A STUDY ON CREEP CRACK PROPAGATION BEHAVIOUR OF AGED CrMoV FOR A LONG TERM USED TURBINE

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ABSTRACT

The rotor and casing parts of steam turbines exposed high temperature and high stress for extensive periods are deteriorated by correlation between creep and fatigue. Microcrack initiates and coalesce with the main crack under creep condition. In order to apply to steam turbine components for creep crack propagation evaluation, the most suitable parameter must be selected for creep crack propagation evaluations of degrade CrMoV. Therefore, in this study, the experimental characteristics of the creep crack propagation behaviour have been investigated by both FEM analysis and creep burst test of cylinder model for the aged CrMoV rotor steel. As a result, comparisons of predicted the crack length to crack propagation time being used by parameter J* and Q* with experimental results show good agreement. In the study, though parameter K is too conservative, both parameters J* and Q* are available to predict of the creep crack propagation behaviour for aged CrMoV steel for practical use.

1. INTRODUCTION

The rotor and casing parts of steam turbines exposed high temperature and high stress for extensive periods are deteriorated by correlation between creep and fatigue. Microcrack initiates and coalesce with the main crack under creep condition.[1] In order to apply to steam turbine components for creep crack propagation evaluation, the most suitable parameter must be selected for creep crack propagation evaluations of degrade CrMoV. Therefore, it is important to understand parameter characteristics such as stress intensity factor K, Creep J - integral J* and Q* parameter for degraded CrMoV rotor steel.

In this study, the experimental characteristics of the creep crack propagation behaviour have been investigated by both FEM analysis and creep burst test of cylinder model for the aged CrMoV rotor steel.

2. EXPERIMENT

2.1 Material

In order to verify the influence of creep crack growth behaviour by creep properties, we carried out field evaluation tests using intermediate-pressure turbine rotor of a 600MW unit.

Steam condition and chemical composition of this rotor is indicated in Table 1 and 2 respectively.

Table 1 Steam condition and operation history

	600MW HIP rotor
Pressure of main steam	24.1MPa
Temperature of main steam	566℃
Total operation hours	143,000
Total number of startings	591

Table 2 Chemical composition of the test metal (wt.%)

C	Si	Mn	P	S	Ni	Cr	Mo	V
0.29	0.21	0.68	0.008	0.01	0.35	1.06	1.3	0.27

2.2 Specimen

The test material is used from aged CrMoV rotor steel. Figure 1 and 2 show the locations in the HIP rotor to get specimen out of respectively. At first, two large blocks were cut out of both the first-stage (Block A) and the journal (Block B), and then specimen were produced from the parts near the bore surface of the Block A. The condition of a Block A is a high temperature and high stress. The specimens from the journal were used to produce the reference the tensile properties and creep data, since that part was not under high temperature and high stress. The 6mm diameter of specimen was used to investigate the tensile strength test and the creep properties near the bore surface. Compact test specimens were produced in the same way.

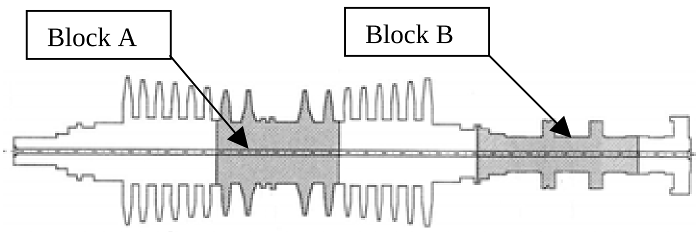


Fig.1 Locations of specimens

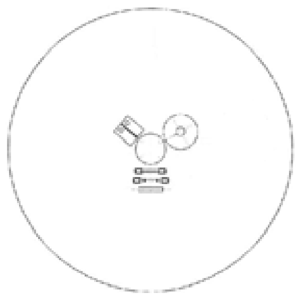


Fig.2 a cross section of a block A

3. TEST RESULTS

3.1 Tensile strength

The tensile test was performed at room temperature and 566℃.

Figure 3 shows the comparison of data with the result of tensile strength test on the used metal, high temperature, high stress and low temperature, low stress. The tensile strength of the used metal decrease by aging, however, the degradation of tensile strength by softening was small.

