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# CRACK GROWTH IN 2014-T6 ALUMINUM TENSILE AND TANK SPECIMENS CYCLICALLY LOADED AT CRYOGENIC TEMPERATURES

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## SUMMARY

An investigation was conducted to determine the cryogenic low-cycle (life under 1000 cycles) fatigue crack growth behavior of 2014-T6 aluminum through-notched uniaxial tensile and biaxial pressure vessel specimens. The specimen thickness was 0.060 inch (0.15 cm). Low-cycle crack growth data were obtained from the notched specimens at $-320^{\circ}$ and $-423^{\circ}$ F ($77^{\circ}$ and $20^{\circ}$ K). Initial notch lengths from 0.125 to 1.0 inch (0.318 to 2.54 cm) and initial R ratios $R_i$ (minimum to maximum initial stress intensity factor, $K_{min,\,i}/K_{max,\,i}$) from 0.07 to 0.36 were studied.

The parameters $R_i$ and $K_{max,\,i}$ appear to be useful for relating crack growth rates in pressure vessels to those in tensile specimens. At $-320^{\circ}$ and $-423^{\circ}$ F ($77^{\circ}$ and $20^{\circ}$ K), the crack growth rates were almost equal for the pressure vessel and corresponding tensile specimen provided the $R_i$ and $K_{max,\,i}$ values were held constant.

The slopes of the curves for crack growth rate da/dN as a function of stress intensity factor range $\Delta K$ varied from 6 to 13 on a log-log plot. This slope is a function of $R_i$ and increases as $R_i$ increases. The values obtained for the slopes were, in general, higher than those in the literature for similar tests conducted at room temperature.

For a given ratio of maximum to critical stress intensity factor, the specimens tested at $-423^{\circ}$ F ($20^{\circ}$ K) had longer lives than those tested at $-320^{\circ}$ F ($77^{\circ}$ K). Also, specimens run with higher $R_i$ ratios had the longer cyclic lives for a given ratio of maximum to critical stress intensity. For similar values of $R_i$ and $K_{max,\,i}$, the cyclic lives of tensile and tank specimens were almost equal, with the tensile specimens generally having longer lives.

## INTRODUCTION

Cryogenic propellant tanks for advanced space missions may be subjected to many

cycles of pressurization and external loading during the test, launch, and flight phases. There may be, therefore, an opportunity for flaws, which were not critical initially, to grow due to cyclic loading to either the leak or burst stage. Such flaws may be present in the parent material or may result from the fabrication processes. Also, some flaws may be added during flight in the form of micrometeoroid damage. Depending on the severity of the damage and the material characteristics, the results can be immediately catastrophic. More likely, however, the damage is of a form that provides an initiation site for flaw growth under sustained load or additional cyclic loading.

To assist in assuring the required reliability, it is necessary to develop a proof testing program for each propellant tank. The loads and pressures applied during the proof test must be of levels that assure the absence of any flaws large enough to grow to a critical size during the required vehicle life. The development of a proof testing program requires knowledge of flaw propagation rates in the material under the appropriate loading and environmental conditions. To obtain the necessary data from pressure vessel type specimens is difficult and expensive. It is highly desirable, therefore, to gather the required data from tests of flawed uniaxial specimens. There are questions, however, that arise in translating the uniaxial flaw growth data into actual tank flaw growth and ultimate failure.

In recent years considerable effort has been expended in studies of flaw growth characteristics under conditions leading to low-cycle fatigue. For example, Paris (ref. 1) developed a thin-sheet flaw growth relation for uniaxial specimens at room temperature. Tiffany, Lorenz, and Hall (ref. 2) developed design criteria for plane strain flaw growth in tanks and uniaxial specimens at room and cryogenic temperatures. At the same time, Eitman and Rawe (ref. 3) developed parametric relations for thin-sheet flaw growth in tank and uniaxial specimens of 2219-T87 aluminum alloy at cryogenic temperatures.

Research was conducted at the Lewis Research Center to establish a correlation of flaw growth between uniaxially and biaxially stressed sheet specimens subjected to cyclic loading at cryogenic temperatures in terms of fracture mechanics concepts. A secondary objective of this research was to determine the effect of initial R ratio $R_i$ (minimum to maximum initial stress intensity ratio, $K_{min,\,i}/K_{max,\,i}$) on the flaw growth relation. In addition, it was desired to explore the low-cycle flaw growth process in a cycle range commensurate with the number of cycles of loading that an advanced propellant tank or pressurization bottle might be expected to undergo during its life. This range was therefore selected to be from 0 to 1000 cycles. The material chosen for this investigation was the aluminum alloy 2014-T6, which is currently being used in several vehicle systems.

Flaws extending through the thickness of the sheet material were chosen for the initial investigation as a first step in the overall program. This was done because of simplifications involved in both the experimental and theoretical approaches to the problem.

It is recognized, however, that flaws extending partially through the thickness are probably of more concern from a practical point of view and subsequent phases of the overall program will be concerned with this type.

This report presents the results of tests to determine the flaw growth characteristics of through cracks in uniaxially and biaxially loaded specimens of 2014-T6 aluminum sheet at $-320^{\circ}$ and $-423^{\circ}$ F ($77^{\circ}$ and $20^{\circ}$ K) resulting from cyclic loading in the 0 to 1000 cycle range. A correlation is presented in terms of fracture mechanics relations and the effect of $R_i$ ratio on the flaw growth and cyclic life is shown.

