ICF100882OR

Damage Progression Behavior under High Temperature Creep and Fatigue Conditions

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Abstract

The effect of high temperature damage progression on crack growth and the life were clarified under creep –fatigue interaction and multiplication conditions. The following results were obtained.Damage progression behaviors initiated around a notch tip show different characteristics depending on applied load frequency and creep ductility. It dominates the life of creep crack growth and high temperature fatigue fracture toughness.

Key words: creep-fatigue interaction and multiplication, damage, crack growth rate, crack growth life, SUS304stainless steel, Cr-Mo-Vsteel

1. Introduction

To clarify the effect of high temperature creep and fatigue interaction on the characteristics of crack growth behavior is important as a problem of phenomenal matter and to predict the life of crack growth. As a method of clarification of these matters, the characteristics of the effect of load frequency(f) on crack growth rate and the life are separately estimated into time dependent and cycle dependent mechanism[1-3]. Furthermore, the crack growth life is dominated by creep and fatigue damage under high temperature condition[2,3]. To clarify the characteristics of damage progression, the machine system was designed to enable automatic observation of the mechanical behavior of deformation and damage progression around a crack tip during fatigue and creep loading under computer control and some results have been obtained for SUS304 and Cr-Mo-V steels[2-4].

In this paper, on the basis of these results, the effect of high temperature damage on crack growth rate and the life were clarified and some analyses were performed.

2. Testing method and specimens

The machine system was designed and developed to enable automatic real-time observational experiments with CCD microscope. This microscope can be moved in x, y and z direction with a specified displacement value and time interval under computer control. It can take pictures of deformation and damage progression around a crack tip. These pictures are digitized and analyzed by computer image analytical system.

A specimen is a V type double notched specimen with 4mm width and 1mm thickness. Notch opening angle is 30° and notch tip radius, ρ is 0.05mm. Experiments were conducted under the vacuum condition of less than 10^{-5}torr.Detailed method was written in another literatures [5-7].

3. Damage progression characteristics of SUS304 stainless steel under creep, fatigue and creep-fatigue interaction and multiplication

Behavior of damage progression around a notch tip under high temperature creep-fatigue interaction for various values of load frequency, f were plotted against non-dimensional time as shown in Fig.1 Where D is damage area, t_f is fracture life for each specimen. These results show remarkable extension of creep damage is observed before creep crack initiation and after that, it saturates to some specified value. Under fatigue condition(1Hz), however, damage area is small at the stage of crack initiation, it lineally increases after crack initiation. This behavior is different from that under creep condition. Even though f decreases, this behavior does not saturates to that under creep condition as shown in the result for f=0.0017Hz.

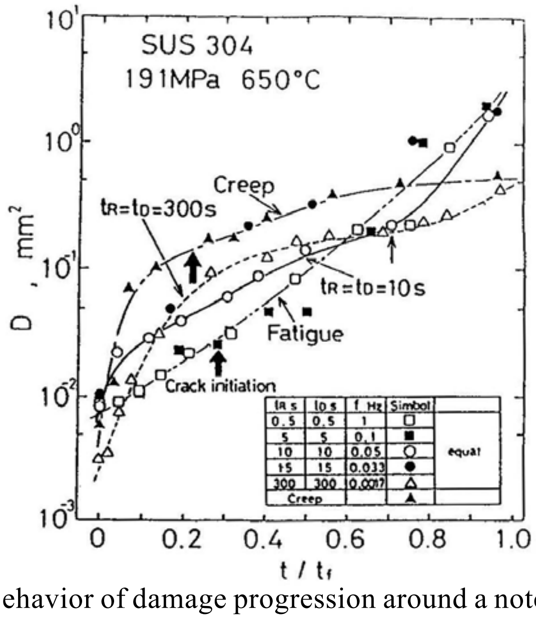

Fig. 1 Behavior of damage progression around a notch tip under high temperature creep-fatigue interaction for various values of *f*.

The results of in situ observation of damage progression behavior under creep and fatigue conditions were shown in Figs.2 and 3. The dark region around a notch tip is damage region. Tensile load is applied in the horizontal direction. Under creep condition, damage spreads over the wide area of specimen and notch opening displacement becomes large.

On the other hand, for the case of fatigue condition with 1Hz, damage localizes around a crack and the value of crack opening displacement is smaller than that for a creep crack. Even though f decreases, for example, f=0.0017Hz, this fatigue effect is also observed in the morphology of damage region.

