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Elevated Temperature Strength Evaluation Rules for BOX Structure in DFBR

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ABSTRACT

Fast breeder reactor core is supported by structures in the reactor vessel cold plenum where temperature is lower than 425°C in normal operating condition. However, under upset, emergency or faulted conditions, the temperature of core support structures rises to the temperature at which creep effect is dominant in short time. It is essential to develop the evaluation procedure for the creep-fatigue damage of various types of welded joints such as T- and L-type configurations in the structural design guide of core support structures.

In this paper, evaluation procedure to estimate the creep-fatigue life is developed for T- and L- type fully penetrated welded joints based on previous experimental study.

1. INTRODUCTION

In the design of the demonstration fast breeder reactor(DFBR) in Japan, the core support structure is assembled of box structures with welded joints in the reactor vessel cold plenum where sodium temperature is lower than 425°C in normal operating condition. However, under upset, emergency or faulted conditions, the temperature of the core support structure rises to the temperature at which creep damage is caused in short duration as shown in Table 1.

Table 1 Maximum Temperature and Elevated Temperature Hold Time in Operating Conditions

Operating Condition	Maximum Temperature (°C)	Time at Elevated Temperature (hour/cycle)	Number of Events (Cycles)	Event
Normal	395	0	—	—
Upset	450 500	0.5 0.3	40 20	Loss of External Power Supply SG Isolation
Emergency	500	6	20	Loss of External Power Supply +1 DG Start-up Failure
Faulted		30	1	Total Blackout

In prototype reactor "Monju", the core support structure has been assembled by the butt joints. On the other hand, in the DFBR in Japan fully penetrated T- and L-type welded joints will be adopted in core support structure design for economical reason. Figure 1 shows such welded joints adopted in the core support structure. The material of core support structure is type 304 stainless steel.

Therefore, improvement of elevated temperature design rules on T- and L-type welded joints is indispensable for the design of core support structures of DFBR.

However, the elevated temperature structure design guide for DFBR (DDS) in Japan[1] originally deals with only base metal and butt welded joints. Generally it is difficult to assess the strain concentration in joints required for the structural design.

In this paper, the rule to assess creep-fatigue damage of fully penetrated T- and L-type welded joints is developed based on the previous experimental study[2].

2. CREEP-FATIGUE DAMAGE EVALUATION RULE

The Creep-fatigue damage evaluation rule is discussed for T- and L-type welded joints in this section.

2.1 The Time-Temperature Region where Creep Effect is Not Significant

The evaluation rule for creep-Fatigue damage of welded joints is developed taking account of the design concept that the core support structure is operated in elevated temperature in limited and short duration. Creep effect on the structure is not considered to be significant if condition described by Eq.(1) and Eq.(2) are satisfied.

