Validity Analysis of a HT9 Creep Correlation

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1. Introduction

- Comparing to previous light water reactors (LWR), sodium-cooled fast reactor (SFR) is characterized with higher temperature (~600 ºC), sodium coolant, higher fast neutron irradiation (~100 dpa) and higher burn-up (~20 at.%). That means, claddings in SFR are to be situated with harsher environment than they used to face in LWR.
- HT9, which belongs to ferritic martensitic steels (FMS), is considered as one of the most primary candidates for cladding in SFR.
- Although HT9 has many advantages to be applied as cladding in SFR, high temperature creep has been considered as one of the most serious concerns.
- Argonne national laboratory (ANL) developed a HT9 creep correlation, and we are planning to use this correlation for a fuel performance analysis. Hence, it is necessary to confirm whether this correlation over-predicts or under-predicts compared to previously reported results.

2. ANL HT9 Creep Correlation

	Equation and constant
In-reactor creep strain ($\varepsilon_{reactor}$), %	$\varepsilon_{reactor} = \varepsilon_t + \varepsilon_I$
Thermal creep strain (ε_t), %	$\varepsilon_t = \varepsilon_{tp} + \dot{\varepsilon_{ts}} t + \varepsilon_{tt}$ $\varepsilon_{tp} = (C_1 exp\left(-\frac{Q_1}{RT}\right)\sigma^{n_1} + C_2 \exp\left(-\frac{Q_2}{RT}\right)\sigma^{n_2} + C_3\exp(-\frac{Q_3}{RT})\sigma^{n_3})(1 - \exp(-C_4 t))$ $\dot{\varepsilon_{ts}} = C_5 \exp\left(-\frac{Q_4}{RT}\right)\sigma^{n_4} + C_6 \exp\left(-\frac{Q_5}{RT}\right)\sigma^{n_5}$ $\varepsilon_{tt} = C_7 \exp\left(-\frac{Q_6}{RT}\right)\sigma^{n_6} t^{n_7}$
	$C_1 = 13.4, C_2 = 8.43 \cdot 10^{-3}, C_3 = 4.08 \cdot 10^{18}, C_4 = 1.6 \cdot 10^{-6}$, $C_5 = 1.17 \cdot 10^9, C_6 = 8.33 \cdot 10^9, C_7 = 9.53 \cdot 10^{21}, Q_1 = 15{,}027$, $Q_2 = 26{,}451, Q_3 = 89{,}167, Q_4 = 83{,}142, Q_5 = 108{,}276, Q_6 = 282{,}700$ $n_1 = 1, n_2 = 4, n_3 = 0.5, n_4 = 2, n_5 = 5, n_6 = 10, n_7 = 4$
Irradiation creep strain (ε_I), %	$\varepsilon_I = (B_0 + Aexp\left(-\frac{Q_7}{RT}\right)\varphi)\sigma^{n_8}$
	$B_0 = 1.83 \cdot 10^{-4}, A = 2.59 \cdot 10^{14}, Q_7 = 73000, n_8 = 1.3$
σ: Effective stress, MPa T: Temperature, K t: Time, s	R: Gas constant, 1.987 cal/(K·mol) Q: Activation energy, cal/mol φ: Neutron fluence, 10^{22} n/cm²

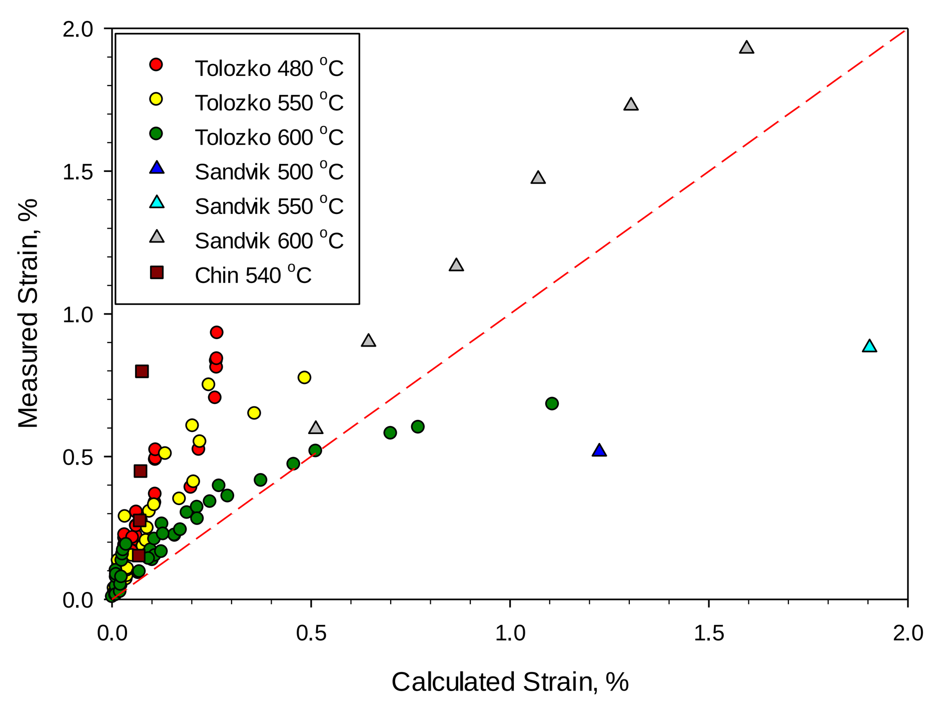
- The correlation composed of two parts: thermal creep and irradiation creep.
- Thermal creep occurs due to thermal activation, and irradiation creep occurs due to the activation by neutron. Hence, thermal creep is more dominant at relative high temperature above 600 °C.

