

In-Reactor Creep Behavior of Zircaloy-2

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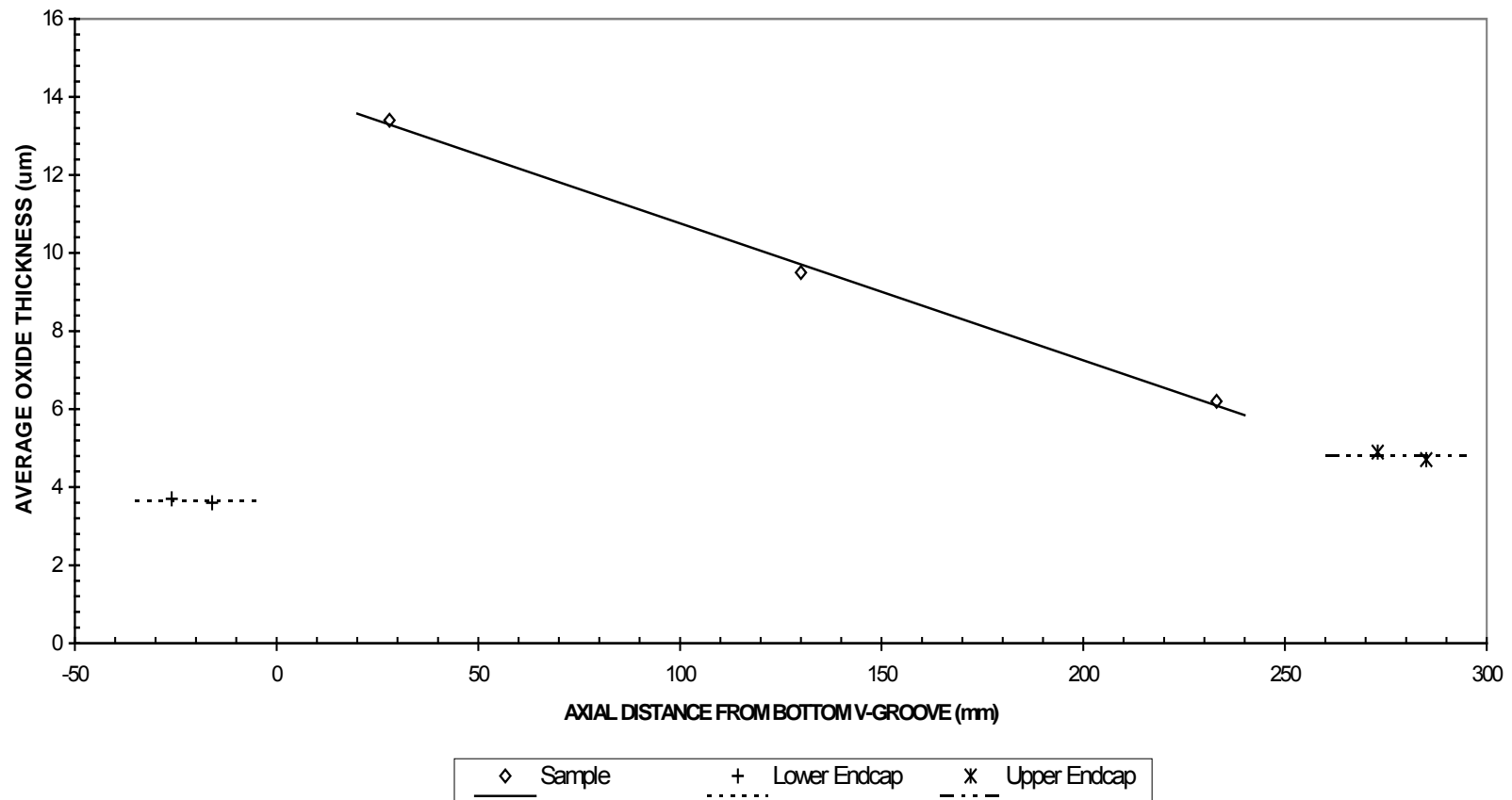
Introduction (1/4)

- Halden Project reported in-reactor Zircaloy-2 creep data for 8 different hoop stress values
- Two different evaluations of the data were previously reported
 - Main difference was the effects of OD oxidation
- PIE oxide thickness measurements were performed on the sample and end-caps (which contain the calibration steps)
 - Oxide metallography revealed two results that prompted this re-evaluation

Introduction (2/4)

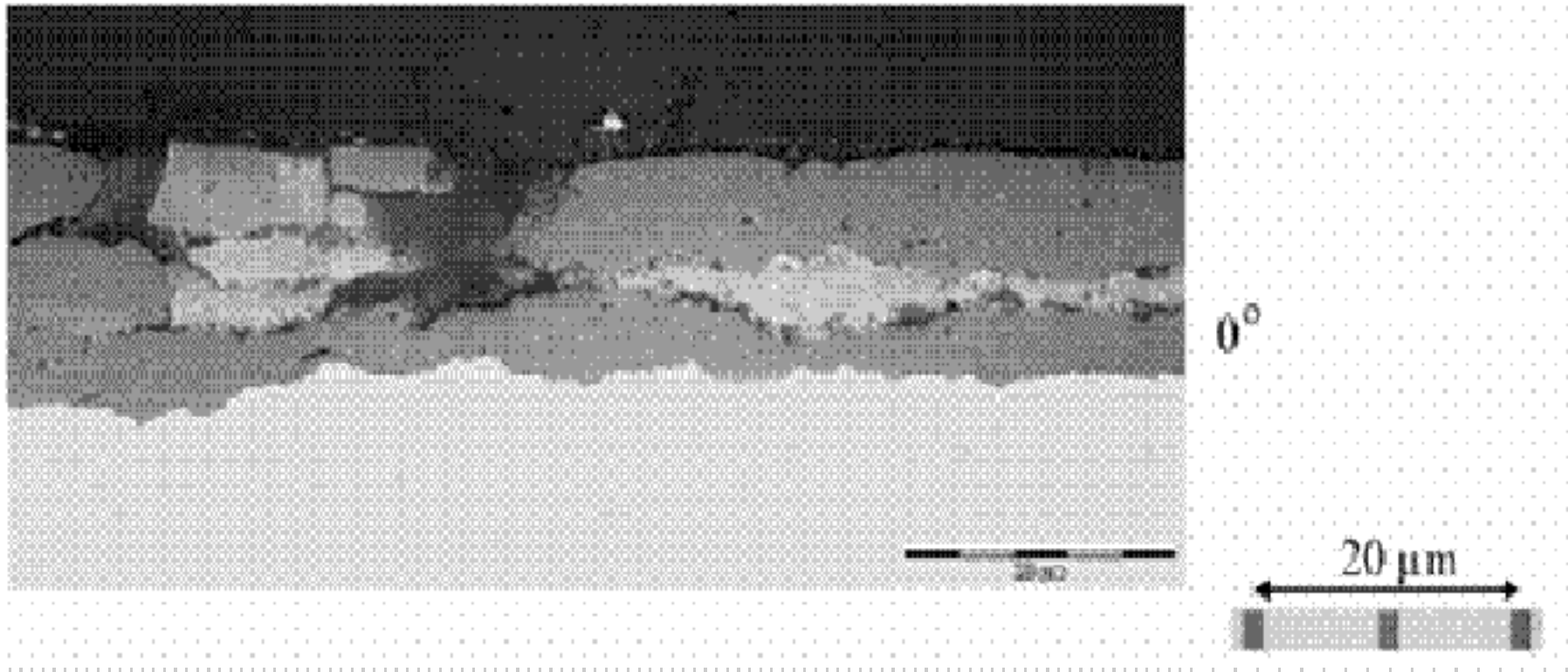
Oxide Thickness at Test Completion

RXA Zr-2 Creep Sample & Endcap Oxide Thickness at the Halden End-of-Testing
IFA-585, 300-323 C



