539.43.013:539.43.096

Paper No. 189-3

Fatigue Strength of Low Carbon Steel Plate with a Sharp Notch and a Precrack under Plane Bending at Elevated Temperatures *

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The effect of the rapid strain aging during fatigue stressing at 350~400 °C on the fatigue strength of a low carbon steel plate was examined. The fatigue tests were made in plane bending at room temperature, 200°C, 375°C and 450°C. Both of the endurance limits of the sharp notched specimen, that is, the critical stress required for crack initiation and that required for crack propagation reached a maximum at 375°C and a minimum at 200°C. The threshold stress intensity factor range of a precracked specimen also reached a maximum at 375°C. The number of cycles to crack initiation and that to fracture at higher stress than the endurance limit showed the same temperature dependence as described above. The rapid strain aging at the peaking temperature is more effective inhibiting the crack propagation than the crack initiation.

1. Introduction

The authors ⁽¹⁾⁽²⁾ have already performed fatigue tests in rotating bending on plain, semi-circular grooved and V-shape grooved round bar specimens of low carbon steels over a temperature range from room temperature to 450°C and obtained the following results.

The fatigue limit of plain specimen σ_{w0} , the fatigue limit for crack initiation of sharp notched specimens σ_{w1} and the fatigue limit for crack propagation of sharp notched specimens σ_{w2} took a minimum at about 200°C and a maximum at about 375°C. The rates of increase of the fatigue limits σ_{w0} and σ_{w1} at 375°C over those at room temperature were about 20%~30%, while the increase of σ_{w2} was about 50%~60%. Further fatigue tests were made on circumferential precracked specimens at room temperature and 375°C. The threshold stress intensity factor range ΔK_{th} was estimated from the fatigue limit of a precracked specimen. The values of ΔK_{th} at 375°C increased by 70% over that at room temperature ⁽²⁾. It was proved that the rapid strain aging at 375°C made a greater contribution to the increase in σ_{w2} than in σ_{w1} . The fatigue lives N_f at higher stress levels than the fatigue limits of both plain and sharp notched specimens took maximum values at 375°C too. It is uncertain whether the maximizing behavior of N_f is attributed to the life increase for crack initiation or that for crack propagation.

In this investigation, the alternating plane bending fatigue tests were made on low carbon steel plates with a sharp notch, in order to clarify a temperature dependence, in particular, the effect of rapid strain aging on the number of cycles to crack initiation at higher stress levels than σ_{w2} . The temperature dependences of σ_{w1} , σ_{w2} and ΔK_{th} of sharp notched and precracked specimens are examined to compare them with the results of rotating beam fatigue tests. The range of testing temperatures in this test as well as in rotating beam fatigue tests is from room temperature to 450°C.

Examination of the temperature dependence of the crack propagation rate and of the effect of rapid strain aging on the crack propagation rate is left for another opportunity.

2. Material and experimental methods

The chemical composition and the mechanical properties of material are shown in Table 1 and 2 respectively. The material was annealed at 920°C for an hour, machined into the shape shown in Fig. 1, longitudinally polished with abrasive papers and then annealed at 920°C for half an hour in vacuo. The specimens were electropolished about 10μm thick prior to the fatigue tests. The stress concentration factor of notch was about 3.4. A precrack about 500μm deep from the notch root was produced at the stress of 10kgf/mm², which was higher than the fatigue limit by 43%, for 3.5×10^5 cycles. The precracked specimen was annealed at 920°C for half an hour in vacuo. The crack length on both sides of the specimen was measured by means of cellulose acetate replicas. The fatigue tests were carried out with a resonance type high temperature plane bending fatigue testing machine of 10 kgf m at about 2000 cpm.

The fatigue limit σ_{w2} of the notched specimen is about 7kgf/mm² as will be described later. At a stress of 16kgf/mm², higher than the fatigue limit, a relationship between the

* Received 4th April, 1979.

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fatigue life N_f and temperature t was obtained. Four specimens were used at each temperature. The fatigue test results are shown in Fig. 2. The fatigue life decreases with an increase in temperature, until it reaches a minimum value at a temperature between 200°C and 250°C, increases to a maximum value at a temperature between 350°C and 400°C and then rapidly decreases again at higher temperatures. This behavior is similar to the results of the fatigue tests under rotating bending.⁽²⁾ The temperatures used in the experiments were room temperature, 200°C, 375°C and 450°C. These temperatures were chosen based upon the results in Fig. 2.

