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The Effects of Three Aqueous Environments on High-Stress Low-Cycle Fatigue of an 18% Nickel Maraging Steel

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ABSTRACT

Side-grooved plane-strain cantilever bend specimens of a 200 KSI yield strength grade of 18% Ni maraging steel were tested in distilled water, water inhibited with Na_2CrO_4, and 3-1/2% saline solution, to determine the steel's susceptibility to these environments while under high stress and low cycle fatigue conditions. In the locations and orientations (of cracks) tested, these environments were found to be not very aggressive under the selected fatigue conditions in either the base plate or the weld metal, with less than 0.001 in. of crack growth per cycle at stress intensities of slightly greater than 100 $KSI\sqrt{in.}$ Greater propagation rates were found in the range of 105 to 130 $KSI\sqrt{in.}$ with a maximum propagation rate of 0.006 in. per cycle at 120 $KSI\sqrt{in.}$

Dead-weight loaded specimens of base plate material showed crack propagation (to fracture) at stress intensities down to 74 $KSI\sqrt{in.}$ during long term (days) exposure in the NaCl solution.

Some delamination-type stress-corrosion cracking was observed in base plate specimens tested in the Na_2CrO_4 solution.

PROBLEM STATUS

This completes one phase of the problem. Work on other aspects is continuing. Quarterly Report for NASA, Project

Number: 1st Amendment of 11 January 1965, W-11763 on NRL Problem 62F01-15.

AUTHORIZATION

NRL Problem Number: 62F01-15 (Mechanics Div)
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INTRODUCTION

The effects of aqueous environments upon high stress intensity crack propagation in the 200 KSI and 250 KSI grades of 18% Ni maraging steel are being investigated in an effort to provide data useful in the prediction of the reaction of pressure vessels of these materials to a limited number of pressurization cycles.

This is a report on the results of tests on base plate and weld metal specimens of the 200 KSI yield strength maraging steel. Work on the 250 KSI yield strength steel is continuing.

MATERIAL AND TEST SPECIMENS

The specimens were 6 in. long, with a square cross-section of 0.6 in. on the edge, and had a 0.090 in. deep 45° notch located at mid-length so as to produce an RT crack. The depth of this stress-concentrator was extended by fatigue cracking to a new total depth of about 0.150 in. The specimens were then side grooved to a depth of 0.060 in. on both sides to insure that no shear lips would develop during crack propagation.

The base plate composition was Fe-18.09% Ni, 7.6% Co, 4.2% Mo, 0.18% Ti, 0.029% Mn, 0.01% P, 0.003% S, 0.007% Si, and 0.124% Al, according to information supplied with the specimens by Shipbuilding and Drydock Company "A". Company "A" used 0.61 in. thick vacuum arc remelted 18% Ni, 200 KSI yield strength grade maraging steel plate and fabricated their 260 in. diameter vessel by tungsten inert gas welding. The weld specimens were TIG welded by Company "A" using material from the same plate and the same weld conditions that were used in the fabrication of their first 260 in. rocket motor case. The weld test specimens were machined to place the length of the weld joint perpendicular to the rolling direction of the base plate. The weld specimens were notched in the center of the weld metal. In both the base plate and center-of-weld specimens the notches were machined so as to propagate a crack through the thickness.

All specimens were aged by Company "A" at 900°F for 8 hours after notching and before fatiguing. The aged 0.2% offset yield strength was 220 KSI for the base plate and 206 KSI for the weld metal as determined by Company "A".

TEST PROCEDURE

Notched specimens were tested as cantilever beams, in a manner described by Brown (1), by fixing one end into a firm support and applying a bending moment to the other end by attaching a lever arm to it and hanging a weight from the free end of the lever arm. This weight consisted of a large aluminum can into which water was pumped to increase the bending moment.

The liquid environments were contained in a polyurethane rubber container which was slipped over the central portion of the specimen before the specimen was placed into the test fixture.

It was originally intended to measure crack growth during testing by plotting bending moment versus beam deflection during each cycle and comparing the slope of this plotted line with slopes obtained similarly from calibration bars having known depths of 1/32 in. wide, 1/64 in. root radii slots. The calibrations were made by applying sufficient bending moments to the bars to cause a calculated stress of approximately one half the yield strength to be developed at the notch root.

Beam deflections were measured by using an extensometer-type linear transformer mounted (1) over the liquid container and central portion of the specimen, and (2) between two posts which were clamped to the specimen on either side of the liquid container and which extended higher than the container. Earlier attempts to measure the deflection of the lever arm proved too unreliable because of slippage and yielding at grips.

The combined weights of the lever arm and empty bucket caused a minimum bending moment in the tests of about one sixth or one fifth of that necessary to break the specimens.

Each test was started by loading the specimen to about one half yield strength at the notch root in air in order to estimate the crack length. By comparing the moment-deflection curves of these initial loadings with those of the calibration bars, the crack lengths were established to within +12 to -16 mils of their true length as measured on the fracture surfaces. Two thirds of the estimates were within 5 mils. All but two were within 10 mils.

Using these estimates of the initial crack lengths, bending moments were calculated which would produce the plane-strain stress intensity selected for the test, and cyclic testing was started in the selected environment.

The cycles consisted of (1) starting at about 20 KSI$\sqrt{\text{in.}}$, (2) pumping water into the bucket at a rate to give a linear increase in K_I of about 8 KSI$\sqrt{\text{in.}}$ per minute (both figures based on a 0.150 in. crack), (3) holding at the pre-selected maximum K_I level for a few minutes as shown in Table 1, and (4) pumping the water out at the same rate at which it was pumped in.

