Fracture at Elevated Temperature for Austenitic Steel Under Cyclic Creep Loading.

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1. Introduction

The effect of cyclic load with relatively low frequency upon the time to rupture and apparent creep rate was investigated for austenitic stainless steel(AISI 316).

2. Experimental Procedure

Cylindrical creep specimens, 30mm in gauge length by 6mm in diameter, were machined from the solution treated material. The test apparatus was a lever type constant load tensile machine. Loading-unloading cycles were performed using periodic motion of a jack. The majority of

Table 1 compositions of the steel used, wt%

C	Si	Mn	P	S	Ni	Cr	Mo
0.06	0.56	1.36	0.030	0.012	10.99	17.37	2.36

tests were conducted at 700°C, with cycle ratio $t_1/t_2 = 1$, where t_1 and t_2 are the time of loading and unloading periods respectively. Creep deformation were measured by a differential transformer, having a sensitivity of 0.001mm. The changes of dislocation density due to creep deformation and also due to recovery were examined.

3. Results

The effect of cyclic loading on the time to rupture is illustrated in Fig. 1, which shows the ratio of the time to rupture under constant load creep t_r to that observed under cyclic loading t_{vr} as a function of cyclic period $\Delta t = t_1 + t_2$. The effect of cycle ratio upon the time to rupture is shown in Fig. 2. From these results, the time to rupture increases with increasing frequency or with increasing unloading period.

The time to rupture vs the minimum creep rate is shown in Fig. 3. All the data points fall on a single line irrespective of the cyclic frequency or cycle ratio, therefore, following relationship can be drawn,

$$t_r \dot{\varepsilon}_m^{u} = t_{vr} \dot{\varepsilon}_{vm}^{u} = \text{const.} \qquad \ldots(1)$$

where $\dot{\varepsilon}_m$ is the minimum creep rate obtained under constant load creep, $\dot{\varepsilon}_{vm}$ the apparent minimum creep rate under cyclic loading, and u is a constant.[1]

The changes of dislocation density during the first one and a half cycles of creep loading were examined and the result is shown in Fig. 4. Examples of transmission electron micrograph are shown in Photo. 1.

4. Discussion

As the density of dislocation decreases during unloading period, the internal stress τ_i must be decreased.[2][3] The rate of decrease can be represented as $d\tau_i/dt = -A\tau_i^{\alpha}$, thus the integration gives us,

$$\tau_i = \tau_{io}\left[1+(\alpha-1)A\tau_{io}^{\alpha-1}t\right]^{-1/(\alpha-1)} \qquad \ldots(2)$$

where A and α are constant, and τ_{io} is the internal stress at just after unloading. Concerning the major origin of the internal stress is the elastic interaction of multiplyed dislocations, τ_i is expressed as a function of dislocation density ρ by,

$$\tau_i = \alpha_0 G b \rho^{1/2} \qquad \ldots(3)$$

where G is modulus of rigidity, b the Burger's displacement and α_0 is a constant. From Eq(2) and (3), we have

$$\rho = \rho_0\left[1+(\alpha-1)A\tau_{io}^{\alpha-1}t\right]^{2/(\alpha-1)} \qquad \ldots(4)$$

where ρ_0 is the density of dislocation at just after the unloading. The density of mobile dislocation ρ_m decreases by piar-wise interaction during recovery process.[4] Since the annihilation rate $d\rho_m/dt$ is to be proportional to ρ_m^2, the following expression can be obtained:

$$\rho_m = q\rho_0/(1+\beta q \rho_0 t) \qquad \ldots(5)$$

where β is stalemating coefficient and $q\rho_0$ is the density of mobile dislocation at just after unloading. The rate of strain recovery $\dot{\varepsilon}_r$ depends on the product of ρ_m, b and the mean velocity of dislocation v, that is,

$$\dot{\varepsilon}_r = bv\rho_m = ba(\tau_i/\tau^*)^{\delta}\rho_m, \text{ and } \delta = 1/n^* kT \ldots(6)$$

where a, τ^* and n^* are material constants,[5] and k and T have usual meanings. After substituting Eq(2) and (5) into Eq(6), integration was made over a full unloading period t_2, which provides the expression

$$\varepsilon_r = (ab/\beta)(\tau_i/\tau^*)^{\delta}\ln(1+\beta q \rho_0 t_2) \qquad \ldots(7)$$

The above theory is consistent well with the observation as shown in Fig. 4(i) and (ii).