Introduction (3/4)

Oxide Thickness Exhibiting Cracking



Introduction (4/4)

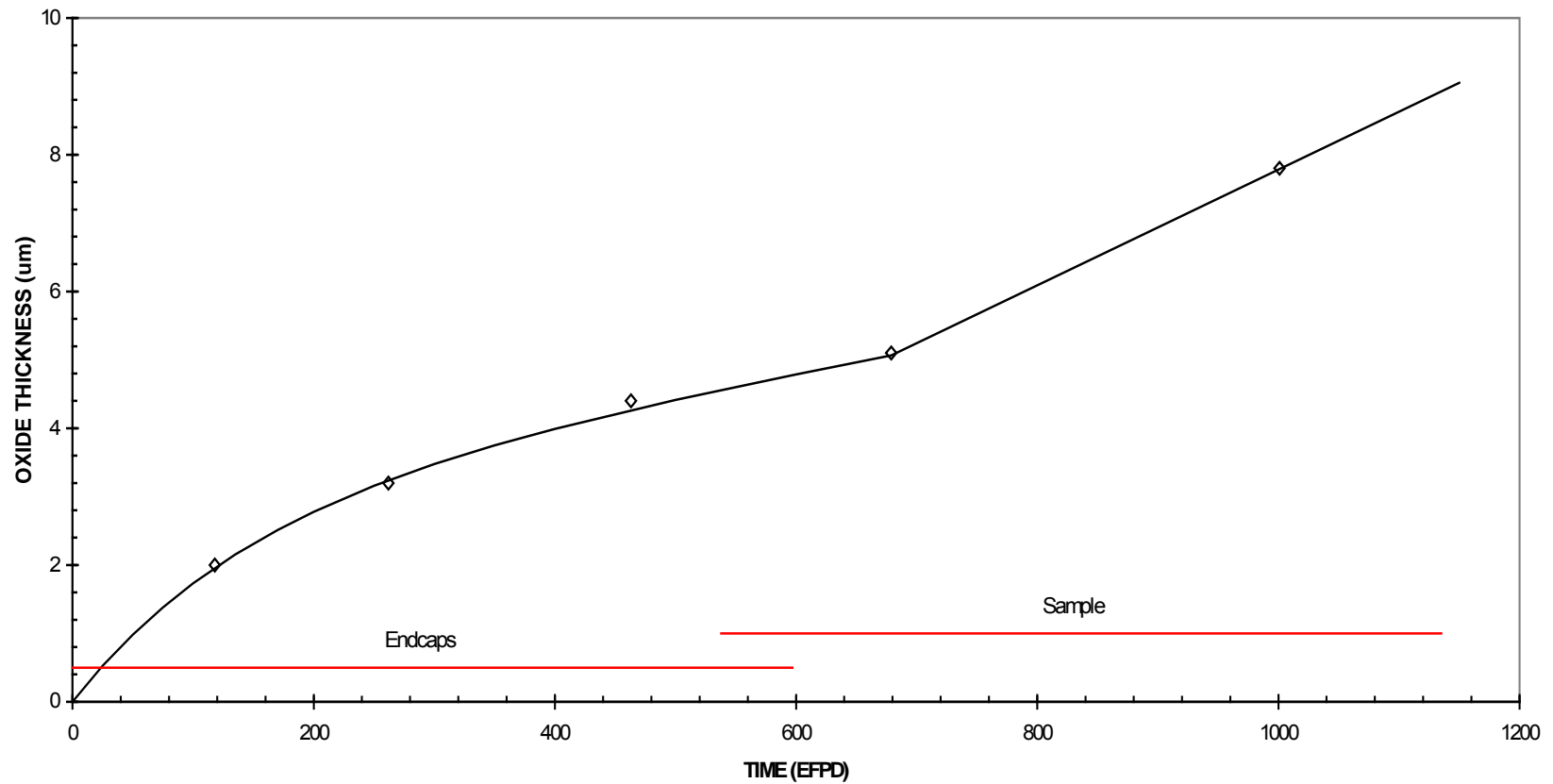
- Oxide metallography showed the following results:
 - Test sample exhibits an oxide gradient
 - Thickest oxide thickness region exhibited internal cracking
 - Mean oxide thickness is 8.2 μm
- Result – re-analysis of the test data was performed

Re-Evaluation of the Data (1/4)

- Generated a new OD data set as a function of time
 - Eliminated the data from the axial region of the sample that exhibited oxide cracking
- Corrected the new OD sample data for oxide thickness

Re-Evaluation of the Data (2/4)

SRA Low Sn Zr-2 Coupon Corrosion in Halden
IFA-638, 300-318 C



Re-Evaluation of the Data (3/4)