The environments used were (1) distilled water, (2) 3-1/2% NaCl solution in water, and (3) 1.75% sodium dichromate in distilled water with the pH adjusted to 7.3 $\pm$ 0.1 by the addition of sodium hydroxide*. The pH in the sodium chromate tests was checked several times a day. It was not necessary to change the solution in order to keep the pH within the selected range during each test.

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* The sodium dichromate ($Na_2Cr_2O_7$) solution was changed to predominantly sodium chromate by this addition of NaOH to raise the pH above 7.

Figure 1 shows a weld specimen which was tested in salt water (BW-6) and whose fracture surface is typical of most of the specimens. It can be seen that the environmental cyclic crack propagation was fastest at the edges of the crack, where the stress concentrations of the side grooves and the starting fatigue crack were combined. In these cases, the maximum crack length (at the arrows) and the crack length at the center of the specimens were averaged. Thus this average probably underrates the material's crack propagation resistance, and the crack propagation rates (per cycle) reported later in this report are probably a little high when compared to service-condition cracks.

Figure 2 shows specimen BL-8 which was cycled 51 times and had the longest crack length of all the specimens. The corrosion-fatigue crack may be seen to be longest at the bottom, indicating a slight lateral misalignment of bending moment which is difficult to inhibit in this test equipment. This specimen's eccentric crack growth is extreme - specimens with shorter cracks showed correspondingly less eccentric crack growth. In all the specimens the maximum and minimum crack lengths were averaged and are reported in Table 1.

RESULTS

Table 1 presents the significant data for the 200 grade base plate and center-of-weld tests. Values of the stress intensity factor were calculated by using the equation due to Kies et al (2):

$$K_I = \frac{4.12\ m \sqrt{\frac{1}{\alpha^3} - \alpha^3}}{B\ D^{3/2}},$$

where m is the bending moment in inch pounds, B is the width of the specimen (minus the two side groove depths), D is the height of the bar, and $\alpha = 1 - {}^{a}/D$. The a in this last equation is the notch plus crack depth.

Maximum stresses at the crack roots were calculated from the equation

$$\sigma = \frac{m}{\frac{B\ h^2}{6}},$$

where B is the width of the specimen (minus side grooves) and h is the height of the bar minus the fatigue crack.

In order to get crack growth, it was necessary to stress the specimens in the range where the material at the tip of the crack was close to, if not above, the uniaxial yield strength of the material without consideration of the stress concentration factor, and the crack growth, when it occurred, could not be monitored by the slope of the moment-deflection curves.

It became quickly apparent that this material was not extremely sensitive to corrosion fatigue under the selected fatigue conditions and in the selected crack orientations and crack locations and in these environments. It should be emphasized however, that these conditions were especially selected to approximate possible conditions in proof tests of rocket motor cases, and that though the material appears better than some of the quenched and tempered steels, and though it shows good resistance to crack propagation under the selected conditions, other, longer-term tests have shown that cracks will propagate at considerably lower K_I levels. These latter tests are described at the end of Results.

BASE PLATE

Base Plate Tested in Salt Water

Four specimens of the base plate were cycled in 3-1/2% saline solution.

Specimen BL-4 was cycled at a K_I of 78 for 20 cycles with no apparent crack growth during these first 20 cycles (the slopes of the deflection-moment lines were constant). Nine additional cycles at successively higher bending moments broke the specimen. Examination of the fracture surface showed a crack extension of 0.018 in. Using this extended crack length and the maximum bending moment on the last cycle, the final K_I was 134 KSI$\sqrt{\text{in.}}$ The holding times during cycling for this specimen were 10 minutes each. Had the crack extended an equal amount during each of the 29 cycles, a crack growth of 0.0006 in. per cycle would have resulted. However, it is much more probable that all of the crack growth occurred during the last 9 cycles where the bending moment was greatly increased.

Specimen BL-8 was cycled to a maximum K_I of 112 KSI $\sqrt{in.}$ for 20 cycles, with 10-minute holding times at maximum load. After the first 20 cycles the bending moment was first increased and then decreased during an additional 31 cycles, with the stress intensity factor varying between 115 and 124. The specimen broke after these 51 cycles, and the fracture surface showed that the crack had extended from 0.150 in. to 0.186 in. Thus, for 51 cycles at a K_I of between 112 and 124 KSI $\sqrt{in.}$, the crack grew 0.036 in. It is probable that, again, most of the crack propagation occurred during the last 31 cycles, and not during the first 20 cycles. However, if one assumes an equal crack propagation for each cycle, the rate would be 0.0007 in. per cycle over the 51 cycles.

Specimen BL-7 was cycled for 20 cycles to a maximum K_I of 115 KSI$\sqrt{in.}$ (based on the original crack length), and the holding time was 2-1/2 minutes. An additional 4 cycles at a slightly higher bending moment caused the specimen to break. A crack growth of 0.015 in. was measured on the fracture surface, with a final K_I of 128 KSI$\sqrt{in.}$ (based on the final crack length). It is likely that crack growth was fairly uniform during each cycle, with a bit more cracking during the last 4 cycles. An average crack growth of 0.0006 in. per cycle was, then, a maximum for the first 20 cycles.

