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# Characterization of fresh EMPIrE and SEMPER FIDELIS plates with PVD-coated U(Mo) particles

X. Iltis<sup>1</sup>, H. Palancher<sup>1</sup>, D. Drouan<sup>1</sup>, N. Tarisien<sup>1</sup>, F. Vanni<sup>2</sup>, J. Allenou<sup>2</sup>, B. Stepnik<sup>2</sup>, A. Leenaers<sup>3</sup>  
S. Van den Berghe<sup>3</sup>, I. Glagolenko<sup>4</sup>, D.D. Keiser<sup>4</sup>

<sup>1</sup> CEA, DEN, DEC, Cadarache, F-13108 Saint-Paul-lez-Durance, France

<sup>2</sup> FRAMATOME CERCA, SPL, ZI Les Bérauds, 54 avenue de la déportation, BP 114, F-26104 Romans-sur-Isère, France

<sup>3</sup> SCK-CEN Nuclear Material Science Institute, Boeretang 200, 2400 Mol, Belgium

<sup>4</sup> Nuclear Fuels and Materials Division, Idaho National Laboratory, P.O. Box 1625, Idaho Falls, ID 83415-6188, USA

## CONTEXT AND GOAL OF THE STUDY

Two irradiation programs are currently in progress:  
 ▪ EMPIrE, on mini-plates, in ATR reactor (USA),  
 ▪ SEMPER FIDELIS, on full-size plates, in BR2 reactor (Belgium).

In both experiments, U(Mo)/Al plates are tested under aggressive irradiation conditions.

Seven fresh plates (5 EMPIrE ones and 2 SEMPER FIDELIS ones), manufactured with atomized U(Mo) particles from KAERI, whether or not heat treated at 1000°C for Mo homogenization, all ZrN-coated by PVD, are examined mainly by SEM.

A particular attention is paid to the integrity of the ZrN coating and to the U(Mo) particles microstructure, in the different types of plates.

## PLATES MAIN CHARACTERISTICS

Irradiation program	Plate designation	Mo homogenization
EMPIrE (mini-plates)	EMP-711	No
	EMP-717	No
	EMP-803	Yes
	EMP-819	Yes
SEMPER FIDELIS (full-size plates)	EMP-828	Yes
	SF-202 (full designation: FIDJ0202)	Yes
	SF-402 (full designation: FIDJ0402)	No

9 x 28 mm<sup>2</sup>

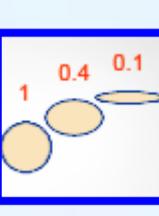
- Sample parallel to fuel-cladding interface:
  - X-Ray Diffraction (XRD), in progress
  - Scanning Electron Microscopy (SEM) + Energy Dispersive spectroscopy (EDS)

- Sample perpendicular to fuel-cladding interface:
  - Optical Microscopy (OM)
  - SEM + EDS

## EXPERIMENTAL DETAILS (for quantified results)

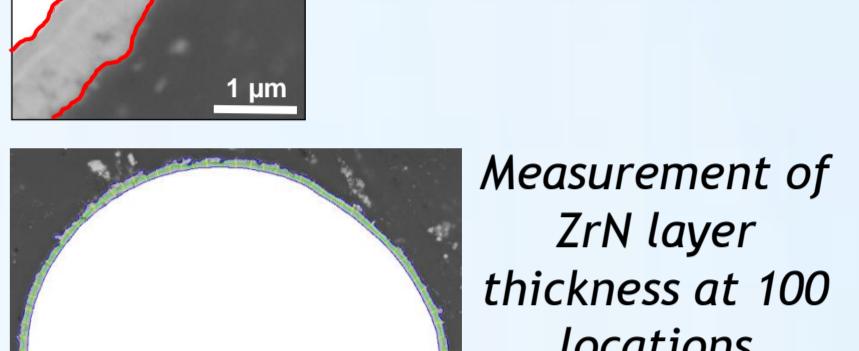
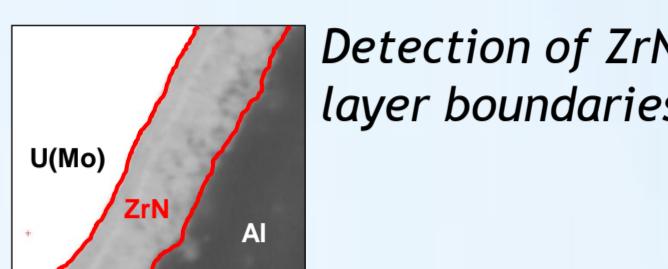
### U(Mo) particles sphericity:

- Defined by the squared ratio between the width and the length of a particle, excluding ZrN coating
- Measured by image analysis on ~ 100 particles per plate ( $\varnothing_{\min} = 70 \mu\text{m}$ )
- Particles with continuous coatings
- 100 measurements per particle