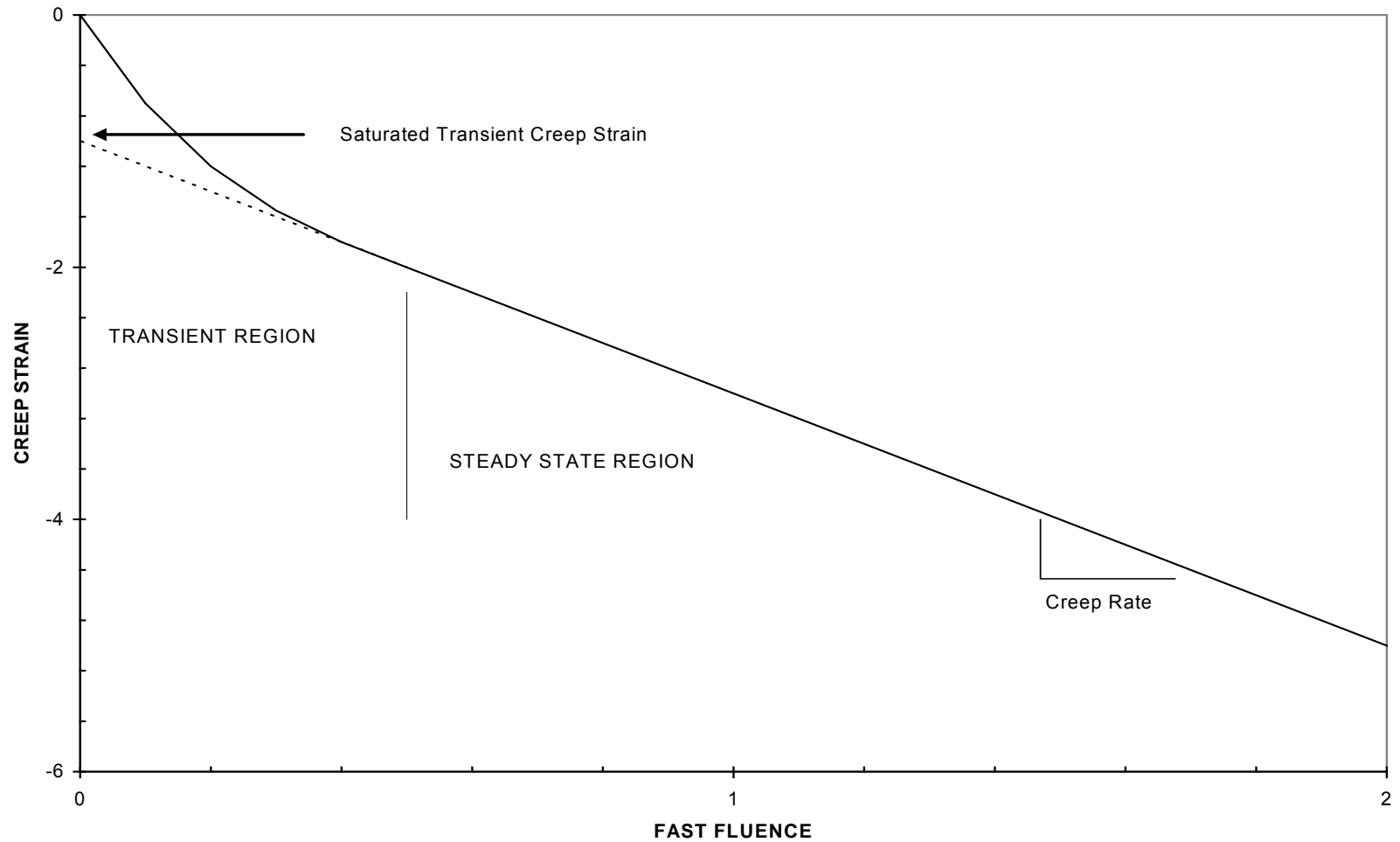
- Initially, at the beginning of the Halden irradiation period the oxide thickness rate of the end-caps is higher than the sample
- After about 20-25% of the Halden irradiation period, the oxidation rate of the sample is higher than the end-caps

Re-Evaluation of the Data (4/4)

- Performed the calculations for 3 different sample oxide thickness cases because the previously estimated oxide thickness at the beginning of the Halden irradiation (expected from the BWR pre-irradiation) could not be reconciled with the PIE measured final sample oxide thickness

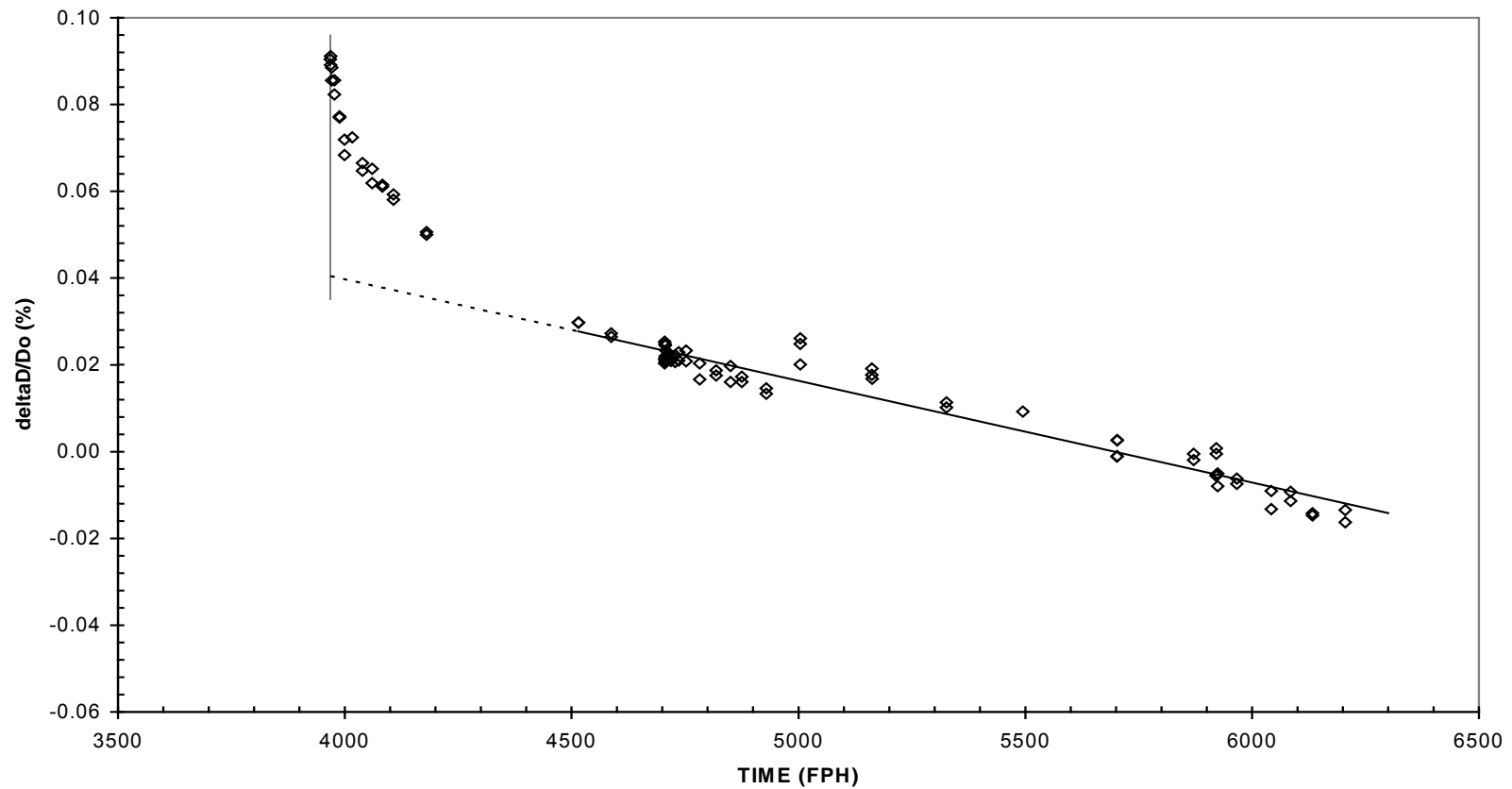
Case	Oxide Thickness (μm)		
	Total	Halden	BWR
No Correction	8.2	0	8.2
Nominal	8.2	4.7	3.5
+35%	8.2	6.3	1.9

