539.43.01:539.43.016

Paper No. 182-3

The Effect of Cyclic Stress Hysteresis at Elevated Temperature on the Crack
Propagation Behavior in Smooth Specimens of 0.45% Carbon Steel *

By Motohisa HIROSE**, Norihiko HASEGAWA***, Yōzō KATŌ****

and Tatsuji HATTORI*****

The specimens prestressed at 200°C and 375°C were fatigued at room temperature in rotating bending. As long as no fatigue crack initiated during prestressing at 375°C, the number of cycles required for crack initiation at room temperature, n_0 , was increased. The increase in n_0 becomes greater as the prestress becomes higher. The prestress at 375°C contributes to a decrease in crack propagation rate, dI/dn . The wellknown relationship $dI/dn = c(\Delta K)^m$ has been proved to be applicable regardless of the precrack length. Both constants c and m become smaller and larger, respectively, as the prestress becomes higher. The increase in n_0 and the decrease in dI/dn may be explained as the result of a rapid strain aging occurring during cyclic stressing at 375°C. With the specimens prestressed at 200°C, the decrease in dI/dn depended on the prestress too, but the effect was less remarkable than that at 375°C.

1. Introduction

It is well known that, as the test temperature increases, fatigue strength of carbon steels decreases to a minimum value at about 200°C, then increases to a maximum value at 350~400°C, and that the peaking behavior is caused by a rapid strain aging during cyclic stressing.⁽¹⁾⁻⁽⁵⁾ Basic fatigue tests on carbon steels with the temperature changed have been made under simple conditions, such as one or multiple steps of two levels of testing temperatures.⁽⁶⁾⁻⁽¹³⁾ However, those investigations were concerned with smooth specimens and most of them were carried out at higher stress levels than the fatigue limits. In examination of the experimental results, it has been discussed whether the linear damage law holds or not with respect to cumulative cycle ratios $\Sigma n/N$. The investigations indicated that, as pointed out by J.A. Dunsby,⁽⁷⁾ the fatigue lives might be estimated almost by the linear damage law, provided the changed temperatures of the tests contain the temperature at which the metallurgical structures are relatively stable during cyclic stressing. Structural change during cyclic stressing which must be considered below the recrystallization temperature, i.e., about 500°C, is a rapid strain aging at the peaking temperature. If the aging temperature is contained in the changed temperatures, the linear damage law does no longer hold and $\Sigma n/N$ becomes considerably greater than unity. The fact that $\Sigma n/N$ becomes considerably greater than unity

may be explained by the prevention of initiation and propagation of fatigue cracks owing to a strong repinning structure of multiplied dislocations which develops during cyclic stressing at the peaking temperature and does not disappear even after the temperature is changed. Details of those behaviors have not been sufficiently confirmed until now. The authors⁽¹⁰⁾⁽¹¹⁾ and Shimizu et al.⁽¹²⁾ reported an increase in $\Sigma n/N$ caused by the cyclic stress hysteresis at the peaking temperature.

However, even if the peaking temperature is not contained within the changed temperatures, $\Sigma n/N$ for a small number of repetitions of temperature change, such as two-step, two-level, differs with the sequence of temperature change. When the test temperature is changed from a certain value to another, $\Sigma n/N$ tends to be greater than unity; but, when the temperature change is converse, $\Sigma n/N$ tends to be smaller than unity.⁽⁶⁾⁽⁸⁾⁽⁹⁾ Although $\Sigma n/N$ differs with the sequence of temperature change, values of $\Sigma n/N$ are in the range of 0.5~2 at most. As the number of repetitions of temperature change is increased, the effect of the sequence of temperature change is reduced gradually and the relationship $\Sigma n/N = 1$ almost holds.⁽⁸⁾⁽⁹⁾ There are two cases when $\Sigma n/N > 1$, in one case $\Sigma n/N > 1$ due to the cyclic stress hysteresis at the peaking temperature even for a large number of repetitions of temperature change, in the other case $\Sigma n/N > 1$ due to a small number of repetitions though the peaking temperature is not contained. In most of the conditions of temperature change for mechanical parts and structural members the number of repetitions is large. In order to estimate the fatigue lives of carbon steels under temperature change up to 500°C, the role of rapid strain aging must be clarified. As pointed out by Taira et al.⁽¹⁴⁾ to solve this sort of problem, not only $\Sigma n/N$ but also the behaviors of initiation and propagation of fatigue cracks under temperature change should be clarified.

