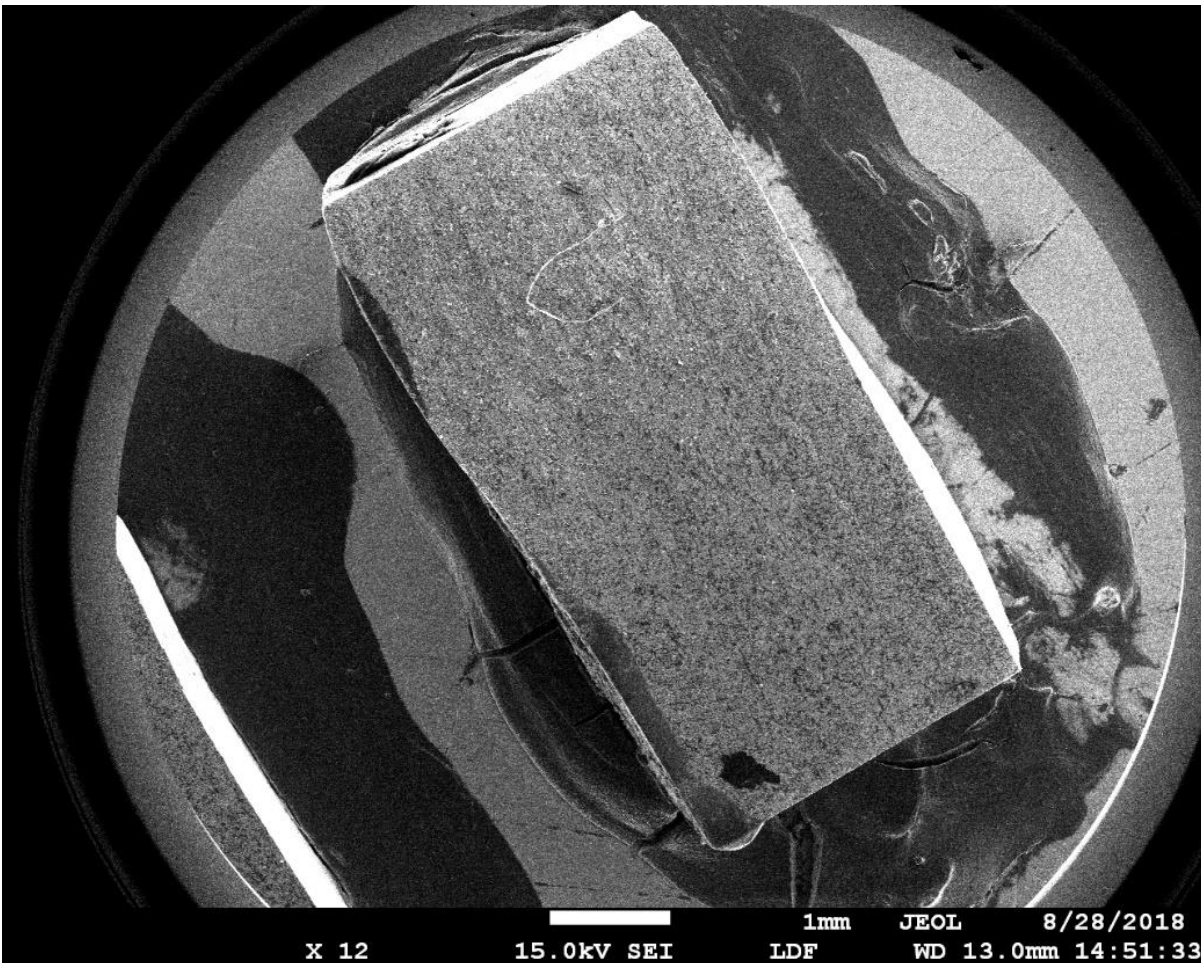


Interface forte

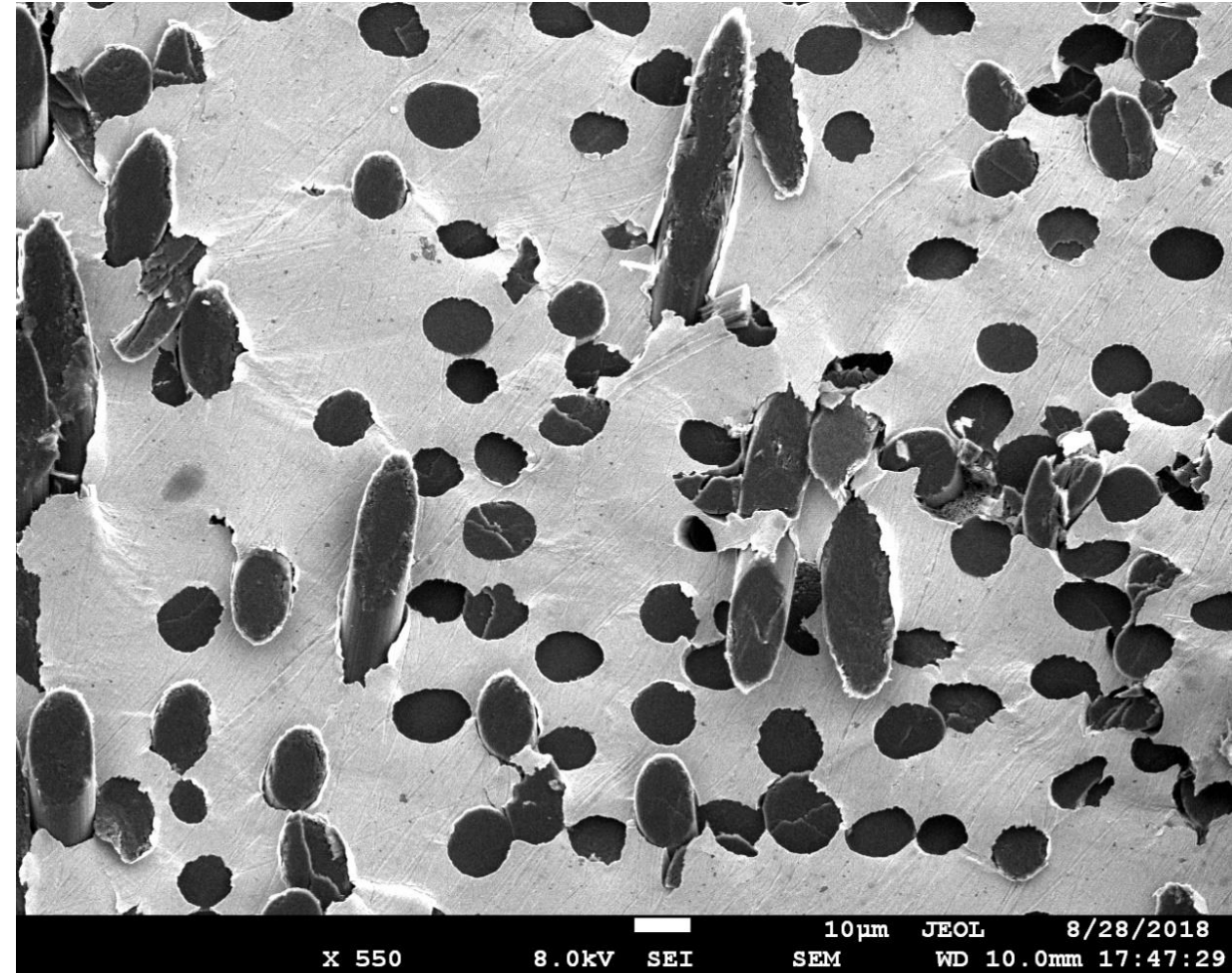
