Evaluation And Adaptation of The RIA Code SCANAIR For Modelling BWR Fuel And Conditions

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The SCANAIR code, developed by the Institut de Radioprotection et de Sûreté Nucléaire (IRSN), is designed for modelling the behaviour of a single fuel rod in fast transient and accident conditions during a reactivity initiated accident (RIA) in pressurized water reactor (PWR). The available material properties, models and correlations are for PWR fuel and conditions, but the code lacks corresponding data concerning Zircaloy-2 (Zry-2) which is the cladding material in BWR fuel rod. **New yield stress ($YS_{0.2}$) and ultimate tensile stress (UTS) laws are now fitted and implemented into SCANAIR** version V_7_2. Comparative simulations are made by applying the code to BWR RIA tests **FK-1 and LS-1** conducted in NSRR (Japan). **Zry-2 cladding failure predictions on FK tests are addressed.**

New Yield stress and UTS correlations

The French PROMETRA experimental data on Zry-2 originates from 12 tensile tests on ring specimens of irradiated cladding (7 cycles up to the discharge burnup of ~58 MWd/kgU), and from 9 tests on fresh cladding specimens. The same fitting formulation for Zry-2 is applied as with the irradiated Zry-4, M5 and Zirlo claddings [1] and with the old correlation based on bibliographic studies:

$$\sigma\,[\,\mathrm{MPa}\,] = \frac{a + b \cdot T\,[\,°C\,]}{1 + e^{c(T[\,°C\,]-d)}}$$

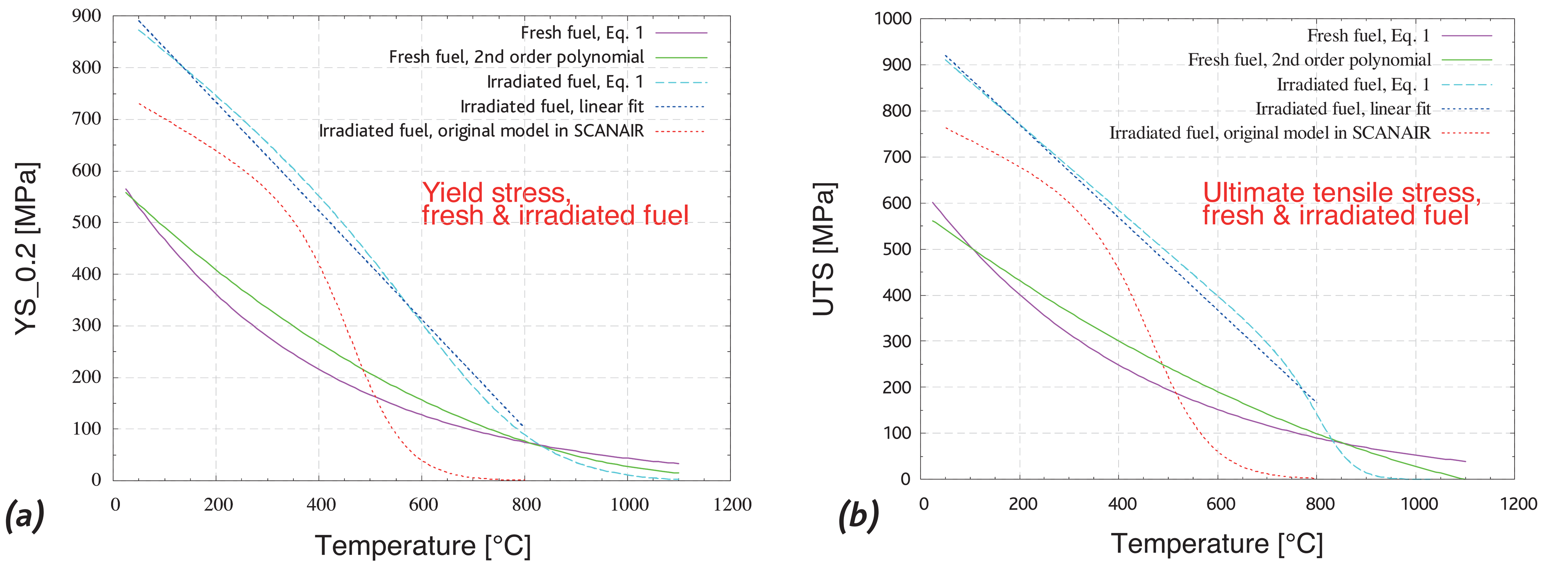

Fig 1 a-b: $YS_{0.2}$ *(a)* and UTS *(b)* of fresh and irradiated Zry-2.

