

Monte Carlo Simulation for Evaluating the Creep Crack Growth Rate of Type 316LN Stainless Steel

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1. Introduction

Type 316LN stainless steel (SS) is widely used as the structural material for liquid metal reactor (LMR) components [1]. The components may be subjected to a non-uniform stress and temperature distribution during a high temperature service. These conditions generate localized creep damage and propagate the cracks and ultimately cause a fracture. A significant portion of the components' life can be spent in crack propagation. Thus, it is very important to evaluate the creep crack growth rate (CCGR) from a design concern and in predicting the residual life of the components [2, 3]. However, so far, the design and/or evaluation of the components have been mostly conducted by deterministic fracture mechanics. This method may bring about overly conservative evaluation by applying highly upper limit values in material properties. So, using probabilistic fracture mechanics, the crack propagation should be evaluated probabilistically.

In this paper, the CCGR data was dealt with from probabilistic viewpoints in order to logically evaluate the CCGR in type 316LN SS. Using Monte Carlo simulation (MCS), a number of random variables were generated, and the CCGR lines are predicted probabilistically. For application of the MCS, in the case of a standard deviation of 1σ for the probability variables, $P(B, q)$, the CCGR lines were predicted, and the results were discussed.

2. Methods and Results

2.1 Monte Carlo simulation (MCS) method

The MCS is applied to generate the random variables (*i.e.* random numbers) for the B and q coefficients. Box and Muller [4] have proposed that random variables (S) with standard normal distribution can be represented as,

$$S = (-2 \ln U_1)^{0.5} \cos 2\pi U_2. \quad (1)$$

U_1 and U_2 are standard uniform variables, which have a uniform probability density function (PDF) between 0 and 1.0. Thus, random variables (x) with normal distribution $N(\mu, SD)$ can be given as [5],

$$x = \mu + SD \cdot S = \mu + SD(-2 \ln U_1)^{0.5} \cos 2\pi U_2. \quad (2)$$

For a lognormal random variable x' , the distribution of $x = \log(x')$ is normal distribution. Thus, if x is a value generated from Eq. (2),

$$x' = 10^x. \quad (3)$$

Eq. (3) becomes a random number for the lognormal distribution with mean μ and standard deviation SD . Eqs. (2) and (3) were used to generate the values of the B and q , which were shown to be a lognormal distribution.

2.2 Results of the MCS for the B and q

The general form between the CCGR (da/dt) and the C^* can be expressed as, $da/dt = B[C^*]^q$. For calculating the da/dt , the material constants, D_1 , m , A , and n were used, as given in Table 1.

Table 1 Material properties at 600°C of type 316LN SS

E (GPa)	σ_{YS} (MPa)	σ_{UTS} (MPa)	Plastic constants		Creep constants	
			D_1	m	A	n
149	104	420	6E-4	2.54	6.35E-33	11.8