Specimen BL-5 was cycled to a K_I of 120 KSI$\sqrt{\text{in.}}$, (based on the original crack length) with holding times of 5 minutes, until it broke during the holding period of the 12th cycle. From measurements on the fracture surface, the crack grew from 0.146 to 0.160 in. Based on the final crack length, the final K_I was 128 KSI$\sqrt{\text{in.}}$ Crack growth during each cycle was probable, with an average crack growth of 0.0012 in. per cycle.

For the specimens cycled in salt water, no growth was evident at 78 KSI$\sqrt{\text{in.}}$, growth of no more than 0.0006 or 0.0007 in. per cycle was found at 112 to 115 KSI$\sqrt{\text{in.}}$, and growth of about 0.0012 in. per cycle was found for a K_I of between 120 and 128 KSI$\sqrt{\text{in.}}$

Base Plate Tested in Sodium Chromate

Five specimens were tested in sodium chromate, with holding times of 10 minutes. The initial stress intensities ranged from 112 to 125 KSI$\sqrt{\text{in.}}$

Specimen BL-14 was cycled at K_I = 112 KSI$\sqrt{\text{in.}}$ (based on the initial crack length) for 20 cycles, with holding times at this maximum K_I of 10 minutes. The bending moment was then increased on the 21st cycle until fracture occurred. A crack growth of 0.010 in. was measured on the fracture surface. Neglecting the probability that a large proportion of the crack growth occurred during the 21st cycle, the average crack growth was about 0.0005 in. per cycle.

Specimen BL-11 was cycled 20 times at a stress intensity of 114 $KSI\sqrt{in.}$ (based on the initial crack length) with holding times of 10 minutes. On the 21st cycle the bending moment was increased until fracture occurred. Considerable crack growth probably occurred on the 21st cycle because the K_I was increased (based on the initial crack length) from 114 to 134 $KSI\sqrt{in.}$ before the test piece broke. Based on the measured final crack length, the final K_I was 153 $KSI\sqrt{in.}$ A crack growth of 0.037 in. was measured on the fracture surface, which gives an average of 0.0018 in. per cycle crack growth for the 21 cycles. The crack growth per cycle for the first 20 cycles was probably appreciably lower than this.

Specimen BL-13 was cycled to a stress intensity of 120 $KSI\sqrt{in.}$, with 10-minute holds, 4 times. The specimen broke on the 5th loading. Crack growth measured from the fracture surface was from 0.151 to 0.173 in. Averaged over 4 cycles, this gives a crack growth of 0.0055 in. per cycle. It would be 0.0044 in. per cycle if averaged over 5 cycles.

Specimen BL-12 broke when the selected maximum K_I of 125 $KSI\sqrt{in.}$ was reached. No evidence of crack growth could be seen on the fracture surface.

Specimen BL-9 also broke on the first loading. The maximum K_I reached was 122 $KSI\sqrt{in.}$ No crack growth was seen on the fracture surface.

For the base plate tested in sodium chromate, with 10-minute holds, a crack growth rate of about 0.0005 in. per cycle was found at a K_I of about 112 KSI$\sqrt{in.}$, a rate of no more than about 0.0018 in. per cycle was found at a K_I of 114 KSI$\sqrt{in.}$, and a rate of about 0.004 to 0.006 in. per cycle was found at a K_I of about 120 KSI$\sqrt{in.}$ At stress intensities of 122 and 125 KSI$\sqrt{in.}$ the specimens broke on loading.

A peculiar corrosion reaction was observed in these base plate specimens tested in sodium chromate solution. This will be described under Discussion of Results.

<u>Base Plate Tested in Distilled Water</u>

Two base plate specimens were tested in distilled water.

Specimen BL-6 was cyc[illegible]imes, starting with a crack length of 0.152 in. and a K_I of 114 KSI$\sqrt{in.}$, and developing a crack length of 0.171 in. during the 20 cycles. This specimen was taken out of the water, heat tinted at 400°F overnight, and broken to reveal the extent of crack growth during the 20 cycles. An average crack growth of just slightly less than 0.001 in. per cycle was found. The stress intensity grew from the initial value of 114 to a final value of 124 KSI$\sqrt{in.}$ during the 20 cycles.

Specimen BL-16 was cycled 20 times, with 10-minute holds, with a starting crack length of 0.137 in. and a starting K_I of 120 KSI$\sqrt{\text{in.}}$ This specimen was also taken out of the water after 20 cycles and heat tinted to reveal the crack length. This final crack length was 0.174 in. which shows that the stress intensity during the final holding period was 143 KSI$\sqrt{\text{in.}}$ and that the average crack growth was about 0.002 in. per cycle.

Base Plate Dry Break

Specimen BL-3 was broken in air, with a "dry break" value of K_I = 120 KSI$\sqrt{\text{in.}}$ This value is not necessarily the K_{I_c} since no "pop-in" was detected short of fracture.

A more sensitive means of detecting changes in deflection may have shown a "pop-in" short of the final fracture, but the reported value is probably close to the actual K_{I_c}.

WELD METAL

Center-of-Weld Tested in Salt Water

Specimen BW-6 was tested in 3-1/2% NaCl in distilled water, with 10-minute holding times. The initial crack length was 0.147 in. and cycling was up to a stress intensity of 120 KSI $\sqrt{\text{in.}}$ based on this crack length. The specimen broke after 8 minutes holding time in the 14th cycle. The final crack length measured on the fracture surface was 0.167 in., giving an average crack growth of 0.0014 in. per cycle, and a final stress intensity of 132 KSI$\sqrt{\text{in.}}$

Center-of-Weld Tested in Sodium Chromate

Four weld specimens were tested in sodium chromate, with the initial stress intensities between 102 and 115 KSI$\sqrt{\text{in.}}$ Holding time at maximum K_I values were 10 minutes for each cycle in all the tests.