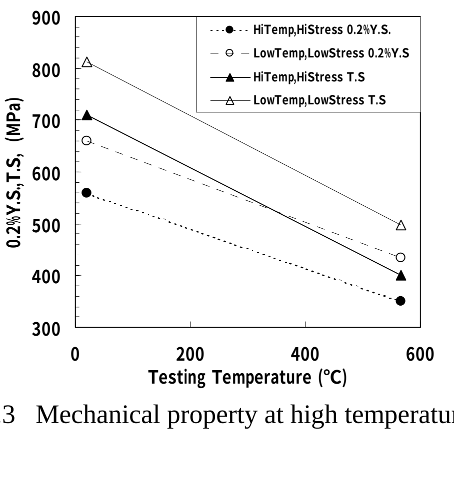


Fig.3 Mechanical property at high temperature

3.2 Creep Rupture Strength

Figure 5 shows the creep rupture test data. The creep strength of the Block A is slightly deteriorated by long term heating. Relationship between the creep damage and Vicker's hardness distribution of Figure 4 are reliable for practical use.

According to Kimura, et al.[2], Larson Miller Parameter is expressed by Eq. (1) using the Hv,

$$LMP=[\Sigma a_i \cdot (\log\sigma)^{i-1}] \cdot Hv + \Sigma b_i \cdot (\log\sigma)^{i-1} \qquad (1)$$

where, $LMP=T(20+\log t_r)$, T is absolute temperature, t_r is creep rupture time, a_i and b_i are constants, Hv is Vicker's hardness, and σ is applied stress.

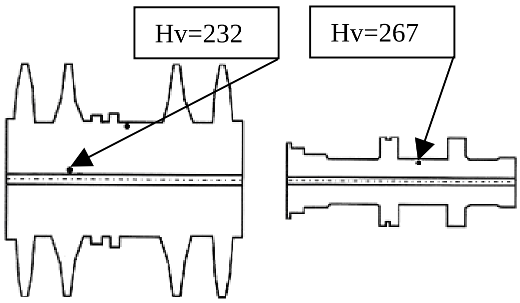


Fig.4 Results of hardness test

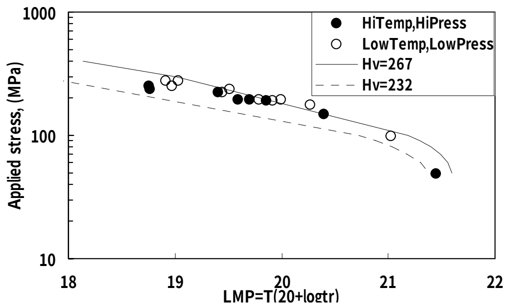


Fig.5 Results of creep rupture test

3.3 Crack propagation behaviour

50.0mm wide and 20mm thick compact type (CT) precracked specimens with electrodes were heated up to the test temperature. Creep test are conducted at 566℃. Figure 6, 7 and 8 show the creep crack growth rate, da/dt, as a function of the stress intensity factor K, Creep J - integral J* and Q* parameter respectively.

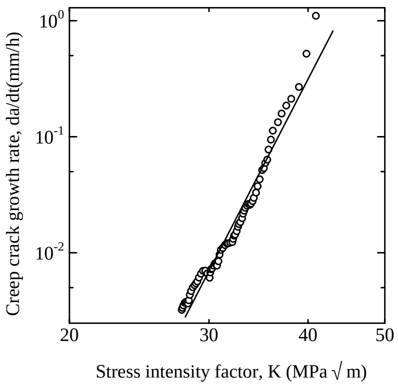


Fig.6 Crack growth rate, da/dt vs. K

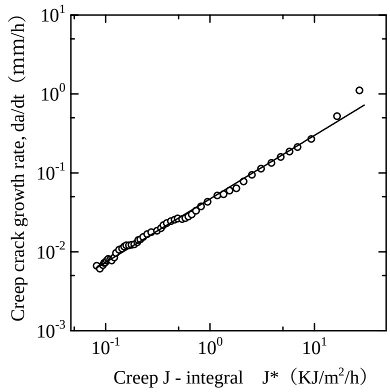
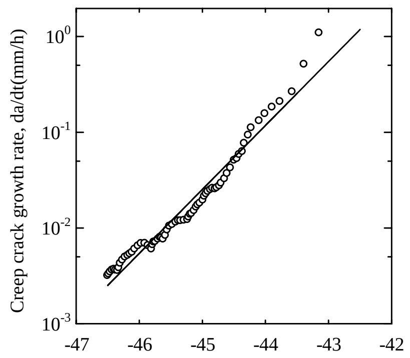


