Comparison between Out-of-Pile and In-Pile Creep Performance of HT9 Cladding

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1. Introduction

The sodium-cooled fast reactor (SFR) is a type of nuclear reactor that uses liquid sodium as a coolant instead of water. Compared to the light water reactor (LWR), SFR operates at higher temperatures and with higher neutron fluence, causing cladding materials in SFR to experience harsh environments. The temperature of cladding can be increased to about ~600 °C, making creep deformation of cladding materials one of the most important life limiting factors.

Austenitic stainless steel was one of the materials considered for use in SFR due to its high-temperature strength, resistance to corrosion, and compatibility with sodium coolant. However, early studies showed that conventional austenitic stainless steels, such as Type 304, were susceptible to creep deformation and cracking at high temperatures. To address this issue, researchers began developing new grades of stainless steel that were more resistant to creep deformation. One such grade is Type 316 stainless steel, which contains molybdenum and other alloying elements that improve high-temperature strength and corrosion resistance. In the 1980s and 1990s, extensive research was conducted on the creep behavior of Type 316 stainless steel [1, 2].

However, since austenitic stainless steels showed poor swelling resistance in SFR conditions, ferritic martensitic stainless (FMS) steel has been researched as an alternative solution. Its high-temperature strength, resistance to corrosion, compatibility with sodium coolant, and swelling resistance make it a suitable material for use in SFR. Many creep tests in SFR conditions have been performed using FMS steels such as HT9 [3].

Since in-reactor creep behavior of austenitic stainless steels has been researched extensively, our knowledge of in-reactor creep behavior is mostly based on the experimental results of austenitic stainless steel. However, as in-reactor creep experiments are limited to some extent, careful comparison of in-reactor creep between austenitic stainless and FMS steels is necessary. Here, one possible difference will be proposed.

2. In-Pile Creep Performance of 316 Stainless Steel

Fig. 1 and Fig. 2 show the out-of-pile and in-pile creep experimental results of 316L stainless steel [1, 2]. In Fig. 1, it is obvious that at temperatures below 550 °C, in-pile creep is much higher than out-of-pile creep. However, as shown in Fig. 2, as the temperature increases to about 650 °C, out-of-pile and in-pile creep strains are almost comparable. Some results even indicate that out-of-pile creep strains are higher than in-pile creep strains. Based on these results, it is known that irradiation creep is dominant at temperatures below 550 °C, and thermal creep is dominant at temperatures above 600 °C.

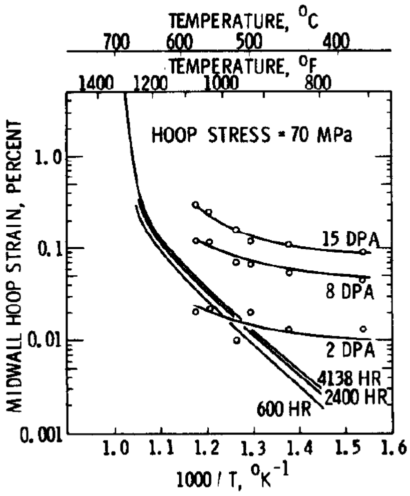

Fig. 1. Comparison between in-pile and out-of-pile creep of 316L stainless steel depending on temperature [1].

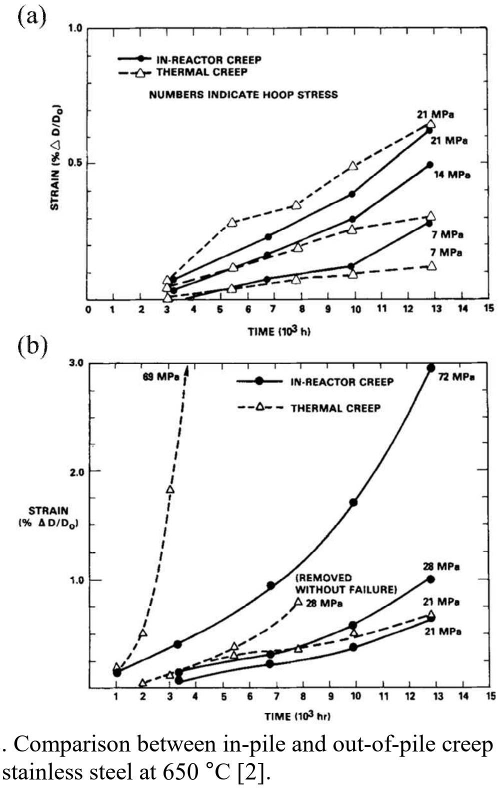

Fig. 2. Comparison between in-pile and out-of-pile creep of 316L stainless steel at 650 °C [2].