Irradiation Creep Terms



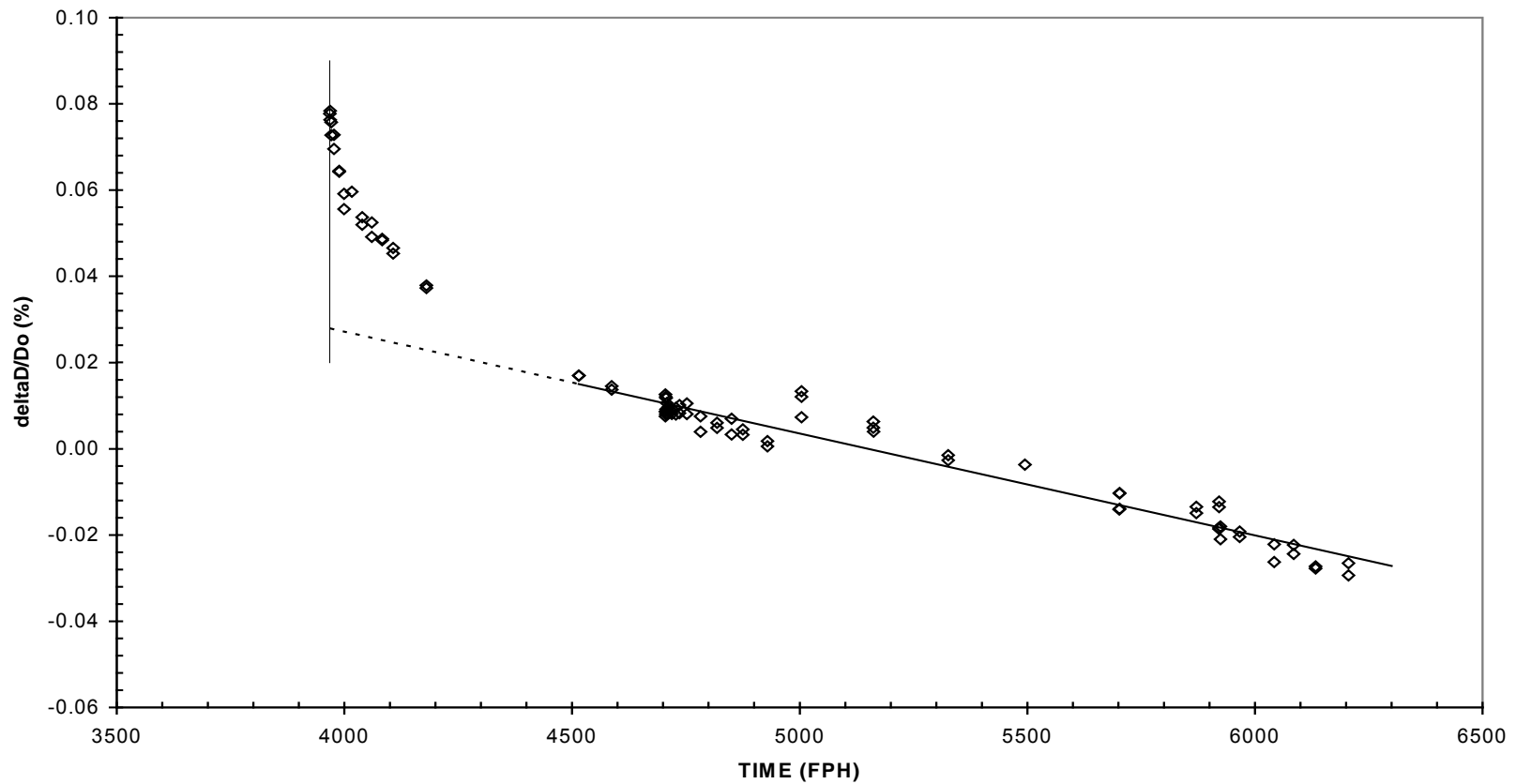
Uncorrected for Oxide Thickness

IFA-585 Period BWR3 Uncorrected for Oxide Corrosion
-159.4 MPa Hoop Stress, -217.7 MPa Hoop Stress Change