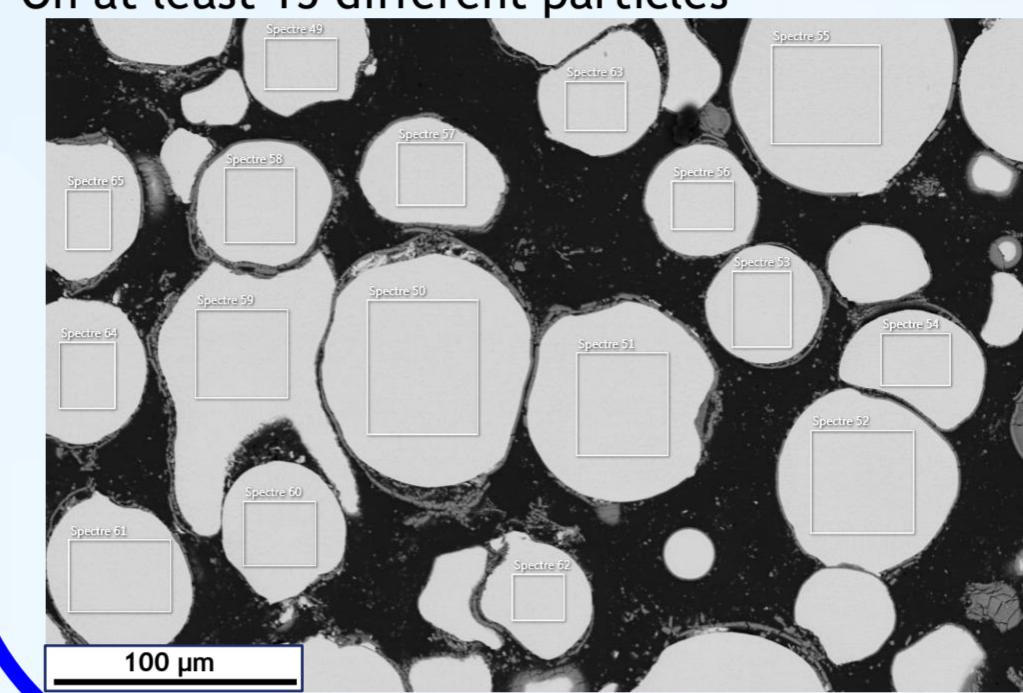
### ZrN layer thickness:

- Measured by image analysis on ~ 30 particles per plate ( $\varnothing_{\min} = 70 \mu\text{m}$ )
- Particles with continuous coatings
- 100 measurements per particle