3. In-Pile Creep Performance of HT9

Fig. 3 shows the out-of-pile and in-pile creep experimental results of HT9 reported by Toloczko [3]. At 480-500 ºC, out-of-pile and in-pile creep strains are almost comparable. At 550 and 600 ºC, in-pile creep strains are higher than out-of-pile creep strains. This result does not agree with the results of 316 stainless steel shown in the previous section.

Fig. 4 shows the out-of-pile and in-pile creep experimental results of HT9 reported by Chin [4]. At 540 ºC, out-of-pile creep strains are higher than in-pile creep strains. This result is opposite to the results from Toloczko.

KAERI also performed out-of-pile and in-pile creep experiments using HT9 claddings to evaluate its performance for use in an SFR [5], and we obtained similar results with that of Toloczko, indicating that the in-pile creep performance of FMS steels depending on temperature might be different from that of austenitic stainless steels. Since there are limited experimental results, more experiments and analysis need to be performed.

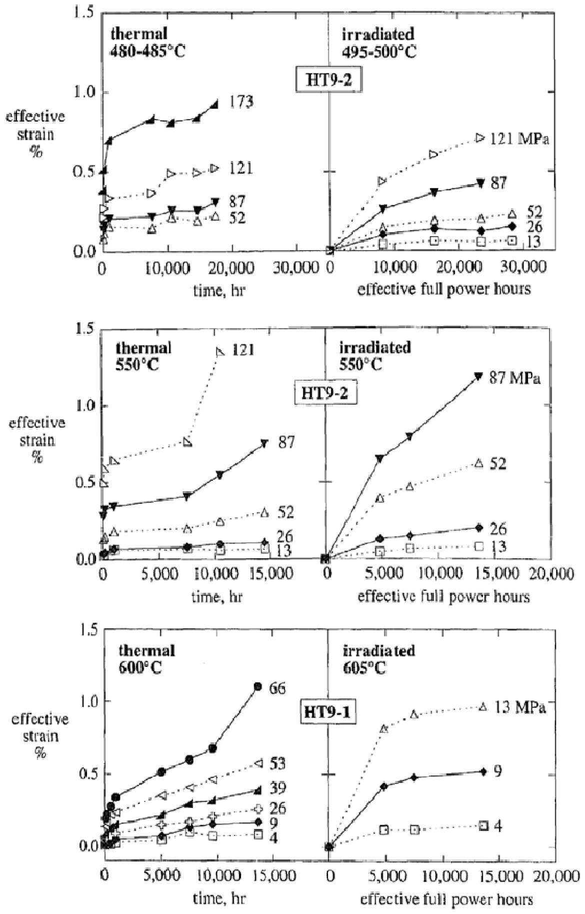

Fig. 3. Comparison between in-pile and out-of-pile creep of HT9 at 480, 550, 600 °C [3].

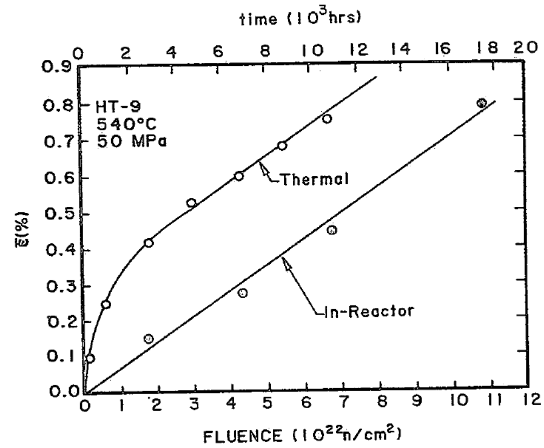

Fig. 4. Comparison between in-pile and out-of-pile creep of HT9 at 540 °C [3].

4. Conclusions

Until now, our understanding of in-reactor creep behavior has primarily been based on experimental results from austenitic stainless steels. It is widely accepted that irradiation creep dominates below 550 °C, and thermal creep dominates above 600 °C. However, our analysis suggests that in-pile creep strains are higher than out-of-pile creep strains for FMS steels at temperatures between 600 and 650 °C. Since claddings in SFR operate in this temperature range, it's crucial to conduct more detailed analyses to better understand the in-reactor creep behavior of FMS steels.

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