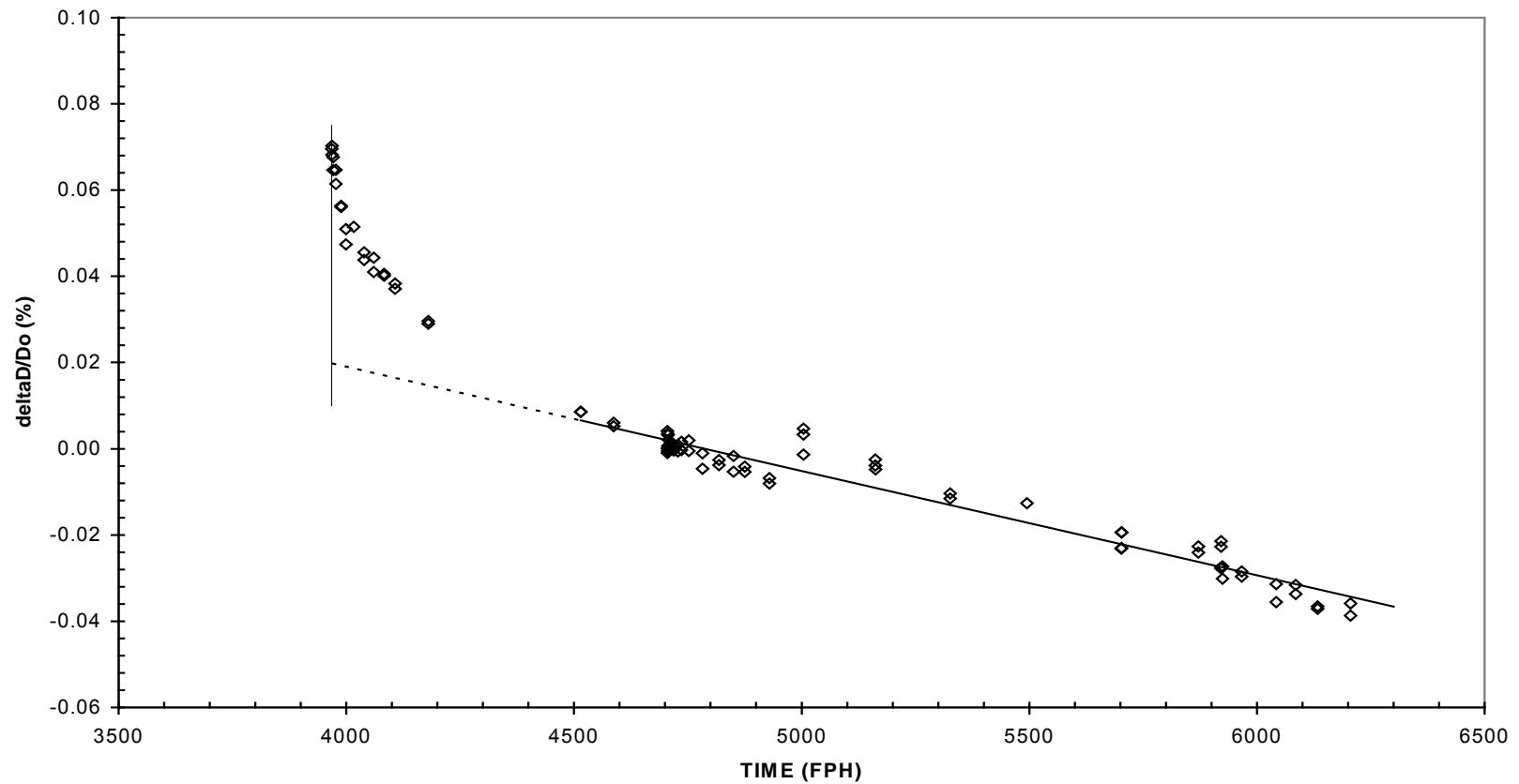
Corrected for Nominal Oxide Thickness

IFA-585 Period BWR3 with Nominal Oxide Correction
-159.4 MPa Hoop Stress, -217.7 MPa Hoop Stress Change



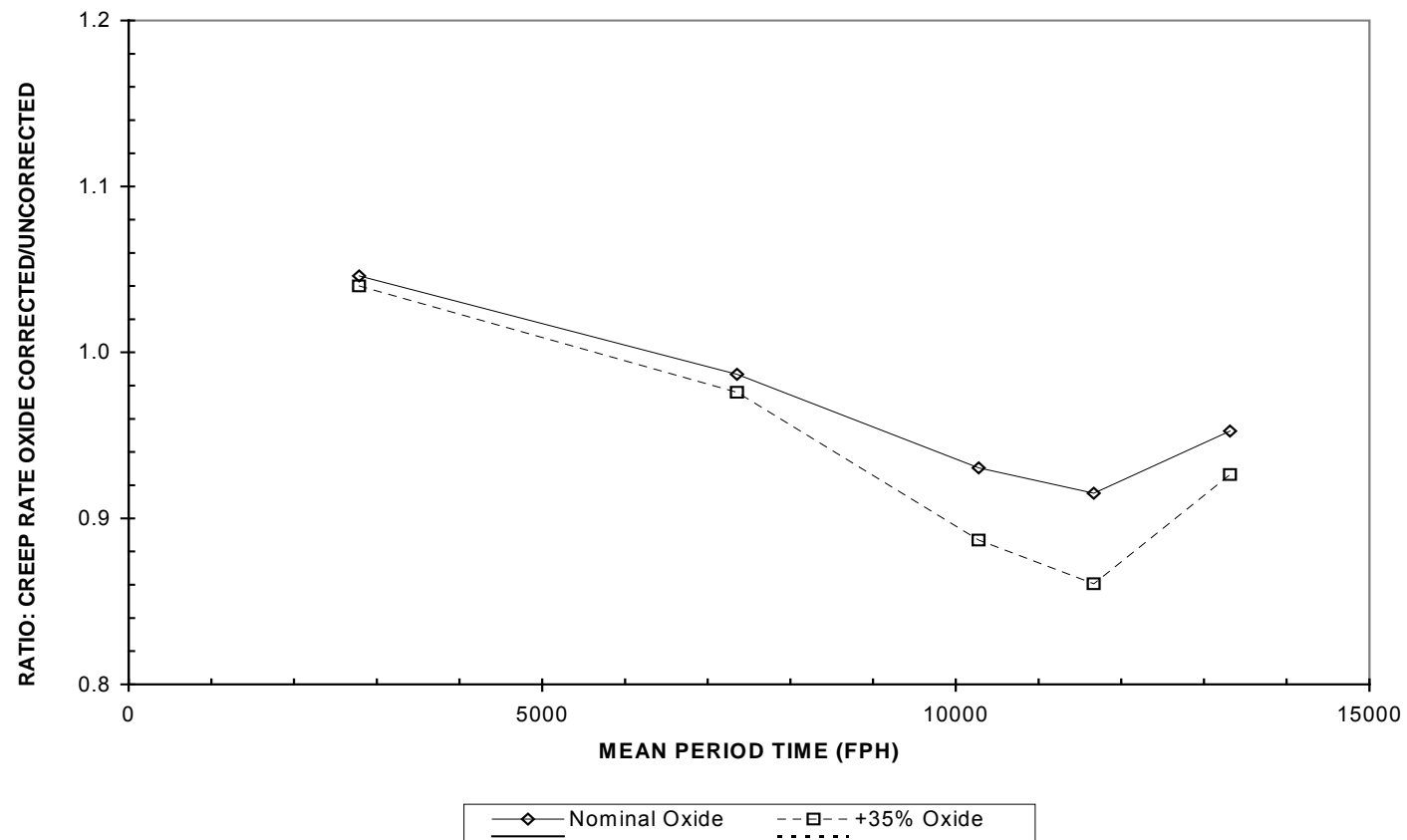
Corrected for +35% Oxide Thickness

IFA-585 Period BWR3 with +35% Oxide Correction
-159.4 MPa Hoop Stress, -217.7 MPa Hop Stress Change



Oxide Correction Effect on the Creep Rates

Effect of the Oxide Correction on the Irradiation Creep Rates in Tension
RXA Zr-2, IFA-585



