CRACK GROWTH CHARACTERISTICS AND DAMAGE IN 12Cr STEEL UNDER HIGH TEMPERATURE CREEP AND CREEP-FATIGUE CONDITIONS

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ABSTRACT

The combined effects of temperature and frequency on the crack growth rate and failure life were investigated using the compact tension specimens of 12Cr steel under creep and creep-fatigue conditions. The creep-fatigue tests were performed by introducing the hold time at the maximum load. At higher frequency where the crack growth rate near the initial stress intensity factor or reciprocal of failure life is proportional to the frequency, the cycle-dependent fatigue process is dominant. The Vickers hardness around the path of crack growth was obtained as a measure of damage during creep and creep-fatigue. Complex fracture surface or branched crack is attributed to the decrease in hardness for creep-fatigue interaction and is characterized by fractal analysis.

1 INTRODUCTION

Many components in high temperature applications are subjected to variable loading patterns during service such as creep, fatigue and creep-fatigue. Creep-fatigue behavior is a complex problem of cyclically applied loading at high temperatures where time-dependent, thermally activated processes can occur. Recently, the combined effects of temperature and frequency on the crack growth rate or reciprocal of failure time under creep-fatigue conditions have been determined and analyzed on the basis of the Arrhenius thermally activated process (Yokobori [1]). It has been shown that the activation energy thus obtained decreases with decreasing hold time or increasing frequency due to the increasing contribution of cycle-dependent fatigue process. Complexity of fracture surface and damage around the crack growth depend on hold-time or frequency. The characterization of fracture surface is difficult only with visual observation technique. Therefore, the complexity of fracture surface has been characterized by using the fractal concept (Yamagiwa [2]).

In this paper, the creep-fatigue tests were performed on the compact tension specimens of 12Cr steel (HR1200) at various combinations of temperature and frequency. The crack growth and failure life were determined and Vickers hardness was obtained as a measure of damage. Fracture surfaces were quantitatively characterized using the fractal concept.

2 EXPERIMENTAL PROCEDURE

The material used was 12Cr steel (HR1200) and its chemical composition is shown in Table I. The test specimen was the compact tension (CT) specimen with side grooves. All the tests were performed using the lever-arm high temperature creep-fatigue machine which could apply stress cycles involving various hold times. The stress wave used for the creep-fatigue loading was a form of trapezoid with the rising and descending times of the same 30 sec. The tests were carried out using the four different hold times t_H of 2, 10, 60 and 600s resulting in frequencies f of 1.6×10^{-2}, 1.4×10^{-2}, 8.3×10^{-3} and 1.5×10^{-3} Hz at test temperatures of 600, 650 and 700℃.

Table I Chemical composition (wt %)

	C	Si	Mn	Ni	Cr
12Cr-2.51W (HR1200)	0.10	0.06	0.46	0.25	10.21

Mo	W	V	Nb	Co	N	B
0.14	2.51	0.21	0.07	2.44	0.017	0.013

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Crack growth behavior

The crack growth rate da/dt is plotted as a function of the stress intensity factor range ΔK for temperature 650℃ in Fig.1. There are two regions except for creep, region I for almost constant or slightly decreasing da/dt, and region II for accelerating crack growth rate. However, for creep only accelerating da/dt occurs. It is evident that the crack growth rates depend on the hold time or frequency.

Figure 2 shows the da/dt-f curves for different temperatures at a given stress intensity factor range $\Delta K=42\text{MPa}\sqrt{\text{m}}$, close to the initial K_{Iin}. At higher frequencies where da/dt is directly proportional to frequency, the cycle-dependent fatigue process is dominant. As the frequency decreases and the temperature increases, the slope of the curves becomes smaller due to the contribution of the time-dependent creep process. The dependence of the reciprocal of failure life t_f on frequency is similar to that of the crack growth rate at the initial stage, as shown in Fig.3. The failure life can be controlled by the stress intensity at the crack tip at the early stage.

Figure 4 shows the side view of the fracture surface at the middle of the specimen thickness for t_H=2s and creep. Crack branches can be observed to occur at many sites under the cycle-dependent fatigue of t_H=2s, while there exist no crack branches for creep. Therefore, it is evident that the crack surface for t_H=2s is more complex than that for creep.