In this investigation, the behaviors of initi-

* Received 12th October, 1978.

** Assistant Professor, Junior Technical College, Gifu University, Kagamigahara.

*** Research Associate, Faculty of Engineering, Gifu University.

**** Professor, Faculty of Engineering, Gifu University.

***** Daido Machine Co., Ltd.

ation and propagation of fatigue cracks in a 0.45% carbon steel were observed in rotating bending fatigue tests under the following conditions of two-step, two-level temperature change.

(1) Significant effects of cyclic stress hysteresis at the peaking temperature on $\Sigma n/N$ are observed at a temperature at which the strong repinning structure is hard to disappear during cyclic stressing and cyclic strain aging cannot be expected after the temperature change.⁽¹⁰⁾ If the temperature after a change is room temperature, fatigue cracks can be observed easily. Accordingly the fatigue tests with temperature changed from the peaking temperature to room temperature were carried out at the overstress levels.

(2) To compare with the above condition, the temperature was changed from the temperature of minimum strength to room temperature.

2. Material and experimental procedure

The chemical composition of the material tested is shown in Table 1. Fatigue specimens were machined to the shape and dimensions as shown in Fig. 1 after annealed at 830°C for an hour. In order to restrict the location of crack initiation, according to Nishitani et al.⁽¹⁵⁾ the specimens were slightly notched at the center to a depth of 0.1 mm. The specimens were polished with emery papers, annealed at 700°C for an hour in vacuo and electropolished to a depth of 10~20 μm in a solution of hyperchloric acid and acetic acid mixed in the ratio of 1:10. Since the stress concentration factor of the notch is about 1.06,⁽¹⁶⁾ the observed behavior of crack propagation may safely be considered as that of smooth specimens. Mechanical properties of the material after the heat treatment are shown in Table 2.

The fatigue tests were made with rotating bending fatigue testing machines for elevated temperatures at a speed of 3600 rpm. Referring to author's previous experiments^{(3)~(5)} and preliminary experiments of this investigation, 375°C and 200°C were chosen as the peaking temperature and the temperature of minimum strength, respectively. Figure 2 shows $\sigma - N$ curves at room temperature, 200°C and 375°C. The fatigue limits σ_{wo} at those temperatures were 23, 22 and 26 kg/mm² respectively. Nonpropagating crack lengths l_{npo} observed at σ_{wo} were about 45, 10 and 50 μm respectively. Every crack length was measured along the circumference on the surface of specimen. Because the

cracks were difficult to be observed owing to oxidation of the surface during cyclic stressing at elevated temperatures, the surface was electropolished by a few microns, then the crack length was measured.

In the two-step, two-level temperature changing tests, the primary cyclic stress at 375°C or 200°C was named prestress and denoted by σ_1 and secondary cyclic stress at room temperature was denoted by σ_2 . Specimens which had been cyclic prestressed at elevated temperatures were called 375°C-prestressed and 200°C-prestressed specimens, respectively. Specimens which had been cyclic stressed at room temperature from the beginning were called original specimens. The number of cycles to crack initiation n_0 and the rate of crack propagation dl/dn in both prestressed and original specimens were obtained for σ_2 at room temperature. The number of cycles to crack initiation n_0 was defined as the number at which the crack length l reached the order of nonpropagating crack length l_{npo} , i.e., about 50 μm .

3. Experimental result

3.1 The effect of cyclic stress hysteresis at the peaking temperature on the crack propagation rate dl/dn at room temperature

Specimens were prestressed for various numbers of cycles n_1 at σ_1 which was 36 kg/mm², that is, about 40% higher than the fatigue limit at 375°C, and then fatigued to fracture at room temperature. The secondary stresses σ_2 at room temperature were 30 and 25 kg/mm² corresponding to about 30 and 9% higher than the fatigue limit at room temperature. Relationships between the cycle ratios n_1/N_1 at σ_1 and n_2/N_2 to fracture at σ_2 are shown in Fig. 3. In this figure, the results for the later mentioned 200°C-prestressed specimens are given too. Prestress σ_1 was 33 kg/mm², i.e., about 40% higher than the fatigue limit at 200°C, and σ_2 was 30 kg/mm² as before.