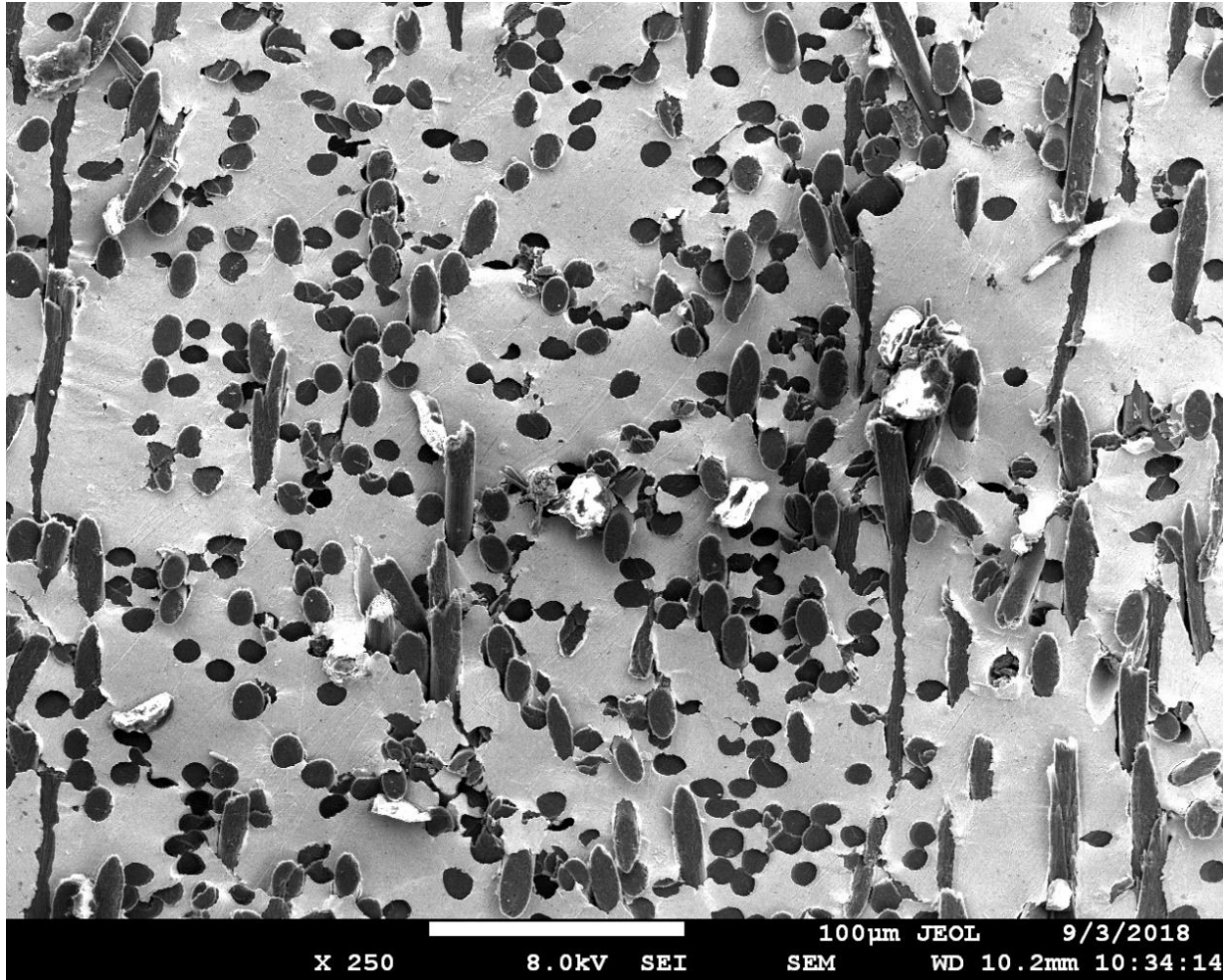
- Décohésion matrice/fibres
- Propagation de la fissure
- Fracture de la fibre
- Interphase adhérente à la matrice