Oxide Correction Effect on the Saturated Transient Strain

- No effect on the saturated transient strain

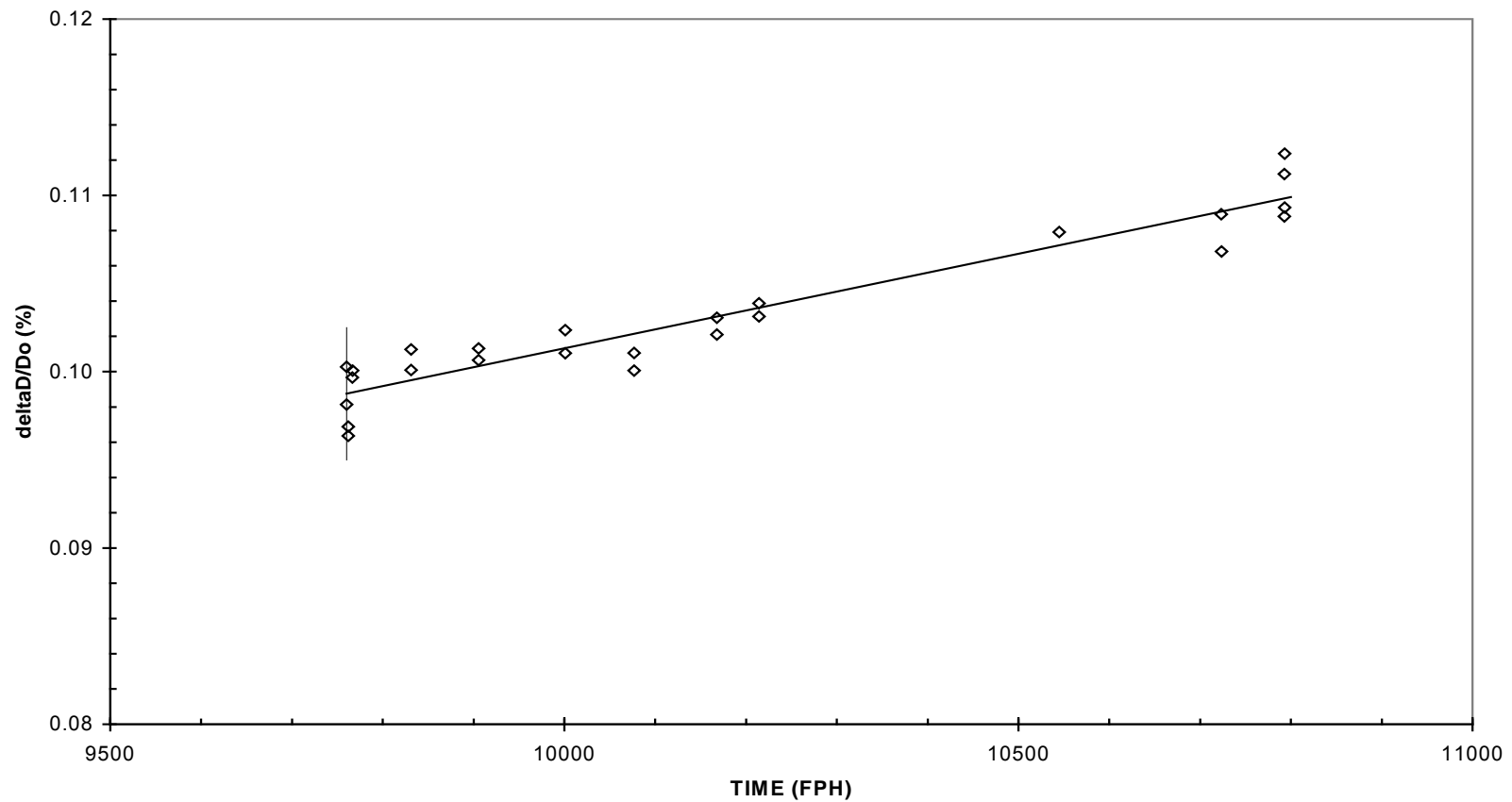
Period	σ_θ (MPa)	<u>$\Delta D/D_0$ Saturated Transient (%)</u>		
		Uncorrected	Nominal	+35%
2	58.3	0.0142	0.0144	0.0144
3	-159.4	-0.0503	-0.0501	-0.0501
4	127.6	0.0666	0.0668	0.0668
5	-64.4	-0.0265	-0.0263	-0.0263
6	-23.7	0	0	0
7	27.6	0.0070	0.0070	0.0070
8	83.5	0.0053	0.0054	0.0054

Summary of the Oxide Correction Effects

- Decreases $\Delta D/D_0$ creep strain
- Decreases or increases the strain rate depending on the sample and end-cap oxide thickness differences
- No effect on the saturated transient component strain

No Saturated Transient Strain for $\Delta\sigma_{\theta}=40.7$ MPa

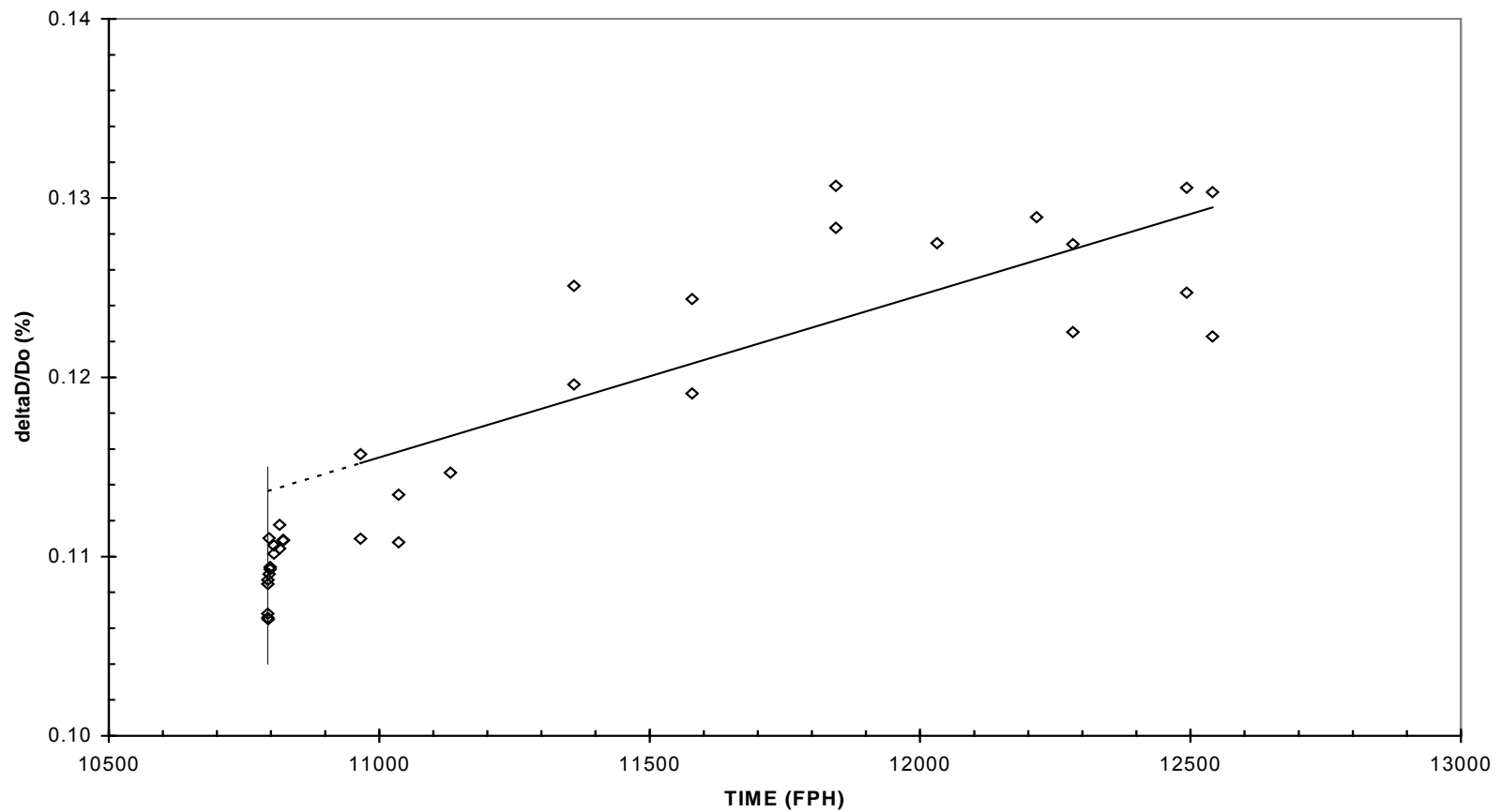
IFA-585 Period BWR6 with Nominal Oxide Correction
-23.7 MPa Hoop Stress, +40.7 MPa Hoop Stress Change