Specimen BW-10 was cycled 20 times at a maximum bending moment which gave an initial maximum K_I of 102 KSI$\sqrt{\text{in.}}$ The bending moment was raised slightly on the 21st loading and the specimen broke. Measurements from the fracture surface showed a crack growth of 0.015 in., or an average rate of 0.0007 in. per cycle, and a final K_I of 110 KSI$\sqrt{\text{in.}}$

Specimen BW-11 was cycled 20 times at a maximum bending moment which gave an initial stress intensity of 105 KSI$\sqrt{\text{in.}}$ The bending moment was then increased during the next 8 cycles until the specimen broke on the 25th loading. Crack growth was from 0.150 to 0.185 in. giving an average crack growth rate of 0.0012 in. per cycle. Considerable crack growth probably occurred during the last 8 cycles, however, and the average cracking rate for the first 20 cycles was probably less than 0.001 in. per cycle.

Specimen BW-9 was cycled to a stress intensity of 108 KSI$\sqrt{\text{in.}}$ and broke during the holding time of the second cycle. A crack growth of 0.003 in. was measured on the fracture surface. Whether this was equally divided between the two cycles is not known.

Specimen BW-8 broke on loading at a K_I of 115 KSI$\sqrt{in.}$

The specimens tested in sodium chromate solution showed an average cracking rate of about 0.0007 in. per cycle at a K_I of 103 KSI$\sqrt{in.}$, a rate of 0.0012 in. per cycle at a K_I of about 105 KSI$\sqrt{in.}$, and a rate of about 0.002 in. per cycle at a K_I of about 108 KSI$\sqrt{in.}$ Fracture occurred upon loading during the first cycle at a K_I of 115 KSI$\sqrt{in.}$

Center-of-Weld Tested in Distilled Water

Two specimens were tested in distilled water, both with holding times of 10 minutes.

Specimen BW-13 was cycled 20 times at a bending moment which gave a stress intensity of 95 KSI$\sqrt{in.}$ during the 1st cycle. The specimen was then left loaded into the weekend, and it broke during the weekend. Crack growth was measured from the fracture surface and found to be 0.037 in. It is probable that a large portion of the crack growth occurred during the long 21st cycle, and no confidence could be placed in an average crack growth calculation.

Specimen BW-12 was cycled for 20 cycles at a bending moment which caused a stress intensity factor of 100 KSI$\sqrt{in.}$ during the 1st cycle. The bending moment was raised considerably on the 21st cycle until fracture occurred. Measurements from the fracture surface showed a crack extension of 0.019 in. during the 21 cycles. Using the final crack length and the bending moment applied during the first 20 cycles, the K_I during the 20th cycle was 110 KSI$\sqrt{\text{in.}}$ Thus for 20 cycles, where the K_I increased from 100 to somewhat less than 110 KSI $\sqrt{\text{in.}}$, the crack grew no more than (probably less than) 0.019 in. or an average growth of no more than 0.001 in. per cycle.

Center-of-Weld Dry Break Test

Specimen BW-4 was broken in air, with a K_I of 113 KSI$\sqrt{\text{in.}}$ Again, this is not necessarily the K_{I_c}, since no "pop-in" was observed. It is probably quite close to the K_{I_c}, however.

Dead-Weight Loaded Specimens

Dead-weight loaded specimens of the weld metal were tested in the saline solution, where the specimens were loaded to a selected K_I level and were left until fracture occurred. This series of tests is continuing, but the results from 4 specimens are given at the bottom of Table 1. These results show the relationship of K_I versus time in solution which Brown (1) has shown in other materials, including maraging steels. Not enough testing has been completed to permit the determination of the K_{Iscc} for the weld metal, but it is not higher than 74 KSI$\sqrt{\text{in.}}$ Work on this particular aspect of the problem is continuing. At this point it is interesting to recall that a weld specimen (BW-13) broke in distilled water at a K_I of somewhat higher than 95 KSI$\sqrt{\text{in.}}$ after an extended period of dead-weight loading, even though it survived 20 cycles with 10-minute holding times.

DISCUSSION OF RESULTS

The results given do not include some of the earlier results on specimens which were (1) tested without side grooves, or (2) tested by slow incremental loading to fracture to serve as a guide for the selection of stress intensities at which the reported specimens were tested and also as an early check on the effects of the "Company "A" inhibitor-material combination.

The calibrations served well in measuring initial crack lengths but were no help in following small amounts of crack growth since all of the tests were conducted at such high stresses that a change in slope could have been caused by plastic flow at the tip of the notch, or crack growth, or a mixture of the two.

Neither the base plate nor the weld specimens were highly sensitive to the three aqueous environments in the cyclic tests. It should be remembered, however, that only the center-of-the weld was tested, and this in only one orientation. Likewise, the base plate was tested only in the RT direction.