Fig.7 Crack growth rate, da/dt vs. J*



$$Q^* = \frac{56.49}{T}10^3 \log\frac{K}{61.38} - 47.531\log\frac{K}{33} - 14.45\log\sigma_g$$

Fig.8 Correlation between crack growth rate and Q^*

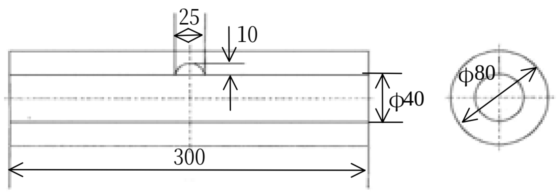


Fig.9 Creep burst test specimen of a cylinder model

3.4 Crack propagation behaviour of a cylinder model

The creep crack propagation test of cylindrical specimen is shown in Figure 9. A semi-elliptical precracked was introduced by machine process. In this study, a semi-elliptical surface crack inner surface of internally was a pressurized cylinder. The material is aged Cr-Mo-V rotor steel, temperature is set to 566℃ uniformly. As experimental result, the total creep fracture life of this precracked model was 261 hours.

4. Analysis

4.1 Creep Crack Propagation Analysis of cylinder model

The parameter K and J* were selected to evaluate creep crack propagation. Those parameters are calculated by using FEM software. In this paper, FEM analysis was carried out by ABAQUS, which is FEM solver available in the market. The finite element model is shown in Figure 10. The quarter-cylinder model was constructed with quadratic elements containing 3714 twenty-node brick. The thickness and the inside radius refer to Figure 9. Position around the crack front is defined by the angle $\theta = 0 \sim 90°$ at the crack front, as shown in Figure 11.

A semi-elliptical surface cracked is subjected to a uniform loading pressure of 157MPa and temperature of 566℃. The calculation of parameter K and J* at the points along the crack front were indicated in Table 3.

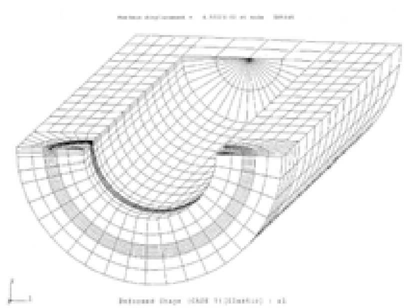


Fig.10 Finite element model of cylindrical specimen containing a semi-elliptical surface crack.

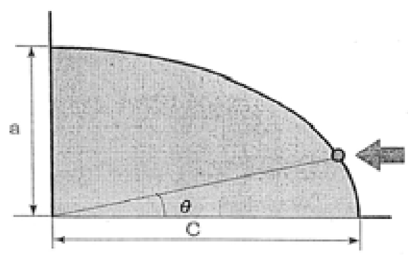


Fig.11 Crack front angle point, θ =90° is the deepest point of crack surface.

Table 3 Analysis results of Stress intensity factor K and creep J – integral J*

a(mm)	K(MP√m)	J*(KJ/m²/h)
10	43.7	0.47
13	53.6	2.32
16	67.6	164.75
18	78.8	574.67

4.2 Crack Propagation Behaviour

As shown in the previous section, in the aged metal, the creep crack growth rate of CT specimen is approximated by equations (2), (3), and (4) respectively.

$$da/dt=1.928\times 10^{-22}\times (K)^{13.24} \quad (2)$$
$$da/dt=0.0465\times (J^*)^{0.8048} \quad (3)$$
$$da/dt=3.155\times 10^{28}\times \exp(1.54Q^*) \quad (4)$$

where, a is crack length. on the other hand, Q* was given by [3]:

$$Q^* = \frac{56.49}{T}10^3 \log\frac{K}{61.38} - 47.531\log\frac{K}{33} - 14.45\log\sigma_g \quad (5)$$

where, T is absolute temperature and K is stress intensity factor, σ_g is gross stress. Specimens were taken from a retired casing which had been in service for 270,000 hours approximately.

In this study, in order to compare K, J* with Q* in the used material, the creep crack growth can be calculated by using equations (2), (3) and (4). Figure 12 and 13 show the example of creep crack propagation evaluation by J* and Q* respectively. These show the crack length as a function of the crack propagation time.