Fig. 1 Fatigue specimen.

Fig. 2 $\sigma - N$ diagrams.

Table 1. Chemical composition of material (wt.%).

C	Si	Mn	P	S	Cu	Ni	Cr
0.46	0.24	0.72	0.021	0.015	0.01	0.02	0.10

Table 2. Mechanical property of material.

Yield point kg/mm ²	Tensile strength kg/mm ²	True strength kg/mm ²	Elongation %	Reduction of area %	Hardness Hv
37.5	63.0	109.2	25	52	167

The cyclic stress hysteresis at the peaking temperature considerably increases the fatigue life n_2 at room temperature. Especially when n_1/N_1 was about 20%, the increase in n_2 was remarkable and $\Sigma n/N$ became maximum. These maximum values were about 4.4 for σ_2 of 30 kg/mm², and for 25 kg/mm² they were so large that the specimens were not broken even at 10^7 cycles. This tendency almost agrees with that obtained in the previous investigation.⁽¹⁰⁾ Pre-crack length l_1 corresponding to the maximum $\Sigma n/N$ was so small that it might disappear after electropolishing to a depth of a few microns.

Crack propagation curves (l - n curves) are shown in Fig. 4. They correspond to Fig. 3(a) in which σ_2 is 30 kg/mm². In Fig. 4, results for the original and 200°C-prestressed specimens are shown too. Two solid lines in the figure indicate the scatter band of experimental results for three original specimens. Relationships between $\Delta\sigma_2\sqrt{l/2}$ and the crack propagation rate

dl/dn obtained from l - n curves, according to the previously reported method,⁽¹⁷⁾ were examined for the prestressed specimens. Since the stress intensity range ΔK had not been obtained for this case, ΔK was replaced by $\Delta\sigma_2\sqrt{l/2}$ in which $\Delta\sigma_2$ represents the stress range at room temperature. Figure 5 shows the results for the original specimens. The abscissa represents $\Delta\sigma_2\sqrt{l/2}$ and its corresponding value of l too. Plotted results on log scales give a straight line and are expressed by the following equation,

$$dl/dn = c(\Delta\sigma_2\sqrt{l/2})^m \quad (1)$$

Both constants m and c differ with the stress at room temperature σ_2 . At the fixed $\Delta\sigma_2\sqrt{l/2}$, dl/dn takes a smaller value for a lower σ_2 . Figures 6 and 7 show the results for 375°C-prestressed specimens. Results for the original specimens at the same σ_2 are shown with broken lines. Cyclic stress hysteresis at the peaking temperature considerably reduces dl/dn at room

Fig. 3 Cumulative cycle ratios of 200°C- and 375°C-prestressed specimens.

Fig. 4 Crack propagation diagrams of original specimens.

(a) $\sigma_2 = 30$ kg/mm²

(b) $\sigma_2 = 25$ kg/mm²

Fig. 5 Crack propagation rate of original specimens.

temperature. At σ_2 of 30 kg/mm², dI/dn tends to decrease once with an increase in I immediately after the temperature change, and then to increase again. If such a propagation process is neglected, experimental results are considered to give a straight line as shown with a solid line over a wide range of I regardless of the pre-crack length I_1 . Accordingly the results for 375°C-prestressed specimens can be rearranged by the same equation as the original specimens.