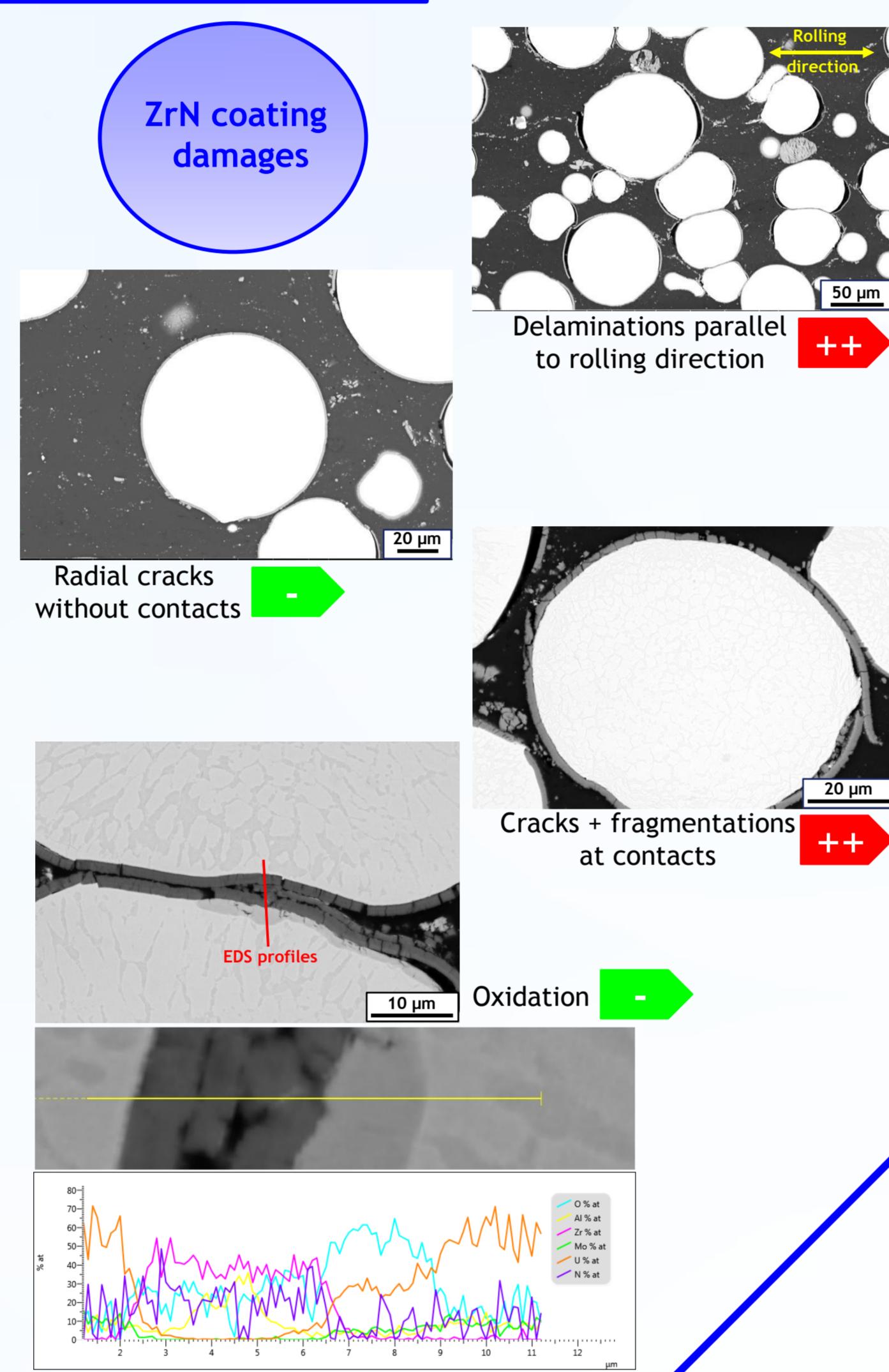
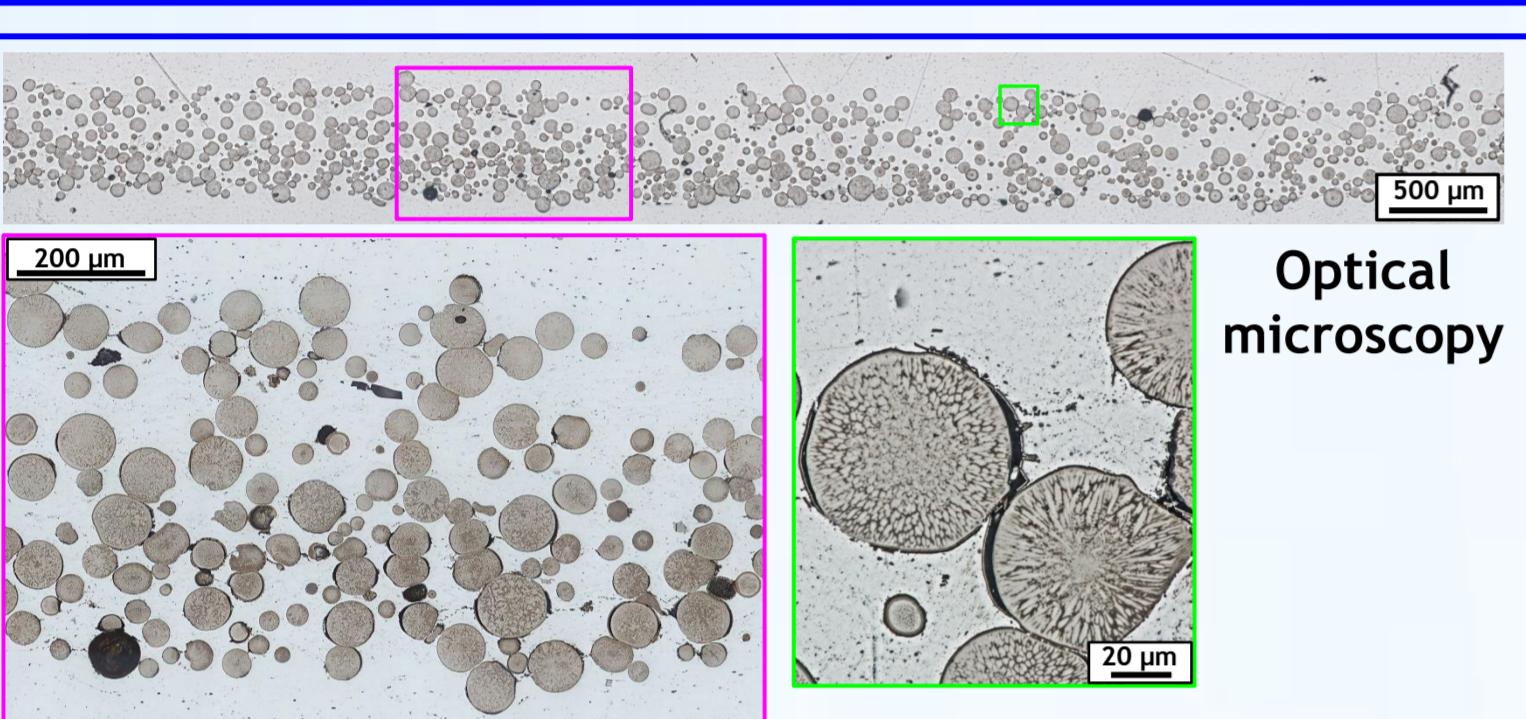