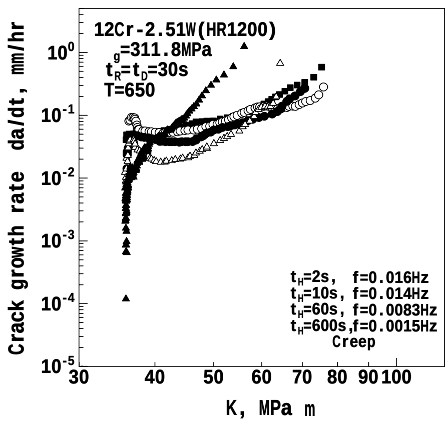


Figure 1 Crack growth rate da/dt versus stress intensity factor ΔK (650□)

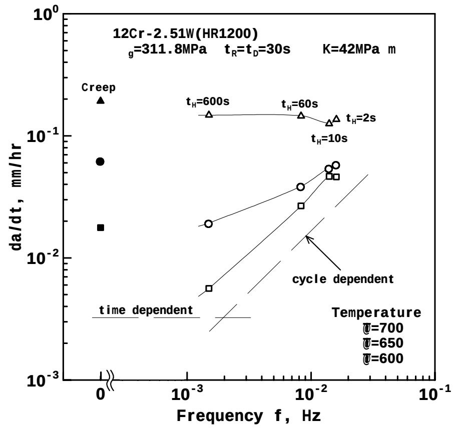


Figure 2 Dependence of da/dt on f

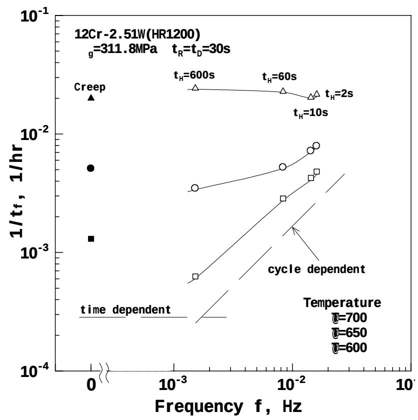


Figure 3 Dependence of $1/t_f$ on f

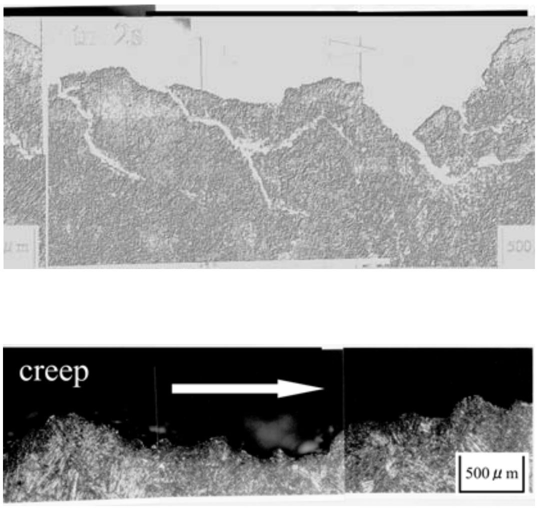


Figure 4 Side view of fracture surface

3.2 Vickers hardness

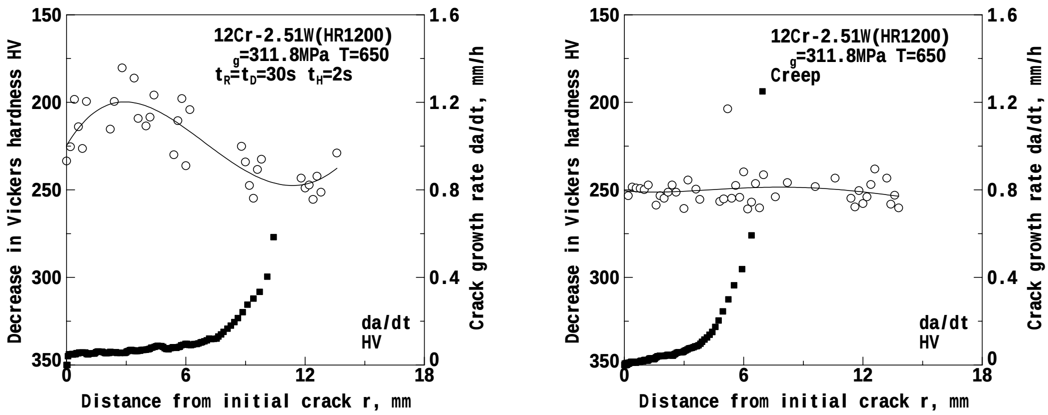
Vickers hardness HV was measured around the fracture surface at the middle of the specimen thickness. Figure 5 shows the decrease in HV versus the distance r from the initial crack tip in the crack growth direction for the cycle-dependent fatigue process of t_H=2s and creep. The hardness HV for t_H=2s decreases considerably at the early stage, while the reduction in hardness HV for creep is small. The almost constant or steady crack growth rate for t_H=2s corresponds to the severely damaged region where the decrease in HV is large, as shown in Fig.5 (a). In this region the crack branches occurred. For creep the crack is accelerated from the initial stage to the final failure.