The fact that the results for prestressed specimens can be rearranged by eq.(1) almost regardless of precrack length I_1 or number of cycles n_1 at σ_1 indicates that the structures with a strong repinning of multiplied dislocations are formed at early stage of cyclic prestressing and contribute to a decrease in dI/dn . Hence the fatigue tests were made when σ_2 was kept at 30 kg/mm² as above described and n_1 was as low as 5×10^3 cycles at various values of prestress σ_1 . The values of prestress σ_1 were about 154 % (40

kg/mm²), 115 % (30 kg/mm²) and 77 % (20 kg/mm²) of the fatigue limit. These results are shown in Fig.8. In this figure the broken line indicates the results for original specimens and the solid line indicates the results for prestressed specimens when σ_1 was 36 kg/mm². Regardless of the relatively small number of cycles at cyclic prestressing, dI/dn for σ_1 of 40 kg/mm² was not larger than that obtained for σ_1 of 36 kg/mm² for different values of n_1 . Except at the early stage at σ_1 of 40 kg/mm², the experimental result lies on each straight line corresponding to σ_1 and can be rearranged by the eq.(1). As σ_1 becomes higher, dI/dn becomes smaller. As above described, the cyclic stress hysteresis makes an evident contribution to the decrease in crack propagation rate at room temperature, though the degree of decrease differs with both σ_1 and σ_2 . A few thousand cycles at the peaking temperature are enough to show these behaviors, but the behavior does not vary with a further increase in cycles.

3.2 The effect of cyclic stress hysteresis at the peaking temperature on the number of cycles for crack initiation at room temperature n_0

In the experimental results at three prestress levels which are shown in Fig.8, pre-cracks did not still initiate because of so small a value of n_1 . The numbers of cycles for crack initiation n_0 and for crack propagation n_p were obtained to estimate the contribution of cyclic stress hysteresis to n_2/N_2 at room temperature, dividing it into n_0/N_2 and n_p/N_2 . As described in the preceding chapter, n_0 is the number of cycles at which the crack length I reaches 50 μ m. The results are summarized in Table 3. In this table, the values of cycle ratio at prestressing n_1/N_1 , those at room temperature n_2/N_2 and $\Sigma n/N$ are given too. The value of n_0/N_2 for original specimen is about 29 %, and that for prestressed specimen at σ_1 of 40 kg/mm² is only 4 %. In 40 kg/mm²-prestressed specimens, a number of micro cracks 10~20 μ m long had been formed during cyclic prestressing. Because

Fig.6 Crack propagation rate of 375°C-prestressed specimens.

Fig.7 Crack propagation rate of 375°C-prestressed specimens.

Fig.8 Crack propagation rate of 375°C-prestressed specimens.

Table 3 Cycle ratios of 375°C-prestressed specimens.

375 °C		Room temperature			
σ_1	$\frac{n_1}{N_1}$	$\frac{n_c}{N_2}$	$\frac{n_p}{N_2}$	$\frac{n_c}{N_2} + \frac{n_p}{N_2} = \frac{n_2}{N_2}$	$\frac{n_1 + n_2}{N_1 + N_2}$
(original)	—	0.29	0.71	1.00	1.00
20kg/mm ²	0	0.87	0.92	1.79	1.79
30	0.00	1.58	1.70	3.28	3.28
40	0.09	0.04	2.29	2.33	2.42

they join each other to macro cracks about 50 μm long, n_c/N_2 becomes smaller. When pre-stressed at σ_1 of 30 and 20 kg/mm² at which the micro cracks could not be observed, n_c/N_2 became 158 and 87 % respectively, about 5.4 and 3 times that of the original specimens. As far as pre-crack was not observed during prestressing, n_c increased with an increase in σ_1 . The value of n_p/N_2 becomes greater with an increase in σ_1 , as shown by $dI/dn - \Delta\sigma_2\sqrt{l/2}$ curves in Fig.8. The value of n_p/N_2 for original specimens is about 71 %. On the other hand, the values for prestressed specimens were 92, 170 and 229 % in order of an increasing σ_1 and they were about 1.3, 2.4 and 3.2 times those for the original specimen respectively. Although the value of n_p/N_2 for σ_1 of 40 kg/mm² was the greatest, $\Sigma n/N$ was smaller than that for σ_1 of 30 kg/mm² because of a very small n_2/N_2 .