### Mo content analysis by EDS:

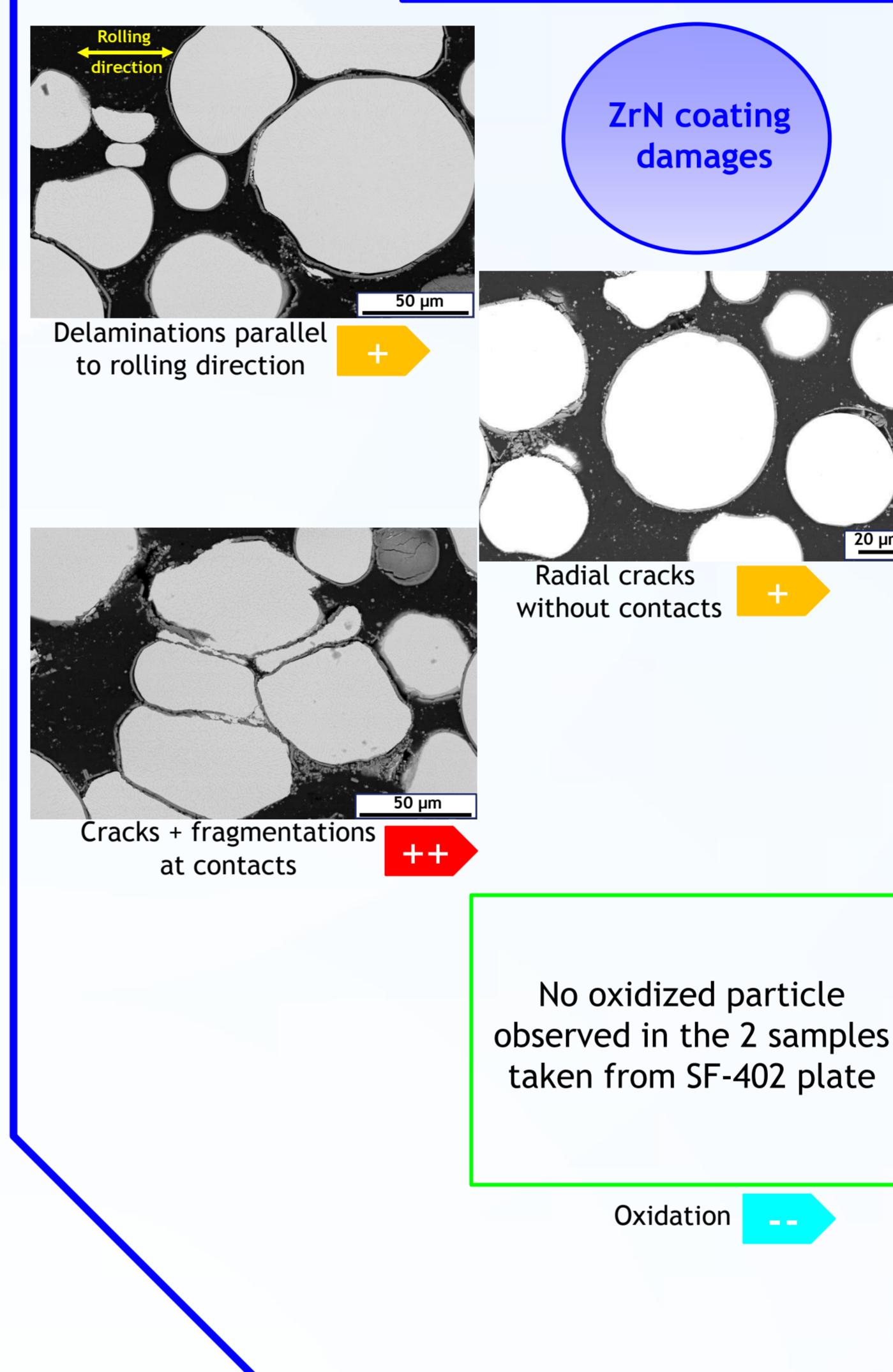
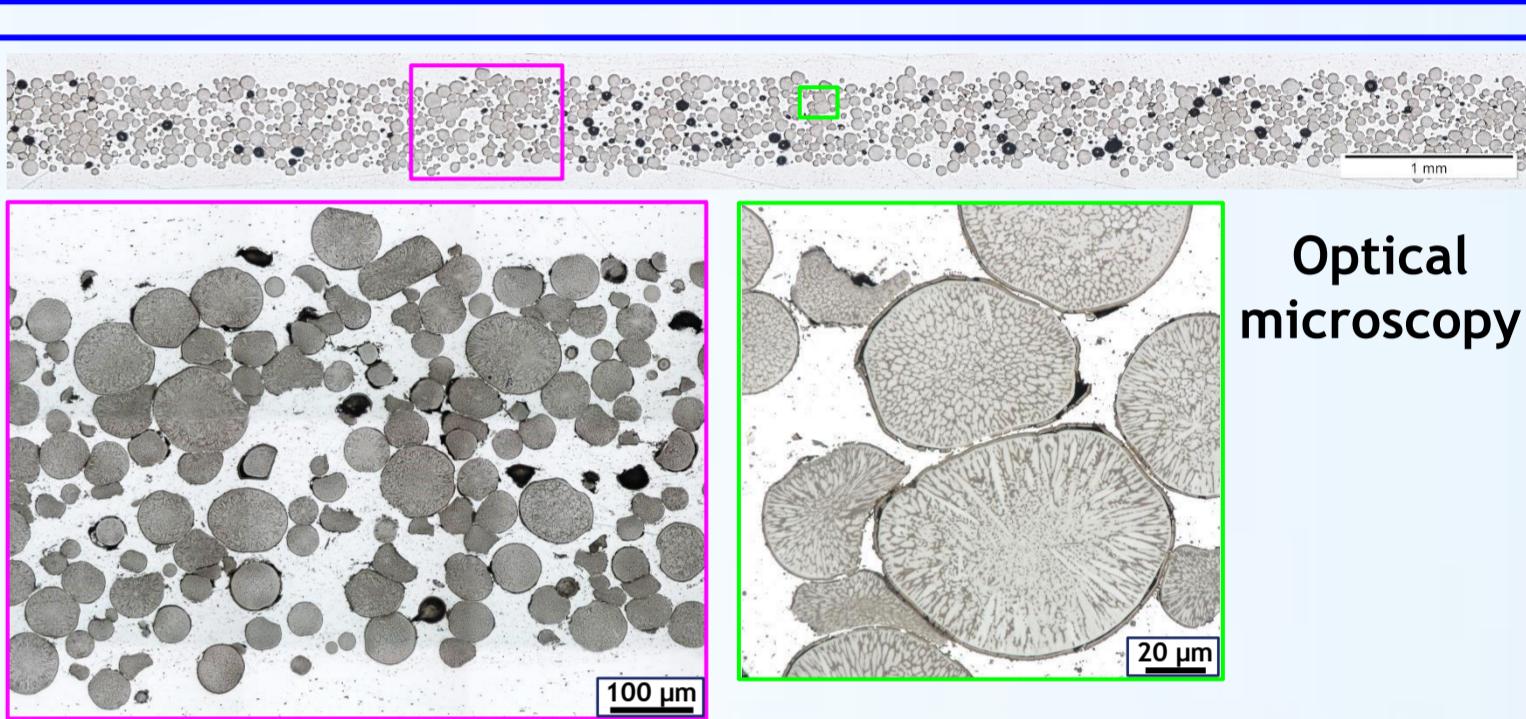
On at least 15 different particles



