COMPARISON OF TWO CREEP CRACK GROWTH PARAMETERS, *C** AND *Q**, WITH F.E. ANALYSIS

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ABSTRACT

This paper presents a numerical study of creep crack growth in a compact tension specimen. The constitutive behaviour of steel is described by a power law creep model. A damage-based approach is used to predict the crack propagation rate. Elastic-plastic-creep analyses are performed to predict crack extension under plane stress and plane strain conditions. The same load is applied at three different temperatures, 320°C, 360°C and 400°C. In addition, three different loads are applied at the same temperature, 360°C. Two parameters, C^* and Q^* parameters, are applied to characterise creep crack growth (CCG) rate for comparison. When C^* parameter is used for the characterisation of CCG rate, tail parts are observed in the early stage for all F.E. predictions, while for Q^* parameters these are not appeared. The F.E. results indicate that under fully steady state da/dt-C^* relationship is little dependent on temperatures, load and stress conditions, while under early stage of CCG da/dt-Q^* relationship is little dependent on temperatures, load and stress conditions.

1 INTRODUCTION

Many components used in power generation plants are continually exposed to high temperatures and failure processes such as creep crack growth can occur within the high temperature regime. Therefore, it is important to predict creep crack growth with high accuracy in order to assess the reliability of such components. In order to characterise creep crack growth (CCG) rate, two parameters, C^*parameter (e.g. [1]) and Q^* parameter (e.g. [2]), have been proposed and applied for various materials (e.g. [3] and [4]).

With advances in finite element (FE) methods, creep crack growth in compact tension (CT) fracture specimen has been predicted and creep parameter C^* was used to correlate the predicted crack growth data under steady state ([5] and [6]). In this paper, using the F.E. results, two creep crack growth parameters, C^* and Q^*, are compared.

2 MATERIAL DATA

The material properties for the carbon manganese (C-Mn) steel at 320°C, 360°C and 400°C were obtained from uniaxial tensile tests and creep tests[7]. The material batch chosen in this study has been designated as a high nitrogen content C-Mn steel. The yield strength, UTS and Young's modulus of the material are taken to be 240 MPa, 570 MPa and 190 GPa respectively, which are the values for the steel at 360°C. Tensile data was available for the material only at 360°C so the post-yield response is assumed to be independent of temperature. Creep deformation is generally considered to be composed of primary, secondary and tertiary creep regimes. The average creep rate, $\dot{\varepsilon}_A$, defined as Equation 1, is used to account for the three stages of creep in a relatively simple way.

$$\dot{\varepsilon}_A = \frac{\varepsilon_f}{t_r} = A\ \sigma^n \quad , \tag{1}$$

where ε_f is failure strain, t_r is the time to rupture and σ is stress applied. For this material ε_f has been found to be relatively independent of stress and temperature and the mean value of uniaxial creep failure strain is estimated as 18%

The value of n is equivalent to 10. The corresponding values of A at 320°C, 360°C and 400°C are 2.82×10^{-31}, 1.78×10^{-30}, 2.47×10^{-29}, respectively.

3 FINITE ELEMENT MODELING

3.1 Damage Accumulation

The creep ductility exhaustion approach ([5], [6] and [8]) is used to account for the accumulation of creep damage. A damage parameter, ω, is defined such that $0 \le \omega \le 1$ and failure occurs at a material point when $\omega = 1$. The rate of damage accumulation is related to the equivalent creep strain rate, $\dot{\varepsilon}_c$, by,

$$\dot{\omega} = \frac{\dot{\varepsilon}^c}{\varepsilon_f^*} \quad , \tag{2}$$

where ε_f^* is the multiaxial creep ductility. In order to calculate ε_f^*, Cocks and Ashby model [9] has been used.

3.2 Finite Element Model

A 2D FE model of a CT specimen is used in this study. The detail of FE modelling is described in

[5], [6] and also in [8]. The mesh shown in Fig. 1 is used, where the mesh size at crack tip is approximately 0.0154 mm which is similar to the grain size for C-Mn steel examined.

Crack growth was modelled using a nodal-release technique—i.e. when damage, ω, reaches unity ahead of the crack tip, the node at the crack tip is released. Both plane stress and plane strain analyses have been carried out. Elastic-plastic-creep analysis has been carried out. Three different loads (5.2 kN, 7.3 kN and 9.0 kN, the corresponding gross stresses are 66 MPa, 93 MPa and 115 MPa, respectively) are applied at 360°C and for three different temperatures (320°C, 360°C and 400°C) the same load (7.2 kN) is used.

All finite element analyses were conducted using ABAQUS 5.8 [10].