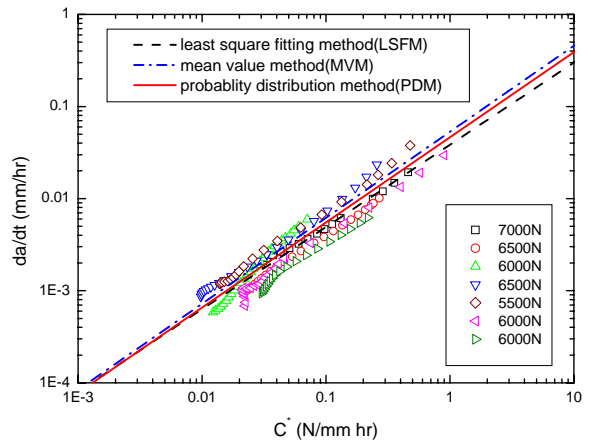


Fig. 1 CCGR lines of the da/dt and C^* relationship

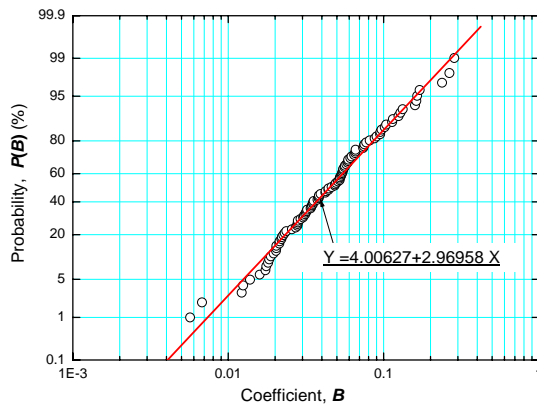


Fig. 2 Results of the MCS for B distribution

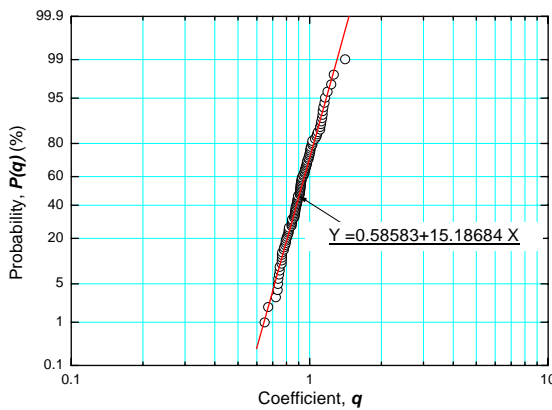


Fig. 3 Results of the MCS for q distribution

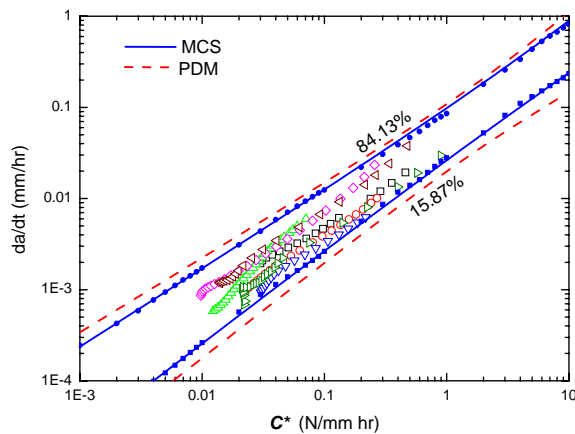


Fig. 4 Comparison of CCGR lines for MCS and PDM in 1σ of B and q values

Fig. 1 shows the results of the relationship between the da/dt and the C^* in the type 316LN SS. To logically obtain the CCGR lines, the least square fitting method (LSFM), a mean value method (MVM), and a

probabilistic distribution method (PDM) were applied. The MVM line showed a good agreement with the experimental data, because the MVM line takes a mean value of each B and q of all the CCGR lines. Probability distribution was investigated for the B and q coefficients. It was investigated as a lognormal distribution. Using the results, the MCS was performed using Eqs. (2) and (3).

Figs. 2 and 3 show the results of the MCS for the B and q coefficients. Fig. 4 shows the comparative results of the PDM and the MCS in the predicted CCGR lines. In the 1σ of the B and q values, the PDM line was wider than the MCS one. However, the PDM and the MCS do not generate a large difference in the CCGR lines. So, the both methods can be well used for predicting the creep crack growth of type 316LN SS. It is also regarded that the MCS were successfully performed without an error. If using the MCS, the CCGR lines can be predicted with a probabilistic reliability

3. Conclusions

Both the B and q coefficients followed a lognormal distribution, although the B a little scattered in the points of the data. Using the MCS, a number of the standard uniform variables were generated, and the CCGR lines were predicted successfully without an error. In the case of the 1σ of the B and q values, The CCGR lines of the PDM were more conservative than those of the MCS. However, the two approaches did not generate a large difference in the CCGR lines. The MCS will be used usefully for evaluating the crack growth rate of the type 316LN SS with a probability.

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