# Effect of Overload on SCC Growth in Stainless Steels in High Temperature Water

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By incorporating the film slip-dissolution/oxidation model and the elastic-plastic finite element method (EPFEM), the effect of the overload on stress corrosion cracking (SCC) growth rate of stainless steel in high temperature water is discussed in this paper. Results show that SCC growth rate of a 20% cold worked 316L stainless steel in high temperature water decrease in the overload affected zone ahead of the growing crack tip. Therefore, a reasonable overload could availably reduce the SCC growth rate during a certain in-service period.

**Keywords:** Stress Corrosion Cracking, Overload, Crack Growth Rate, Finite Element Analysis

## 1. Introduction

Stress corrosion cracking (SCC) is a failure mechanism that is caused by environment, susceptible material and tensile stress near the crack tip area. Since various stainless steel or nickel based alloy components are subjected to SCC behaviors in light water reactor (LWR), many efforts have been done to understand the underlying mechanism of SCC of core nuclear power engineering materials [1]. Among all mechanism proposed, the film slip-dissolution/oxidation model is widely accepted as a reasonable description of SCC of austenitic alloys in high temperature oxygenated aqueous systems [2]. This mechanism attributes the crack growth to a result of the oxidation at the crack tip that occurred periodically following the rupture of the oxide by crack tip strain. Efforts have been done to utilize the model to quantify the SCC growth rate [3].

The effect of overload on fatigue crack growth has been investigated that indicated the overload could delay retardation of the crack propagation and reduce the crack growth rate [4]. This draws the interests of researchers in the SCC field that whether the overload could also affect the SCC growth rate of structural materials in high temperature water. By incorporating the film slip-dissolution/oxidation model that describes the SCC growth mechanism, the elastic-plastic finite element method (EPFEM) and the former SCC experimental data, the effect of the overload on SCC growth rate of stainless steel in high temperature water is discussed in this paper

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## 2. Calculation Model

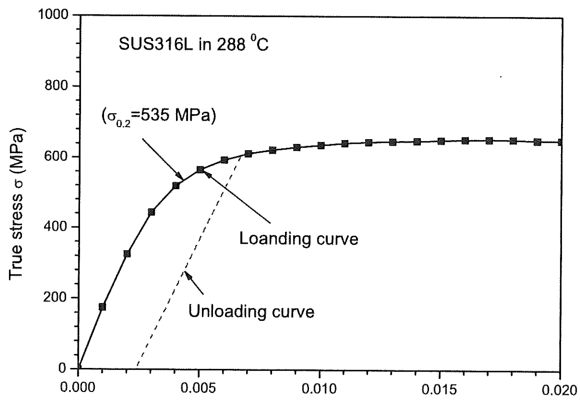
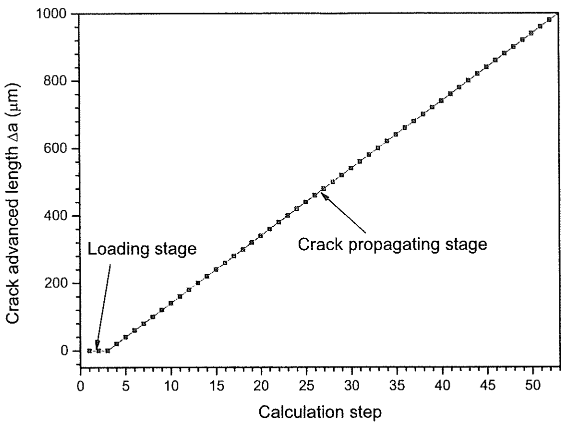


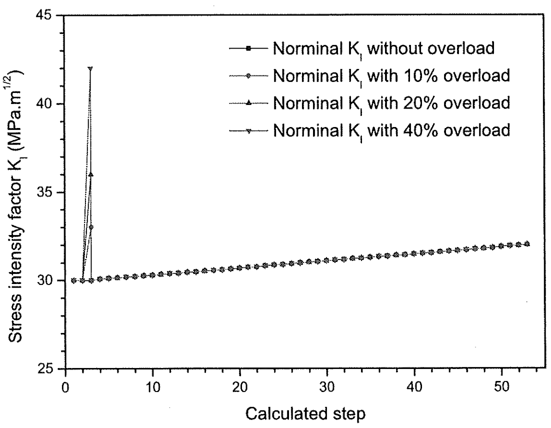

Fig.1 Material mechanical property during loading and unloading course

One inch compact tension (1T-CT) specimen with a constant load $K_I$ is usually used in SCC experiments in high temperature water. Therefore, to investigate the effect of the overload on SCC growth rate, a simulated SCC numerical test with 1T-CT specimen is performed in this study. The numerical analysis process satisfies American Society for Testing and Materials (ASTM) E 813 standards [5].