3. Experimental results and discussion

3.1. Temperature dependence of the number of cycles to crack initiation at the finite life region of the notched specimen

At every temperature, the first microcracks were found at the center of the notch root. They slightly grew along the notch root and joined together to form a through plate crack. The crack was propagated toward the neutral axis under bending until the whole specimen fractured. There, the number of cycles to through plate crack initiation is different from that to crack initiation only at the center of the plate. The former is denoted by n_c , and the latter by n_c' . Some of the microcracks which were just initiated at the center of the notch root are shown in Figs. 3 and 4. The surface of the microcrack is semi-elliptic.

The relationships between σ and n_c' , between σ and n_c and between σ and N_f are shown in Figs. 5~8. In these figures the symbol $\circ$ means the number of cycles at which no crack was observed, the symbol Δ the number of cycles at which a microcrack was observed only at the center of the notch root and the symbol $\bullet$ the number of cycles at which a through plate crack was observed. Because

Table 1. Chemical composition of material (wt %)

C	N	Si	Mn	P	S	Cu	Ni	Cr	Al
0.08	0.011	0.26	0.43	0.006	0.032	0.08	0.09	0.06	0.043

Table 2. Mechanical properties of material

Yield point kgf/mm ²	Tensile strength kgf/mm ²	True strength kgf/mm ²	Elongation %	Reduction of area %
25.4	37.7	77.2	40	66

Fig. 1 Shape of specimen

Fig. 2 Relationship between the fatigue life N_f and temperature t

Fig. 3 Microcrack which was initiated at the center of notch

Fig. 4 Fracture surface of microcrack

Fig. 5 Relationships between σ and n_c' , between σ and n_c and between σ and N_f at room temperature

Fig. 6 Relationships between σ and n_c' , between σ and n_c and between σ and N_f at 200°C

Fig. 7 Relationships between σ and n_c' , between σ and n_c and between σ and N_f at 375°C

Fig. 8 Relationships between σ and n_c' , between σ and n_c and between σ and N_f at 450°C

an interruption of testing should affect the crack initiation behavior at elevated temperatures, these experimental data were obtained on individual specimens. An optical microscope of 200 magnification was used for observation of the cracks. The numbers of cycles n_c' , n_c and N_f are estimated from these experimental data and all points are connected by smooth curves. The range of stress levels is from 10 kgf/mm² to 16 kgf/mm², and the former is slightly higher than the fatigue limit at 375°C. The numbers of cycles n_c' , n_c and N_f at 10 kgf/mm² and 16 kgf/mm² are estimated from $\sigma - n_c'$, $\sigma - n_c$ and $\sigma - N_f$ curves respectively. The relationships between these cycles and temperature t are shown in Fig. 9. If the strain aging does not affect the numbers of cycles n_c' , n_c and N_f , these curves which represent the relationships between these numbers of cycles and temperature would monotonously fall with an increasing temperature⁽³⁾. These curves have a tendency to have a maximum at about 375°C. Such a tendency is more prominent at higher stress level than lower. At the same stress level, this tendency of N_f is more prominent than those of n_c' and n_c . The ratios of n_c' , n_c and N_f at elevated temperature to those at room temperature are shown in Table 3 respectively. At 375°C, the values of N_f/N_{fRT} are larger than those of $n_c'/n_{c'RT}$ or n_c/n_{cRT} , therefore, the contribution of the strain aging to N_f is greater than that to n_c' or n_c . The values of N_f at 375°C are about 67%~70% of those at room temperature. The values of n_c' and n_c at 375°C are merely about 11%~23% and about 10%~28% of those at room temperature respectively. Noting the ratios n_c'/N_f and n_c/N_f , the experimental results are rearranged and shown in Fig. 10 and Table 4. At both stress levels, both n_c'/N_f and n_c/N_f decrease with an increasing temperature until they reach a minimum at about 375°C and then they increase. The ratio n_c/N_f at room temperature is about 6~7%, but that at 375°C is only about 0.9~3%. The ratio n_c'/N_f at 375°C is also 0.1~0.3% while that at room temperature is 0.8~0.9%.

The rapid strain aging which occurs at 375°C makes a greater contribution to the increase in N_f than to the increase in n_c' and n_c . It means that at finite life region in a sharp notched specimen the rapid strain aging makes a greater contribution to the increase in number of cycles to crack propagation than that to crack initiation.

