CREEP PLASTIC ZONE AND CRACK INITIATION AT 923K OF 304 STAINLESS STEEL COMPACT TENSION SPECIMEN

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Creep plastic zone (CPZ) with plastic strain above 0.02 in notched 0.4 compact tension specimens crept for 10 to 5800h was observed by a recrystallization-thermal etching technique. The CPZ increases with creep time. The relation between specimen deformation such as notch tip opening displacement and creep plastic zone size lies on a curve, even though creep time varies by a factor of two order. Notch tip opening displacement at crack initiation decreases with increasing crack initiation time t_i. Creep plastic zone at crack initiation decreases also with t_i.

INTRODUCTION

Because of the existence of stress raisers in high temperature components, creep crack initiation behaviour is now of prime interest. Creep plastic deformation will take place around the stress raisers before crack initiation. So the observation and measurement of such localized deformation is needed to examine the cracking behaviour. Creep zone has been analyzed theoretically (Riedel(1)), Ehlers and Riedel(2) and Leung et al.(3)), while experimental measurement of long time creep zone does not seem to have been carried out. This would be due to lack of a useful experimental technique.

The recrystallization technique has been used for plastic zone around fatigue crack(Iino(4)), for short time (below 120h) creep plastic zone(Iino(5)) and for high temperature monotonic plastic zone(Iino(6)). From engineering point of view, it is necessary to extend the technique to long time creep.

In this paper, it is shown that the recrystallization technique can be successfully used for long time creep plastic zone in 304 stainless steel. Creep plastic zone in notched compact tension (CT) specimen was measured and the

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zone size is related to notch tip opening displacement.

RECRYSTALLIZATION-THERMAL ETCHING TECHNIQUE OF CREEP PLASTIC STRAIN

It is necessary to examine whether the technique can be used for creep strain measurement, since if critical strain for occurrence of recrystallization ε_{CR} is time dependent, the application would be complex. It was ascertained that the technique can be used for creep plastic zone, i.e. 1. long time aging(11000h) at 923K of the specimen tensile-strained at 923K has no effect on ε_{CR}: ε_{CR} after the aging is 0.02 as well as without aging and 2. creep plastic strain above 0.02 in smooth tensile specimen crept at stress of 88MPa at 923K(creep rupture time was 2750h) can be detected well: ε_{CR} of creep strain is also 0.02.

EXPERIMENTAL PROCEDURE

6mm thick 0.4in. CT specimen with 0.35mm wide notch(Fig.1(a)) was made of the same 304 stainless steel as in (1). It was crept at 923K in air at five values of apparent stress intensity factor(notch is assumed to be crack), $K_{\rho a}$ = 24.8, 21.1, 16.6, 13.6 and 10.8MPa$\sqrt{m}$ to various creep times. Some specimens were reloaded after dimension measurement. Notch opening displacement at two points, ΔL_0 and ΔV_g(Fig.1(a)) was measured after interruption using a profile projector and the notch root surface was observed using a stereoscope to detect creep crack growth. Creep crack initiation time was determined as time for visible microcrack formation at the notch root surface.

The crept specimens were cut at midthickness, mechanically polished and annealed at 1223K for 24h in a vacuum furnace for creep plastic zone. Pin-loaded tensile smooth specimen(gauge part of 5.6mm diameter and 20mm gauge length) were creep-ruptured at 923K in air to determine creep fracture strain.

RESULTS AND DISCUSSION

The relation between creep rupture time t_r and creep fracture strain ε_{fc} is shown in Fig.2. ε_{fc} decreases with increasing t_r. Creep curve of the CT specimen was similar to that of smooth specimens, i.e. both ΔL_0 and ΔV_g increases rapidly at first, then linearly and rapidly again. During the linear increase region, creep crack initiates and grows. Similar observation has been reported (Lee and Choi(7)).

Fig.3 shows the macroscopic recrystallized zone(dark zone in the micrograph) which corresponds to creep plastic zone with creep strain above 0.02, CPZ. One can well see the increase of CPZ with creep time. It should be noted that compressive creep plastic zone appears and increases in size also with time. The recrystallized grain size becomes small toward notch tip or crack tip as illustrated in Fig.3(e), reflecting higher creep strain near the notch tip than CPZ front. CPZ size from the notch tip to the zone front in crack growth direction $R_{x0.02}$ and that in loading direction $R_{y0.02}$(Fig.1(b)) were measured on such micrographs as in Fig.3.