The material mechanical property of a 20% cold worked SUS316L stainless steel at high temperature (288°) is adopted in this simulation calculation. The mechanical relation of the material during loading and unloading processes is depicted by Fig.1, where the loading mechanical relation is obtained by a tensile strength test and the unloading mechanical relation is simply represented by a linear elastic relation.




a) Crack advanced length




b) Applied load

Fig.2 Parameters change in calculation process

The plastic strain ahead of the crack tip and the SCC growth rate are investigated with the nominal load $K_I$ of 30 MPa·m$^{1/2}$ in this study. The 10%, 20% and 40% overload are separately applied on the specimen during the crack being stationary, which is known as the loading stage. And then the crack propagates 20 μm in each step, and the final length is 1.0 mm, which takes 50 steps in this period. This course is known as crack advanced stage. As will be shown in the following, the total crack increment of 1 mm is generally larger than the overload affected zone that ensures the disappearance of the overload effect at the crack tip at the end of the simulation. The crack increment and applied $K_I$ vs. calculation steps during the simulated numerical process are shown in Fig. 2 (a) and Fig. (b). As can be seen in Fig.2 (b), the applied $K_I$ is slightly increased by the crack propagation, which simulates a process of crack propagation under constant load.

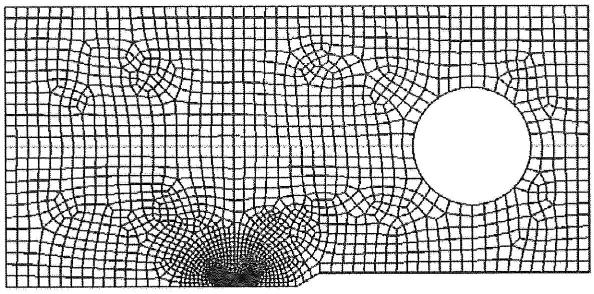


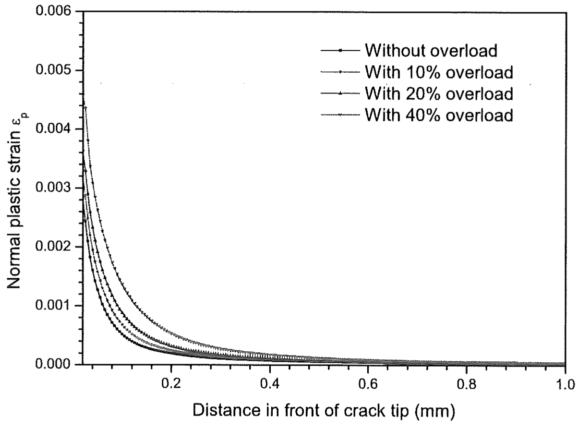
Fig.3 Finite element model of specimen (plane strain)

A commercial FEM code ABAQUS is used in this simulated analysis [6]. A half of the specimen is calculated based on the symmetry condition. Mesh of specimen is shown in Fig.3. 11961 8-node biquadrate plane strain quadrilateral elements are adopted in this model. The mesh in the vicinity of the growing crack tip is observably refined in order to investigate the detailed plastic strain and plastic strain rate in front of the crack tip. X-axis is the opposite direction of the crack growth and Y-axis is the normal direction of the crack growth in the coordinate system. The course of steadily growing crack is simulated by the node release method in ABAQUS. The stationary crack and steadily growing crack are calculated under the elastic-plastic loading and linear-elastic unloading condition, respectively.