Cu/CF40%

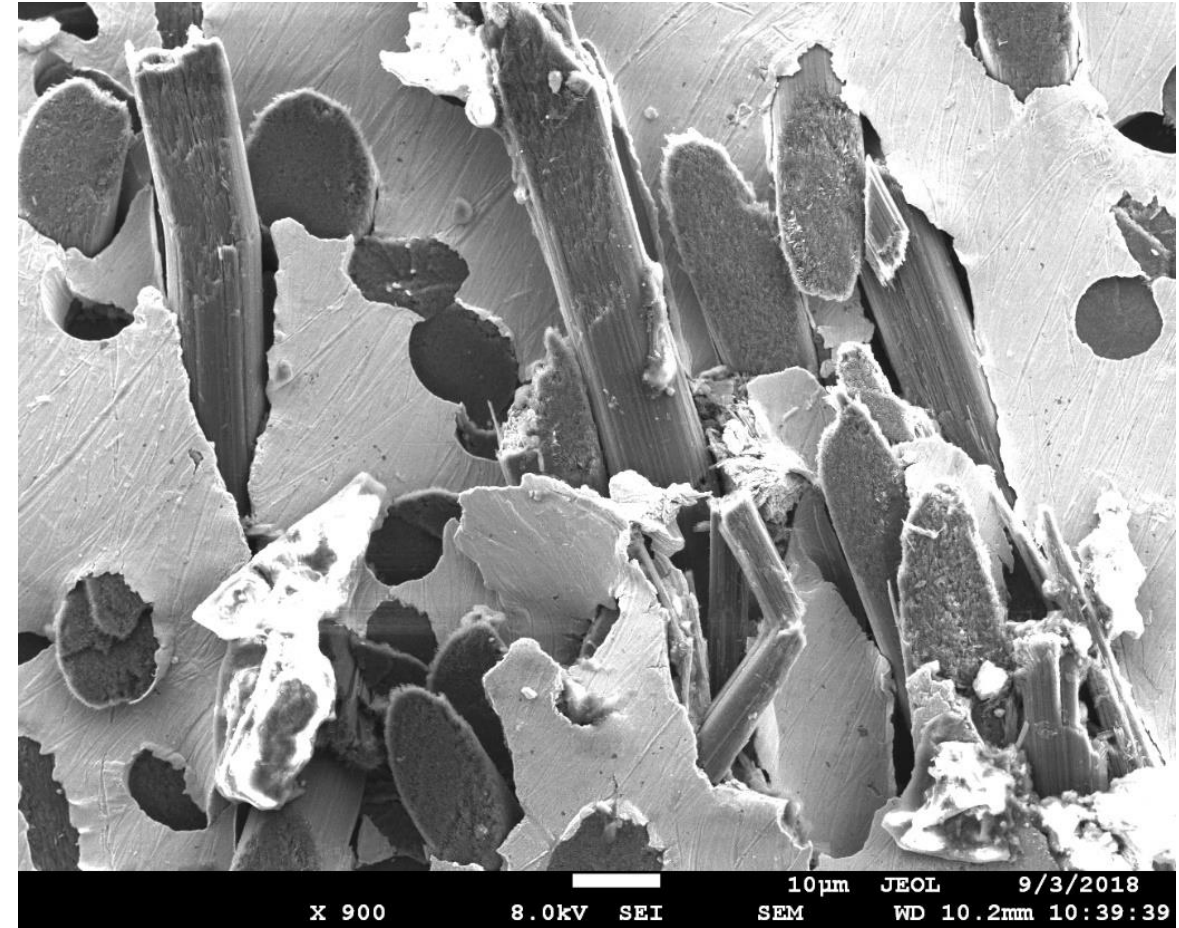
