HIGH TEMPERATURE CREEP CRACK GROWTH OF AUSTENITE STAINLESS STEEL 1Cr18Ni9Ti

Jiang Weizhi (姜伟之) Wang Chunsheng (王春生)
Beijing Institute of Aeronautics and Astronautics, China

ABSTRACT

The creep crack growth (CCG) tests of an austenite stainless steel 1Cr18Ni9Ti were carried out over the temperature range 575°–650°C and the stress range 150.1–165.6 MPa. It was found that the crack growth is a thermal activated process. Its activation energy (Q_{cg}) appoaches the grain boundary sliding activation energy (Q_s) of the alloy, and the stress singularity of crack provides an average energy (Q_{av}) for the crack growth. Since the Q_{av} falls into the range of 44–49% Q_{cg}, so it much decreases the apparent activation energy (Q_a) of CCG process.

INTRODUCTION

The CCG behaviour of high temperature material, as an important supplement of conventional creep rupture properties, has been investigated recently[1-6]. Close atttention was paid to the CCG for the brittle creep case.

Under the conventional creep condition, it is difficult to form the crack nuclei, so the specimen life mainly depends on the crack nucleation, but the real components always have notches and crack is easy to nucleate, so its life mainly depends on the crack growth. Therefore the investigation of high temperature materials CCG behaviour is very important.

MATERIAL AND METHOD

In this investigation 2mm thick annealed sheet was used, its composition and room temperature conventional properties are listed in Table 1 and 2 respectively. The specimen configuration is shown in Fig.1. Two side notches are made by Mo wire cutting, its root radius ρ=0.075mm with stress concentra-

Table 1

Composition	C	Mn	Si	P	S	Ni	Cr	Ti	Fe
%	.09	1.53	.72	.031	.008	9.8	18.1	.053	Rem

Table 2

$\sigma_{0.2}$	σ_b	δ	E
295.0 MPa	671.3 MPa	49.7%	19.8×10^4 MPa

tion factor K_t=9.48. Taking into account of the effect of the initial notch, the K_1 can be expressed as

$$K_1 = \Phi(\eta)F(\lambda)(a_n+a_t)^{0.5}\sigma \quad (1)$$

where

$$\Phi(\eta) = 1 - 0.656\exp(-49.17) \quad (2)$$

$$\eta = a_t/(W - a_n)$$

$$F(\lambda) = 1.98+0.36\lambda - 2.12\lambda^2+3.42\lambda^3 \quad (3)$$

$$\lambda = (a_t+a_n)/W$$

$\Phi(\eta)$ given by FEM represents the initial notch effect,[7] and F (λ) is the shape factor of the rectangular plate with symmetrical edge cracks.

The modified creep testing machine type ZST-3/3 was used, its furnace and measuring system are shown in Fig.2. The specimen surface was coated with a protective layer for the benefit of crack measurement.

The tests were carried out over the temperature range 575°–650°C and the stress range 150.1–165.6 MPa.

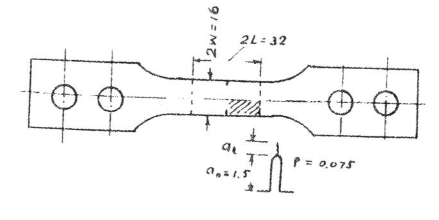

Fig.1 Specimen configuration (in mm)

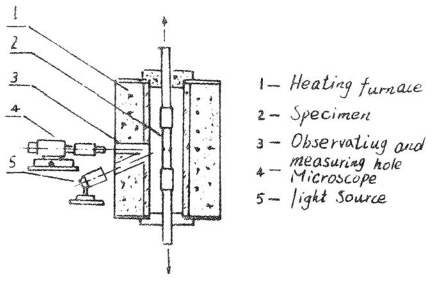

Fig.2 Schematic illstration showing experimental apparatus

RESULTS

The CCG data (a vs. t) over the temperature and stress range mentioned above are shown in Fig.3. At σ=165.6 MPa, the relationships between the

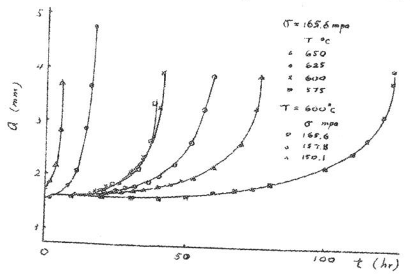

Fig.3 The CCG data in various conditions

CCG rate da/dt and the stress intensity factor (SIF) K_1 for different temperatures are shown in Fig. 4. The plot of da/dt of second stage CCG vs. 1/T, the reciprocal of testing temperature is shown in Fig. 5, from which it can be seen that CCG is a thermal activated process, i.e.