Relatively Small Saturated Transient Strain for $\Delta\sigma_{\theta}=51.3$ MPa

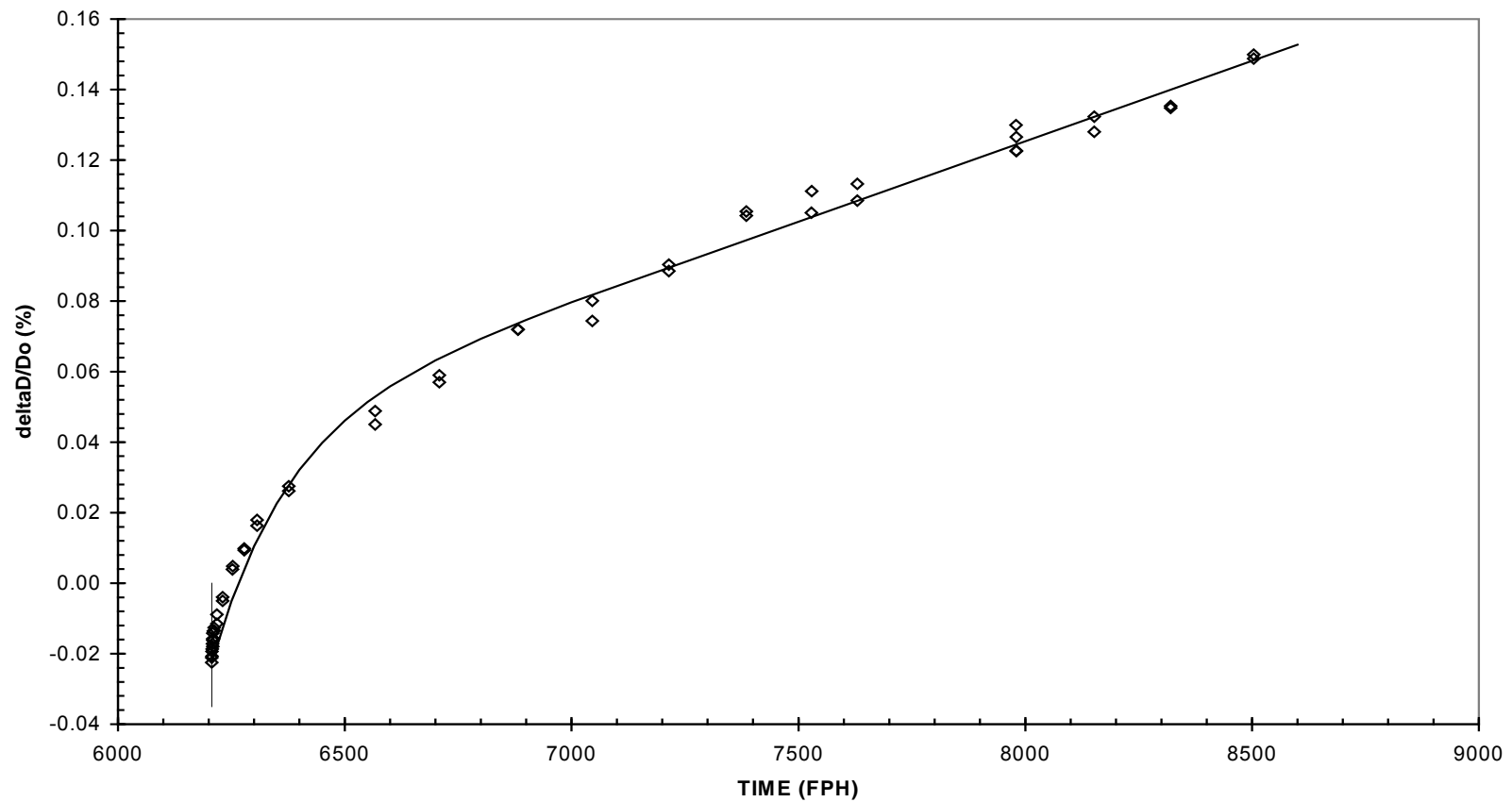
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IFA-585 Period BWR7 with Nominal Oxide Correction
27.6 Mpa Hoop Stress, 51.3 Mpa Hoop Stress Change



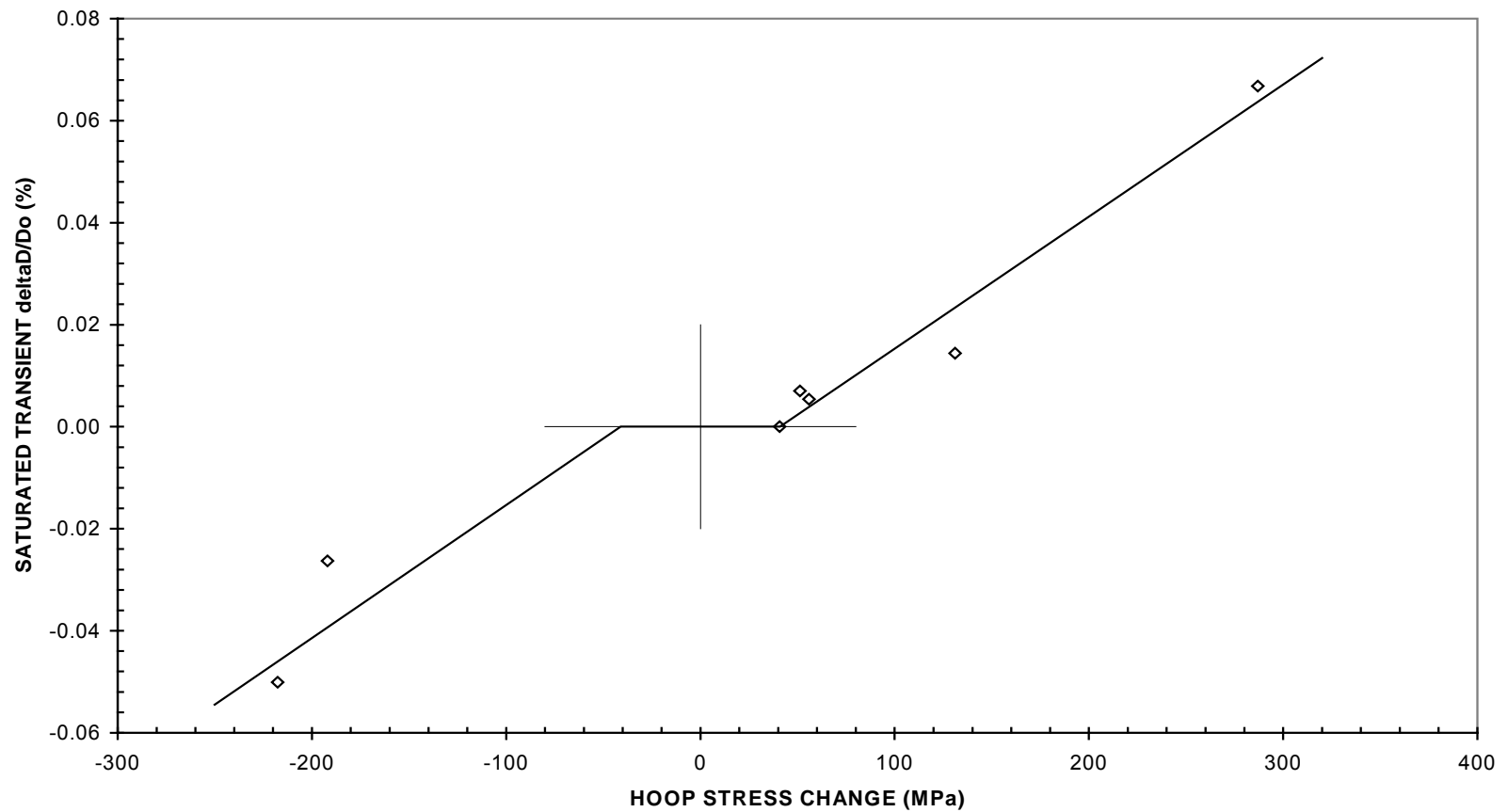
Relatively Large Saturated Transient Strain for $\Delta\sigma_{\theta}=287.0$ MPa

