Analysis of Current HT9 Creep Correlations and Modification

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1. Introduction

HT9 is one of the most promising materials for fast reactor cladding. It has high thermal conductivity, high mechanical strength and low irradiation induced swelling. However high temperature creep of HT9 has always been a life limiting factor. Above 600ºC, the dislocation density in HT9 is decreased and the $M_{23}C_6$ precipitates coarsen, these processes are accelerated if there is irradiation[1]. Finally microstructural changes at high temperature lead to lower creep strength and large creep strain. For HT9 to be used as a future cladding, creep behavior of the HT9 should be predicted accurately based on the physical understanding of the creep phenomenon.

Most of the creep correlations are composed of irradiation creep and thermal creep terms. However, it is certain that in-pile thermal creep and out-of-pile thermal creep are different because of the microstructure changes induced from neutron irradiation. To explain creep behavior more accurately, thermal creep contributions other than neutron irradiation should be discriminated in a creep correlation. To perform this work, existing HT9 creep correlations are analyzed, and the results are used to develop more accurate thermal creep correlation. Then, the differences between in-pile thermal creep and out-of-pile thermal creep are examined.

2. Validation analysis of existing HT9 creep correlations

Existing HT9 creep correlations include Ryu's HT9 creep correlation and the one described in MIT report[2,3]. Each correlation is compared to out-of-pile and in-pile creep experiment results. Out-of-pile creep experiments were performed by Tolczko, Sandvik and Chin[4-6]. In-pile creep experiments were performed by Toloczko, Paxton, Chin, Straalsund and Puigh et al[4,6-11].

2.1 Ryu's HT9 creep correlation

Ryu's HT9 creep correlation is using Garafalo equation. This is of the form

$$\varepsilon_{ps} = \varepsilon_p[1 - \exp(-m\,t)] + \dot{\varepsilon}_s t \qquad (1)$$
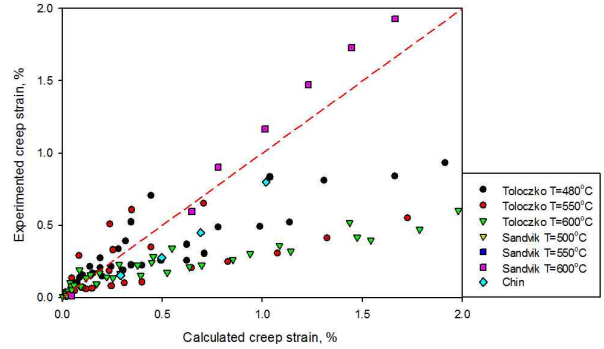

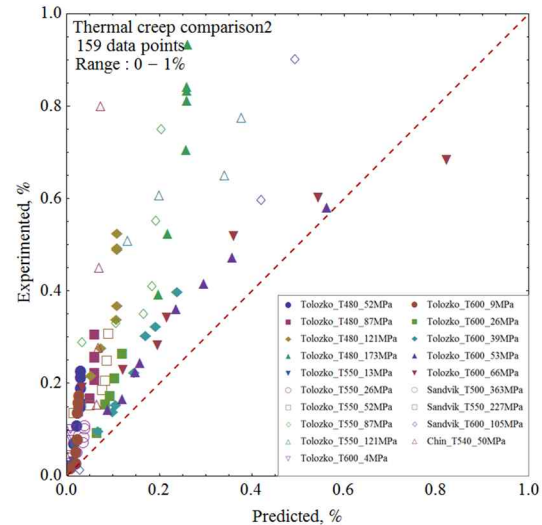Fig. 1. Comparison of out-of-pile creep experiments and Ryu's HT9 creep correlation

Fig. 2. Comparison of out-of-pile creep experiments and the HT9 creep correlation

where ε_p is the primary (transient) creep strain, m is a material constant and $\dot{\varepsilon}_s$ is the steady-state creep rate. This correlation has been checked within the narrow temperature range of 0.4 to 0.6 T_m for ferritic and stainless steels[12], where T_m is the melting temperature.

The correlation is compared with existing out-of-pile experimental results, which is shown in Fig.1. Most of the calculated creep strains are larger than experimental creep strains. This is because this correlation takes conservative $\dot{\varepsilon}_s$.
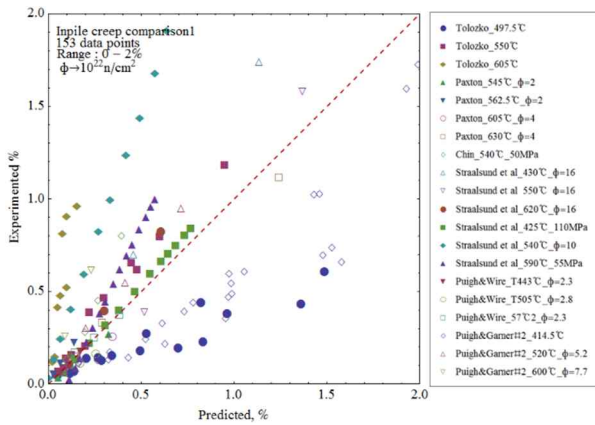
Fig. 3. Comparison of in-pile creep experiments and the HT9 creep correlation

Fig. 4. Comparison of modified Ryu's HT9 creep correlation and out-of-pile creep experimental results.

2.2 HT9 creep correlation[2]

The correlation consists of irradiation creep and thermal creep. The thermal creep consists of primary, secondary and tertiary creep.

Comparison with out-of-pile data is shown in Fig.2, most of the calculated creep strains are smaller than the experimented creep strains. It seems that the thermal creep correlation is deduced from the in-pile thermal creep data.

Comparison with in-pile data is shown in Fig.3. Most of the calculated creep strains are consistent with the experimented creep strains, but some of the data scatter around the red line. This scattering could be caused by inaccurate informations on the experiment condition and flux variation.

3. Thermal creep design

Existing thermal creep correlations are not consistent with the out-of-pile thermal creep experiments. So, a new out-of-pile thermal creep correlation is defined. This new correlation is based on Ryu's creep approach.

Ryu's steady state creep rate is determined based on Chin's HT9 creep rate. However, Chin's data are always higher than other experiment results. So, new steady state thermal creep rate is defined excluding Chin's data. The modified correlation is compared with the out-of-pile creep experiments shown in Fig.4. Compared with Fig.1, the modified correlation is more consistent with the existing data.

4. Summary

Final goal of this work is to estimate the effect of the neutron irradiation on in-pile thermal creep, and incorporate this effect into the HT9 creep correlations. To achieve this goal, current out-of-pile thermal creep correlations are analyzed and modified. The modified model is more consistent with the existing out-of-pile creep experiment results. Further, the irradiation effect on in-pile thermal creep is being investigated.
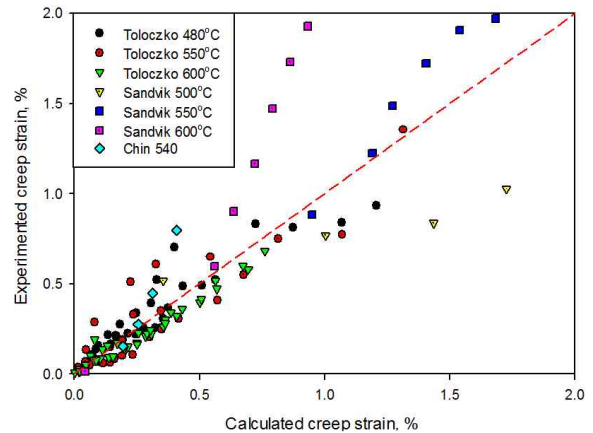
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