Figure 3 shows the results summarized on one graph. Under no conditions did the crack grow a thousandth of an inch per cycle below a stress intensity of 100 KSI$\sqrt{\text{in.}}$ Below 100 KSI $\sqrt{\text{in.}}$, some crack growth can be expected for longer stressing periods, but not much for a few cycles with 10-minute holding times. The lower limit of crack propagation, where cracks would not grow in a reasonable period of time (days or weeks) has not been established, but is probably less than 74 KSI$\sqrt{\text{in.}}$ The one test on the base plate in saline solution at a K_I of 78 showed that this value of K_I is below the stress intensity that is necessary to get crack propagation in 20 cycles.

The base plate specimens tested in sodium chromate suffered from a peculiar corrosion phenomenon. In the specimens which were tested for 20 cycles (and other specimens that were held under stress for longer periods of time) in sodium chromate, a galvanic cell was set up which caused corrosion cracking parallel to the rolling plane, and a deposition of rust in the machined notch portions of the specimen (which were more open to the solution). Figure 4 shows specimen BL-14, with the three arrows on the right indicating these cracks. A severe case of this is shown in Fig. 5 where a base plate specimen was dead-weight loaded at high K_I values for several days. Such cracking would tend to lessen the severity of a crack which was oriented perpendicular to the rolling plane (as all of the cracks in these tests were), but would hasten the propagation of a crack oriented parallel to the rolling plane. These particular cracks did not occur at the tip of the fatigue cracks, but were initiated and grew perpendicular to the fatigue crack surfaces at some point behind the fatigue crack tips (between the notch roots and the fatigue-crack roots) as seen in Fig. 4. Such cracks would probably not be a problem in hydrotesting since they did not appear in the specimens which broke on loading or in the specimens which lasted for 4 cycles (40 minutes at maximum K_I).

Such secondary cracks were not observed in any of the tests in other environments.

Corrosion inhibitors have evolved as a means of combatting pitting and general corrosion, but no research has been directed toward understanding or evaluating the ability of these standard inhibitors to influence stress-corrosion-crack propagation. Experience with titanium alloys has forcefully shown that there can be a great deal of difference between susceptibility to corrosion and susceptibility to stress-corrosion cracking. Caution should be exercised when one draws upon <u>general corrosion</u> experience in selecting an inhibitor for <u>stress-corrosion-crack propagation</u>.

Sodium chromate should be kept on the basic side of the pH scale and in adequate concentration to prevent general corrosion, but little is known about what pH or concentrations are necessary to slow or stop stress-corrosion cracking. Preliminary work at NRL has shown <u>no</u> effect of the inhibitor upon crack propagation in AISI 4340 tempered at 400°F. At a K_I of about 30 $KSI\sqrt{in.}$ no differences were found between distilled water, water with 1.75% Na_2CrO_4 at a pH of 7.2, water with 7% Na_2CrO_4 at a pH of 11.9, or several other combinations of pH and concentrations including several in the acid range.

In addition, the concentration and the pH of the sodium chromate at the tips of long tight cracks may well be different from those of the bulk solutions.

The odd stress-corrosion cracking of the maraging steel base plate is, therefore, a manifestation of corrosion conditions at or near the tips of cracks - conditions that are of considerable importance to crack growth rates, but which have not been investigated to a degree where an effective inhibitor can be specified.

SUMMARY

Testing of the 200 grade of 18% Ni maraging steel is essentially completed. A few more tests at K_I values of around 90 or 100 will be conducted in order to more closely establish the K_I at which cracking does not occur in sodium chromate during 20 cycles with 10-minute holding times.

Tests are continuing in an effort to establish the K_{Iscc} of the base plate and weld metal in saline solution.

The weld metal showed comparable crack propagation rates at slightly lower K_I levels than the base plate, but both the base plate and the weld metal show good resistance to severe crack propagation at high K_I levels in up to 20 cycles of simulated hydro-test conditions.

It should be emphasized again that the sodium chromate solution promoted a slow, but definite, stress-corrosion cracking in base plate specimens along planes parallel to the rolling plane.

It also ought to be re-emphasized that slow, but definite, cracking occurs in the weld metal at stress intensity levels as low as 74 KSI$\sqrt{\text{in.}}$ in saline solution, and to some extent in distilled water.

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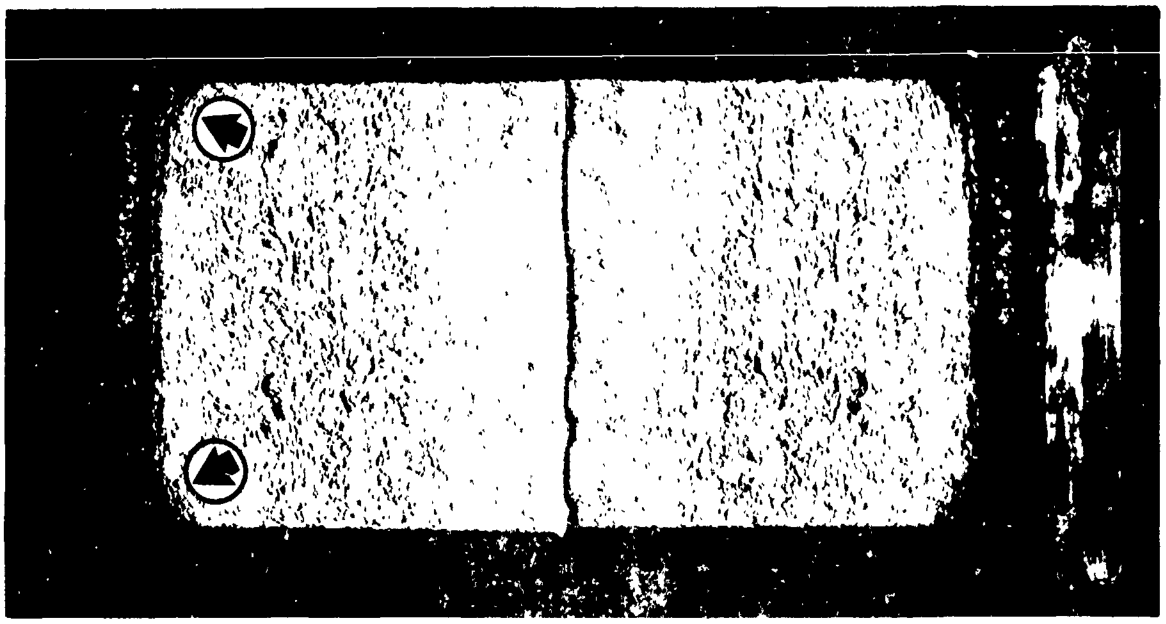