IFA-585 Period BWR4 with Nominal Oxide Correction
127.6 MPa Hoop Stress, 287.0 MPa Hoop Stress Change



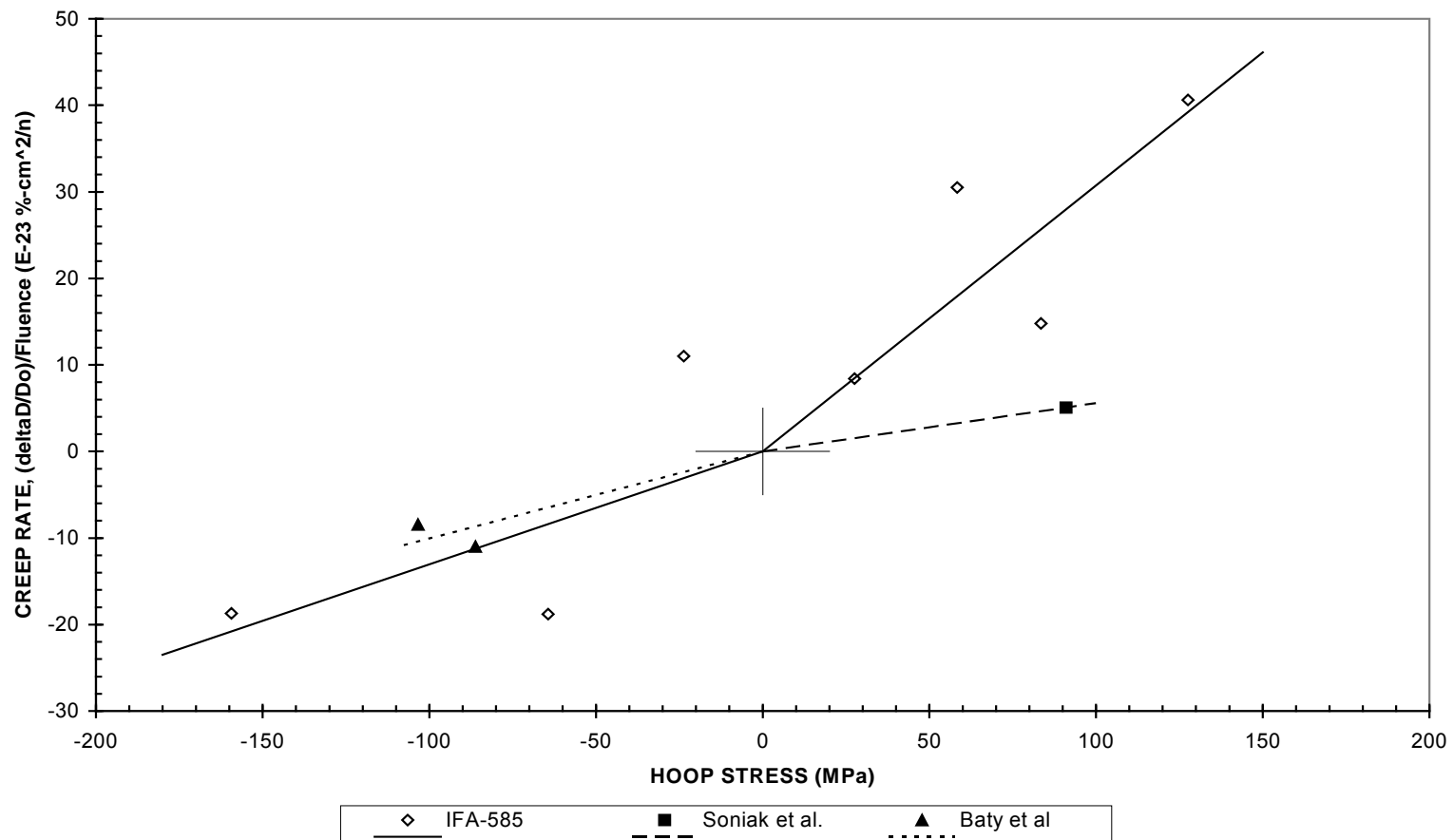
Saturated Transient Strains

Saturated Transient Irradiation Creep Component
RXA Zr-2, Nominal Oxide Correction, IFA-585



Creep Rates

RXA Zr-2 and RXA Zr-4 Steady State Irradiation Creep Rates
(IFA-585 data has the nominal oxide correction)



Summary of the Saturated Transient and Creep Rate Effects

- Saturated transient strain is dependent on the hoop stress change and exhibits a threshold of about 41 MPa
 - Confirmation of the threshold in compression is necessary
- Creep rates suggest higher values for tension versus compression
 - Comparison with other investigations suggests that steady state creep has not been reached
 - Samples may be in transient irradiation creep
 - Possible that RXA Zr-2 and RXA Zr-4 exhibit significant creep differences

Conclusions (1/2)

- Oxide correction was made to the data with the results that:
 - Strain decreased
 - Strain rate decreased or increased depending on the relative values of the sample and end-cap oxide corrections
 - Saturated transient strain was unaffected
- Saturated transient strain is dependent on the hoop stress change and exhibits a threshold of about 41 MPa

Conclusions (2/2)

- “Apparent” steady state creep rates indicate higher values for tension versus compression
 - Comparison with other investigations suggests that steady state creep has not been reached (that is, the samples are in transient irradiation creep) or there are significant creep differences between RXA Zr-2 and RXA Zr-4