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# Study on the estimation of high temperature fracture parameter for mismatched weld creep cracks

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ABSTRACT

Evaluation of the creep crack growth is very important for predicting the life of high temperature structures. Since $C_t$ can uniquely characterize creep crack growth from the small scale creep stage to the extensive steady state creep stage, an engineering estimation method of $C_t$ was proposed for a crack located in the weld with mismatched material properties between the base material and the weld material based on the simulation results of compact tension specimens. For the crack located in the center of welding seam, $C_t$ was estimated by the proposed method under the small scale creep stage and by the reference stress method under the extensive steady state creep stage; in this way, $C_t$ was estimated under the whole creep stage. The estimated results agreed well with the simulation results if the width of welding seam of $h$ was no smaller than the size of the stress intensity factor dominance zone.



## 1. Introduction

Weld cracks widely exist at high temperature structures. The cracks are often found along the heat affected zone (HAZ) or the weld fusion line between the base material (BM) and the weld material (WM) [1,2]. Mismatched weld cracks usually exist at these regions for them with various material properties. $C^*$ is often used to characterize the crack tip stress and strain fields and the creep crack growth. In order to estimate $C^*$ of the mismatched weld cracks, the traditional way is simply to assume that the weld structure is a homogeneous material with the weakest material properties among BM, WM and HAZ; but Tu [3,4] showed that a few large errors were possibly produced by this way and he introduced a material mismatch coefficient to consider the effects of mismatched material properties and geometries on $C^*$. Based on the reference stress method, Xuan [5] proposed a method to estimate $C^*$ for a mismatched weld crack; the method was verified by finite element method (FEM); furthermore, he modified the calculation equation of $C^*$ in the American Society for Testing Materials (ASTM) for mismatched weld cracks and also validated it by FEM [6]. However, $C^*$ can only be used under the extensive steady state creep stage, even though a lot of works prove [7,8] that there are good correlations between creep crack growth (CCG) rates and $C^*$.

From the small scale creep stage to the extensive steady state creep stage, Saxena [9–11] has proved that $C_t$ can uniquely characterize CCG rates for a variety of materials. Based on the simulation results, Yoon [12] proposed a method to estimate $C_t$ for a kind of weld interface cracks with mismatched material properties. For weld non-interface cracks with mismatched material properties, there is currently no method that can estimate $C_t$.

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**Nomenclature**

| | |
|---|---|
| $A$ | power-law creep coefficient |
| $a$ | crack length |
| $B$ | specimen thickness |
| $C_t$ | high temperature fracture parameter |
| $(C_t)_{SSC}$ | $C_t$ under the small scale creep stage |
| $(C_t)_{SS}$ | $C_t$ under the extensive steady state creep stage |
| $(C_t)_{SS-(9)}$ | $(C_t)_{SS}$ estimated by Eq. (9) |
| $(C_t)_{SS-(10)}$ | $(C_t)_{SS}$ estimated by Eq. (10) |
| $C^*$ | A path-independent $C$-integral defined under the extensive steady state creep stage |
| $C^*_{FEM}$ | $C^*$ calculated by FEM |
| $E$ | Young's modulus |
| $\varepsilon_c, \dot{\varepsilon}$ | creep strain and creep strain rate, respectively |
| $F$ | $K_I$-calibration function |
| $F'$ | derivative of $F$ with respect to $a/W$ |
| $G$ | energy release rate |
| $g$ | modified calibration parameter caused by mismatched material properties |
| $h, l$ | width of welding seam |
| $h_1$ | dimensionless function of $a/W$ |
| $I_n$ | dimensionless function of $n$ |
| $K_I$ | mode I stress intensity factor |
| $K_{I-FGM}$ | mode I stress intensity factor of functionally graded materials |
| $M$ | mismatch ratio |
| $n$ | power-law creep exponent |
| $n_{eq}$ | equivalent power-law exponent |
| $\eta$ | a dimensionless function dependent on $a$, $W$ and $n$ |
| $\eta_m$ | modified calibration factor caused by mismatched material properties |
| $P$ | applied load |
| $r_c, \dot{r}_c$ | radius of the creep zone and expansion rate of the creep zone, respectively |
| $\tilde{r}_c$ | dimensionless function dependent on $n$ and $\theta$ |
| $\theta$ | angle measured from the crack plane ahead of the crack tip |
| $t$ | elapsed time after loading |
| $t_T$ | transition time |
| $\dot{V}_c$ | load line deflection rate |
| $(\dot{V}_c)_{SSC}$ | $\dot{V}_c$ under the small scale creep stage |
| $(\dot{V}_c)_{SS}$ | $\dot{V}_c$ under the extensive steady state creep stage |
| $W$ | specimen width |
| $\alpha$ | dimensionless function of $n$ |
| $\beta$ | scaling factor |
| $\upsilon$ | Poisson's ratio |
| $\sigma, \dot{\sigma}$ | stress and stress rate, respectively |

In this paper, correlative theories of $C_t$ were introduced first and then FEM was used to calculate $C_t$ of mismatched weld cracks (a kind of non-interface cracks). The weld model was an idealized bi-material "sandwich" structure without considering HAZ and residual stress. Finally, based on the FEM results, an estimation method of $C_t$ was proposed.

## 2. Theory background

Under the small scale creep stage, the high temperature fracture parameter of $C_t$ is defined by Saxena [9] as follows:

$$(C_t)_{SSC} = \frac{P(\dot{V}_c)_{SSC}}{BW}\frac{F'}{F} \tag{1}$$

where $(\dot{V}_c)_{SSC}$ is the load line deflection rate $(\dot{V}_c)$ under the small scale creep stage, $W$ is the specimen width, $B$ is the specimen thickness, $P$ is the applied load and $F$ is a $K_I$-calibration function. $F' = dF/d(a/W)$ where $a$ is the crack length. $(\dot{V}_c)_{SSC}$ can be experimentally measured or estimated as follows for plane strain:

$$(\dot{V}_c)_{SSC} = \frac{2BK_I^2}{EP}(1-\upsilon^2)\beta\dot{r}_c(\theta, t) \tag{2}$$