



HAL
open science

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

X. Iltis, H. Palancher, D. Drouan, N. Tarisien, F. Vanni, J. Allenou, B. Stepnik, A. Leenaers, S. Vandenberghe, Irina Glagolenko, et al.

► To cite this version:

X. Iltis, H. Palancher, D. Drouan, N. Tarisien, F. Vanni, et al.. Characterization of fresh EMPIrE and SEMPER FIDELIS plates with PVD-coated U(Mo) particles. RRFM 2018, Mar 2018, Munich, Germany. cea-02339253

HAL Id: cea-02339253

<https://cea.hal.science/cea-02339253>

Submitted on 14 Dec 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

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).

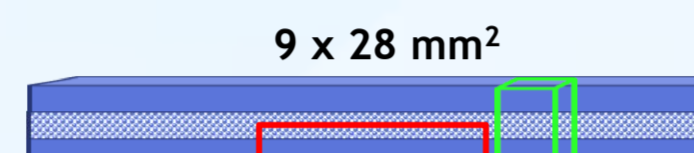
In both experiments, U(Mo)/Al plates are tested under aggressive irradiation conditions.

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
	EMP-828	Yes
SEMPER FIDELIS (full-size plates)	SF-202 (full designation: FIDJ0202)	Yes
	SF-402 (full designation: FIDJ0402)	No



- **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

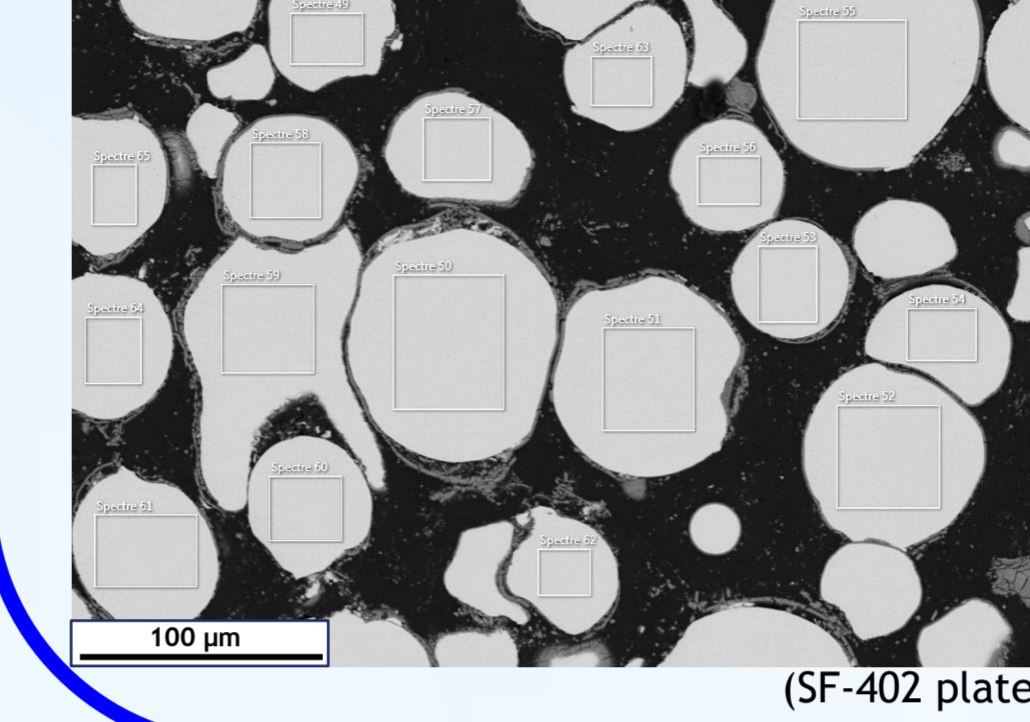
EXPERIMENTAL DETAILS (for quantified results)

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 ($\varnothing_{\min} = 20 \mu\text{m}$)

Mo content analysis by EDS:

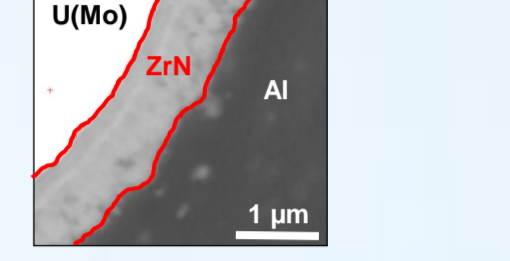
On at least 15 different particles



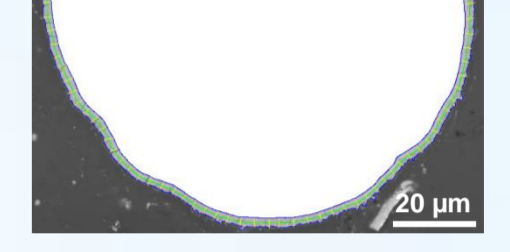
ZrN layer thickness:

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

Detection of ZrN layer boundaries



Measurement of ZrN layer thickness at 100 locations



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

ZrN coating damages

- Delaminations parallel to rolling direction ++
- Radial cracks without contacts +
- Cracks + fragmentations at contacts ++
- Oxidation ++

Fuel-cladding interface

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

ZrN coating damages

- Delaminations parallel to rolling direction +
- Radial cracks without contacts +
- Cracks + fragmentations at contacts ++
- Oxidation --

No oxidized particle observed in the 2 samples taken from SF-402 plate

Fuel-cladding interface

EMP-819 MINI-PLATE, MADE WITH HOMOGENIZED PARTICLES

ZrN coating damages

- Delaminations parallel to rolling direction +
- Radial cracks without contacts +
- Cracks + fragmentations at contacts ++
- Oxidation ++

Fuel-cladding interface

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

ZrN coating damages

- Delaminations parallel to rolling direction +
- Radial cracks without contacts +
- Cracks + fragmentations at contacts ++
- Oxidation +

Fuel-cladding interface

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	ZrN coating thickness (μm)			
	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:

- Delaminations: preferentially observed in plates made with as-atomized particles, more marked in EMPIRE mini-plates.
- Radial cracks: related to the layer thickness, which varies between 1 and 2 μm in both types of plates.
- Damages linked to contacts: high in all plates.
- Coating loss of adherence linked to powder oxidation: greater in plates made with homogenized particles, and especially in EMPIRE ones.