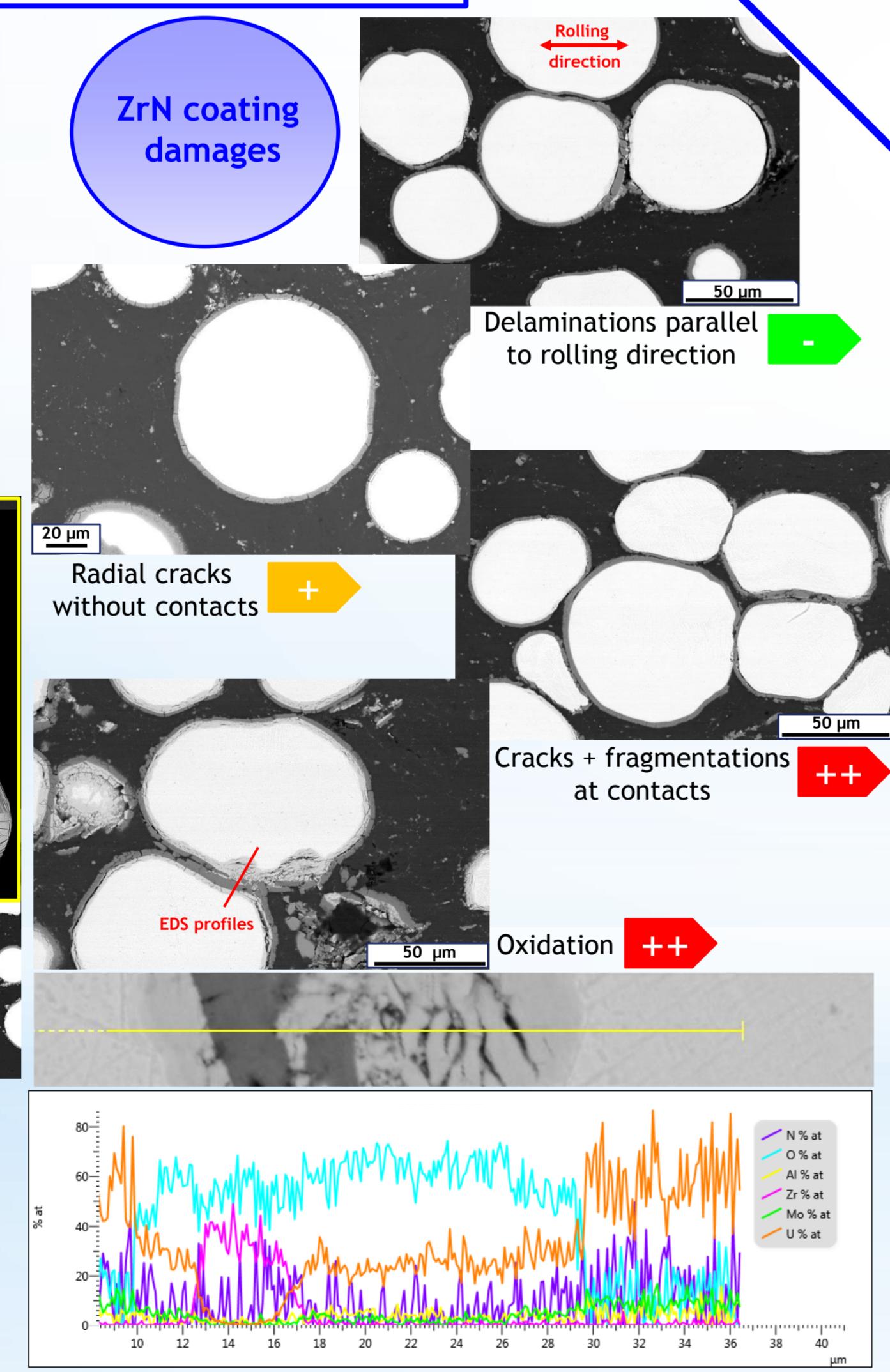
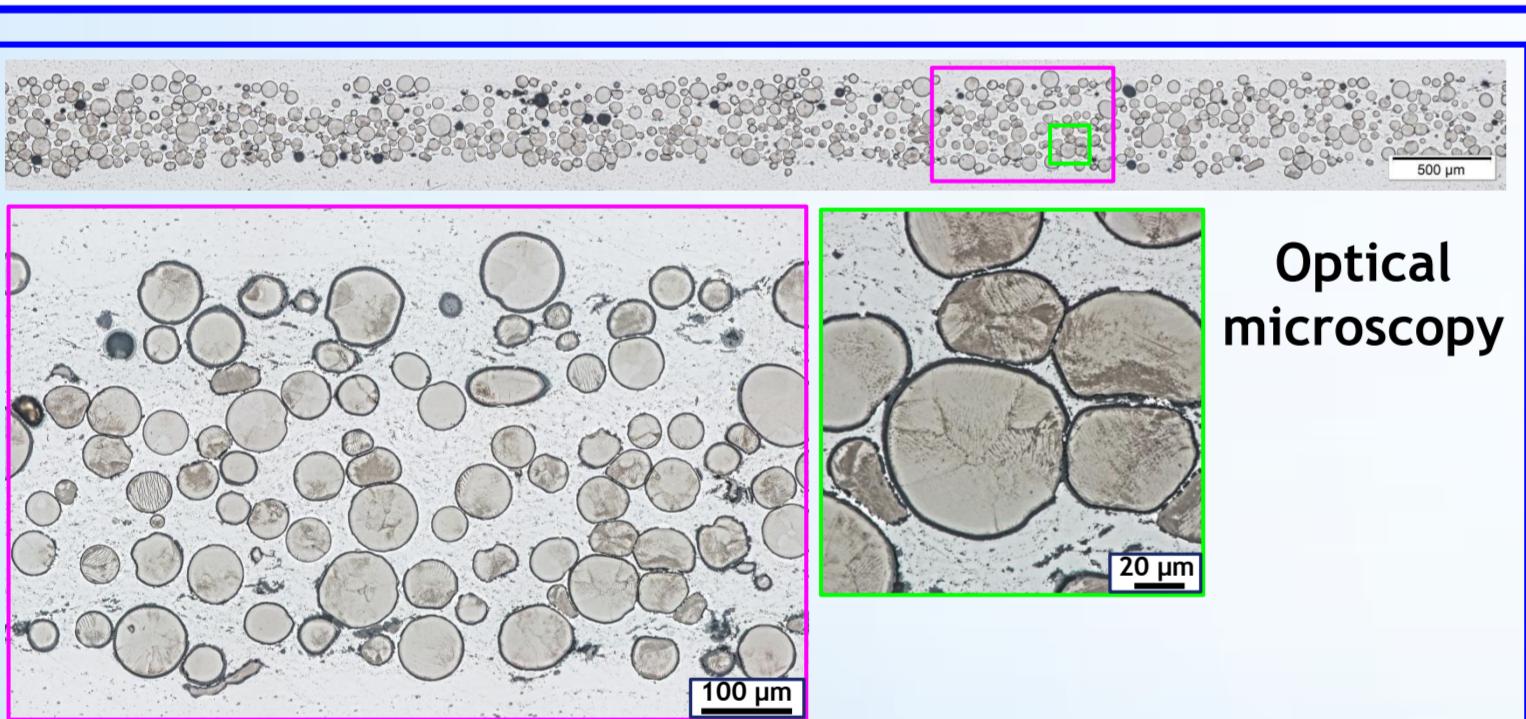
## EMP-717 MINI-PLATE, MADE WITH AS-ATOMIZED PARTICLES