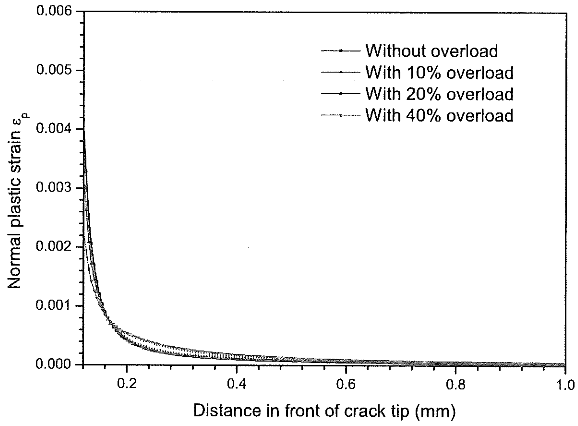
## 3. Results and Discussions

### 3.1 Plastic strain and plastic strain rate in front of the crack tip

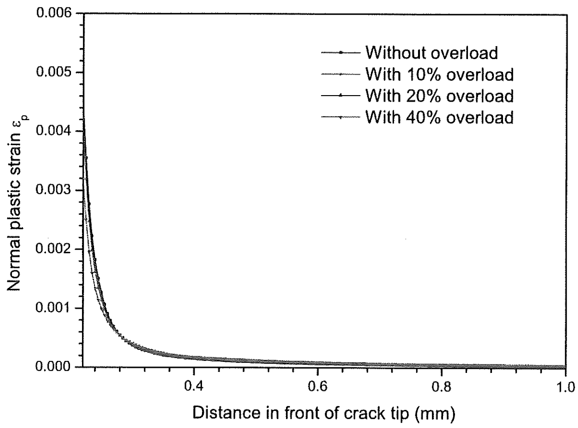
The normal plastic strain in front of the stationary and growing crack tip is shown in Fig. 4. The plastic



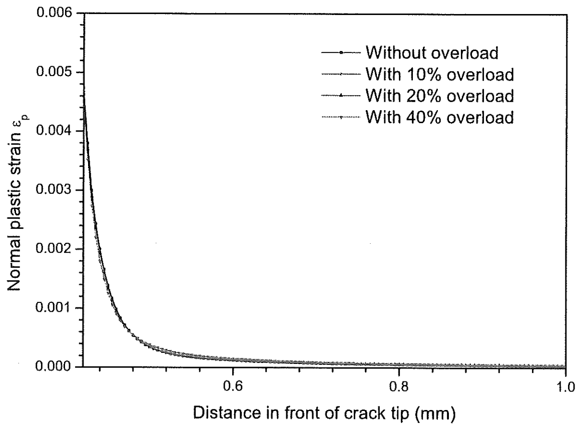

a) Δa=0 μm




b) Δa=100 μm




c) Δa=200 μm




d) Δa=400 μm

Fig.4 Normal plastic strain ahead of stationary and growing crack tip

strains close to the stationary crack tip are increased after the overload is applied, Fig.4 (a). Once the crack starts to propagate, however, the overload decreases the plastic strain at the vicinity of the growing crack tip, Fig. 4(b) and Fig. (c). Further, Fig. 4(a) through Fig. 4 (d) also show that the effect of overload on the plastic strain ahead of the growing crack tip is gradually weaken by the crack propagation until the effect disappears. In addition, the overload affected zone is larger at higher overload level. At 40% overload, the affected zone at the crack tip is about 0.4 mm.

The normal plastic strain at a characteristic point in front of the growing crack tip is shown in Fig. 5, where the distance from the characteristic point to the growing crack tip, $r_0$ adopts 10 μm in this study. The effect of the overload on the plastic strain in front of the growing crack tip could be clearly distinguished in Fig.5. Therefore, the 10 μm could be a reasonable distance from the growing crack tip for investigating the plastic strains in the growing crack tip under the mechanical consideration. Because the applied load $K_I$ increase with the crack propagation, the normal plastic strain at a characteristic point in front of the growing crack tip is slowly increased during the crack propagation.

The effect of the overload on the normal plastic strain rate at the characteristic point in front of the growing crack tip could also be clearly distinguished, Fig.6. Therefore, the 10μm could also be a reasonable distance from the growing crack tip for investigating the plastic strain rate in the growing crack tip under the mechanical consideration

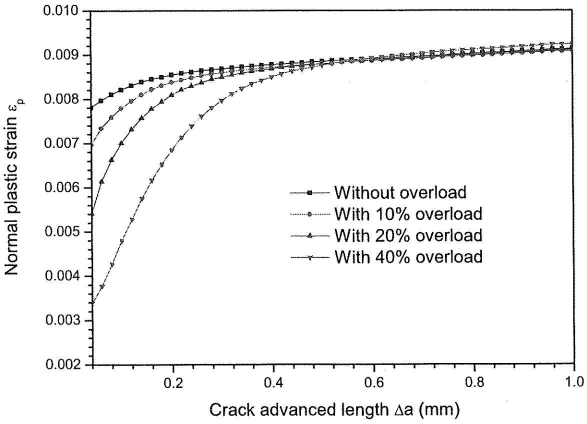



Fig.5 Normal plastic strain at characteristic point ahead of growing crack tip ($r_0$=10μm)