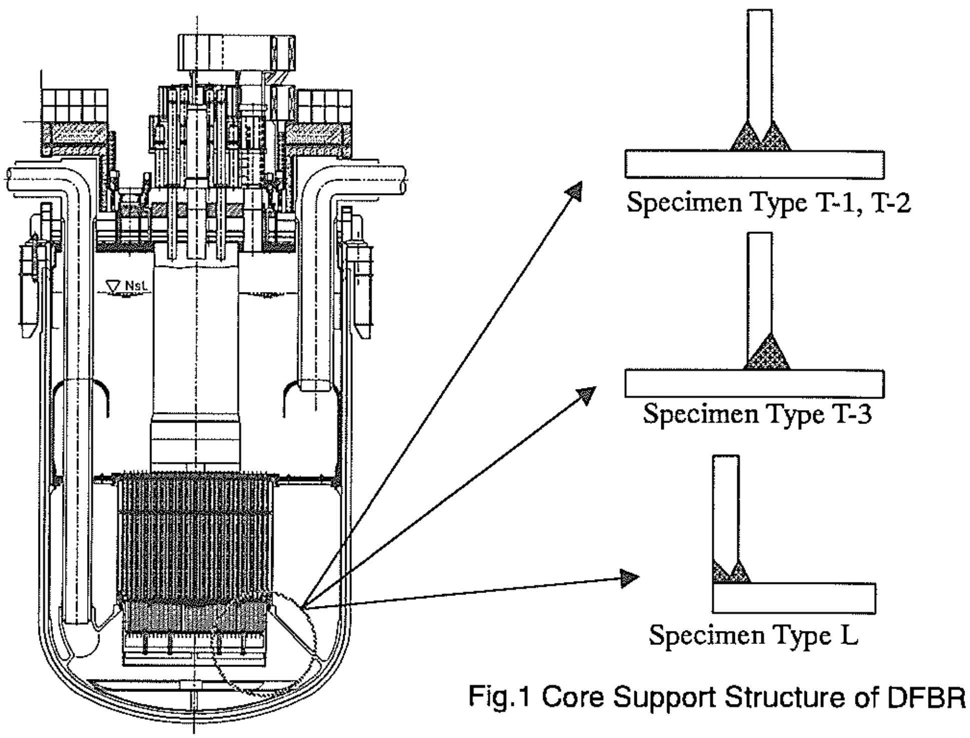

Fig.1 Core Support Structure of DFBR

$$2\sum_{i} t_i / t_{di} \leqq 0.1 \quad (1)$$

$$\sum_{i} \varepsilon_i \leqq 0.02 \quad (2)$$

Where, t_i, t_{di} and ε_i are duration time, creep rupture time under the stress 1.5Sm and creep strain caused by stress 1.5Sm at temperature T_i , respectively. And Sm means design stress intensity limit at temperature T_i.

The relation between time and temperature described by Eq.(1) and Eq.(2) is compared with the creep crossover curve given in ASME Code Case N201[3] as shown in Fig. 2.

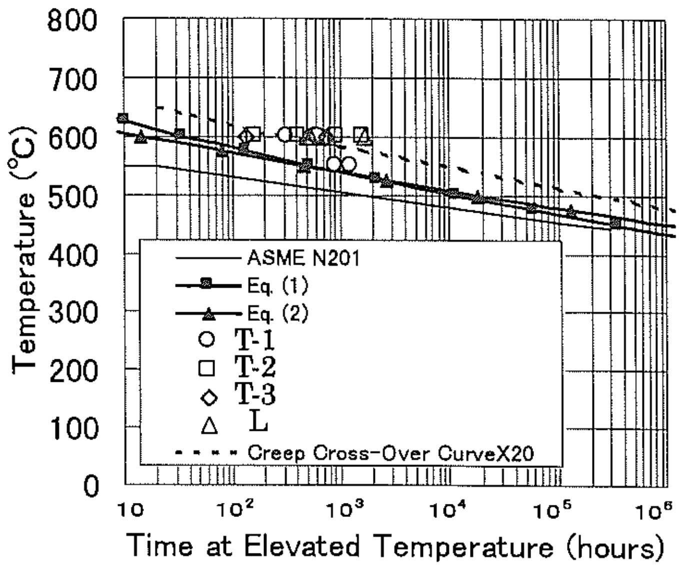

Fig. 2 Creep-Crossover Curves and Test Conditions

2.2 Creep-Fatigue Test of Welded Joints

The creep-fatigue test has been performed on a series of test specimens as shown in Fig. 3[2]. Geometry of specimens have been modeled on the actual design of the core support structure and welded by the same way applied to the actual structures in order to simulate the characteristics of material and structural discontinuities between base and deposit metals.