3.3 The effect of cyclic stress hysteresis at the temperature of minimum strength on the crack propagation rate dI/dn at room temperature

As shown in Figs.3 and 4, the cyclic stress hysteresis at 200°C contributes to the increase in n_2/N_2 and n_p at room temperature, but its contribution is less than that of prestressing at 375°C. Relationships between dI/dn and $\Delta\sigma_2\sqrt{l/2}$ are shown in Fig.9. The broken and solid lines in Fig.9 indicate the results for original and 375°C-prestressed specimens respectively (Figs.5 and 6). For some time after the temperature change dI/dn decreases in the same way as the results

Fig.9 Crack propagation rate of 200°C-prestressed specimens.

at 375°C, then it approaches the results for original specimen with an increase in l . Therefore, in this case, c and m in eq.(1) cannot be determined as constants independent of precrack length l_1 . In Fig.3, the cycle ratio of prestress at which $\Sigma n/N$ takes a maximum is about 25% and the corresponding precrack length l_1 is about 200 μm .

4. Discussion

4.1 Values of c and m

Except the crack propagation immediately after the temperature change, the eq.(1) almost holds for 375°C-prestressed specimens in the same way as for original specimen. As shown in Figs.6 and 7, c and m were obtained by drawing a straight line over the whole experimental range of $\Delta\sigma_2\sqrt{l/2}$. Relationships between these constants and prestress σ_1 are shown in Fig.10. In this figure, the values when $\sigma_1 = 0$ are constants for original specimen. Symbols (○) and (Δ) indicate the results for σ_2 of 30 and 25 kg/mm² respectively. In Figs.5~8, when prestress σ_1 was an overstress and σ_2 was 30 kg/mm², all the experimental results were not easy to represent by a single straight line, even if the propagation terms immediately after the temperature change were omitted. However, in such cases, experimental results can be naturally represented by a single straight line for $\Delta\sigma_2\sqrt{l/2}$ larger than 50 kg/mm^{3/2} and the values of c and m were denoted by a symbol (●). Symbols (○) and (●) exist on single straight lines which are solid and broken respectively, in the range of σ_1 larger than 20 kg/mm², that is, for the prestress larger than about 80% of the fatigue limit. Thus they can be rearranged by the following equations,

$$m = a + b(\sigma_1 - 0.80\sigma_{w0}) \quad (2)$$

$$\log c = p + q(\sigma_1 - 0.80\sigma_{w0}) \quad (3)$$

where a , b , p and q are constants dependent on σ_2 . The values of these constants are shown in Fig.10. As σ_1 increases, dI/dn considerably decreases because of a decrease in c , while dI/dn approaches that of the original specimen relatively sooner with an increase in crack length l because of an increase in m . For σ_2 of 25 kg/mm² denoted by a symbol (Δ), straight lines through these points are given as two-dot chain lines with analogy to the results for σ_2 of 30 kg/mm², in spite of very few experimental results. With a decrease in σ_2 , c tends to be smaller and m to be larger for both original and prestressed specimens. In other words the same tendency was recognized as that observed when prestress σ_1 becomes larger for a fixed σ_2 .

4.2 The dominating parameters for dI/dn of the smooth specimen

Kitagawa et al.⁽¹⁸⁾ reported on the crack propagation behavior for smooth specimens of a carbon steel in rotating bending. According to their results the constants c decreased with a decrease in σ_2 in the same way as the results for original specimens by the authors. However m did not change with σ_2 very much. The results were rearranged as follows. The cracks in smooth specimens were relatively small in length

(a) Values of m

(b) Values of c

Fig.10 Relationships between m and σ_1 and between c and σ_1 .

and were subjected to higher stresses than the cracks to which the linear fracture mechanics was applicable, even if ΔK was equal for both cases. In smooth specimens, however, plastic deformation is not restricted only to the crack tip area and a number of slip bands are observed in the other regions. In this case, as the dominating parameter of dI/dn , the strain intensity factor range ΔK_e is more applicable than the stress intensity factor range ΔK . Rearranging the experimental results with ΔK_e from the above view point, it is found that dI/dn may be determined only by ΔK_e independently of σ_2 . Since the deviation from linearity becomes greater after cyclic prestressing at higher σ_1 , ΔK becomes greater, making c and dI/dn greater.