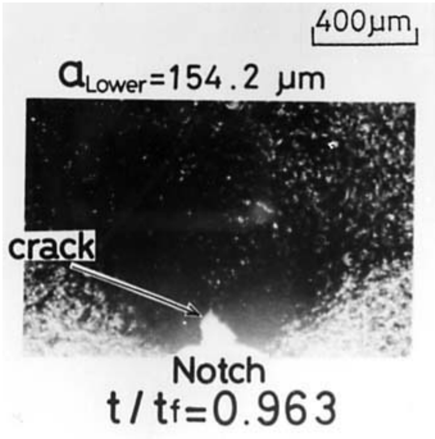

Fig. 2 The results of in situ observation of damage progression behavior under creep condition.

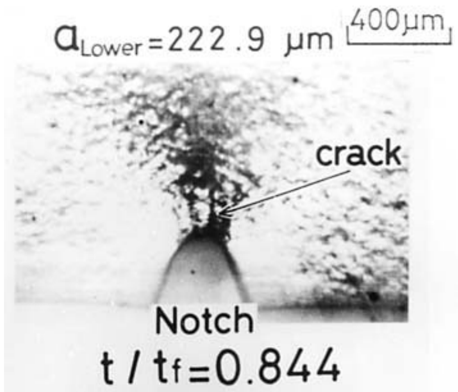

Fig. 3 The results of in situ observation of damage progression behavior under fatigue condition (f=1Hz).

The characteristics of damage progression behavior under creep and fatigue multiplication conditions with stress hold time, t_H were plotted against non-dimensional time as shown in Fig.4.

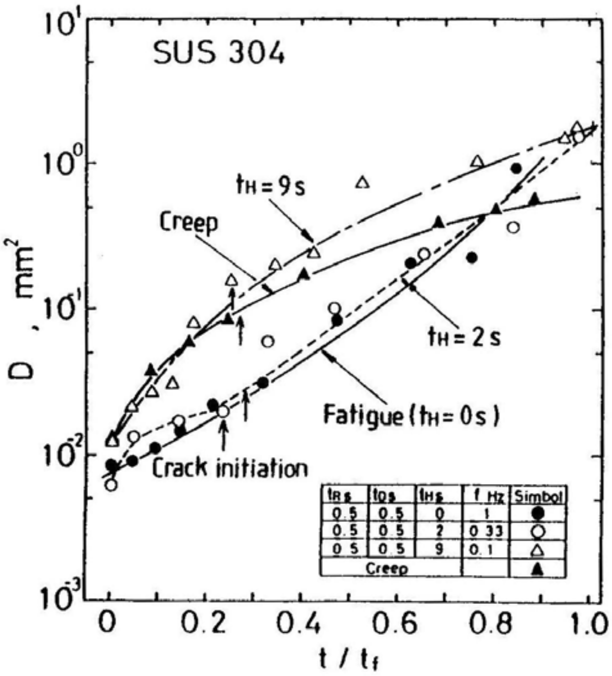

Fig. 4 The characteristics of damage progression behavior under creep and fatigue multiplication conditions with stress hold time, t_H.

These results show, with increase in t_H, that is, $t_H \geqq 9$s, the characteristic is in good agreement with that under creep condition and the definite transition from fatigue to creep occurs, which is different from the characteristics of f under fatigue condition(creep-fatigue interaction).

4. The characteristics of f on crack growth rate(CGR), its life and fatigue fracture toughness under creep-fatigue interaction and multiplication condition for SUS304 stainless steel

The effect of f and stress hold time on CGR and its life were plotted against $f(=1/(t_H+2t_R)$ as shown in Figs.5(a),(b) and 6(a),(b). Where t_R is stress increasing and decreasing time. The characteristic of f on the life of each crack growth is qualitatively in good agreement with each characteristics of f on the low CGR when a crack starts to grow. Furthermore, even though f decreases, the characteristics of f on CGR and inverse value of the life do not saturate to those under creep condition and it was affected by fatigue effect as shown in Figs5(a) and (b).