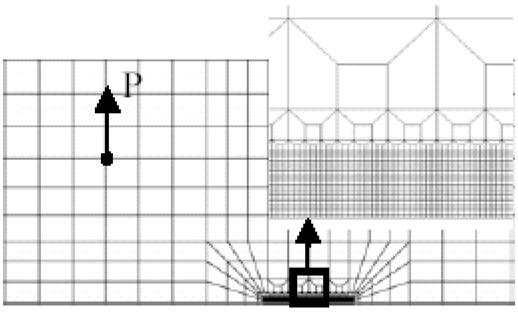

Figure 1: Finite element mesh for creep crack growth analysis of a CT specimen.

4 FINITE ELEMNT RESULTS

In order to calculate Q^* parameter for FE analysis, the results from plane stress conditions are firstly used. Fig. 2 shows the relation between CCG rate and stress intensity factor, K, under plane stress conditions. It is seen that there is no dependence of the slope on temperature and load applied. From Fig. 2(a), the index can be determined as 17.2. The relation between CCG rate and temperature is shown in Fig. 3, which is obtained from Fig. 2(a). It is seen that the CCG rate is dominated by a thermal activated process and the thermally activation energy under creep crack process can be calculated as Q = 185 J/molK. Fig. 4 shows the relationship between CCG rate and gross stress, σ_g, at K = 30 MPam$^{0.5}$ and 360°C. It is seen that CCG rate is correlated with gross stress and the slope is calculated as – 6.25.

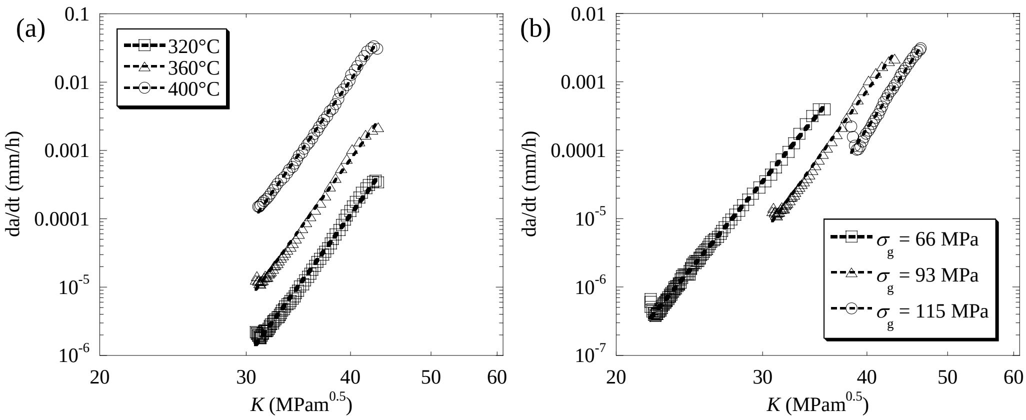

Figure 2: Relationship between CCG rate and Stress intensity factor, *K*.

(a) at three different temperatures and (b) different load

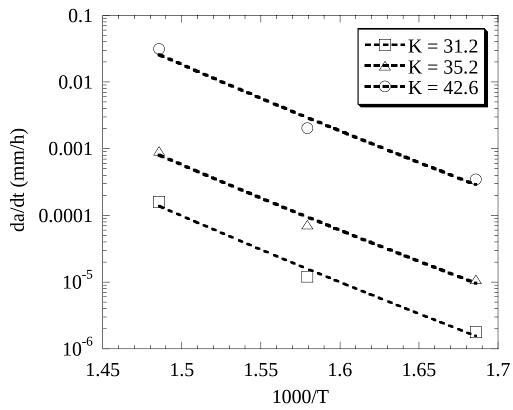

Figure 3: Relation between CCG rate and inverse value of absolute temperature

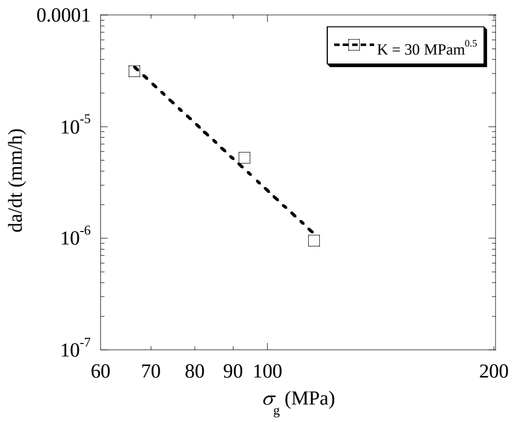

Figure 4: Relation between CCG rate and σ_g at K = 30 $MPam^{0.5}$ and 360°C

From Fig. 2 to Fig. 4, Q^* parameter of C-Mn steel under plane stress conditions can be obtained as

$$Q^* = -6.2545*\text{Log}(\sigma_g)+17.2*\text{Log}(K)-185.5457/(8.31*10\hat{}-3*(T))*\text{Log}(e) \quad (3)$$

Figure 5 shows the relationship between CCG rate and Q^* parameter for plane stress conditions. It is seen that there is very good single correlation between CCG rate and Q^* parameter. Whilst, Fig. 6 shows the relationship between the CCG rate and Q^* parameter (Equation (3)) under plane strain conditions. The band of plane stress condition (see Fig. 5) is also plotted. It is seen that initial part of CCG rate for all CCG data is located in plane stress band However as crack grows, the data of plane strain conditions diverts from plane stress band.