Applying this assumption for 375°C-prestressed specimens, the above experimental results may be interpreted qualitatively at least as follows. Relationships between $\Delta K/E^{(18)}$ and ΔK_e are shown schematically in Fig.11. The strain aging develops so rapidly at the peaking temperature 375°C that the multiplied dislocations are repinned every cycle. Consequently even for so small number of cycles as 5×10^3 at 375°C, the multiplied dislocations in prestressed specimens are repinned strongly. As the prestress

Fig.11 Relationship between ΔK and ΔK_e .

σ_1 becomes higher, a structure with a strong repinning is obtained because of higher density of multiplied dislocations during cyclic prestressing and hence the resistance to plastic deformation is increased. As shown in Fig.11, though ΔK , that is, σ_2 for a certain crack length is fixed, ΔK_e corresponding to higher σ_1 becomes smaller because of less deviation from linearity and dI/dn is considerably decreased.

The authors⁽⁹⁾ reported about the hardness distribution in the cross section of a specimen which had been prestressed at the peaking temperature. According to the result, the hardening in the surface layer of the prestressed specimen was considerably greater than that of the original specimen. This hardening was saturated at an early stage of cyclic stressing. As the prestress σ_1 becomes higher, this saturated value becomes greater and the hardened layer becomes thicker. Those results verified the validity of above assumption about the strength of repinning. According to the latest report by Taira et al.⁽¹⁹⁾ on the propagation rate in static and dynamic prestressed specimens of a low carbon steel, a decrease in propagation rate due to prestraining was recognized. They tried to rearrange the results with crack tip opening displacement and cyclic J-integral. Those parameters should be considered in the discussions of author's experimental results, too.

4.3 Contribution of the strain aging hysteresis to the number of cycles for crack initiation n_0

When no crack is formed during cyclic prestressing at 375°C, n_0 increases, as shown in Table 3, because of the restriction for cyclic slip deformation at room temperature caused by the strong repinning of multiplied dislocations. Since the diffusion rate of solute atoms at 200°C is smaller than that at 375°C, a relatively long time is required to obtain the structure with a strong repinning. Strength of such a structure depends on the number of cycles of prestressing n_1 . This is inferred from the experimental results that hardening becomes more remarkable with an increase of n_1 in the hardness tests for 200°C-prestressed specimens.⁽⁹⁾ When prestressed to an overstress for a small number of cycles n_1 at which a crack is not initiated, the structure with a strong repinning is not obtained and an increase in n_0 is not expected. Because the structure depends on n_1 , both m and c cannot be regarded as constants independent of pre-crack length l_1 , unlike in the case of 375°C-

Fig.12 Ratios of crack depth to crack length.

prestressed specimens. But when no crack initiates during a long time of cyclic prestressing at 200°C, n_0 at room temperature increases.⁽¹¹⁾

4.4 Relationships between crack depth t and crack length l

Above arguments are based on the crack length l observed on the surface of specimens. An investigation of crack propagation behavior from the surface to the core is necessary, but the crack depth t will be difficult to observe continuously. Relationships between t and l were obtained by the heat tinting method. The results are shown in Fig.12. The macroscopic shape of crack surface was semi-elliptical and t/l was about 0.4. There was no change in t/l with temperature.

5. Conclusions

After prestressing at 375°C and 200°C, both crack initiation and propagation behaviors at room temperature were examined for smooth specimens of 0.45% carbon steel under rotating bending. The results obtained are as follows.

(1) For 375°C-prestressed specimens subjected to more than a few thousand stress cycles, the propagation rate dl/dn was rearranged by the following equation almost regardless of the precrack length, in the same way as the original specimens,

$$dl/dn = c (\Delta\sigma_2 \sqrt{l/2})^m$$

where constants c and m depend on both the prestress σ_1 and the secondary stress at room temperature, σ_2 . When σ_1 ranged from about 80% to 150% of the fatigue limit σ_{w0} , the effects of σ_1 on the constants were estimated by the following equations,

$$m = a + b (\sigma_1 + 0.80 \sigma_{w0})$$

$$\log c = p + q (\sigma_1 + 0.80 \sigma_{w0}),$$

where a , b , p and q are constants dependent on σ_2 . As σ_1 becomes higher, c becomes greater and a decrease in dl/dn by prestressing becomes much greater. Because m increases with an increase in σ_1 , dl/dn increases and rapidly approaches that of the original specimens. As σ_2 increases, c tends to be smaller but m tends to be larger.