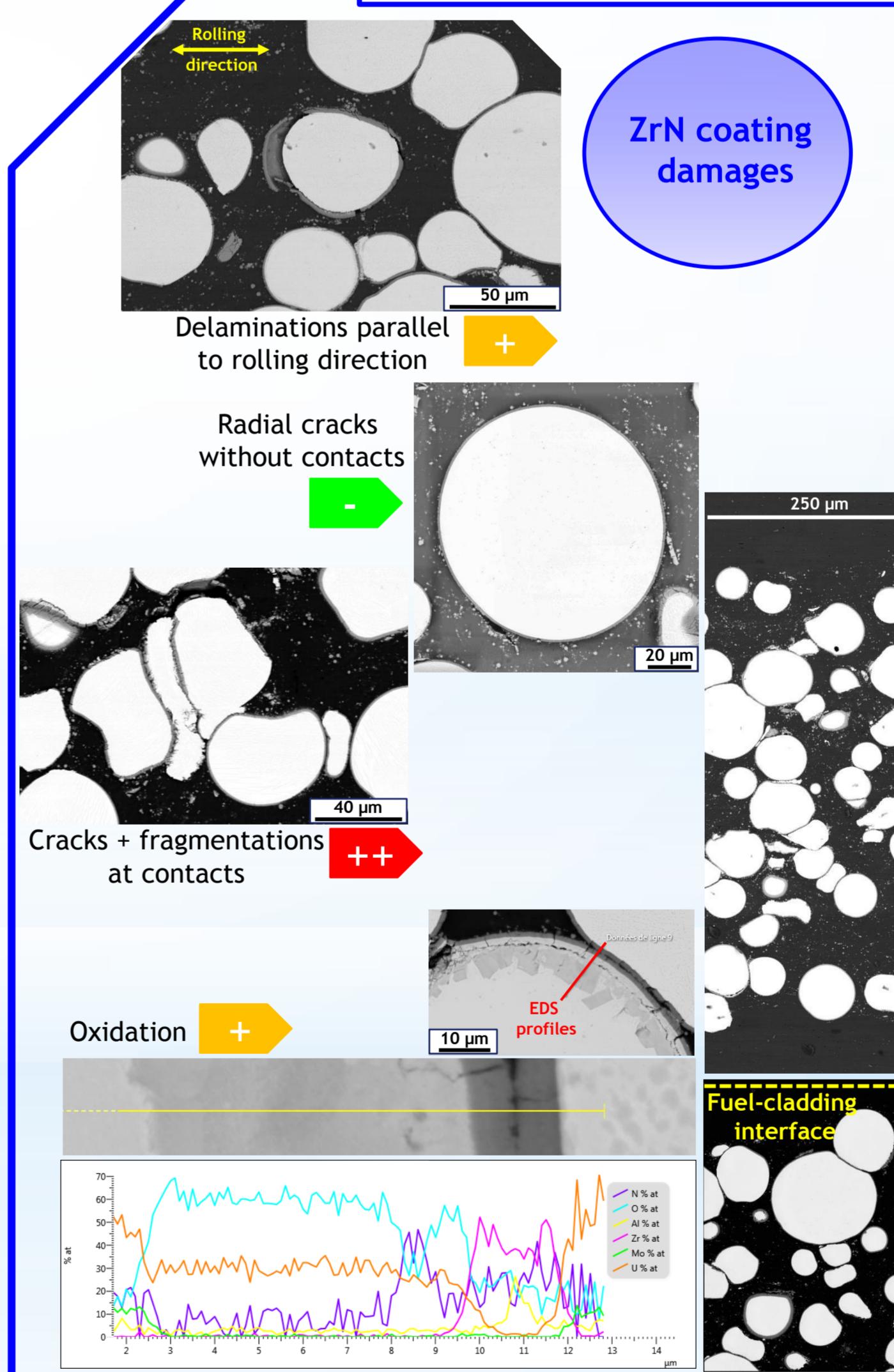
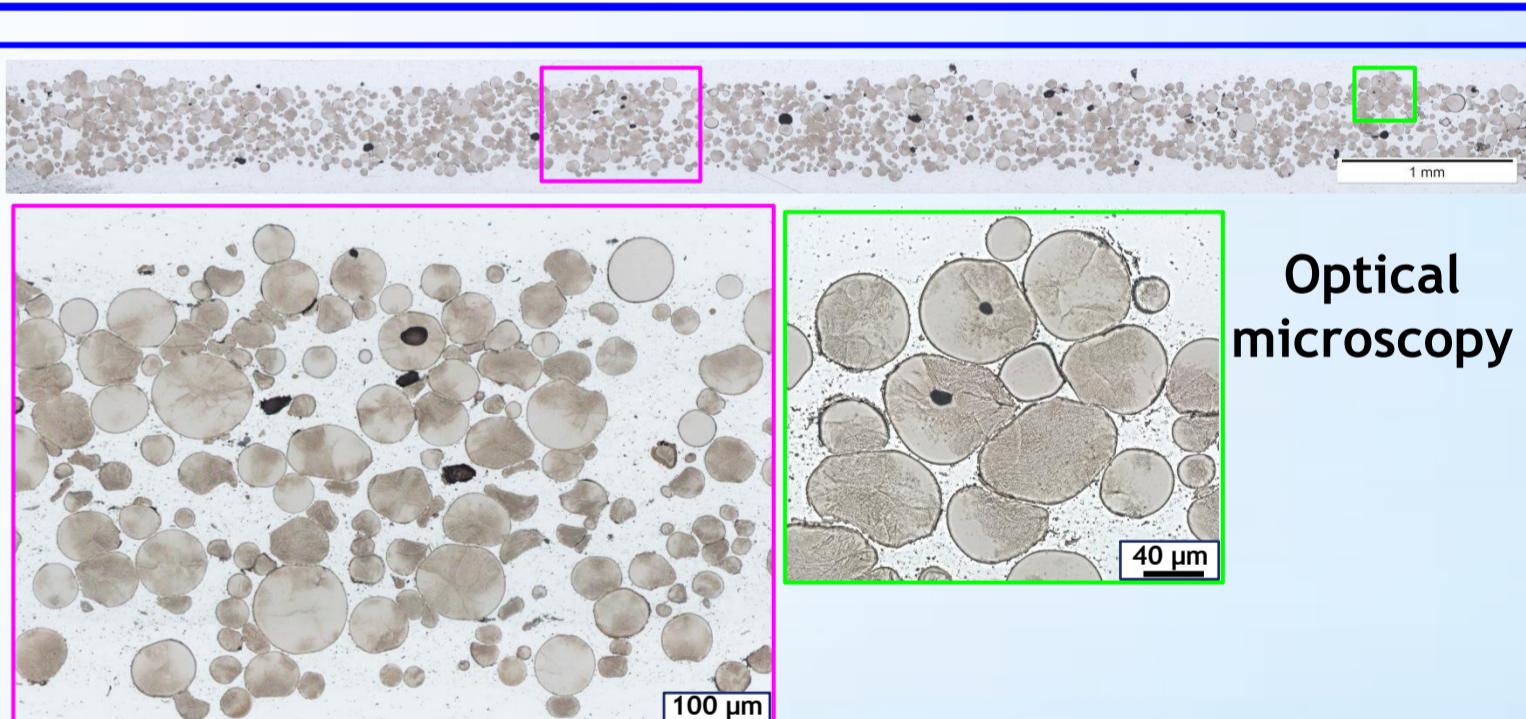
## SF-402 FULL-SIZE PLATE, MADE WITH AS-ATOMIZED PARTICLES