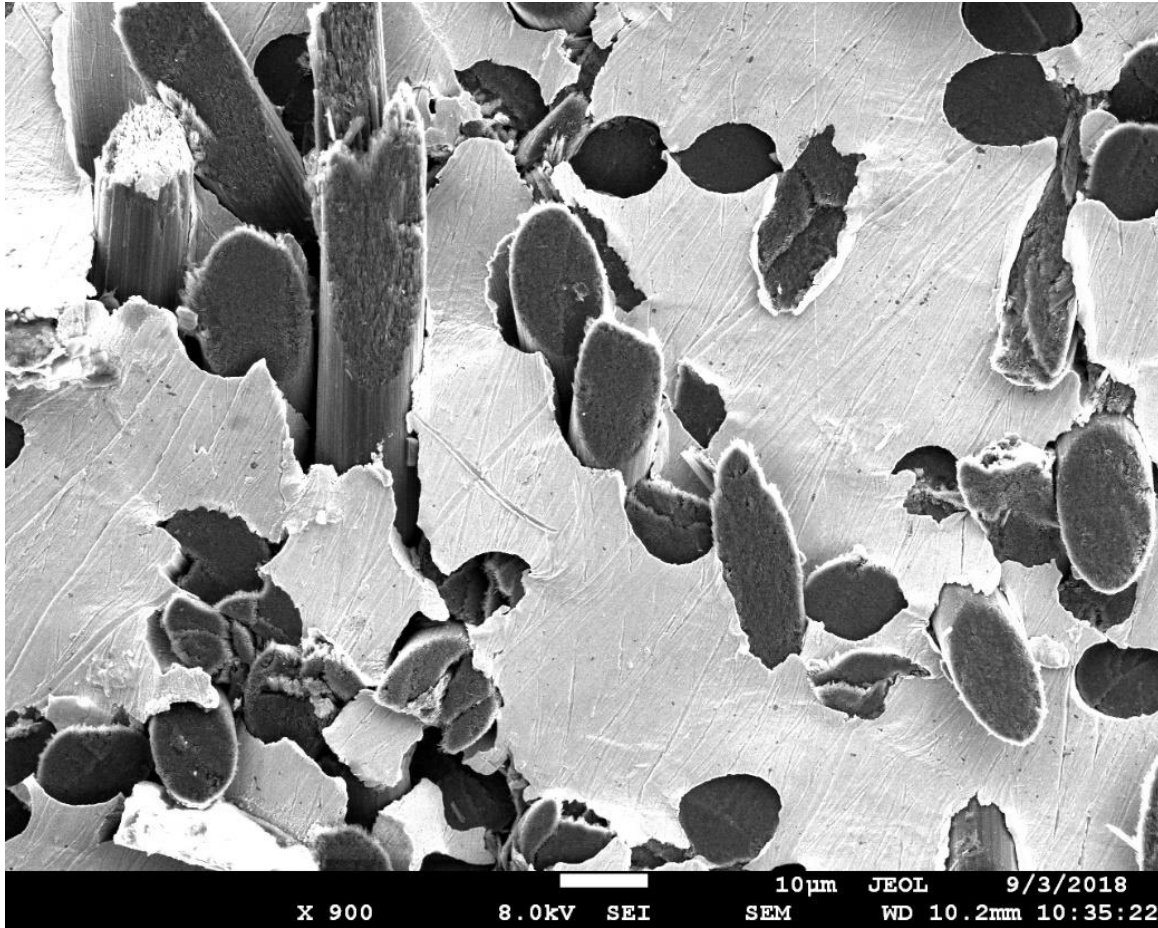
=> Pas de propagation de fissures



