Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 29-30, 2014

Comparison of Thermal Creep Strain Calculation Results Using Time Hardening and Strain Hardening Rules

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1. Introduction

The design of the fuel rod (U-10Zr fuel with FMS cladding) for PGSFR is in progress at KAERI and ANL under joint work. The fuel rod is designed to satisfy the functional and operational requirements. A fuel performance code is used in determining whether design results met the design criteria. One of the design criteria for the fuel rod in PGSFR is the thermal creep strain of the cladding, because the cladding is exposed to a high temperature for a long time during reactor operation period. In general, there are two kind of calculation scheme for thermal creep strain: time hardening and strain hardening rules [1]. In this work, thermal creep strain calculation results for HT9 cladding by using time hardening and strain hardening rules are compared by employing KAERI's current metallic fuel performance analysis code, MACSIS [2]. Also, thermal creep strain calculation results by using ANL's metallic fuel performance analysis code, LIFE-METAL [3] which adopts strain hardening rule are compared with those by using MACSIS.

2. Time Hardening and Strain Hardening Rules

Thermal creep strain equation of HT9 cladding is composed of primary, steady-state and tertiary creep term [4]. Fig. 1 shows the difference between time hardening and strain hardening rules with creep strain model. The time hardening rule states that the primary variable governing the thermal creep strain rate is the time at the particular temperature involved, regardless of the stress history. Let the stress be $\bar{\sigma}_{old}$ at the current time, $t_{current\ time}$. If the stress is suddenly changed to $\bar{\sigma}_{new}$, a new point at which thermal creep strain rate is calculated is located on the $\bar{\sigma}_{new}$ curve vertically above $\bar{\sigma}_{old}$ curve. On the other hand, strain hardening rule states that the primary variable governing the thermal creep strain rate is the strain. Thus, under variable-stress history, corresponding point on the $\bar{\sigma}_{new}$ curve at which thermal creep strain rate is calculated is obtained by proceeding along horizontal line from $\bar{\sigma}_{old}$ curve as shown in Fig. 1. Here, dummy creep time, t_{dummy} is the time where thermal creep strain at the current time, $\bar{\varepsilon}^{current\ time}_{thermal\ creep}$ is obtained on the $\bar{\sigma}_{new}$ curve. The dummy creep time can be obtained by using Newton-Raphson method as shown in Fig. 2, where, f and $\dot{f}$ denote the total thermal creep stain and thermal creep strain rate, respectively. Here, note that tertiary creep starts earlier in time hardening rule than in strain hardening rule, as shown in Fig. 1.

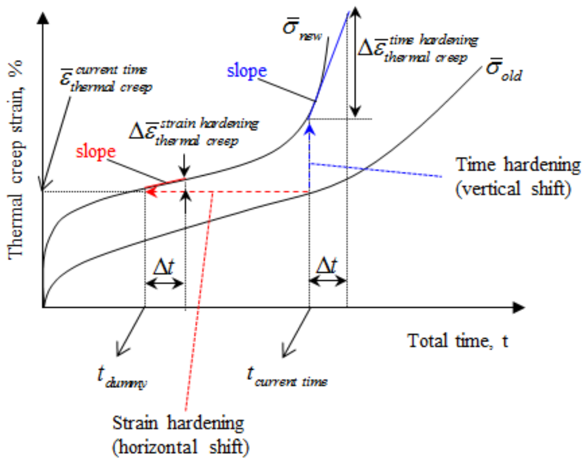

Fig. 1. Time hardening and strain hardening principle.

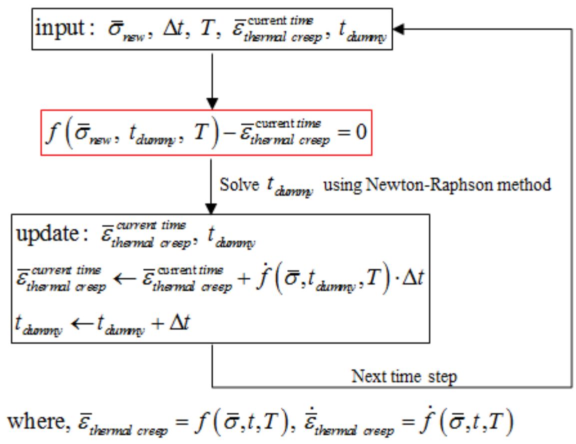

Fig. 2. Solution procedure of strain hardening rule.

3. Results and Discussions

Simulation conditions are summarized in Table I. Peak linear power and coolant mass flow rate were maintained at constant during 1595 EFPD: 33.6 kW/m and 0.11 kg/sec. Also, axial power/flux profile was maintained at constant along fuel rod axial direction, so that maximum cladding mid-wall temperature was maintained at 600 °C during 1595 EFPD.

Table I: Simulation conditions

Cladding mid-wall temperature (°C)		600
Geometry (mm)	Fuel slug diameter (length)	5.54 (850)
	Cladding OD (thickness)	7.4 (0.5)
	Plenum length (sodium height)	1275 (25.4)
Coolant condition	Inlet temperature (°C)	390
	Mass flow rate (kg/sec)	0.11
Power and flux	Peak linear power (kW/m)	33.6
	Peak flux ($\times 10^{15}$ n/cm^2·sec)	2.76
	Power history	Constant
	Axial power profile	Constant
	Axial flux profile	Constant
EFPD		1595

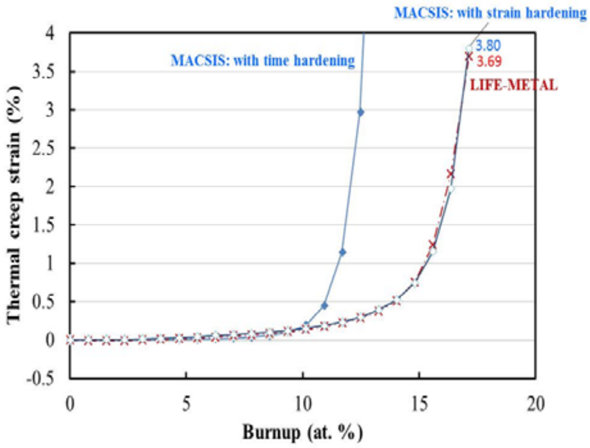

Fig. 3. Thermal creep stain calculation results.

Fig. 3 shows thermal creep strain calculation results with time hardening and stain hardening rules by using MACSIS. In addition, those by using LIFE-METAL which adopts strain hardening rule are presented. As shown in Fig. 3, tertiary creep starts earlier in time hardening rule than in strain hardening rule. Also, calculation results by MACSIS with strain hardening and those obtained by using LIFE-METAL are almost identical to each other.

4. Conclusions

Thermal creep strain calculation results for HT9 cladding by using time hardening and strain hardening rules were compared by employing KAERI's current metallic fuel performance analysis code, MACSIS. Also, thermal creep strain calculation results by using ANL's metallic fuel performance analysis code, LIFE-METAL which adopts strain hardening rule were compared with those by using MACSIS. Tertiary creep started earlier in time hardening rule than in strain hardening rule. Also, calculation results by MACSIS with strain hardening and those obtained by using LIFE-METAL were almost identical to each other.

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