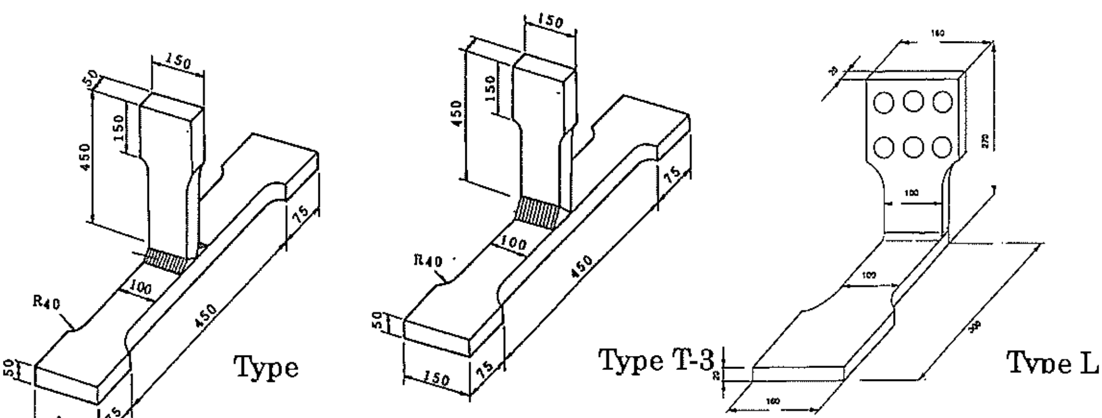

Fig. 3 Dimensions of test specimens

Fatigue and creep fatigue tests were performed at 600°C, which is higher than the maximum operating temperature (550°C), in order to evaluate the strength of joints conservatively. The total holding time was set to be about 500 hours in the creep fatigue test. This has been determined taking account of the margin of 20 times the 25 hours for which the creep damage is not notable at 600 ° C, according to the creep crossover curve defined by Eq.(1) and Eq.(2).

2.3 Evaluation Rule for Creep-Fatigue Damage

Based on creep-fatigue tests, two types of the evaluation method are developed as follows.

2.3.1 Procedure Using the Local Strain Range at Weld Toe

In this procedure, the creep-fatigue damage is estimated by the local strain range at the weld toe which is calculated by Neuber's rule[4] and elastic stress concentration factor as follows.

The equation proposed by Ogura et al[5] is used which incorporates the equivalent stress, σ_{eq} and strain, ε_{eq} to account for the effect of the plane strain condition:

$$K_t^{*2} = K_\sigma^* \cdot K_\varepsilon^* \quad (3)$$

where,

$$K_t^* = \sqrt{(1-\nu+\nu^2)}K_t$$
$$K_\sigma^* = \sigma_{eq}/\sigma n$$
$$K_\varepsilon^* = \varepsilon_{eq}/[(2/3)\{(1+\nu)/E\}\sigma_n].$$

Where, E, ν and σn are Young's modulus, Poisson's ratio and the nominal stress, respectively.

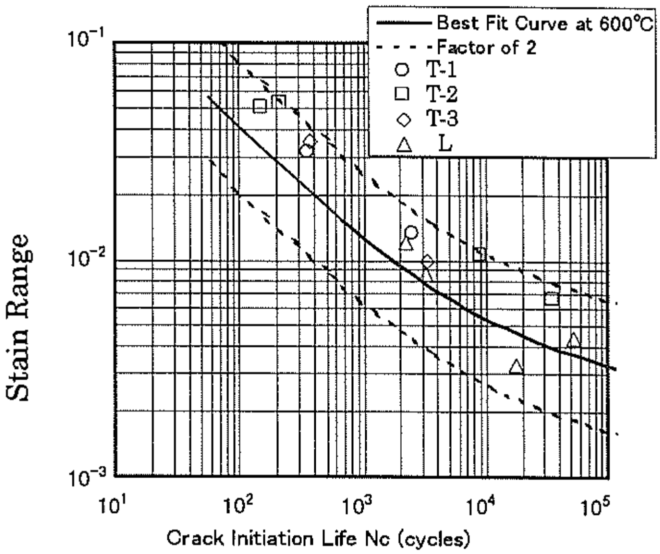

Fig. 4 Relationship between Local Strain Range and Crack Initiation Life at 600 ℃