Application to FK-1 and LS-1

The gap size has a large impact on the calculated. Strain Energy Density (SED) as seen in *Fig 2a*.

If the gap is closed, the SED increases by about 3 MJ/m³ when using the new correlations. If the gap is open (FK-1), the maximum SED remains unchanged.

There is **no significant impact on cladding outer temperatures** when using the old or the new correlations.

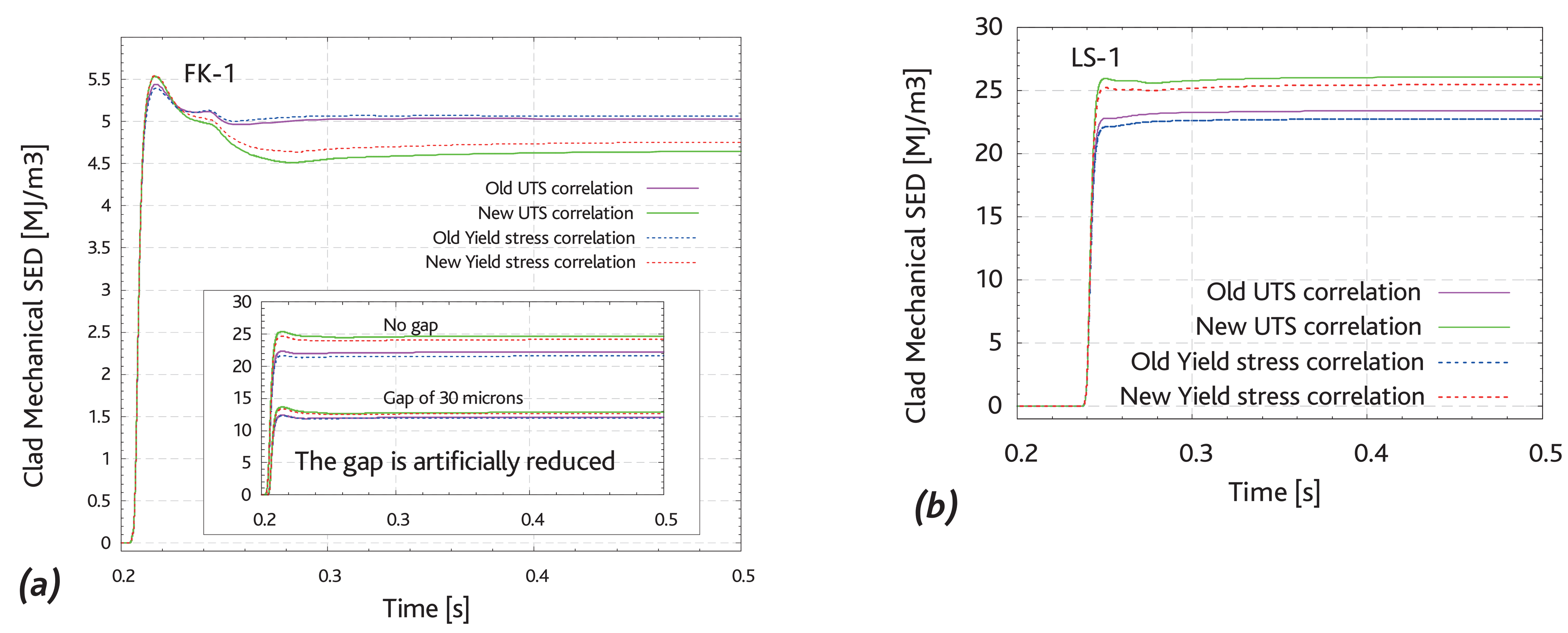

Fig 2 a-b: Cladding mechanical SED in FK-1 *(a)* and LS-1 *(b)* tests with the old and the new YS and UTS correlation.