Let's assume that the transient creep strain appeared just after reloading in each cycle is negligible small compared to the amount of recovery strain on the material used. Then apparent creep rate, $\dot{\varepsilon}_{vm}$ at any given cycle in the minimum creep rate range is determined by,

$$\dot{\varepsilon}_{vm} = (\dot{\varepsilon}_{m1} t_1 - \varepsilon_r)/t_1 \qquad \ldots(8)$$

where $\dot{\varepsilon}_{m1}$ is average creep rate in the loading period concerned. From the record of strain measurement, it is probable to assume that $\dot{\varepsilon}_{vm}$ is approximately equal to $\dot{\varepsilon}_m$ which is the minimum creep rate obtained under constant load test at the same peak stress values. Then the following expression results from Eq(7) and (8) as well as Eq(1),

$$\left(\frac{t_r}{t_{vr}}\right)^{1/u} = \frac{\dot{\varepsilon}_{vm}}{\dot{\varepsilon}_m} = 1 - \frac{ab}{\dot{\varepsilon}_m t_1 \beta}\left(\frac{\tau_{io}}{\tau^*}\right)^{\delta} \ln(1+\beta q \rho_o t_2) \quad \ldots(9)$$

Since the right hand side of Eq(9) can be determined without using cyclic load creep data, the time to rupture under cyclic load creep can be predicted from the data of constant load creep. Fig. 1 and 2 show that the calculated curves of t_r/t_{vr} are in reasonable agreement with the experimental data.

5. Conclusion

The results of this investigation illustrate that the strain recovery taken place during unloading period is an important factor in cyclic creep behavior of austenitic stainless steel. The creep rupture life is longer and the minimum creep rate is lower in cyclic load creep compared to those obtained under constant load creep at the same peak stress values.

References

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(3) C.R. Barrett, C.N. Aklquist and W.D. Nex: Met. Scie. J. 4 (1970), 41.
(4) J.J. Gilman: J. App. Phys. 36 (1965), 2772.
(5) T. Yokobori: "An Interdisciplinary Approach to Fracture and Strength of Solids" Wolters-Noordhoff Ltd., Groningen, The Netherlands, (1968). Chap. 7

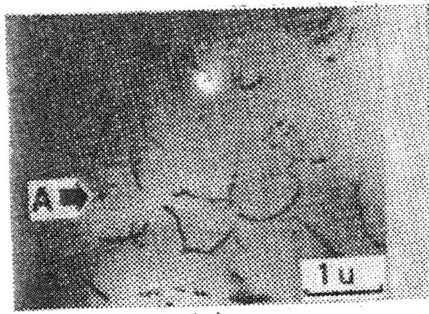

Photo. 1 (a)

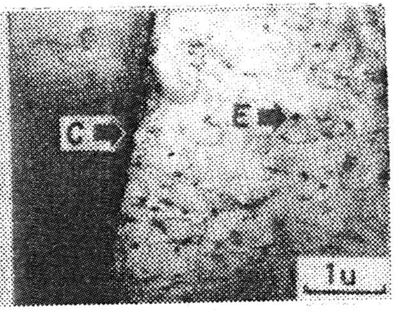

Photo. 1 (b)

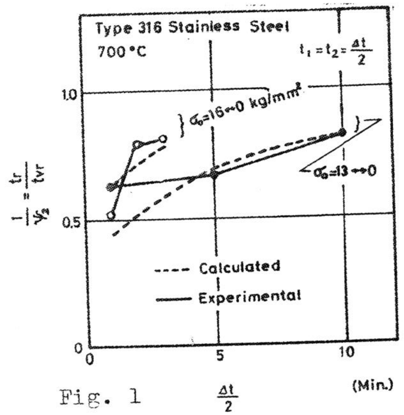

Fig. 1

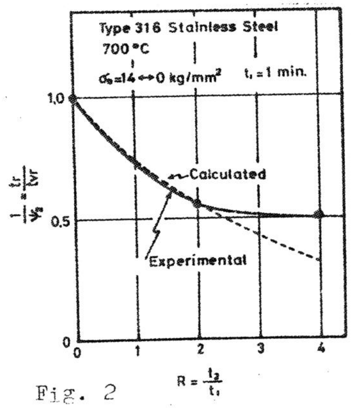

Fig. 2

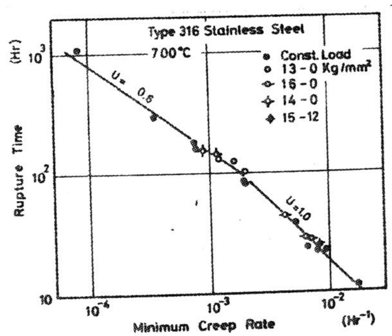

Fig. 3

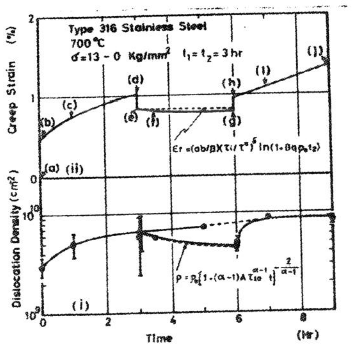

Fig. 4

Photo. 1 (a) Solution treated specimen heated at 700°C for 10hr.

Photo. 1 (b) Unloaded after crept at 700°C for 3hr.