Since the CPZ is localized near notch tip, the most intimately related displacement parameter would be notch tip opening displacement δ_t, which is measured on the sectioned specimen at the point 0.5mm from the notch tip (Fig.1(b)). Fig.4 shows the relation between δ_t and $R_{x0.02}$, $2R_{y0.02}$, $BR_{x0.02}$ (see Fig.1(b)) and rotational angle θ(θ is determined using the relation $\tan\theta = (\Delta L_0 - \Delta V_g)/8$). Linear lines are drawn for δ_t-$R_{x0.02}$ and δ_t-$2R_{y0.02}$ relation according to fracture mechanics. Experimental point lies on the line when δ_t<~0.2. Leung et al.(3) reported that the relation between creep zone rate and load line deflection rate is linear. If it is assumed that the relation between the load line deflection and the notch tip opening displacement is linear, the present experimental result agrees well with the analytical result. The δ_t-$R_{x0.02}$ and δ_t-$2R_{y0.02}$ relations deviate from the linear line when δ_t>~0.2(Fig.4) because of saturation of $R_{x0.02}$ and $R_{y0.02}$. δ_t-θ relation is linear till δ_t=~1mm.

It can be concluded from Fig.4 that even though creep time varies by a factor of two order(10 to 5800h), plastic zone size depends on deformed specimen configuration independent upon creep time. Fig.3 is helpful for one to see this, i.e. the order of δ_t is (c)<(a)<(d)<(b) and so is the plastic zone size.

Fig.5 shows the relations between creep crack initiation time t_i and notch tip opening displacement at the initiation δ_{ti} and between t_i and $R_{x0.02}$ at the initiation $R_{x0.02i}$. It is seen that δ_{ti} decreases gradually with t_i, while $R_{x0.02}$ is almost constant till t_i=~1000h because of the limitation of the specimen size, then decreases at t_i=5000h. Decrease of δ_{ti} with t_i is said to be due to decrease of ε_{fc} with t_i(Fig.2), since it is reasonable to assume $2\rho\varepsilon_{fc}=\delta_{ti}$.

CONCLUSIONS

1. Recrystallization-thermal etching technique using 304 stainless steel can be applied to measure local creep plastic zone with creep plastic strain above 0.02.

2. Creep plastic zone is notched 0.4 CT specimens increases with creep time. The relation between notch tip opening displacement and creep plastic zone size is independent upon creep time in range of creep time 10 to 5800h.

3. Both notch tip opening displacement and creep plastic zone size at creep

crack initiation decrease with creep crack initiation time.

SYMBOLS USED

$R_{x0.02}$ = creep plastic zone size in crack growth direction(mm)

$R_{x0.02i}$ = $R_{x0.02}$ at crack initiation(mm)

$R_{y0.02}$ = creep plastic zone size in loading direction(mm)

$R_{y0.02i}$ = $R_{y0.02}$ at crack initiation(mm)

t_i = creep crack initiation time(h)

δ_t = notch tip opening displacement(mm)

δ_{ti} = δ_t at crack initiation(mm)

θ = rotational angle(°)

ε_{fc} = creep fracture strain

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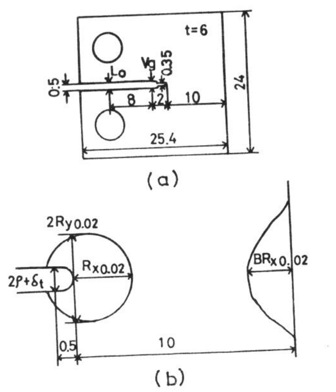

Figure 1 (a) Notched 0.4 CT specimen (b) scheme of creep plastic zone size.

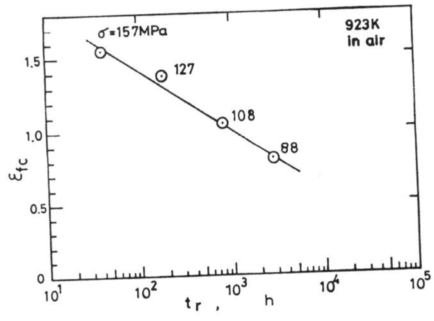

Figure 2 Creep rupture time t_r vs creep fracture strain ε_{fc}. σ: creep stress.