3.2. Temperature dependence of $\sigma w_1'$, σw_1 and σw_2 of the notched specimen

Corresponding to the numbers of cycles to crack initiation n_c' and n_c , the fatigue limits for microcrack initiation and that for through plate crack initiation can be determined. The former is denoted by $\sigma w_1'$ and the latter by σw_1 . The values of $\sigma w_1'$, σw_1 and σw_2 were determined by examining whether the specimen which remained unbroken at 10⁷ cycles has a crack or none. It will be discussed later whether these cracks which were observed at the stress level ranging σw_1 to σw_2 were nonpropagating or not. The relationships between these fatigue limits and temperature t are shown in Fig. 11 and

Table 5. In this table the ratios of fatigue limits at elevated temperatures to those at room temperature r are shown too. Each fatigue limit reaches a minimum at about 200°C and a maximum at about 375°C, which is the same as the result of the rotating bending fatigue test⁽²⁾. As is evident from the values of r in Table 5, both of the fatigue limits for crack initiation at 375°C σ_{w1}' and σ_{w1} are higher than those at room temperature by about 20%. The increasing rate is smaller than that in a sharp notched specimen under rotating bending (about 30%). The fatigue limit σ_{w2} at 375°C is higher than that at room temperature by about 30% too, but the increase is considerably smaller than that under rotating bending (about 60%). However, these results in two types of stressing show a similar tendency that the rapid strain aging makes a greater contribution to the increase in σ_{w2} than to the increase in σ_{w1} .

The relationships between σ and ℓ_{npc} are shown in Fig. 12. The nonpropagating crack length ℓ_{npc} at about σ_{w2} is about 150 μm at room temperature, while at 200°C, 375°C and 450°C, it is 300, 500 and 400 μm respectively.

Table 3. Ratios of n_c' , n_c and N_f at elevated temperature to those at room temperature

	n_c' / n_{cRT}		n_c / n_{cRT}		N_f / N_{fRT}	
	16	10	16	10	16	10
room temp.	1	1	1	1	1	1
200°C	0.25	0.16	0.28	0.17	0.53	0.61
375°C	0.23	0.11	0.28	0.1	0.71	0.67
450°C	0.12	0.06	0.08	0.08	0.09	0.14

Table 4. The values of n_c' / N_f and n_c / N_f

	16 kgf/mm ²		10 kgf/mm ²	
	n_c' / N_f	n_c / N_f	n_c' / N_f	n_c / N_f
room temp.	0.009	0.068	0.008	0.061
200°C	0.004	0.036	0.002	0.012
375°C	0.003	0.027	0.001	0.009
450°C	0.011	0.056	0.003	0.034

Table 5. The values of the fatigue limits

	σ_{w2}		σ_{w1}		σ_{w1}'	
	kgf/mm ²	r	kgf/mm ²	r	kgf/mm ²	r
room temp.	7	1	5.5	1	4.75	1
200°C	6.5	0.93	5	0.91	3.25	0.68
375°C	9.25	1.32	6.5	1.18	5.75	1.21
450°C	7	1	4.25	0.77	2.75	0.58

Fig. 9 Relationships between n_c' and temperature t , between n_c and temperature t and between N_f and temperature t

Fig. 10 Relationships between n_c' / N_f and temperature t and between n_c / N_f and temperature t

Fig. 11 Relationships between the fatigue limits and temperature t

3.3. Temperature dependence of the threshold stress intensity factor range ΔK_{th} of the precracked specimens

In obtaining ΔK_{th} , the K-decreasing method is usually employed but, in this investigation, ΔK_{th} was estimated from the fatigue limit of a precracked specimen. The results of the fatigue tests are shown in Fig. 13. The ordinate in the figure is the initial stress intensity factor range ΔK_i . The values of ΔK_i were estimated by the following equation⁽⁴⁾.

$$\Delta K_i = \sigma_0 \sqrt{\pi a} F(\xi),$$

where $\sigma_0 (= 6M/W^2)$ is the bending stress of the top and bottom, M is the bending moment per unit thickness, a is the effective crack length (i.e. the sum of the notch depth and the precrack length), W is the height of a specimen including the notch depth, $\xi = a/W$ and

$$F(\xi) = 1.22 - 1.4\xi + 7.33\xi^2 - 13.08\xi^3 + 14.0\xi^4.$$

The values given by the side of each experimental point in Fig. 13 are precrack length and crack length which were measured in an unbroken specimen at 10^7 cycles. These values are expressed in microns. In some of the specimens which were unbroken at 10^7 cycles, the precracks grew slightly. In the other specimens, precracks did not grow so in observations from both sides of specimens. At every temperature except room temperature,