$$da/dt = (da/dt)_0 \exp(-Q_a/RT) \qquad (4)$$

where Q_a is the apparent activation energy, R is the gas constant, $(da/dt)_0$ is a constant which generally relates to the applied stress, T is the testing temperature,°K. Fig.5 also shows that Q_a is a function of K_1. Q_a values for different K_1 are listed in Table 3. When we take the material

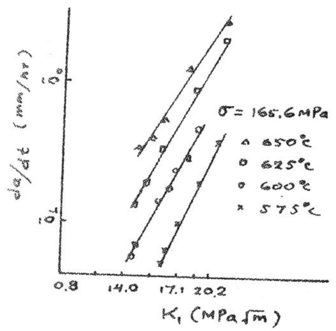

Fig 4 Relationship between da/dt and K_1

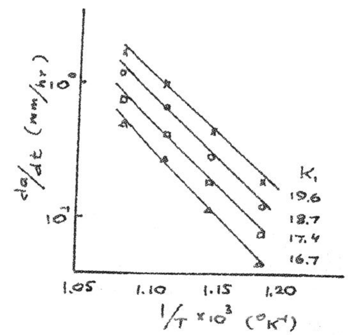

Fig. 5 Relationship between da/dt and 1/T

Table 3

K_1 MPa$\sqrt{m}$	16.7	17.4	18.7	19.6
Q_a Kcal/col	43.9	43.2	42.4	41.7

constant $G\sqrt{b}$ as a unit SIF[8], in which G is the modulus of rigidity and b is Burgers vector, there is a linear corelation between Q_a and $\ln(K_1/G\sqrt{b})$

$$Q_a = Q_{cg} + \alpha_k \ln(K_1/G\sqrt{b}) \qquad (5)$$

and the correlation coefficient r=0.996, so we get the process activation energy Q_{cg}=82.7 kcal/mol and the coefficient $\alpha_k = -13.8$ kcal/mol. These results show that:

1. Since Q_{cg} approaches the grain boundary sliding activation energy Q_s of alloy (Q_s = 76 — 85 kcal/mol[9]), we can consider that the CCG is mainly controlled by the grain boundary sliding.

2. The $\alpha_k \ln K_1$ is an average energy Q_{av} which is provided by the stress singularity characterized by K_1, so in the CCG process the energy barrier which must be overcome was decreased.

3. From eqn.(5) we get Q_{av}=36.7 — 41.1 kcal/mol, and Q_{av}/Q_{cg} = 0.44 — 0.49

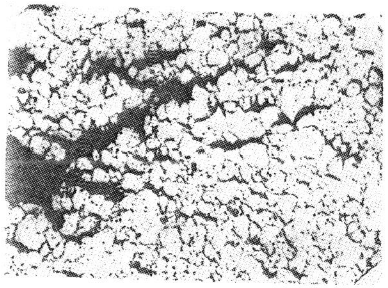

Fig. 6 Microphotograph of crack growth at σ=165.6MPa, T=575°C

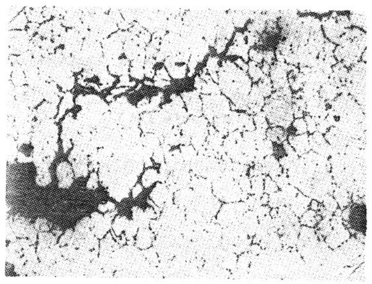

Fig. 7 Microphotograph of crack growth at σ=165.6MPa, T=600°C

The microphotographs of CCG are shown in Fig.6 and 7. The fracture paths in these figures are all along the grain boundaries, this fact agrees with the above analyses.

For CCG of 1Cr18Ni9Ti alloy the dominant intergranular damage can be seen over the range of T=575° — 650°C and σ=150.1 — 165.6 MPa. The experimental data show that CCG is a process which is controlled by thermal activation, its activation energy Q_{cg} approaches the Q_s, and the stress field characterized by SIF provides an average energy Q_{av} falls into the range of 44—49%Q_{cg}, so it much decreases the apparent energy Q_a of CCG process.

ACKNOWLEDGMENT

The authers are indebted to prof. C.Q. Chen for valuable suggestions and discussions on the present work;and also to B.C. Shun, C. shin, K.L. Tsan, F. Tsan, E. Lu for their taking part in this work.

REFERENCES

[1] M.J.Sivens et al., Int.J.Fract., 9,199(1973).
[2] E.G.Ellison et al., J.Strain anal., 13,35(1978).
[3] H.P.Ven Leenween, Eng. Fract. Mach., 9,951(1977).
[4] M.P.Pulo et al., Acta Met., 22,629(1974).
[5] V.Vitek, Acta Met.,26, 1345(1978).
[6] J.T.Barnby, Eng.Fract.Mech., 7,299(1975).
[7] Y.Murekami, Eng.Fract.Mech., 8,643(1976).
[8] T.Yokobori, Eng.Fract.Mech., 13,536(1979).
[9] F.Garofalo, Foundamentals of creep and creep rupture in metals(1965).