Fig. 1 - Specimen BW-6 showing a maximum crack length at the two ends of the crack (at arrows). 5X.

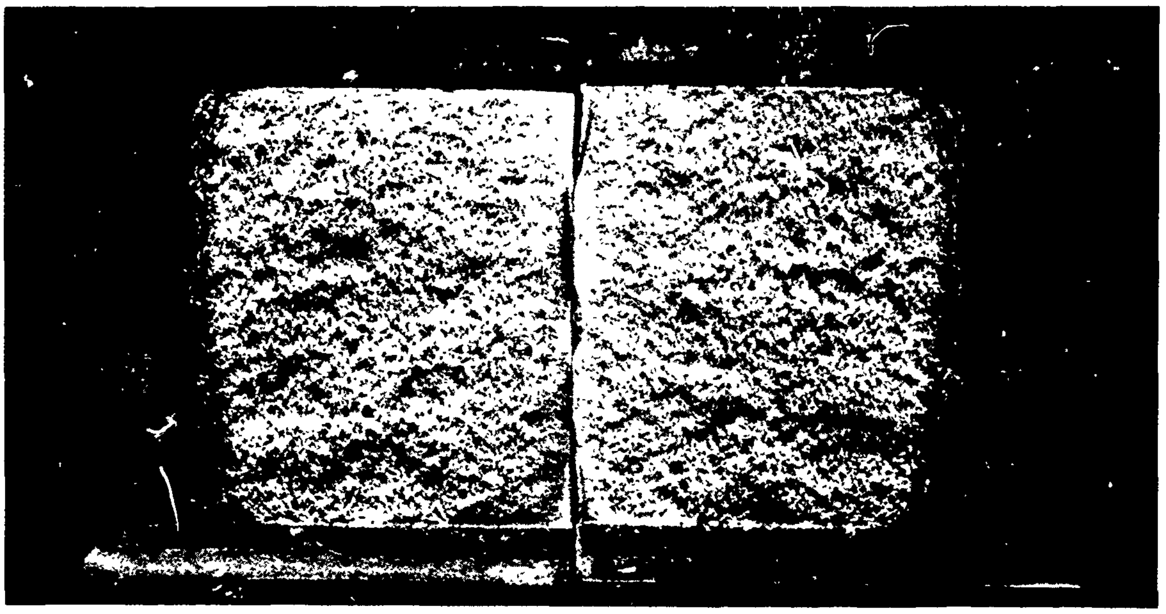

Fig. 2 - Specimen BL-8 showing the most crack growth and the worst eccentricity of crack growth. 5X.

Table 1
Summary of Data

Location	Environment	Initial Crack Length (inch)	Crack Length After 20 Cycles (inch)	Final Crack Length (inch)	Initial K_I (KSI $\sqrt{inch}$)	K_I after 20 Cycles (KSI $\sqrt{inch}$)	Time at Max. K_I (each cycle) (min.)	Initial σ_{max} at Crack Root (KSI)	Number of Cycles	Specimen Number
Base Plate	Dry	0.171	-	0.171	120	-	-	225	-	BL 3
Base Plate	Salt	0.142	-	0.160	78	78	10	149	29	BL 4
Base Plate	Salt	0.146	-	0.160	120		5	228	12	BL 5
Base Plate	Salt	0.137	-	0.152	115	124	2-1/2	220	24	BL 7
Base Plate	Salt	0.150	-	0.186	112	133	10	212	51	BL 8
Base Plate	Na_2CrO_4	0.147	-	0.147	122	-	-	233	-	BL 9
Base Plate	Na_2CrO_4	0.128	-	0.165	114	135	10	216	21	BL 11
Base Plate	Na_2CrO_4	0.144	-	0.144	125	-	-	235	-	BL 12
Base Plate	Na_2CrO_4	0.151	-	0.173	120	-	10	228	4	BL 13
Base Plate	Na_2CrO_4	0.151	-	0.161	112	118	10	214	21	BL 14
Base Plate	H_2O	0.137	0.174	0.174	120	143	10	231	20	BL 16
Base Plate	H_2O	0.152	0.171	0.171	114	124	10	214	20	BL 6
Weld	Dry	0.191	-	0.191	113	-	-	216	-	BW 4
Weld	Salt	0.147	-	0.167	120		10	230	14	BW 6
Weld	Na_2CrO_4	0.140	-	0.140	115	-	10	223	-	BW 8
Weld	Na_2CrO_4	0.150	-	0.153	108		10	204	2	BW 9
Weld	Na_2CrO_4	0.152	-	0.167	102	110	10	196	21	BW 10
Weld	Na_2CrO_4	0.150	-	0.185	105	126	10	204	28	BW 11
Weld	H_2O	0.128	-	0.147	100	100	10	193	21	BW 12
Weld	H_2O	0.137	-	0.174	95	102	10	184	21	BW 13
DEAD-WEIGHT LOADED SPECIMENS										
Weld	NaCl	0.149	-	0.193	95.4	-	8.5 hours	-	-	BW 5
Weld	NaCl	0.143	-	0.185	92.0	-	38 hours	-	-	BW 17
Weld	NaCl	0.156	-	0.206	85.5	-	104 hours	-	-	BW 19
Weld	NaCl	0.130	-	0.213	73.5	-	153 hours	-	-	BW 21