The elastic stress concentration factor, K_t is estimated by the following equation[6]:

$$K_t = 1+\{\exp(0.16-0.14(h/t))\cdot (\rho/t)^{-0.309}-1\}\cdot f_1 \quad (4)$$

$$f_1 = f_2 / f_3$$
$$f_2 = 1.02+\{0.00076+0.00068\cdot \ln(h/t)\}/(\rho/t)$$
$$f_3 = 1+(9.8+0.027/\rho)\exp(-f_4\cdot \theta)$$
$$f_4 = (\rho/t)^{0.5}(12.6+8.6(h/t))+4.8-0.76\ln(h/t)$$

where, ρ, θ and h are the toe radius, Flank angle and leg length, respectively, and t is the plate thickness. The cyclic stress-strain curve is assumed in this estimation.

A good agreement has been obtained between K_t given by Eq.(4)

and K_t obtained by the FEM analysis for T- and L-type specimens.

The relationship between strain range calculated by Eq. (3) and the crack initiation life at 600°C are shown in Fig. 4. The figure also shows the best fit fatigue curve of DDS, and the curves of a factor of 2 obtained by multiplication of the strain range with 1/2 and 2.

Since most of the results are located between the curves based on a factor of 2 with slight scatter, the local strain at the weld toe can be estimated by determining the elastic stress concentration factor K_t by Eq.(4) and applying Nueber's rule[4] with the plane strain condition correction. Creep damage caused by a single load holding, dc is estimated Eq. (5) with local stress and strain at weld toe, considering the relaxation of local stress at weld toe with elastic follow up factor q=3.

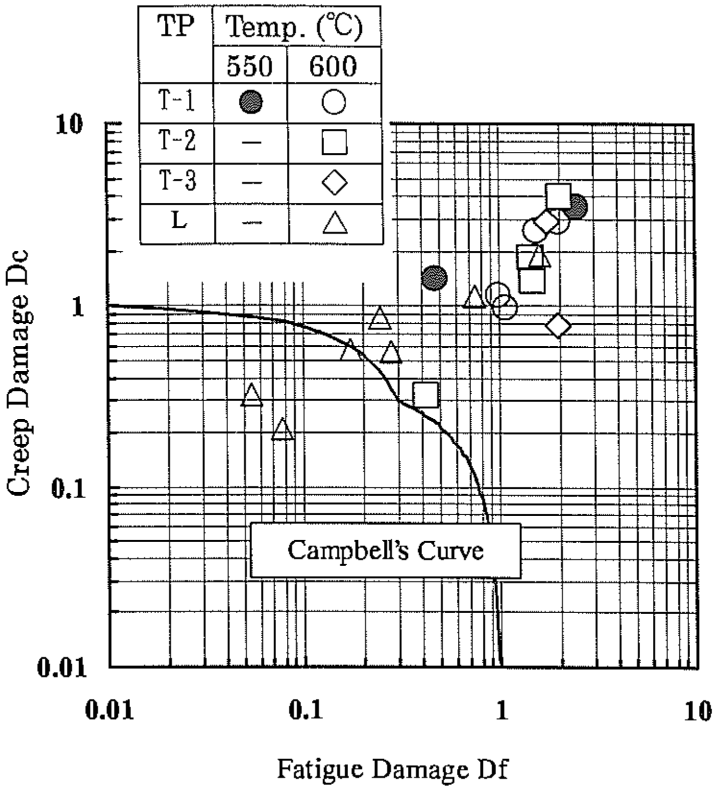

Fig. 5 Relationship between Creep Damage and Fatigue Damage Calculated by Local Stress and Strain

$$dc= \int_{0}^{t_H} dt / tf \qquad (5)$$

where, t_H is the time of load holding, and tf is the creep rupture time under the stress σ at time t . Initial stress in the load holding is estimated by cyclic stress-strain curve with local strain calculated by Eq. (3). Creep damage, Dc which is given by multiplication of dc with crack initiation life Nc and fatigue damage, Df are compared with Campbel's curve[8] as shown in Fig. 5. This figure shows that creep-fatigue damage is predicted conservatively by using this procedure.

