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Intercomparison of Creep-Fatigue Rules for High Temperature Design Evaluations of GEN-IV Systems

Gyeong-Hoi Koo and Jae-Han Lee
Korea Atomic Energy Research Institute
ghkoo@kaeri.re.kr

1. Introduction

In this paper, comparison studies of the design codes, standards, and procedures for high temperature design evaluations of the GEN-IV systems developed throughout the world are carried out to investigate the theoretical background of the total strain range determinations with an elastic analysis results for the creep-fatigue damage limits rules.

2. Comparison and Results

To accomplish the elevated temperature design or an assessment for the GEN-IV systems, the codes such as ASME-NH (USA)(1), RCC-MR (France)(2), R5 (United Kingdom)(3), and DDS (Japan)(4) have been developed and many efforts are being made to extend and modify the material database and a reduction of the conservatism contained in the rules.

All design codes or assessment procedures are focused on the inelastic strain limits and the creep-fatigue limits rules. This paper will describe an intercomparison of the theoretical rules on a total strain range determination required for creep-fatigue evaluations.

2.1 Total Strain Ranges

In elevated temperatures, fatigue damage is mainly induced by a strain-controlled low cycle fatigue mechanism and it interacts with the creep damage. Therefore, in all the design codes, the evaluation rules of a creep-fatigue limit are based on the calculation of a total strain range. The rules of a total strain range calculation are compared as follows;

<u>ASME-NH</u>

$$\varepsilon_t = K_v \Delta\varepsilon_{\text{mod}} + K\Delta\varepsilon_c = K_v \left(\frac{S^*}{\bar{S}}\right) K^2 \Delta\varepsilon_{\max} + K\Delta\varepsilon_c \quad (1)$$

<u>RCC-MR</u>

$$\varepsilon_t = (\Delta\varepsilon)_{e+p} + \Delta\varepsilon_c = (\overline{\Delta\varepsilon_1} + \overline{\Delta\varepsilon_2} + \overline{\Delta\varepsilon_3} + \overline{\Delta\varepsilon_4}) + \Delta\varepsilon_c \quad (2)$$

<u>DDS</u>

$$\varepsilon_t = K_\varepsilon \varepsilon_n + K_L \varepsilon_c + K_T \varepsilon_F = K'_e \left(\frac{S^*}{\bar{S}}\right) K^2 \varepsilon_n + K_L \varepsilon_c + K_T \varepsilon_F \quad (3)$$

<u>R5</u>

$$\varepsilon_t = \Delta\bar{\varepsilon}_{el} + (\Delta\sigma_{rD}) / \overline{E} + \Delta\bar{\varepsilon}_{pl} + \Delta\bar{\varepsilon}_{vol} \quad (4)$$

Fig. 1 to Fig. 4 demonstrate Eq.(1) to Eq.(4) above, which are for calculating the total elastic-plastic strain range from the elastic structural analysis. As shown in the figures and the equations, all the code rules have the same basic concept by using Neuber's rule to consider the local geometric stress concentration. For the ASME-NH, the monotonic isochronous curves modified with the stress relaxation strength S_{rH} , which may be determined by performing a pure uniaxial relaxation analysis starting with an initial stress of 1.5 S_m and holding the initial strain throughout the time interval equal to the time of service are used in obtaining the total strain range while the RCC-MR and the R5 use the cyclic material curves. The concept of the RCC-MR is based on the total equivalent stress range obtained from the elastic structural analysis and the cyclic material curves modified with the modified elastic modulus. This rule includes an elastic followup by the primary stress and the creep strain increment by a given creep equation. The rules of a DDS for a total strain range determination are almost the same as the ASME-NH but they include the peak thermal strain range multiplied by the elastic stress concentration factor. The R5 has two approaches for the calculation. One is a simplified calculation method of the elastic-plastic strain range and the other one is the detailed construction method of the hysteresis loop. Eq. (4) above is for the former case when a creep is significant and the dwell is at the peak of the cycle. Like the RCC-MR, R5 is based on the total equivalent stress range calculated by the elastic structural analysis. This method uses the modified cyclic material curve or an isochronous curve.