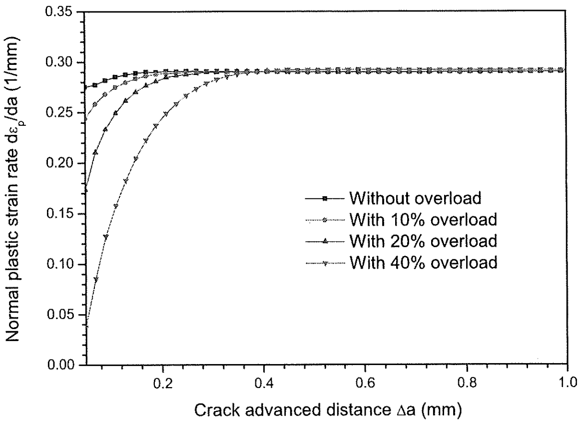



Fig.6 Normal plastic strain at characteristic point ahead of growing crack tip ($r_0$=10μm)

## 3.2 Estimation of SCC growth rate of stainless steel in high temperature water

The crack tip strain $\varepsilon_{ct}$ is the main mechanical affecting SCC growth rate in the film slip-dissolution /oxidation model. Because the cracks tip strain $\varepsilon_{ct}$ is difficulty obtained directly, it is proposed to replace $\varepsilon_{ct}$ by the plastic strain $\varepsilon_p$ at a characteristic distance $r_0$ in front of the crack tip in FRI model [2]. The estimation formulation of the SCC growth rate by incorporating the FRI model and EPFEM is as following [3].

$$\frac{da}{dt} = \kappa_a^{'} \cdot \left(\frac{d\varepsilon_p}{da}\right)^{1/(1-m)} \qquad (1)$$

where $\kappa_a$ is the crack tip oxidation rate constant, which is crack tip is increased and the plastic strain and plastic determined by the electric-chemical environmental and material in the crack tip area, $d\varepsilon_p/da$ is the variation of tensile plastic strain with crack growth at a characteristic distance $r_0$ in front of the crack tip, m is the exponent of the current decay curve in the crack tip.

SCC growth rate of a 20% cold worked 316L stainless steel in high temperature water at 288°C is investigated in this study. Because the main focus of this research is the effect of the overload on SCC growth rate, the crack tip oxidation rate constant $\kappa_a^{'}$ is simply appointed as $5.5\times10^{-7}$, and the exponent of the current decay curve m is appointed as 0.5 based on the experimental data adopted in the similar material and similar experiment conditions [7].

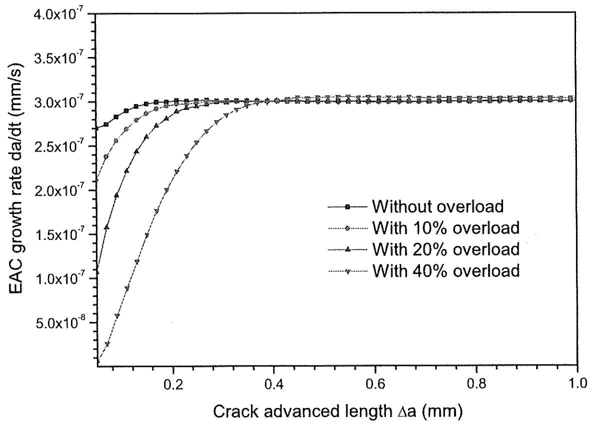



Fig.7 Effect of overload on EAC crack growth rate

The calculated SCC growth rate of SUS316L stainless steel in high temperature water at 288° using Eq. (1) is shown in Fig.7. As can be seen, the overload affected zone is about 400 μm in front of the growing crack tip, and the SCC growth rate in the overload affected zone is observably reduced by the overload. The degree of the decrease in SCC growth rate is increased as the overload level increases.

## 4. Conclusions

1. The overload will availably affect the plastic strain and the plastic strain rate at both the stationary and growing crack tips. Further, the plastic strain close to the stationary strain rate at the vicinity of the growing crack tip will be

decreased after the overload is applied.

2. SCC growth rate of 20% cold worked 316L stainless steel in high temperature water at 288°C is decreased in the overload affected zone ahead of the growing crack tip. Therefore, a reasonable overload could availably reduce the SCC growth rate during a certain in-service period.

## Acknowledgement

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