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Elastic Creep-Fatigue Damage Evaluation: Less Restrictive Design Rules for SNR-2 Components

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Abstract

To achieve less conservative design rules for LMFBR Class 1 components in elevated temperature service, two modifications of the elastic creep-fatigue evaluation in use are proposed: (1) In the creep-damage evaluation, the relaxation of residual stresses during hold-times shall be taken into account; (2) In the fatigue-damage evaluation, the creep effects on the cyclic stress-strain hysteresis loop shall be considered by adding the net relaxation strain during hold-times to the elastic-plastic strain range, and design fatigue curves without hold-time shall apply.

1. Introduction

For economical and practical reasons, the use of elastic methods is not to abandon in the design of LMFBR Class 1 components in elevated temperature service, even though the elastic region of the material behavior is exceeded. Since elastic methods should be adequately reliable, they necessarily are conservative to a certain degree compared with inelastic methods.

In the practical design, the elastic methods and rules currently in use, e.g. N 47 /1/ and RCC-MR /2/, are experienced to be rather conservative and thus often lead to either undesirable designs or inelastic analyses.

One of the crucial elements of the elastic design is the creep-fatigue evaluation on an elastic basis. So as to the SNR-2, less restrictive rules for the elastic creep-fatigue damage evaluation of Class 1 components are proposed. For this purpose two evident conservativisms shall be eliminated: (1) In the creep-damage evaluation: the relaxation of residual stresses during the hold-time period shall be taken into account rather than to assume the total initial stress being constant during the hold-time period (see Fig. 1); (2) In the fatigue-damage evaluation: to account for creep effects, the net relaxation strain during the hold-time period shall be added to the elastic-plastic strain range rather than to add the creep strains from constant stresses. Note: In the absence of reversed stresses during creep - which on the whole is the case in SNR-2 components - pure creep strains merely contribute to the total accumulated strain but do not enlarge the cyclic stress-strain hysteresis loop (see Fig. 2).

2. Proposed Procedure

The creep-damage of the considered cycle followed by a hold-time period shall be calculated according to the following procedure (see Fig. 1):

$U_C = U_{Crel} + U_{Csust}$

$U_{Crel} = \int_{o}^{t_h} \frac{dt}{t_r(\sigma(t)/0.9)}$

= creep damage from a stress $\sigma(t)$ which relaxes uniaxially during the hold-time period t_h and whose initial value is the lesser of the maximum elastically calculated stress during the cycle and the 1.4-fold yield stress*)

$U_{Csust} = \frac{t_h}{t_r(P/0.9)}$

= creep damage from a stress P which is constant during the hold-time period t_h and whose value equals the equivalent primary membrane stress

t_r = minimum time to creep rupture

The fatigue-damage of the considered cycle followed by a hold-time period shall be calculated according to the following procedure:

$U_F = \frac{1}{N_d}$

N_d = allowable number of stress cycles according to the design fatigue curve without hold-time for the total strain range ε_t

$\varepsilon_t = \varepsilon_{elpl} + \Delta\sigma/E$

ε_{elpl} = elastic-plastic strain range evaluated according to the established procedures

$\Delta\sigma$ = uniaxial stress relaxation during the hold-time period with the initial stress value being the lesser of the maximum elastically calculated stress during the cycle and the 1.4.fold yield stress*)

E = Young's modulus

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*) If the elastic-plastic stress history during the cycle is known the stress at the end of the cycle (i.e. at the beginning of the hold-time period) may be taken as the initial value.

The creep-fatigue damage during the whole service life shall meet the condition

$$U_{CF} = \mathrm{MIN} \left| \begin{matrix} \sum\limits_i n_i U_{Ci} + \frac{7}{3} \sum\limits_i n_i U_{Fi} \\ \sum\limits_i n_i U_{Fi} + \frac{7}{3} \sum\limits_i n_i U_{Ci} \end{matrix} \right| \overset{!}{\leq} 1$$

n_i = Number of individual cycles of loading condition i

Note that $\sum\limits_i n_i t_{hi}$ must equal or ecceed the total specified elevated temperature service life.

3. References

[1] Class 1 Components in Elevated Temperature Service Section III, Division 1
ASME B&PVC Case N47, December 11, 1981

[2] Règles de conception et de constuction des matériels mécaniques des îlots nucléaires RNR (RCC-MR), afcen, décembre 1983

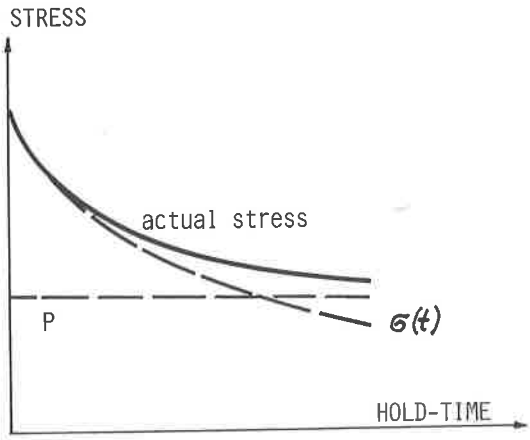

Fig. 1: Stress relaxation

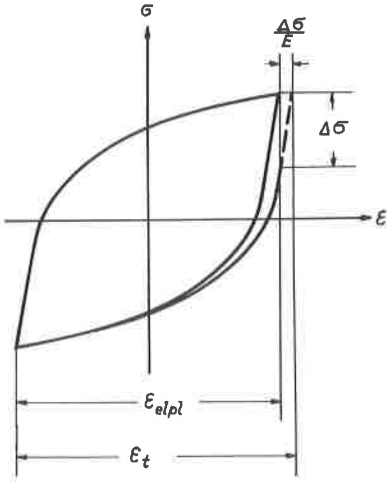

Fig. 2: Enlargement of stress-strain hysteresis loop by stress relaxation