Fig. 12 Relationships between σ and l_{npc}

Fig. 13 Relationships between ΔK_i and N_f

cracks propagating from the precracks are observed at ΔK_{th} . The values of ΔK_{th} are shown in Table 6. The values of ΔK_{th} estimated from σ_{w2} and the effective crack length (i.e. the sum of l_{npc} and the notch depth) are also shown in this table. The values in the parentheses in this table stand for the ratios of ΔK_{th} at elevated temperatures to that at room temperature. As shown in the table, there is little difference between ΔK_{th} of precracked specimens and that of notched specimens. The values of ΔK_{th} reach a maximum at 375°C but do not reach a minimum at 200°C. The increases of ΔK_{th} at 375°C to that at room temperature in precracked and notched specimen are about 40% and about 50% respectively, and larger than the increase of σ_{w1} and σ_{w2} (about 20%) or that of σ_{w2} (about 30%). The tendency for the increase in ΔK_{th} to reach a maximum at 375°C has also been observed in the rotating bending tests. However, the increase of ΔK_{th} is smaller than that in the rotating bending tests (about 70%).

3.4. Crack propagation behavior under critical conditions for crack propagation σ_{w2} and ΔK_{th}

As shown in Fig. 12, at the fatigue limit for crack propagation of notched specimen σ_{w2} , cracks of about 150 μm length are observed at room temperature and ones of about 300 ~ 500 μm length at elevated temperatures. As shown also in Fig. 13, at ΔK_{th} in precracked specimens at every temperature except room temperature, cracks which had grown from the precracks were observed. In order to confirm the existence of σ_{w2} and ΔK_{th} at elevated temperatures as well as at room temperature, it is necessary to examine whether these cracks are propagative or not.

First, the crack propagation behavior of precracked specimens is discussed. Mean crack propagation rates $d\ell/dn$ which have been estimated from crack lengths given by experimental points in unbroken specimens at 10^7 cycles are as follows. The values of $d\ell/dn$ at 200°C, 375°C and 450°C are about 5×10^{-9} , 4.8×10^{-9} and 1.5×10^{-9} mm/cycle respectively at ΔK_i which is regarded as ΔK_{th} . When the specimen was stressed to 2×10^7 cycles at a lower level of ΔK_i than ΔK_{th} at 375°C, $d\ell/dn$ is the order of 10^{-9} mm/cycle, so that the crack propagation rate is very small. The value of $d\ell/dn$ at 375°C tends to decrease with an increase in number of cycles.

Next, in notched specimens, room temperature and 375°C where l_{npc} was longest were selected as typical temperatures and the relationships between the crack length ℓ and the number of cycles n over the stress range

Table 6. The values of ΔK_{th} (kgf/mm^{3/2})

	Precracked specimen	Notched specimen
room temp.	13.0 (1)	12.2 (1)
200°C	13.1 (1.01)	12.3 (1.01)
375°C	18.0 (1.38)	18.1 (1.48)
450°C	14.0 (1.08)	13.6 (1.11)

from σ_{w1} to σ_{w2} were obtained. The relationships between ℓ and n at room temperature and 375°C are shown in Figs. 14 and 15 respectively. These results were obtained with a single specimen at each stress level. The fatigue stressing was interrupted each time when the crack length was measured on both sides of specimen. The interruption of the stressing might affect the crack propagation behavior at 375°C , but the present discussion is done on these results. As is expected from the shape of ℓ - n curves, $d\ell/dn$ decreases with an increasing number of cycles at both temperatures. This shows the same tendency as that which has been observed at room temperature.⁽⁵⁾ Cracks were not arrested completely at these numbers of cycles at 375°C . Figure 16 shows the relationships between $d\ell/dn$ and n which were obtained from results in Figs. 14 and 15. At 375°C , $d\ell/dn$ decreases with an increasing number of cycles but it is still about 10^{-8} mm/cycle at 10^7 cycles. This rate is almost equal to that of ΔK_{th} at 375°C (about $4.4 \sim 8.1 \times 10^{-9}$ mm/cycle). At 375°C , ℓ_{npc} at σ_{w2} is considerably long and almost equal to the sum of precrack length and crack length which grew from precracks at ΔK_{th} . Therefore it seems that the region of crack tip is not influenced by the notch and that the nonpropagating crack in the notch root at σ_{w2} is equivalent to the crack which grew from precrack at ΔK_{th} . Therefore the propagation rates of both cracks take almost the same value and, as shown in Table 6, ΔK_{th} at 375°C is almost equal to that estimated from σ_{w2} . As shown in Fig. 16, at about 10^6 cycles, $d\ell/dn$ at room temperature became nearly equal to zero and the growth of a crack was arrested once but it began to be propagated

again at about 10^7 cycles. It seems that the growth of a crack was not completely arrested at room temperature either.