It is necessary to determine ρ , θ and h for this procedure and actuary this is complicated requirements for design.

2.3.2 Simplified Procedure Using Effective Elastic Stress Concentration Factor

It is considered that the simplified method is more suitable for the design rule and the procedure with effective elastic concentration factor is developed as follows.

A constant value of elastic stress concentration factor Ktr for all specimens tested at 600°C was determined so that the strain range of data points is multiplied to approximate the best fit fatigue curve for smooth base metal[7] using Eq.(3) as shown in Fig. 6. From this figure, test results are found to be fairly approximated by K_{tr}=1.88.

In this procedure strain range ε_t at weld toe is calculated from Eq. (6) using the effective elastic stress concentration factor K_{tr} that describes the effect of material and structural discontinuities on creep-fatigue life which can be determined based on test results. Equation (6) is the basic equation to evaluate strain concentration of the base metal by elastic calculation in DDS[1]

$$\varepsilon_t = K_\varepsilon \cdot Ke' \cdot \varepsilon_n \qquad (5)$$

$$Ke' = \{1+(q_n-1)\cdot(1-3Sm/(E\cdot\varepsilon_n))\}$$

Where, q_n, Sm and E are elastic follow up factor, design stress intensity limit and Young's modulus, respectively. And strain concentration factor K_ε is determined by Nueber's rule[4] with the effective elastic stress concentration factor K_{tr}.

Creep-fatigue damages estimated from local strain range calculated by Eq. (5) with K_{tr}=1.88 and q_n=3 are compared with Campbel's curve[8] as shown in Fig. 7. This figure shows that creep-fatigue damage is predicted conservatively by using this procedure. Therefore, the effective elastic stress concentration factor Ktr is determined to be 2 for the evaluation method which uses Eq.(5).

2.3.2 Simplified Procedure with Fatigue Life Reduction Factor

For simplicity of the evaluation procedure, the fatigue life reduction factor Kf is determined considering the load holding effect at elevated temperature under the condition which satisfies Eq.(1) and Eq.(2). From Fig. 8, Kf is determined to be 5 for the simplified evaluation procedure.

