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DESIGN LIMITS FOR HT9 CLADDING USING STRESS-INDUCED AGING DATA

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Stress-temperature design guidelines are developed for the ferritic/martensitic cladding material HT9. High temperature operation for HT9 may cause microstructural changes/aging which softens the structure and causes increased creep rates. Higher creep strains means cladding breech becomes more probable before the end of the expected pin lifetime. Tertiary creep is considered an indication of microstructural changes and is to be avoided in fuel pin operation. The creep rate correlation, which includes tertiary creep, is examined for information on stress-temperature relationships which promote aging. This approach leads to design limits for HT9 which are compared with expected hot channel conditions for fuel pins in the Core Demonstration Experiment (CDE) planned for FFTF. The results show aging should not be significant for CDE.

DESIGN LIMITS FOR HT9 CLADDING
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INTRODUCTION

Fuel pins normally operate at high temperatures to improve plant thermal efficiency. However, cladding made from ferritic/martensitic materials such as HT9 may age soften at these higher temperatures resulting in excessive creep rates. Therefore it is imperative in designing fuel pins with HT9 cladding to define the temperature limits of softening to avoid creep failure. The age softening involves microstructural changes relatable to those occuring in tertiary creep. Therefore it is possible to use creep measurements which include the effects of time and temperature at stress to define softening temperature limits. This paper describes an analytical method using the data base of in-reactor creep rates of HT9 to infer age softening and therefore define an operating range or design limits for a HT9 clad fuel pin. These results are compared with design conditions for the Core Demonstration Experiment[1] (CDE) and conclude age softening should not be significant for CDE.

DESCRIPTION OF CREEP STAGES

The equation used to define HT9 creep rates contains separate terms for irradiation and thermal creep. In addition, the thermal creep is divided into stages representing primary, secondary, and tertiary creep as shown in Figure 1. Primary creep occurs early in life and has comparatively high rates. Secondary creep follows primary creep and takes place at slower rates because of strain hardening. Tertiary creep is an accelerating rate which occurs near end of life and is caused by necking, microcracking, or microstructural changes. (In the analysis that follows, necking is excluded because it usually occurs late in life and causes a stress increase through area reduction which is inappropriate for the constant stress creep correlation.)

Figure 1 shows predicted thermal creep strains for HT9 at constant stress for three different temperatures. The dashed lines represent the sum of primary and secondary creep components whereas the solid line also includes tertiary creep. The difference between the solid and dotted lines represent added strain caused by tertiary creep. For the time periods shown here, (500 days or less), creep at 900 K (1160°F) remains in the secondary stage, 920 K (1196°F) represents a temperature for the onset of tertiary creep, and 940 K (1232°F) produces an extensive tertiary creep phase.

SIGNIFICANCE OF TERTIARY CREEP

The tertiary phase implies microstructural changes are occuring. It is important to define when this occurs because this phase should be avoided in fuel pin design.

ESTABLISH AGING CRITERION

It is necessary to select a measure or boundary when microstructural changes are occuring. The criterion selected here is a 10% increase in creep rate beyond the secondary creep rate. This is judged to provide a significant change in rates however the increase in accumulated strain from the tertiary portion is still quite small and the likelihood of cladding breech is not increased significantly.

STRESS-TEMPERATURE RELATIONS FOR AGING

Iterative calculations are performed to evaluate the combinations of stress and temperature which activate the aging process. Time periods of 200, 500, and 1000 days are chosen to show the effect of time. These results are shown in Figure 2. At stress and temperature combinations less than those defined by the time curves, age softening will not occur. Note that time is not an extremely important parameter. The temperature difference between results for 200 and 500 days corresponds to about 21 K (38°F) whereas it is about 16 K (29°F) for between 500 and 1000 days.

AGING GUIDELINE FOR CDE

Using the above results, design limit conditions for temperature and stress are established for CDE which is to be run in the Fast Flux Test Facility. The HT9 creep correlation is based on data for constant stress and temperature conditions whereas the fuel pin cladding has increasing stress and decreasing temperature during its typical 900-day lifetime. In addition, the irradiation time effects must also be considered. It is believed to be reasonable to select the onset of aging as defined by constant stress and temperature conditions for a 500-day period (about 1/2 CDE lifetime).

The results are shown in Figure 3 by the curve defined as "AGING ONSET". (Aging effects on creep rate may be considered insignificant below this curve.) An upper temperature limit of 922 K (1200°F) is also chosen which incorporates results of diamond pyramid hardness (DPH) measurements at a variety of temperatures and times. DPH measurements are also a measurement of age softening, however, they do not include the effect of stress as in the creep test results.

COMPARISON WITH CDE IRRADIATION CONDITIONS

The design limit curve established above can be compared with the stress-temperature history for a CDE pin. SIEX3P[2] results for the hot channel pin (which conservatively includes 100% gas release) in the hottest assembly are also shown in Figure 3. These results lie below the AGING ONSET curve and indicate cladding microstructural changes should be insignificant for operating conditions chosen for CDE.