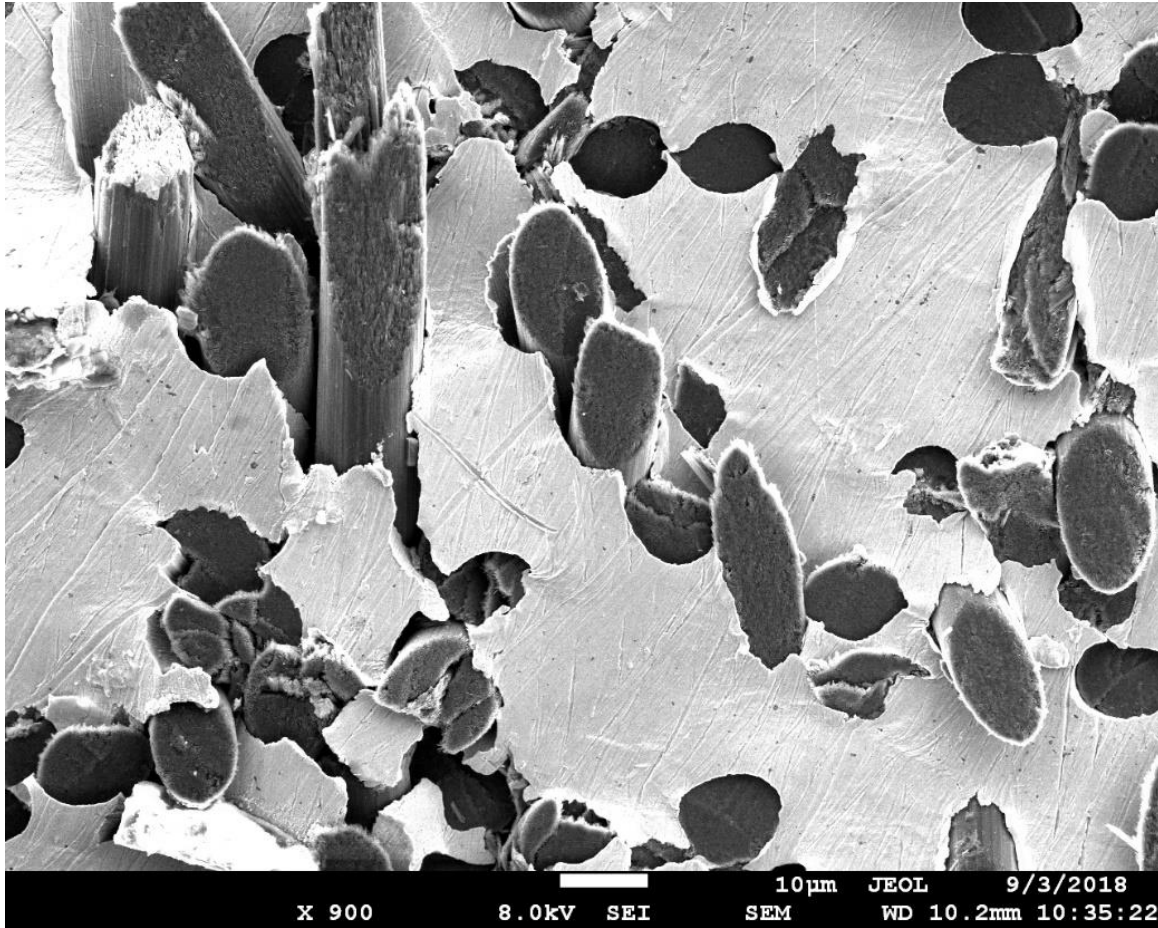
Cu/CF40%



Cu/CF40%

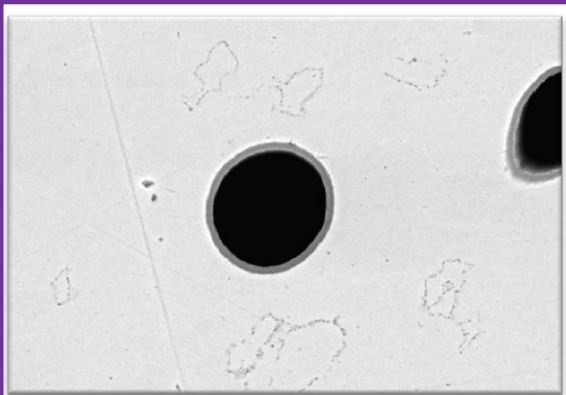


Cu/CF40%

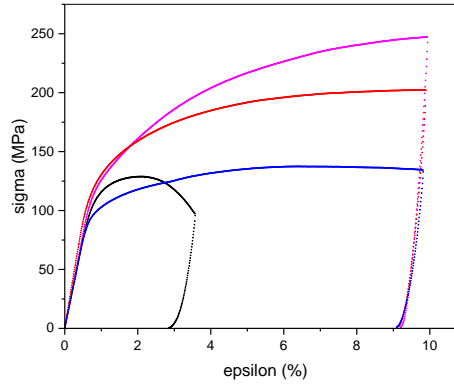


Interface faible

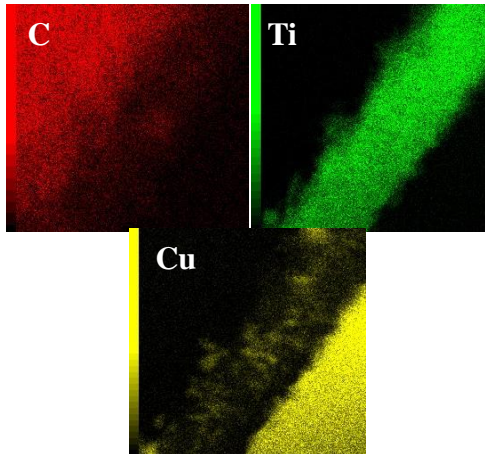
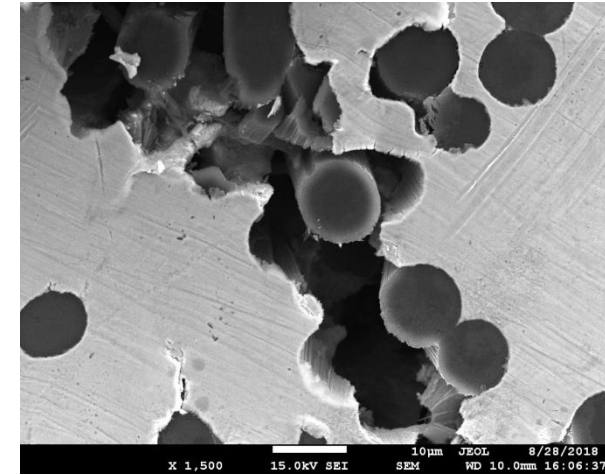
- Pas de propagation de fissures
- décohésion aux interfaces et glissement
- extraction des fibres.