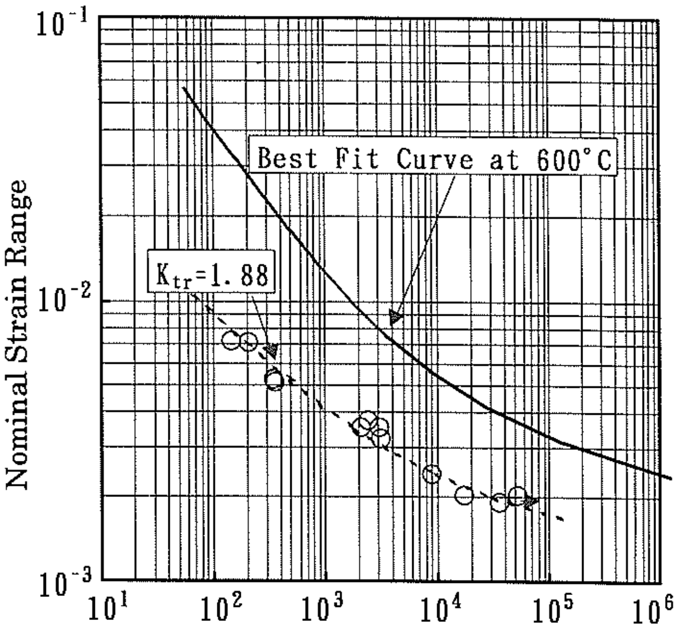

Fig. 6 Effective Elastic Stress Concentration Factor Ktr on Fatigue at 600 ℃

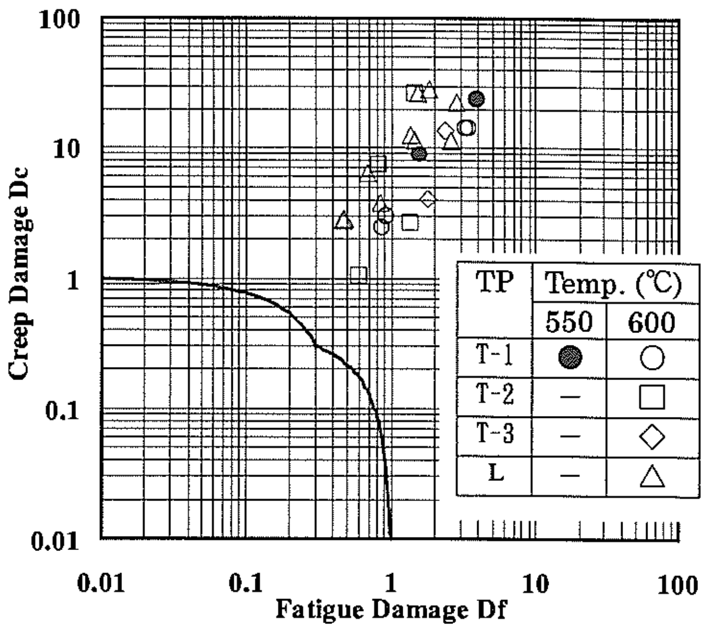

Fig. 7 Relationship between Creep Damage and Fatigue Damage Calculated by Ktr

3. CONCLUSION

In this paper, the procedure to predict local strain range at weld toe are discussed and it is found that the creep-fatigue damage at weld toe is predicted conservatively with local stress and strain at weld toe.

Two types of the simplified evaluation procedure of creep-fatigue damage are developed for T- and L- type welded joints based on this observation. In the One, effective elastic stress concentration factor is introduced to assess the local strain at weld toe. In the other, which is more simple procedure, the fatigue life reduction factor is developed considering creep effect under short limited hold times at elevated temperature.

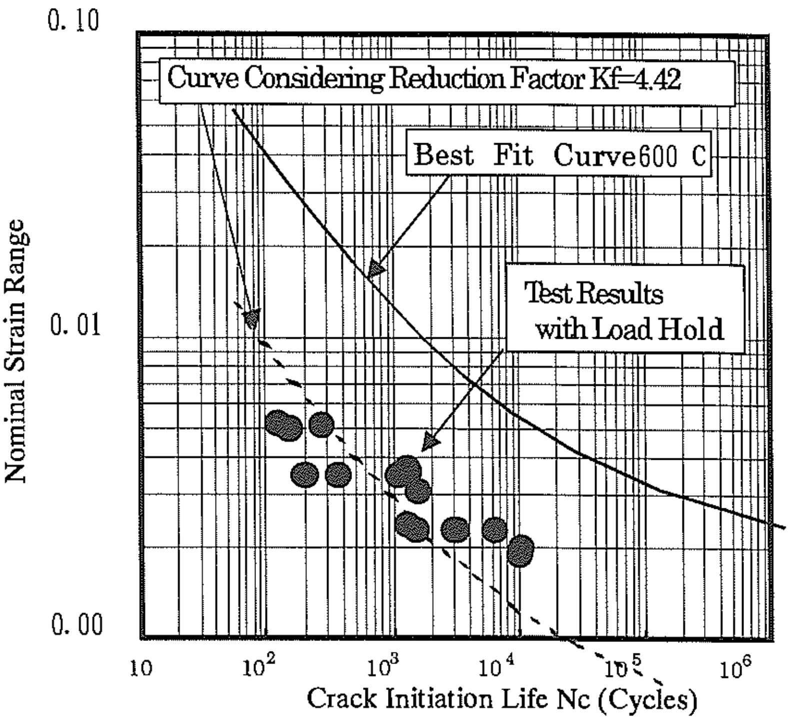

Fig. 8 Fatigue Life Reduction Factor

4. ACKNOWLEDGEMENT

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