Test	SED: Max. mechanical SED by SCANAIR [MJ/m³] "Basic case"	"Thermal gap"	"Zero gap"	Max. calculated SED by FALCON [MJ/m³] [4]	CSED: CSED evaluated from oxido layer *(using a correlation)*	CSED from max. hydrogen content	CSED from EPRI report n°.1021036	Survived / Failed — Mispredictions are marked with RED (failure enthalpy, [cal/g]): In the test	"Basic case"	"Thermal gap"	"Zero gap"
FK-1	5.5	12.3	--	13	14.3	17.9	17.5	Survived	Survived	Survived	--
FK-2	0.30	0.40	--	2.1	13.2	17.9	17.5	Survived	Survived	Survived	--
FK-3	9.9	16.9	--	16	12.5	17.9	17.5	Survived	Survived	Failed	--
FK-4	21.9	29.8	--	20.2	14.0	16.2	14.4	Survived	Failed (131)	Failed	--
FK-5	0.58	3.7	--	7.4	14.0	16.2	14.4	Survived	Survived	Survived	--
FK-6	19.1	27.0	29.1	19	10.8	5.0	7.3	Failed (70)	Failed (95)	Failed (64)	Failed (54)
FK-7	17.5	25.1	27.0	19.3	10.8	5.0	7.3	Failed (62)	Failed (94)	Failed (64)	Failed (55)
FK-8	0.79	4.7	6.4	5.1	10.8	7.9	8.8	Survived	Survived	Survived	Survived
FK-9	3.9	10.8	12.6	12	10.8	7.9	8.8	Failed (86)	Survived	Failed (77)	Failed (69)
FK-10	6.1	13.3	15.2	13.3	10.8	5.0 (8.5*)	7.4	Failed (80)	Failed (98)	Failed (67)	Failed (58)
FK-12	3.0	9.5	10.3	10.3	10.8	5.0 (8.5*)	7.4	Failed (72)	Survived	Failed (68)	Failed (59)

Min. (FK-1 to FK-5: CSED evaluated from oxido layer); Min. (FK-6 to FK-12: CSED from max. hydrogen content)

Tab 1: SCANAIR calculations of mechanical SED in FK tests vs. the CSED (EPRI).

Failure criteria for Zry-2 cladding: CSED approach

The failure of Zry-2 cladding is evaluated by **comparison of the maximum SED to the critical SED (CSED)** given as an input data.

The **CSED criterion developed by EPRI,** function of total absorbed hydrogen content [2], is applied:

$$\mathrm{CSED[MJ/m^3]} = 35.89e^{-0.0114H[ppm]} + 2.09$$

The correlation, based on two open-end burst test series at room temperature, is valid during the early phase of the transient. When the hydrogen content is not known, it can be correlated to the cladding outer oxide layer thickness. The calculated SEDs of the FK test series are compared to the CSEDs given by the EPRI criterion (Tab 1).

Conclusion

The predictions are rather accurate in terms of failure/non-failure but the results are very sensitive to the initial gap size calculated by the irradiation code (FRAPCON 3.4). Compared to this source of uncertainty, the new YS and UTS correlations have only a minor significance to the failure predictions.

[1] B. Cazalis et al.: "The PROMETRA Program: Fuel Cladding Mechanical Behavior Under High Strain Rate", Nuclear Technology Vol. 157, March 2007.

[2] W. Liu et al.: "Analysis of High Burnup Fuel Failures at Low Temperatures in RIA Tests Using CSED", Proceedings of 2010 LWR Fuel Performance/TopFuel/WRFPM, Orlando, Florida, USA, September 26-29, 2010, Paper 131.

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