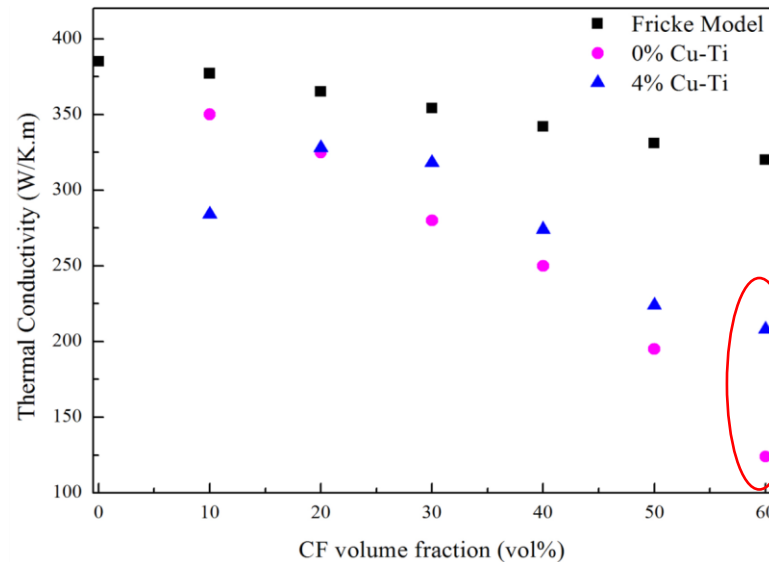
Controlled interphase geometry



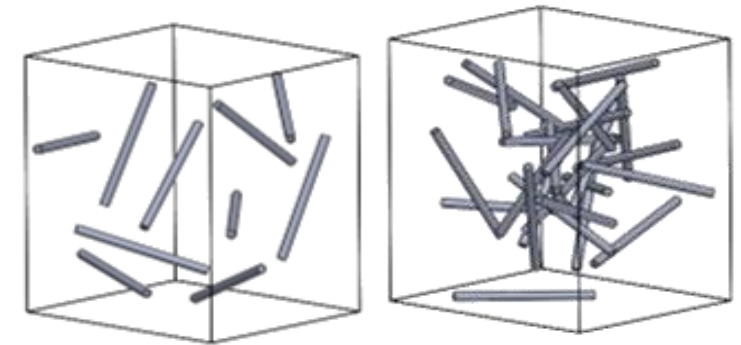
Propriétés mécaniques :
 interfaces fortes
 => fracture du composite



Controlled interphase chemistry



Propriétés thermiques



❑ **Decrease of the CTE : geometry of the preform and CF content**

❑ **Increase of the thermal properties: geometry and chemistry of the interphase**