The crack propagation behavior at 200°C and 450°C was not investigated on the notched specimens. At these temperatures, the values of ℓ_{npc} at σ_{w2} were considerably large, i.e., $300 \sim 400 \mu\text{m}$. As shown in Table 6, ΔK_{th} of a precracked specimen was equal to that estimated from σ_{w2} at each temperature. At these temperatures as well as 375°C , there seems to be little difference between the behavior of both cracks, one grew from the notch root and the other grew from the precrack.

The crack propagation behavior at the side of the specimen has been discussed above. Next the crack propagation behavior on the inside of the specimen will be compared with that on the outside.

Fig. 15 ℓ - n curves at 375°C

Fig. 14 ℓ - n curves at room temperature

Fig. 16 Relationships between $d\ell/dn$ and n

The fracture surfaces of unbroken specimens at ΔK_{th} of precracked specimens are shown in Fig. 17. The fracture surfaces of unbroken specimens at σ_{w2} of notched specimens are shown in Fig. 18. They were brittle and broken in liquid nitrogen. In the precracked specimen, it is difficult to distinguish the part of a precrack from the part of a crack which has grown from the precrack. The crack surfaces in both specimens have the following features. In every case except for the notched specimen at 200°C, the crack propagation rate on the outside of the specimen was greater than that on the inside, and the shape of the crack front was concave. In the notched specimen at 200°C, on the other hand, the crack propagation rate of the inside was greater than that of the outside, and the shape of crack front was convex. But the propagation process of the crack from the notch root to the crack front during 10^7 cycles at σ_{w2} in the notched specimen was not examined. Since the shape of the nonpropagating crack front is concave at room temperature and 375°C in spite of relatively short and long ℓ_{npc} , respectively, the

shape of crack front during propagation process may be regarded as convex. Therefore, the values of $d\ell/dn$ at room temperature and 375°C shown in Fig. 16 which were obtained by observing from the outside are slightly overestimated. If the values of $d\ell/dn$ at 200°C were examined by observing from the outside, the values of $d\ell/dn$ would be slightly underestimated.

In precracked specimens, when observed from the side of specimens, cracks were propagated about $15\sim 80\mu\text{m}$ during 10^7 cycles at ΔK_{th} at elevated temperatures except room temperature. It was difficult to evaluate from these photographs the difference between the length of the propagation on the outside and that on the inside. As is apparent from the shape of the crack front at room temperature where the precrack did not at all propagate on the outside, the shape of the precrack surface was concave and its curvature was almost similar to those at elevated temperatures. The values of $d\ell/dn$ obtained from the length of propagation on the outside during 10^7 cycles at 200°C, 375°C and 450°C, i.e. about 5×10^{-9} , 4.8×10^{-9} and $1.5\times 10^{-9}\text{mm/cycle}$ respectively, are almost equal to

Fig. 17 The fracture surface of unbroken specimens at ΔK_{th} of precracked specimen

Fig. 18 The fracture surface of unbroken specimens at σ_{w2} of notched specimen

those obtained from the length of propagation at the inside. However these values are mean values of the propagation rates during 10^7 cycles. At ΔK_i slightly lower than ΔK_{th} at 375°C , the tendency of $d\ell/dn$ to decrease with cycles was recognized when the specimen was stressed to 2×10^7 cycles. Therefore, the crack propagation rate when stressed to 10^7 cycles at ΔK_{th} may become much smaller than the mean value. In Figs. 17 and 18, at 375°C and 450°C where ℓ_{npc} at σ_{w2} was nearly equal to the precrack length, the shapes of the crack surfaces in notched specimens were similar to those in precracked specimens. This result verifies the above argument that the crack from the notch root at σ_{w2} at equivalent to the crack from the precrack at ΔK_{th} at elevated temperatures where ℓ_{npc} is considerably long.

At σ_{w2} or ΔK_{th} , $d\ell/dn$ of the outside was slightly different from that of the inside. The experimental values are slightly overestimated in most cases of this investigation. A complete arrest of the crack propagation can be confirmed satisfactorily by observing from outside of the specimens.