3.3 Fractal analysis

The complexity of fracture surface can be characterized using the fractal concept. The Box Counting method (Yokobori [3]) was used to make the fractal analysis of fracture surface. Fractal dimension which characterizes fracture property is defined by the following relationship

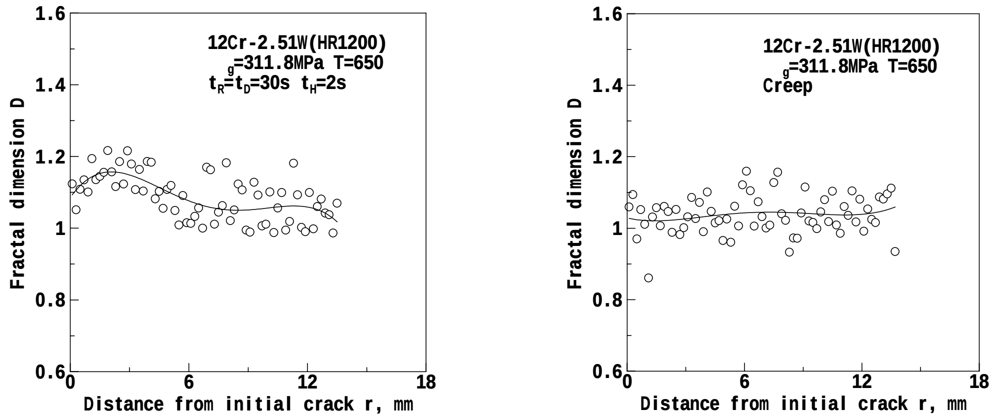
$$N=C\eta^{-D} \qquad (1)$$

where N is the total number of elements, η the unit length of each element and D the fractal dimension. The fractal dimension was obtained for the same fracture surface at the middle of the specimen where Vickers hardness was already measured. Fractal dimension D along the entire



(a) σ_g=311.8MPa, T=650℃, t_H=2s (b) σ_g=311.8MPa, T=650℃, Creep

Figure 5 Decrease in HV and da/dt versus the distance r from the crack tip



(a) t_H=2s (b) Creep

Figure 6 The relationship between fractal dimension and observation site

fracture surface for t_H=2s is D=1.088, which is larger than D=1.014 for creep at the temperature of 650℃.

Figure 6 shows the local fractal dimension as a function of distance r from the initial crack for t_H=2s and creep. In this case, local fractal dimension was obtained at intervals of 0.2mm from the initial crack. The fractal dimension D for t_H=2s increases at the early stage, which corresponds to the decrease in hardness, although there is some scatter in D. The trend in D is similar to that in hardness. In this region the crack grows in a zigzag manner due to crack branching. The dimension

D for creep is constant along the crack path and the crack grows smoothly.

4 CONCLUSIONS

High temperature creep and creep-fatigue tests were carried out using the CT specimens of 12Cr steel (HR1200) with various hold times.

(1) At higher frequency the cycle-dependent fatigue process is dominant, while the contribution of the time-dependent creep process increases with decreasing frequency and increasing temperature.

(2) For cycle-dependent fatigue process, the hardness around the crack path decreases considerably due to damage, while the reduction in hardness is small for creep.

(3) The trend in fractal dimension is similar to that in reduction in hardness. For the fatigue process, the fractal dimension is large compared with that for the creep process. The increase in fractal dimension leads to the nearly constant crack growth rate.

ACKNOWLEDGEMENTS

The present study was supported by the Research for the Future Program (97R12101) from JSPS and partly by Nihon University Individual Research Gant for 2003.

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