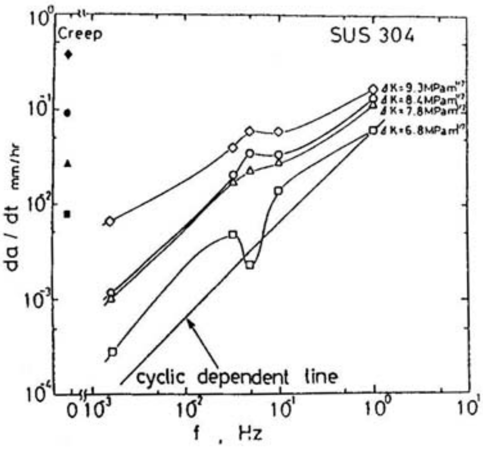

Fig. 5(a) The effect of *f* and stress hold time on CGR

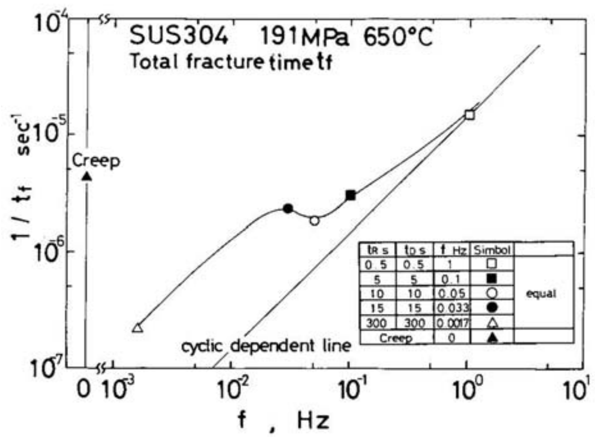

Fig. 5(b) The effect of *f* and stress hold time on CGR

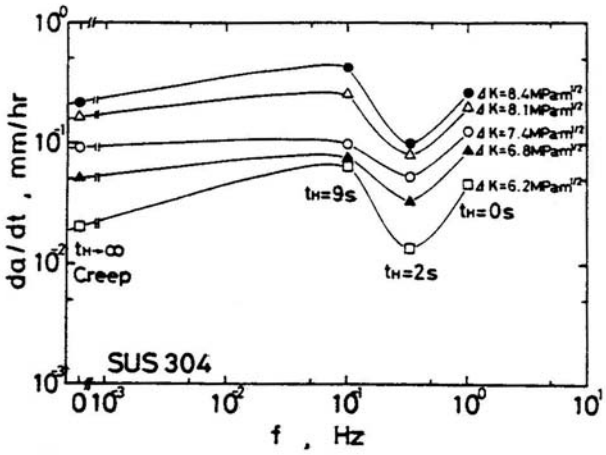

Fig. 6(a) The effect of *f* and stress hold time on CGR

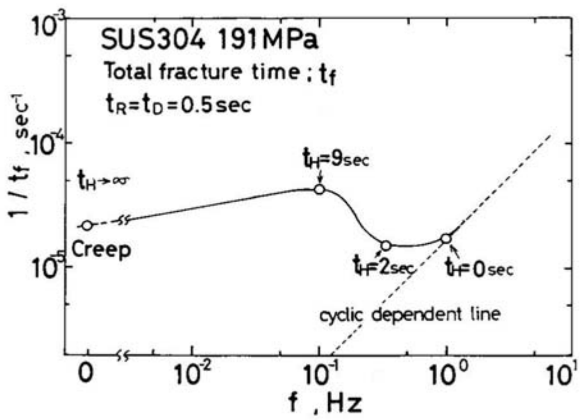

Fig. 6(b) The effect of *f* and stress hold time on CGR

On the other hand, with increases in t_H, both characteristics saturates to those under creep condition as shown for the case of $t_H \geqq 9s$ in Figs6(a) and(b). These characteristics are in good agreement with that of damage progression as shown in Fig.4.

The inverse value of damage area accumulated in the low $\triangle K$ region is plotted against f as shown in Fig.7 which is in good agreement with the characteristics of low CGR and $1/t_f$ as shown in Figs.5(a) and (b). The relationship between Da and fatigue fracture toughness, K_{fc}(stress intensity factor when final fracture occurs) was shown in Fig.8 which shows good correlation each other. That is, K_{fc} is found to be dominated by Da.

Therefore, under creep-fatigue interaction, low CGR, crack growth life and K_{fc} are found to be dominated by Da. These results were observed also for the case under creep-fatigue multiplication condition, that is, t_H effect. These results show damage progression behavior in the initial creep crack growth region dominates the crack growth life and K_{fc} under high temperature creep-fatigue interaction and multiplication conditions.

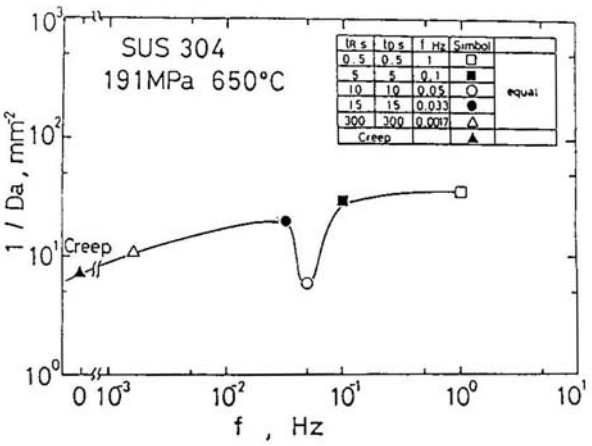

Fig. 7 The inverse value of damage area accumulated in the low ⊿K region.