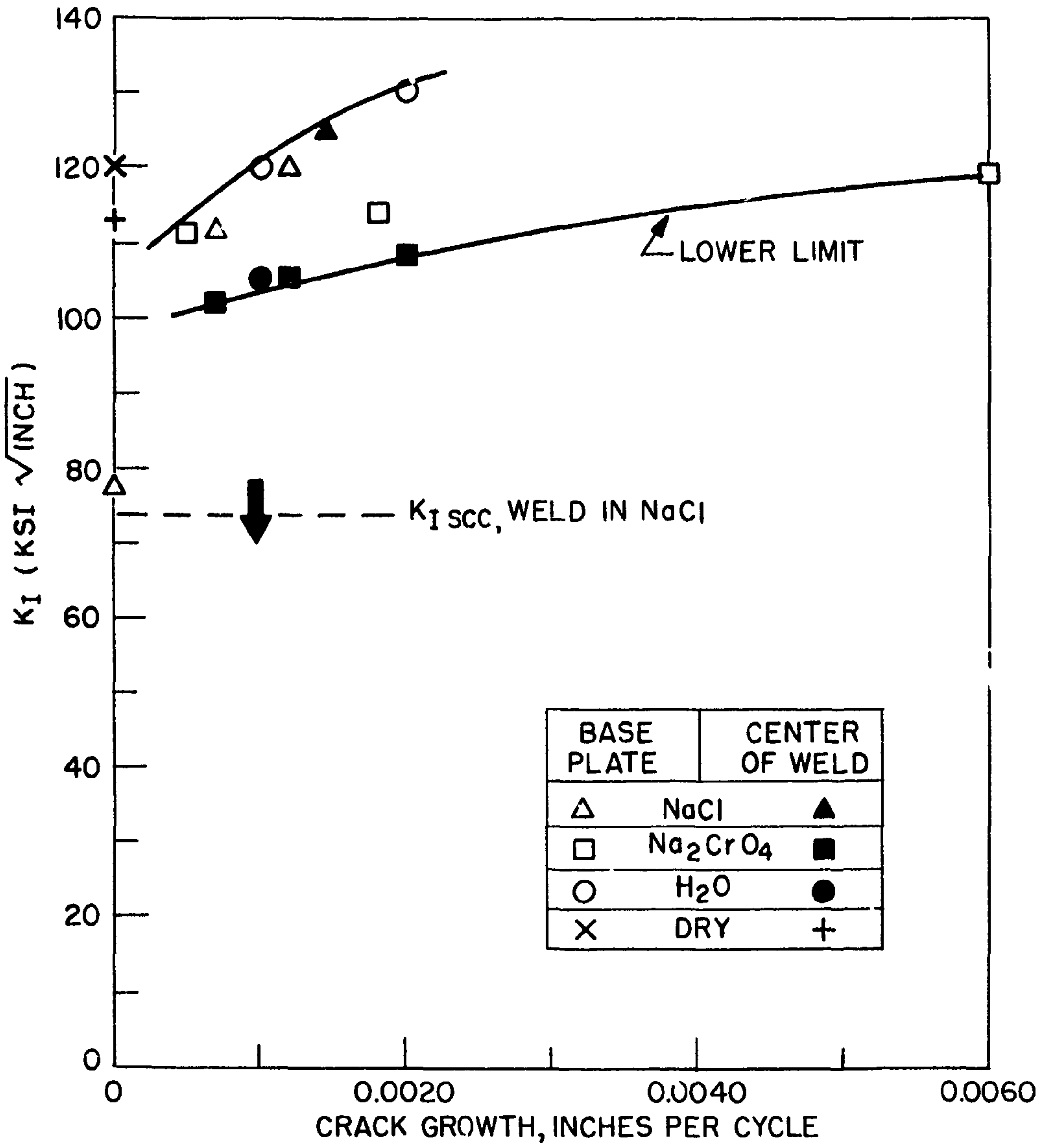

Fig. 3 - Environmental effects upon high-stress fatigue in an 18% Ni maraging steel.