(2) Prestressing at 375°C reduces dl/dn at room temperature. Furthermore it increases the number of cycles for crack initiation at room temperature n_0 when no crack initiates during prestressing. Even a prestressing at σ_1 of only 0.77 σ_{w0} for a few thousand cycles contributes to

the increase in n_0 . As σ_1 becomes higher, the increase in n_0 becomes greater.

(3) For 200°C-prestressed specimens, an increase in dl/dn is recognized but it is smaller than the increase for 375°C-prestressed specimens. Since the crack propagation behavior depends on the precrack length, m and c cannot be determined as functions of σ_1 and σ_2 , unlike in the 375°C-prestressed specimens. A structure with a strong repinning of multiplied dislocations which contributes to the decrease in dl/dn is produced for a few cycles of prestress at 375°C. Since the diffusion rate of solute atoms at 200°C is smaller than that at 375°C, more cycles are required to repin effectively. The very intensity of repinning depends on the number of cycles at prestressing. Therefore it seems that there arises the above mentioned difference between the crack propagation behaviors of 375°C- and 200°C-prestressed specimens.

The authors wish to express their gratitude to Mr. Hiramatsu for his help in the experiment.

References

- (1) Forrest, P.G., J. Iron and Steel, Vol.200, No. 6 (1962-6), p.452.
- (2) Kawasaki, T., et al., Trans. Amer. Soc. Metals, Vol.60, No.4 (1967-12), p.707.
- (3) Kato, Y. and Hirose, M., J. Japanese Soc. for Strength and Fracture of Materials (in Japanese), Vol.5, No.1 (1970-5), p.11.
- (4) Hasegawa, N., et al., Trans. Japan Soc. Mech. Engrs. (in Japanese), Vol.43, No.370 (1977-6), p.1995.
- (5) Hirose, M., et al., Trans. Japan Soc. Mech. Engrs. (in Japanese), Vol.43, No.376 (1977-12), p.4337.
- (6) Ando, Z., et al., J. Japan Soc. Test. Mat. (in Japanese), Vol.11, No.105 (1962-6), p.379.
- (7) Dunsby, J.A., Proc. ASTM, Vol.65 (1965), p.736.
- (8) Kawamoto, M., et al., J. Japan Soc. Mat. Sci. (in Japanese), Vol.14, No.140 (1965-5), p.396.
- (9) Kawamoto, M., et al., Proc. 8th Japan Cong. Test. Mat., (1965), p.36.
- (10) Kato, Y. and Hirose, M., J. Japanese Soc. for Strength and Fracture of Materials (in Japanese), Vol.5, No.4 (1971-1), p.115.
- (11) Hirose, M., et al., J. Japan Soc. Mat. Sci. (in Japanese), Vol.23, No.252 (1974-9), p.777.
- (12) Shimizu, M., et al., J. Japan Soc. Mat. Sci. (in Japanese), Vol.24, No.267 (1975-12), p.1108.
- (13) Nakamura, H., et al., J. Japan Soc. Mat. Sci. (in Japanese), Vol.26, No.289 (1977-10), p.922.
- (14) Taira, S., et al., J. Japan Soc. Mat. Sci. (in Japanese), Vol.22, No.234 (1973-3), p.242.
- (15) Nishitani, H. and Ikenaga, T., Trans. Japan Soc. Mech. Engrs. (in Japanese), Vol.42, No. 361 (1976-9), p.2661.
- (16) Hirose, M., et al., J. Japan Soc. Mat. Sci. (in Japanese), Vol.27, No.300 (1978-9), p.841.
- (17) Hirose, M., et al., Trans. Japan Soc. Mech. Engrs. (in Japanese), Vol.44, No.381 (1978-5), p.1424.
- (18) Kitagawa, H., et al., Preprint of 11th Symposium on "Recent problems in fatigue" (in Japanese), (1977-11), p.11.
- (19) Taira, S., et al., Preprint Japan Soc. Mech. Engrs. (in Japanese), Vol.780, No.4 (1978-4), p.134.