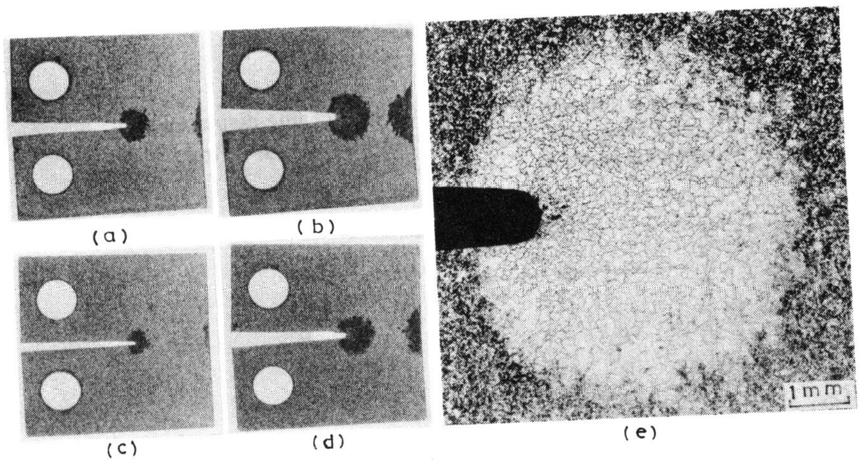

Figure 3 Macroscopic recrystallized zone(dark zone)=creep plastic zone with creep strain above 0.02 at midthickness.
Apparent stress intensity factor $K_{\rho a}$(MPa$\sqrt{m}$)=(a) and (b) 16.6, (c) and (d) 10.8. Creep time (h) and notch tip opening displacement (mm) = (a) 65, 0.22, (b) 270, 0.55, (c) 3000, 0.11, (d) 5827, 0.37, respectively. (e) enlarged view of the recrystallized zone of (b).

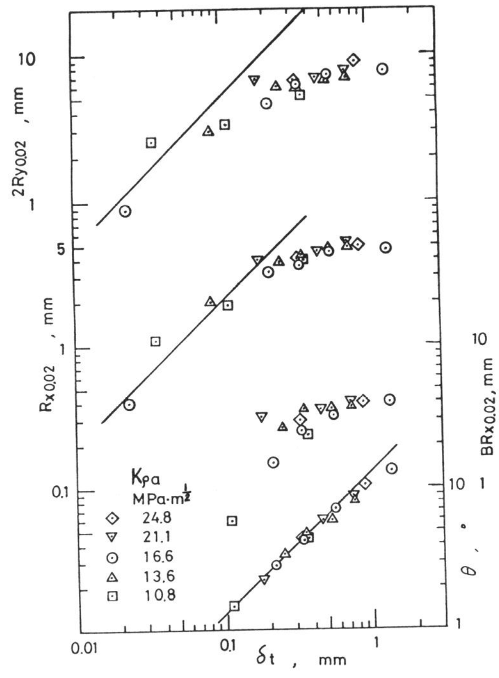

Figure 4 Relation between notch tip opening displacement δ_t and creep plastic zone size $R_{x0.02}$, $2R_{y0.02}$, $BR_{x0.02}$ and rotational angle θ.

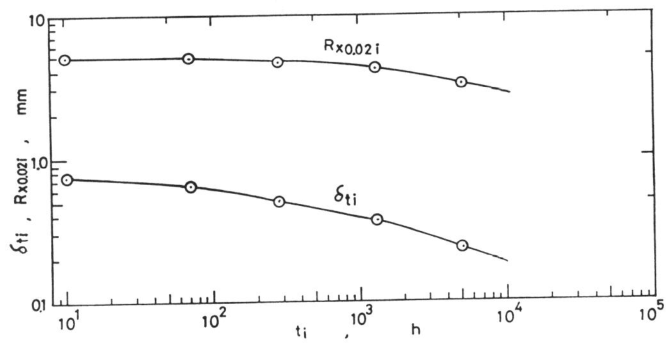

Figure 5 Relation between creep crack initiation time t_i and notch tip opening displacement at crack initiation δ_{ti} and creep plastic zone size at crack initiation $R_{x0.02i}$.