## EMP-819 MINI-PLATE, MADE WITH HOMOGENIZED PARTICLES



## SF-202 FULL-SIZE PLATE, MADE WITH HOMOGENIZED PARTICLES



## QUANTIFIED RESULTS

### Sphericity and Mo content of U(Mo) particles

Plate designation	Mean sphericity	Mean Mo content (wt%)
EMP-711	0.90	6.2
EMP-717	0.85	6.2
EMP-803	0.76	6.5
EMP-819	0.85	6.3
EMP-828	0.73	6.3
SF-202	0.71	6.3
SF-402	0.71	6.3

**U(Mo) particles sphericity:** related to the metallurgical state, in EMPIrE mini-plates (excepting EMP-819), systematically lower in SEMPER FIDELIS plates.

**Mean Mo content of U(Mo) particles:** - identical in all plates.

### ZrN coating thickness measurements

Plate designation	Minimum thickness	Maximum thickness	Mean thickness	Standard deviation
EMP-711	0.80	1.74	1.19	0.22
EMP-717	0.94	2.02	1.37	0.26
EMP-803	1.05	2.16	1.53	0.29
EMP-819	1.59	2.52	1.98	0.23
EMP-828	1.03	2.01	1.36	0.24
SF-202	0.68	1.40	1.06	0.20
SF-402	1.11	2.35	1.71	0.33

**ZrN thickness:** varies between 1 and 2 µm in both types of plates.

## CONCLUSION

**EMPIrE mini-plates and SEMPER FIDELIS full-size plates have very similar microstructural characteristics.**

- Fuel core thickness and U(Mo) particles distribution: slightly more irregular in EMPIrE mini-plates.
- U(Mo) particles microstructure: similar in both types of plates, depending on the heat treatment.
- **ZrN layers damages:** 4 types identified in all plates:
  - ① Delaminations : preferentially observed in plates made with as-atomized particles, more marked in EMPIrE mini-plates.
  - ② Radial cracks: related to the layer thickness, which varies between 1 and 2 µm in both types of plates.
  - ③ Damages linked to contacts: high in all plates.
  - ④ Coating loss of adherence linked to powder oxidation: greater in plates made with homogenized particles, and especially in EMPIrE ones.