Life Prediction of Low Cycle Fatigue in Mod.9Cr-1Mo Steel at 600 ℃

Woo-Joong Kim*, Chang-Gyu Park, Jong-Bum Kim
Korea Atomic Energy Research Institute, Daedeok-daero 989-111, Yuseong, Deajeon, Korea
**Corresponding Author :kimwj@kaeri.re.kr*

1. Introduction

Several grade of 9~12Cr tempered martensitic steels are candidate materials for structure components for Generation IV nuclear power plants. Mod.9Cr-1Mo steel (ASTM Grade 91) became to be used as the structural material for high temperature components of a Sodium-cooled Fast Reactor [1] such as IHTS piping and heat exchangers, since it has high strength, toughness and resistance to degradation in corrosive of oxidizing environment compared to austenitic steels.[2~3].

Mod.9Cr-1Mo steel structure can be damaged by creep, fatigue and creep-fatigue interaction due to high temperature operating condition in a sodium-cooled fast reactor.

This paper addresses the high temperature isothermal low cycle fatigue of Mod.9Cr-1Mo steel. Repeated cyclic strain between tension and compression loading is applied. The test is carried out for a temperature at 600℃ and strain condition range of 0.8~1.2%. The low cycle fatigue(LCF) damage that accounts for 20 percent of total damage represents a prominent failure mode [4].

The set of data is plotted based on the Coffin-Manson method and strain energy method. Then, the unknown parameters of each method were estimated. In order to predict the low cycle fatigue life of Mod.9Cr-1Mo steel, relations between strain energy density and number of cycles to failure are examined.

2. Low cycle fatigue evaluation methods

2.1 Coffin-Manson method

The stress-strain curve for low cycle fatigue is comprised of two parts that is both linear elastic and plastic strain.

$$\frac{\Delta\varepsilon}{2} = \frac{\sigma_f'}{E}(2N)^b + \varepsilon_f'(2N)^c \quad (1)$$

Where σ_f', ε_f', b and c are material parameters

2.2 Strain energy method

The plastic strain energy of material suffered for repeated loading is as like follows (R=-1). This energy represents integration of area on hysteresis loop.

$$\Delta W_p = 4K''^{\left(-\frac{1}{n'}\right)}\sigma^{\frac{1+n'}{n'}}\frac{1-n'}{1+n'} \quad (2)$$

The total strain energy of material suffered for repeated loading is as like follows (R=-1).

$$\Delta W_t = \Delta W_p + \Delta W_e = 4K''^{\left(-\frac{1}{n'}\right)}\sigma^{\frac{1+n'}{n'}}\frac{1-n'}{1+n'} + \frac{\sigma_{max}^2}{2E} \quad (3)$$

The total strain energy method is used for small strain amplitude. Because strain amplitude is proportional to plastic strain energy, it has trouble in measuring very small strain energy density [5~6].

A relationship between plastic strain energy density and cycles-to-failure(N_f) may be written as Eqs.(4~5):

$$\Delta W_p = A(N_f)^m \quad (4)$$

$$\Delta W_t = \chi(N_f)^\alpha \quad (5)$$

where A, m, χ, and α are material parameters.

3. Experimental procedures

The material used in this study was Mod.9Cr-1Mo steel. The chemical composition is shown in Table1.

LCF specimens are manufactured to uniform gauge type according to ASTM E 606[7]. The test is carried out by using electro hydraulic servo-controlled fatigue testing machine. The high temperature extensometer, of which gage length is 12.5 mm, is used to control the strain. The loading frequency is 0.25 Hz.

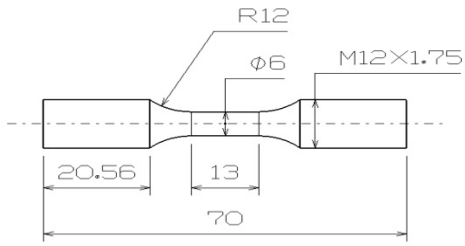


Fig. 1 Shape and dimension of LCF test specimen

Table 1. Chemical composition of the Mod.9Cr-1Mo steel (wt.%)

Compositions	C	Cr	Si	Mn	Ni	Mo	V	Nb
Mod.9Cr-1Mo steel	0.1	8.59	0.39	0.43	0.007	0.96	0.21	0.07

Table 2. Equation of calculated results by the Coffin-Manson method

Temp. (°C)	Coffin-Manson formula
600	$\Delta\varepsilon_t/2 = 10^{-0.43316}(2N_f)^{-0.1292} + 10^{4.12832}(2N_f)^{-1.57862}$

Table 3. Equations of calculated results by plastic and total strain energy densities

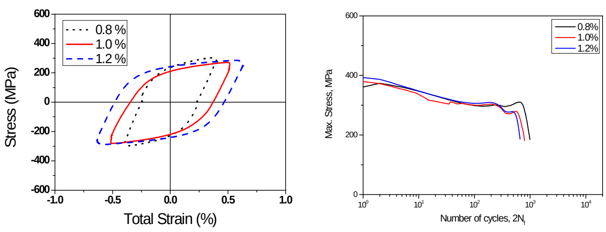
Temp. (°C)	Plastic strain energy density	Total strain energy density
600	$W_p = 5845073.81(N_f)^{-1.46139}$	$W_t = 2761404.32(N_f)^{-1.34033}$

3. Results and Discussions

Fig. 2 shows both hysteresis loop and stress-life curves at 600℃ for Δε=0.8, 1.0, and 1.2 %, respectively. With increasing strain amplitude, the stress range is decreased and plastic deformation area is increased. But, maximum stress makes no difference for stress-life curves. Simply, strain-softening behavior was observed to see a decreasing maximum stress as test cycle continues.

Fig. 3 represents relationship between strain amplitude and fatigue life obtained from the Coffin-Manson and Table 2 shows evaluated Coffin-Manson formula. The transition fatigue lives are 1401 reversals and LCF dominant fracture is obtained under transition fatigue lives.

Table 3 shows both plastic and total strain energy densities obtained by calculating area of each hysteresis loops.



(a) hysteresis loops (b) stress-life curves

Fig. 2 LCF characteristic of Mod.9Cr-1Mo at 600℃ for various strain range

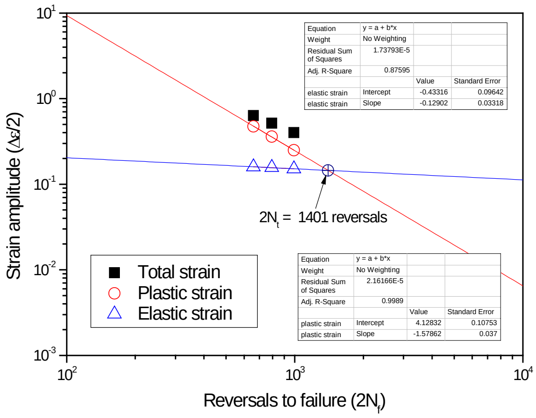


Fig. 3 Relationship of strain-life curves at 600℃

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