From there result of calculation, in the case of parameter K, the precracked 1.0mm was indicated 33hours. On the other hand, precrack depth, which require 260 hours of the creep fracture life approximately are 8.6mm as J* and 11.7mm as Q* respectively. Therefore, the creep crack propagation shows a good approximation of experimental creep fracture life, while parameter K is too conservative. It is reasonable to use the parameter J* and Q* as a prediction of creep crack growth for the evaluation of aged Cr-Mo-V steel.

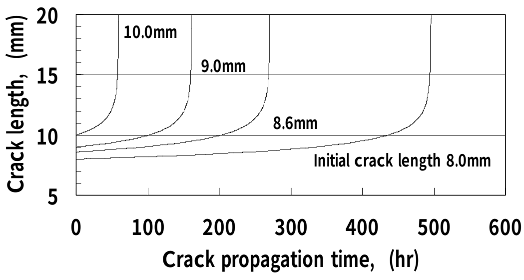


Fig.12 Prediction result of crack length evaluated by J*

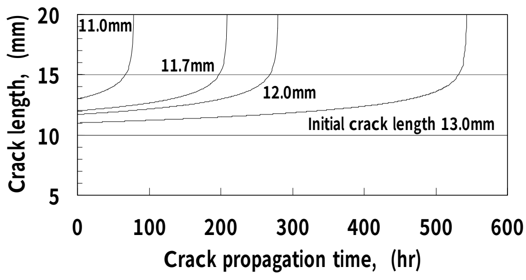


Fig.13 Prediction result of crack length evaluated by Q*

5. DISCUSSION

The crack extension behaviour was in Figure 12 and 13 respectively. From these results, comparisons of predicted crack length to the crack propagation time being used by parameter J* and Q* with experimental results show good agreement. Though both parameters are applicable for practical use, Parameter J* is slightly conservative. The creep crack length observed from CT specimen is plotted as a function of the nondimensional time in Figure 14. The crack propagation rate characteristic of J* have a tendency to take the region of higher creep crack growth rate, as shown in Figure 14. In the case of J*, there is a tendency for crack growth rate to use the region where the data is concentrated near the higher da/dt value which occupies 20〜30% of the total fracture life as shown in Figure 15. On the other hand, Q* has the region of occupied 50〜60% of that life accelerated region of creep crack growth. It is found that the reason Parameter Q* is not slightly conservative.

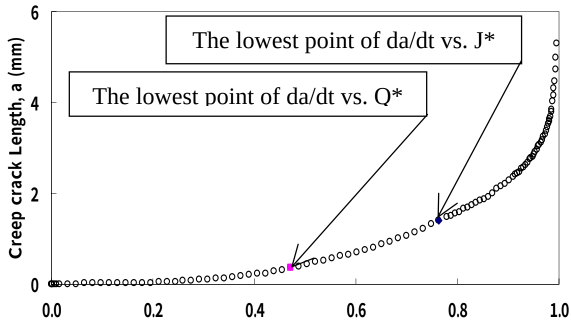


Fig.14 Creep crack length a vs. t/t_f ; t_f=creep fracture life

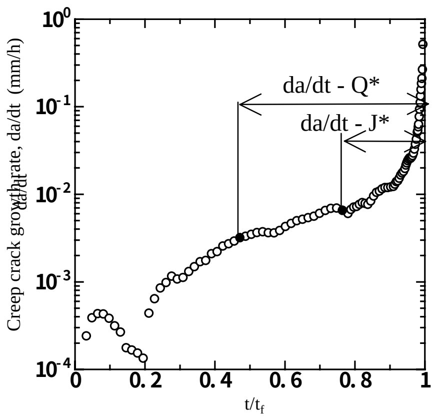


Fig.15 Creep crack growth rate of CT precracked specimen, da/dt vs. t/t_f

6. CONCLUSION

In the study, comparisons of predicted the crack length to crack propagation time being used by parameter J* and Q* with experimental results show the good agreement. Therefore though parameter K is too conservative, both parameters J* and Q* are available to predict of the creep crack propagation behaviour for aged CrMoV steel for practical use.

ACKNOWLEDGMENT

This work was conducted as a part of the joint research supported by Inukai, Toshiba Corporation and Tohoku Electric Power Co., Inc.

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