Whilst, Fig. 7 and 8 are relationship between CCG rate and *C**parameter under plane stress and plane strain conditions, respectively. From Fig.7 and 8 dual part (tail part) is seen for all FE results. However it is seen in Fig. 7 that the data under plane stress conditions are plotted within the narrow band. It is seen in Fig. 8 that the data under plane strain conditions are close to plane stress conditions with crack grows.

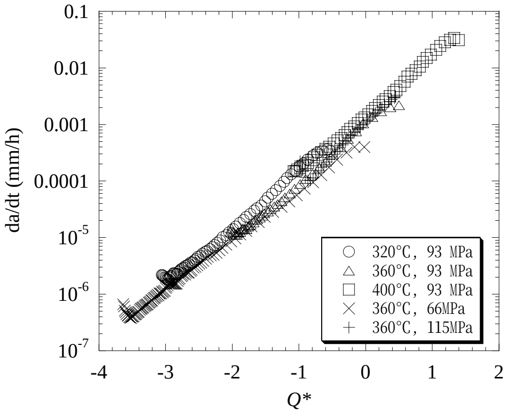

Figure 5: Relation between CCG rate *Q** parameter for pale stress conditions

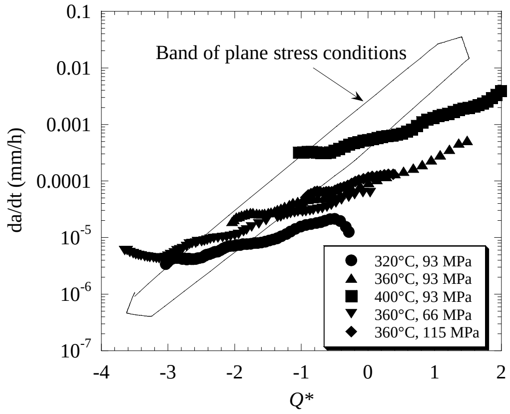

Figure 6: Relation between CCG rate *Q** parameter for pale strain conditions

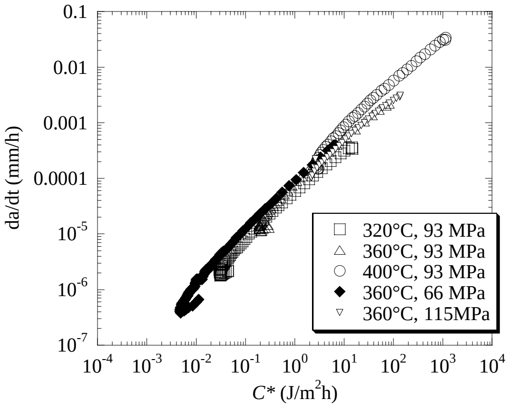

Figure 7: Relation between CCG rate *C** parameter for pale stress conditions

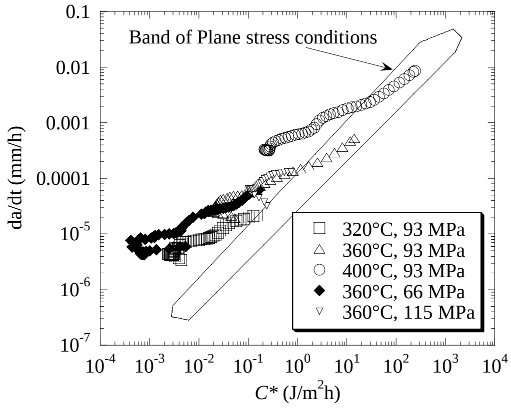

Figure 8: Relation between CCG rate *C** parameter for pale strain conditions

5 Discussion and Conclusion

In this paper, two creep crack growth parameters, *C** and *Q**, are compared using F.E. CCG model of C-Mn steel.

When C^* parameter is used for the characterisation of CCG rate, tail parts are observed in the early stage for all F.E. predictions, while for Q^* parameters these are not appeared. The F.E. results indicate that under fully steady state d*a*/d*t*-C^* relationship is little dependent on temperatures, load and stress conditions, while under early stage of CCG d*a*/d*t*-Q^* relationship is little dependent on temperatures, load and stress conditions. This might indicate that Q^* parameter is

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