CONCLUSIONS

In-reactor creep data provide valuable information on microstructural changes in HT9 cladding. These define a boundary which should not be exceeded for fuel pin design. CDE's operating conditions are shown to be below this design guideline.

REFERENCES

1 A. J. Lovell, G. L. Fox, W. H. Sutherland, and S. L. Hecht, "Demonstration of a High Burnup Heterogeneous Core Using Ferritic/Martensitic Materials," Proc. International Conference on Reliable Fuels for Liquid Metal Reactors, Tucson, Arizona, September 7-11, 1986.

2 R. B. Baker, D. R. Wilson, and L. A Lawrence, "SIEX3 - A Correlated Code for Prediction of Fast Reactor Mixed Oxide Fuel and Blanket Pin Performance," Proc. International Conference on Reliable Fuels for Liquid Metal Reactors, Tucson, Arizona, September 7-11, 1986.

FIGURE 1. Thermal Creep of HT9

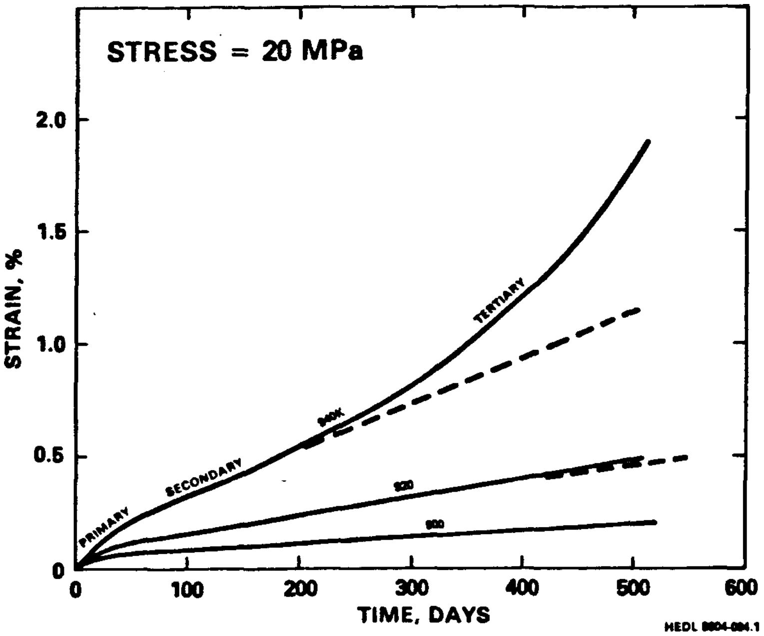

FIGURE 2. Onset of Aging for HT9.

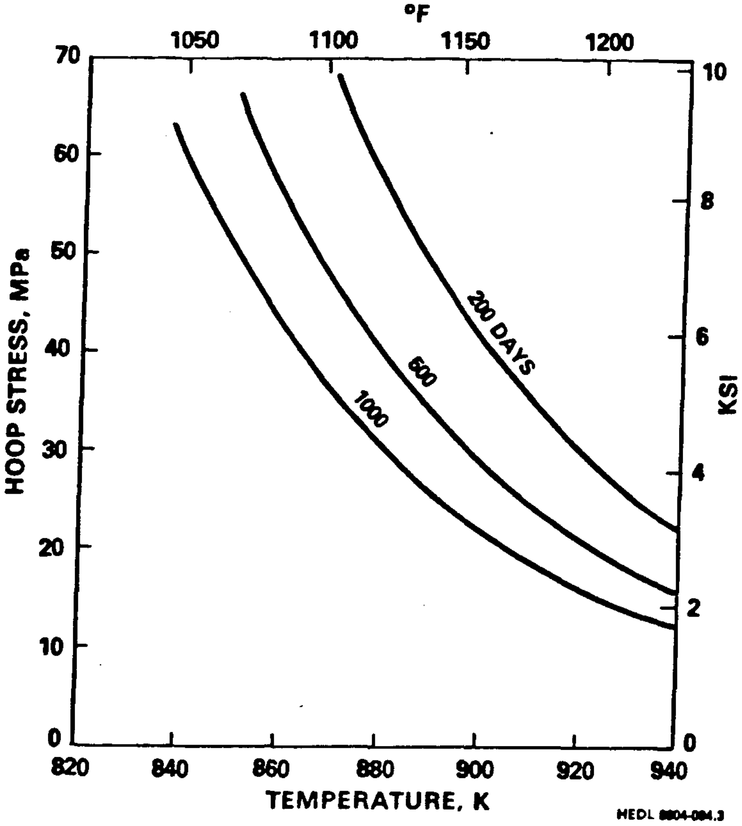

FIGURE 3. HT9 Design Guideline.