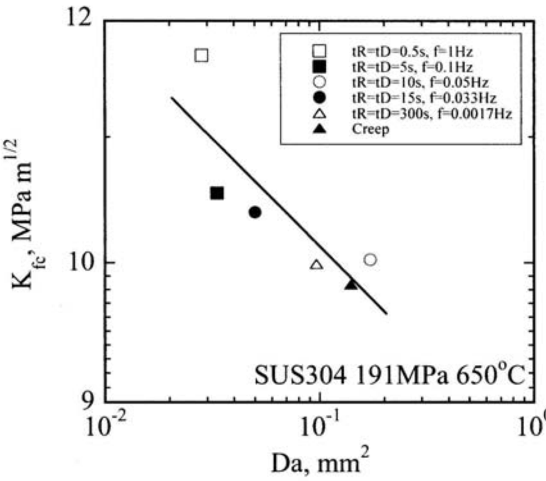

Fig. 8 The relationship between Da and fatigue fracture toughness, K_{fc}.

5. The characteristics of f on the life of creep crack growth and damage progression under creep-fatigue interaction conditions for Cr-Mo-V steel

The inverse values of the life of creep crack growth, $1/t_f$, under creep-fatigue interaction condition for Cr-Mo-V steel were plotted against f as shown in Fig.9[4]. With decrease in f, this characteristic saturates to that under creep condition, that is, time dependent mechanism. The characteristic of f on damage progression obtained by in situ observation is shown in Fig.10[8].

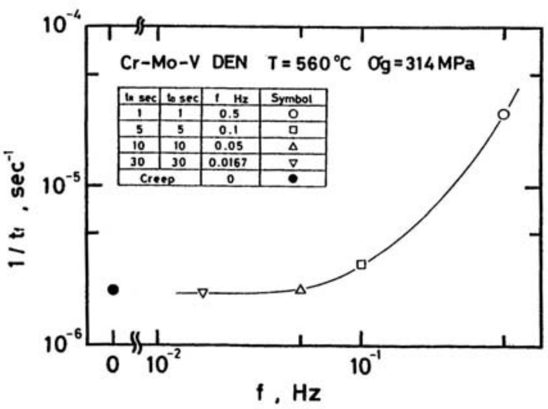

Fig. 9 The inverse values of the life of creep crack growth, $1/t_f$, under creep-fatigue interaction condition for Cr-Mo-V steel.

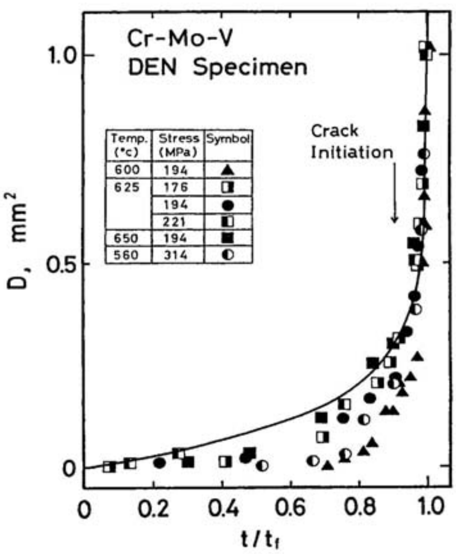

Fig. 10 The characteristic of *f* on damage progression obtained by in situ observation

It is well represented by concave damage law based on Kachanov-Rabatonov theory[9,10] given by eqn.(1). These characteristics are different from that for SUS304 stainless steel as shown in Figs.1 and 5. This will be due to the difference of creep ductility between Cr-Mo-V and SUS304 steels. These results show Kachanov-Rabatonov law will be applicable to that for creep ductile materials such as Cr-Mo-V Steel.

$$D = 1 - (1 - \frac{t}{t_f})^{1/7} \qquad (1)$$

6. Conclusions

Under creep-fatigue interaction and multiplication conditions, damage progression behavior initiated around a notch tip show different characteristics depending on applied load frequency and creep ductility. It dominates the life of creep crack growth and high temperature fatigue fracture toughness.

Acknowledgements

Thanks should be made for financial aid to the Japan Society for promotion of Science(JSPS) of the RFTF program 97R12101. We also appreciate the fruitful discussion about this work by Prof.Takeo Yokobori.

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