From the above points of view, at σ_{w2} and ΔK_{th} which were determined by the fracture of specimens at 10^7 cycles, the crack is not arrested completely at other temperatures than room temperature. However the crack propagation rate is extremely small, merely about $10^{-8} \sim 10^{-9} \text{ mm/cycle}$ at about 10^7 cycles. Since $d\ell/dn$ decreases with an increasing number of cycles, there is the possibility that a crack may be arrested by further stressing. If the critical condition for crack propagation exists even at elevated temperatures, in the sense that cracks are arrested, σ_{w2} and ΔK_{th} determined in this investigation can be regarded as reasonable values, considering that the crack propagation rate was very small. Otsuka, et al.⁶ confirmed that a crack which had grown from a precrack was arrested in a low carbon steel plate at room temperature. At such elevated temperatures as in this investigation, further fatigue tests over a long period are will be necessary to confirm whether cracks are arrested or not.

4. Conclusions

Alternating plane bending fatigue tests were carried out on low carbon steel plates with a sharp notch and a precrack. The test temperatures were room temperature, 200°C , 375°C and 450°C . The following conclusions were obtained.

(1) In the notched specimen, at a finite life region, both the number of cycles to microcrack initiation n_c' and that to through plate crack initiation n_c do not gradually decrease with an increase in temperature but reach a maximum at about 375°C where a rapid strain aging occurs, and then decrease again. The contribution of the rapid strain aging to the increase of n_c' or n_c is smaller than that of fatigue life N_f . The rapid strain aging makes a greater contribution to the increase in number of cycles to crack propagation than that to crack initiation.

(2) In the notched specimen, the fatigue limit for microcrack initiation σ_{w1}' and that for

through plate crack initiation σ_{w1} were determined by observing whether these cracks occurred or not after 10^7 cycles. Each fatigue limit reaches a minimum at about 200°C and a maximum at about 375°C . The increases of both σ_{w1}' and σ_{w1} at 375°C over those at room temperature are about 20%. Therefore, the rapid strain aging contributes to the increase of the fatigue limits for crack initiation too.

(3) In the notched and precracked specimens, the fatigue limit for crack propagation σ_{w2} and the threshold stress intensity factor range ΔK_{th} were determined by critical condition of whether specimens broke or not at 10^7 cycles. The value of σ_{w2} reaches a minimum at about 200°C and a maximum at about 375°C , while the value of ΔK_{th} does not reach a minimum at 200°C but gradually increases with an increasing temperature and reaches a maximum at about 375°C and then decreases. The increases of σ_{w2} and ΔK_{th} at 375°C over those at room temperature are about 30% and about 40% respectively, and the rapid strain aging contributes to the increase of the critical values for crack propagation too.

(4) Comparing the increase of the critical value for crack initiation with that for crack propagation, the contribution of the rapid strain aging to the increase of the critical value for crack propagation is larger than that for crack initiation. Such a tendency is similar to that under rotating bending, but, in general, the increase under plane bending is smaller than that under rotating bending.

(5) The nonpropagating crack length ℓ_{npc} at σ_{w2} is about $150 \mu\text{m}$ at room temperature, while at 200°C , 375°C and 450°C , it is considerably long, i.e., about 300, 500 and $450 \mu\text{m}$ respectively. The crack propagation rate at σ_{w2} decreases with an increasing number of cycles. At elevated temperatures, a complete arrest of the crack was not observed and the propagation rate was still $10^{-8} \sim 10^{-9} \text{ mm/cycle}$ at 10^7 cycles. In precracked specimens also, at elevated temperatures except room temperature, cracks which had grown from the precracks were observed and the propagation rates were equal to those of ones which had grown from the notch root. Thus the critical condition for crack propagation σ_{w2} and ΔK_{th} whose temperature dependence has been discussed in the present paper, cannot be called critical conditions in the sense that cracks are arrested completely.

References

- (1) Hasegawa, N., et al., Preprint Japan Soc. Mech. Engrs. (in Japanese), Vol. 780, No. 4 (1978-4), p. 137.
- (2) Hirose, M., et al., Bulletin of the JSME, Vol. 21, No. 158 (1978-8), p. 1201.
- (3) Levy, J.C., and Sinclair, G.M., Proc. ASTM, 55 (1955), p. 866.
- (4) Tada, H., et al., The Stress Analysis of Cracks Handbook, (1973), p. 2.
- (5) Aoki, I., et al., J. Japan Soc. Mat. Sci. (in Japanese), Vol. 15, No. 149 (1966-2), p. 95.
- (6) Otsuka, A., and Mori, K., Proc. 22th Japan National Symposium on Strength, Fracture and Fatigue (in Japanese), (1977), p. 1.