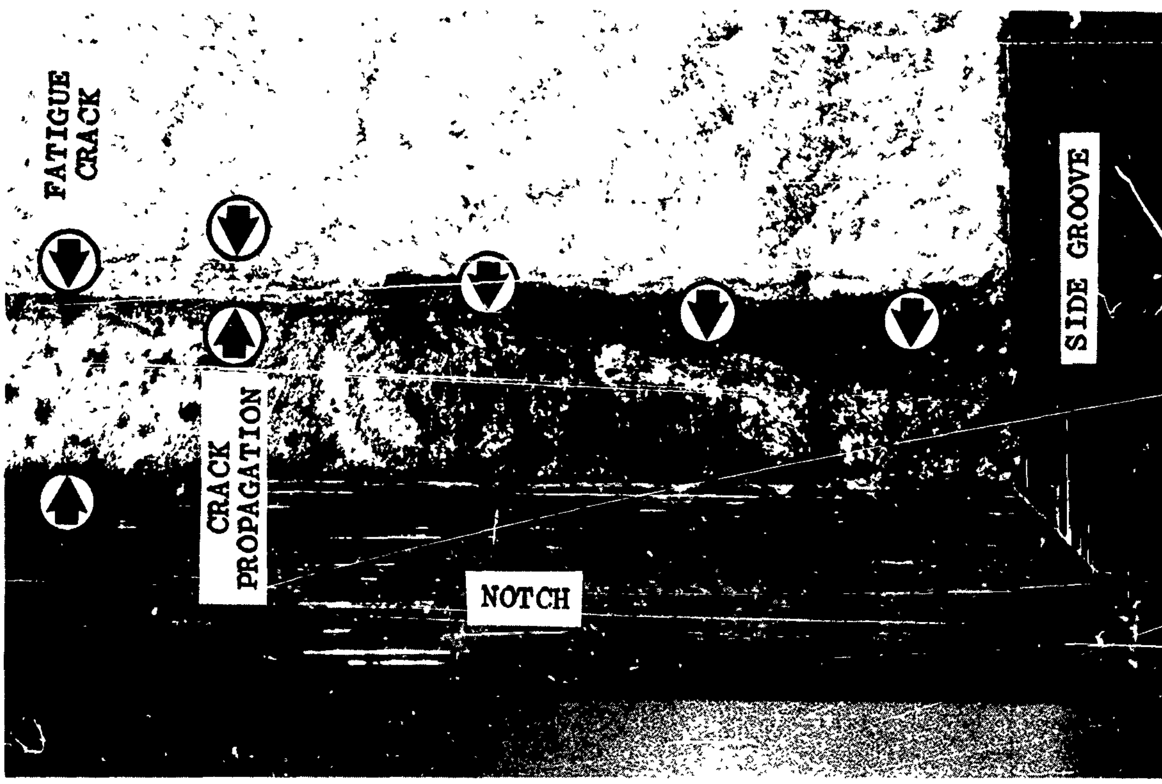

Fig. 4 - Fracture surface of specimen BL-14 showing secondary cracks below the three arrows on the right. 15X.

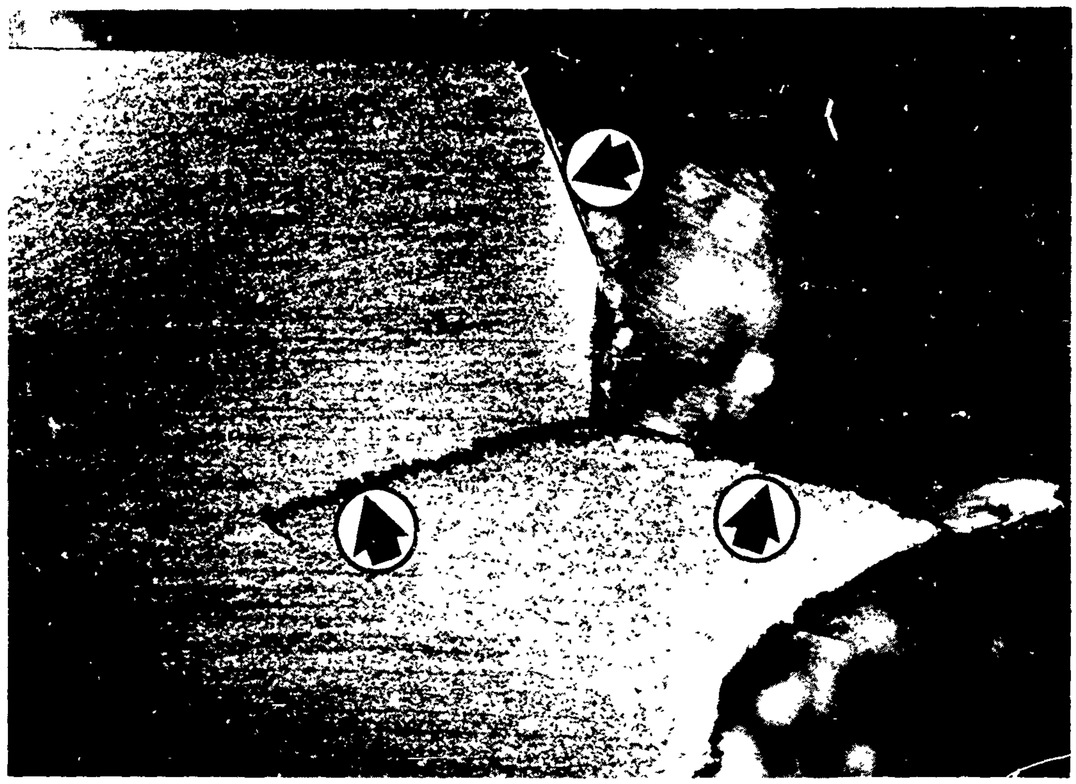

Fig. 5 - Metallographic section of specimen BL-15, dead-weight loaded for several days, showing notch (top arrow), fatigue crack, and secondary cracks (two bottom arrows). 5X.