3. Validity Analysis

Summary of previous results

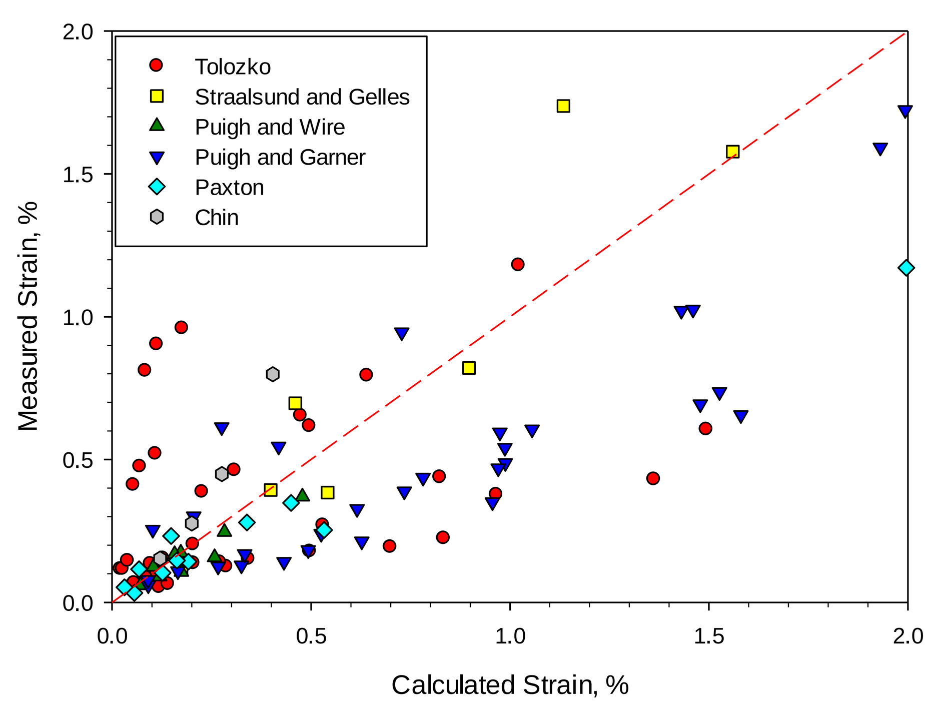
Author	Reactor	Temperature, °C	Stress, MPa	Fluence, 10^{22} n/cm²	Reference
Toloczko et al.	FFTF	495-500	13, 26, 52, 87, 121	25.5	[1]
		550	13, 26, 52, 87	12.2	
		605	4, 9, 13	12.3	
Paxton et al.	EBRII	545	24, 48, 95	2	[2, 3]
		560-565	13, 25, 47	2	
		605	25, 47, 98	4	
		625-635	13, 26, 47	4	
Chin	EBRII	432	55, 110, 165	1.7-10.2	[4]
		540	50	10.7	
Straalsund and Gelles	EBRII	425	95	0-10.8	[5]
		430	48, 96, 141	16	
		540	0-80	10	
		550	19, 46, 94	16	
		590	48	0-10.8	
		620	14, 23	16	
Puigh and Wire	EBRII	443	43, 65, 86	2.3	[6]
		505	43, 65, 86	2.8	
		572	43, 65, 86	2.3	
Puigh and Garner	FFTF	414.5	52, 87	10, 15, 23, 31	[7]
			121, 173	10, 15, 24, 32	
			54, 86, 124, 175	2.4, 9.8, 15.6, 23.5, 31.4	
		520	26, 50, 85	5.2	
		600	12, 26, 61	7.7	
Puigh	FFTF	417	60, 100, 140, 200	2.7-10.0	[8]
		505	63, 105	3.2-10.9	
		520	60, 100, 140	10.6	

Comparison with out-of-pile creep data



- The correlation under-predicts compared to the previous results.
- It may be due to the difference between in-reactor thermal creep and out-of-pile thermal creep.

Comparison with in-pile creep data



- Although there is some scattering, the correlation agrees with the previous results.
- The scattering may be due to that it is not easy to control experimental parameters such as temperature and fluence during in-reactor creep experiments.

4. Summary

- For HT9 to be applied as a fuel cladding in SFR, it is necessary to predict creep behavior accurately.
- Validity of HT9 creep correlation developed from ANL was analyzed by comparing with previously reported results.
- It was found that the HT9 creep correlation from ANL is in agreement with the previously reported in-pile creep experimental results.

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