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, therefore, many candidate materials have been researched to ascertain they sustain mechanical integrity during operations. Within those materials, HT9, which belongs to ferritic martensitic steels (FMS) is considered one of the most primary candidates. It has been studied since 1970s and has many good characteristics to be applied to SFR [1]: high heat transfer coefficient, high mechanical strength, irradiation stability, and low swelling rate.

Although HT9 has many advantages to be applied as SFR cladding, high temperature creep has been considered as one of the most serious concerns. According to a previous study [2], below 570 ºC, HT9 shows lower creep deformation than CW316 stainless steel under neutron irradiation. However, HT9 shows lower creep strength and larger creep strain above 600 ºC than CW316 stainless steel, as the dislocation density reduced and the M23C6 precipitates coarsened. Therefore, it is necessary to predict creep deformation of HT9 at temperature ranges of 600 ºC.

2. HT9 Creep Equation from ANL

ANL developed a new HT9 creep correlation [3], which is shown in Table 1. The correlation composed of two parts: thermal creep and irradiation creep. Thermal creep refers to creep deformation that occurs due to thermal activation, hence it is more effective at high temperature. Whereas, irradiation creep occurs due to the activation by neutron, which involves point defects generation from irradiation and stress induced absorption of defects on dislocations that lead to glide of the dislocations [4]. Hence, the effect of temperature on irradiation creep is smaller than that on thermal creep, so irradiation creep is usually more dominant at low temperatures where thermal creep is relatively not serious. According to Klueh [4], thermal creep of FMS becomes dominant above $0.5T_m$ (T_m is absolute melting temperature).

Table I: HT9 Creep Equation from ANL

	Equation and constant
In-reactor creep strain ($\varepsilon_{\mathrm{reactor}}$), %	$\varepsilon_{\mathrm{reactor}} = \varepsilon_{\mathrm{t}} + \varepsilon_{\mathrm{I}}$
Thermal creep strain (ε_{t}), %	$\varepsilon_{\mathrm{t}} = \varepsilon_{\mathrm{tp}} + \dot{\varepsilon_{\mathrm{ts}}} t + \varepsilon_{\mathrm{tt}}$ $\varepsilon_{\mathrm{tp}} = (C_1 exp\left(-\frac{Q_1}{RT}\right)\sigma^{n_1} + C_2 \exp\left(-\frac{Q_2}{RT}\right)\sigma^{n_2} + C_3 \exp(-\frac{Q_3}{RT})\sigma^{n_3})(1 - \exp(-C_4 t))$ $\dot{\varepsilon_{\mathrm{ts}}} = C_5 \exp\left(-\frac{Q_4}{RT}\right)\sigma^{n_4} + C_6 \exp\left(-\frac{Q_5}{RT}\right)\sigma^{n_5}$ $\varepsilon_{\mathrm{tt}} = C_7 \exp\left(-\frac{Q_6}{RT}\right)\sigma^{n_6} t^{n_7}$
	$C_1 = 13.4, C_2 = 8.43 \cdot 10^{-3}, C_3 = 4.08 \cdot 10^{18}, C_4 = 1.6 \cdot 10^{-6},$ $C_5 = 1.17 \cdot 10^9, C_6 = 8.33 \cdot 10^9, C_7 = 9.53 \cdot 10^{21}, Q_1 = 15{,}027,$ $Q_2 = 26{,}451, Q_3 = 89{,}167, Q_4 = 83{,}142, Q_5 = 108{,}276, Q_6 = 282{,}700$ $n_1 = 1, n_2 = 4, n_3 = 0.5, n_4 = 2, n_5 = 5, n_6 = 10, n_7 = 4$
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/cm^2

3. Methods and Results

Validity of the HT9 creep correlation from ANL was analyzed by comparing with previous in-pile and out-of-pile creep experiment results [5-10]. Fig. 1 shows the comparison between the HT9 creep correlation and the out-of-pile creep experiment results. It can be confirmed that the correlation underpredicts compared to the previous results. It may be due to the difference between in-reactor thermal creep and out-of-pile thermal creep. Fig. 2 shows the comparison between the HT9 creep correlation and the in-pile creep experiment results. Although there is some scattering, it appears that the correlation agrees with the previous experiment results.

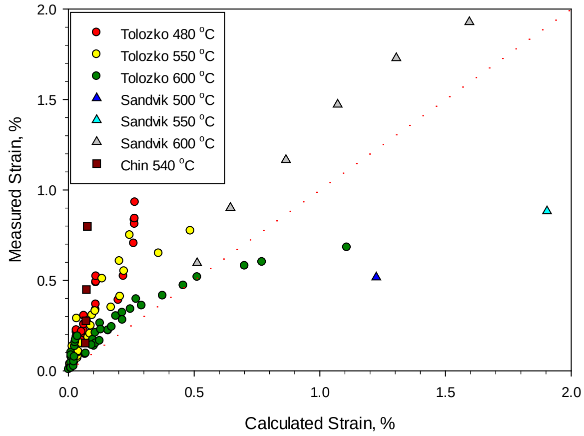

Fig. 1. Comparison of HT9 creep correlation from ANL and out-of-pile creep data from previous studies.

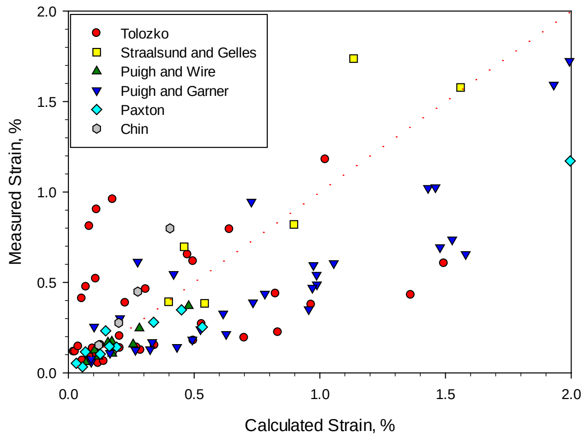

Fig. 2. Comparison of HT9 creep correlation from ANL and in-pile creep data from previous studies.

4. Conclusions

Although HT9 has many advantages to be applied as a SFR cladding, high temperature creep of HT9 has been considered as one of the most serious concerns for many years. Hence, creep deformation of HT9 at temperature ranges of 600 ºC needs to be predicted accurately. The HT9 creep correlation was developed from ANL, and the validity of the correlation was analyzed by comparing with previous in-pile and out-of-pile HT9 creep experiment results. It was found that the correlation underpredicts compared to the previous out-of-pile creep experiment results, and the correlation is in agreement with the previous in-pile creep experiment results.

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