2.2 Creep-Fatigue Rules

To predict the design lifetime for elevated temperature reactor components and structures, the models such as a linear damage rule, damage rate equations, strain range partitioning equations, frequency separation equations, ductility exhaustion equations, and so on are published world-wide. For the creep-fatigue damage limit evaluation, the ASME-NH, the RCC-MR, and the DDS have the same concept of a linear damage summation rule with criteria by using the creep-fatigue interaction diagram. However, the R5 procedure permits the use of the ductility exhaustion method for a creep-fatigue evaluation if the material data is available, which can consider a metal surface creep crack initiation. If appropriate data is not available, a linear damage summation similar to that of the ASME-NH can be used.

Recently, the strain partitioning method has been positively reviewed as an alternative rule for creep-fatigue evaluations in the ASME-NH design code.

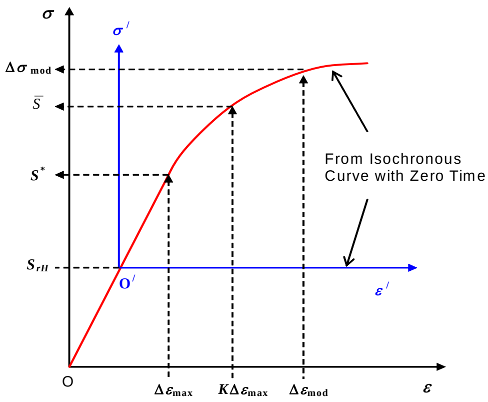

Fig. 1 Concept of the total strain Range calculation by the ASME-NH

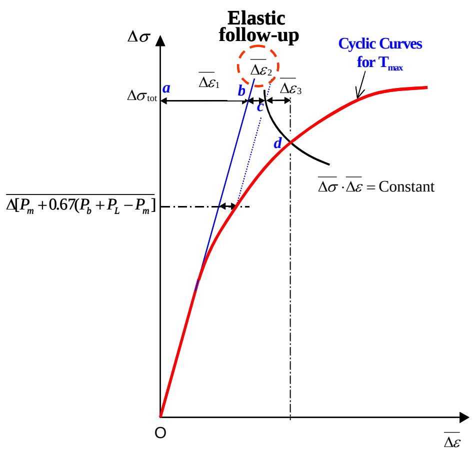

Fig. 2 Concept of the total strain Range calculation by the RCC-MR

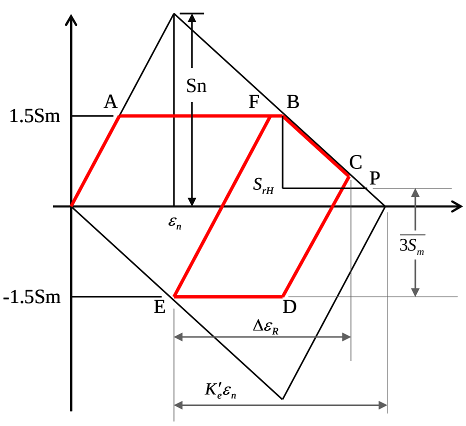

Fig. 3 Concept of the total strain Range calculation by the DDS

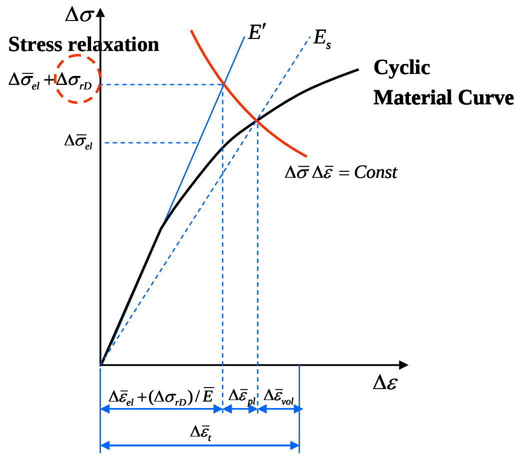

Fig. 4 Concept of the total strain Range calculation by the R5

3. Conclusions

In this paper, an intercomparison of the codes, standards, and assessment procedures was carried out for the total strain range determination concepts used in creep-fatigue damage evaluations. In conclusion, the basic concept is all the same in the rules but the treatments of the local effects and cyclic effects are slightly different. Therefore, it is hard to say which rules are conservative or not.

ACKNOWLEDGMENTS

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