## SYMBOLS

| | |
|---|---|
| 2a | crack length, in.; cm |
| C | dimensionless bulge coefficient (eq. (2)) |
| C* | constant in crack propagation equation accounting for mean load, loading frequency and environment (eq. (3)) |
| $C_1, C_2$ | constants in crack propagation equations accounting for material and environment (eqs. (4) and (5)) |
| K | stress intensity factor, ksi$\sqrt{\text{in.}}$; $MN/m^{3/2}$ |
| $\Delta K$ | stress intensity factor range, $K_{max} - K_{min}$, ksi$\sqrt{\text{in.}}$; $MN/m^{3/2}$ |
| N | load cycles |
| n | exponent in crack propagation equation (eq. (4)) |
| R | ratio of $K_{min}/K_{max}$ in a given cycle |
| r | radius of tank, in.; cm |
| w | sheet width, in.; cm |
| $\gamma$ | slope on a log-log plot of da/dN against $\Delta K$ |
| $\sigma$ | uniform gross stress acting normal to plane of crack, psi; $MN/m^2$ |
| $\Delta\sigma$ | stress range ($\sigma_{max} - \sigma_{min}$), psi; $MN/m^2$ |
| $\sigma_y$ | uniaxial yield strength, psi; $MN/m^2$ |
| $\sigma_{yB}$ | yield strength in 2:1 stress field, psi; $MN/m^2$ |

Subscripts:

| | |
|---|---|
| c | critical |
| F | failure |

| | |
|---|---|
| H | hoop direction in cyclindrical tank |
| i | initial condition (start of test) |
| L | last complete cycle |
| max | value at maximum cyclic load |
| min | value at minimum cyclic load |

# MATERIAL, APPARATUS, AND PROCEDURES

## Material and Specimens

The material used in this investigation was from a single heat of unclad 2014-T6 extruded aluminum alloy tubing. The chemical analysis of this heat is given in table I.

The tensile specimens were machined from the same tubing as the tank specimens. Pieces of tubing were cut longitudinally, annealed, flattened, and reheat-treated to the T6 condition. Hardness tests were performed as a check for the T6 condition. Specimens were machined from the flattened tubes to the shape shown in figure 1. All specimens were transverse with respect to the extruding direction. A finished notched specimen with continuity gages is shown in figure 2.

The tank specimens were machined from the 6 inch (15.2 cm) outside diameter by 0.25 inch (0.63 cm) wall extruded tubing. The finished wall thickness was $0.060\ ^{+0.002}_{-0.000}$ inch $\left(0.152\ ^{+0.005}_{-0.000}\ \text{cm}\right)$ with a mean diameter of 5.63 inches (14.3 cm). Longitudinal notches were machined in the tanks and were shaped as shown in figure 1. A finished specimen with special ends, strain gages, and continuity gages is shown in figure 3.

The actual dimensions for each specimen were used in the calculations and data presented. The tolerances are given to show the range of a particular dimension. Machined notches were used instead of fatigue tipped for two primary reasons:

(1) Previously unpublished data by the author indicated practically no difference between failure stresses for machine notched (0.0002 in., 0.0005 cm, radius) and fatigue-tipped-notched tanks in this material and thickness.

(2) Because the specimens exhibited crack growth on the first cycle, no initiation time was involved.

Once crack growth occurs, the original notch should have little, if any, effect on the growth process, provided the notching process does not affect adjacent material.

## Apparatus

Static tensile tests. - A tensile machine with a hydraulically actuated loading frame was used for the tensile tests. A vacuum-jacketed cryostat was used to contain the cryogenic fluid that surrounded the test specimen. Strain was measured by using a clamp-on differential-transformer extensometer with a 2-inch (5-cm) gage length and an autographic stress-strain recorder.

Static tank tests. - In references 4 and 5 a complete description is given of the method used for bursting tanks at -320° and -423° F (77° and 20° K). The system is capable of bursting tanks at pressures up to 3000 psi ($20.7\times10^6$ N/m$^2$).

Cyclic tensile tests. - The tensile fatigue testing machine is shown in figure 4. It consists of a load frame and cryostat. A hydraulic piston is located on top of the load frame and loads through a load cell at the top. In the figure the cryostat is lowered to show the position of the test specimen; during testing the cryostat is raised to surround the test specimen. The machine uses a servo-controller in conjunction with a function generator to control the load history. Load capacity is 20 000 pounds (89 000 N), and the cyclic rate used was 3 cycles per minute (0.05 Hz).

Cyclic tank tests. - The test cell, cryostat, and special tank end closures are described in references 4 and 5. For the -320° F (77° K) cyclic tank tests, gaseous nitrogen was used as the pressurizing medium instead of gaseous helium as outlined in reference 4. Cycling was accomplished by alternately pressurizing and venting the gaseous nitrogen. Pressure controlled valves were used to control the flow of gaseous nitrogen. Cycle rate was 3 cycles per minute (0.05 Hz).

The tank tests at -423° F (20° K) were similar to the -320° F (77° K) test except that liquid hydrogen was used for pressurization. A 2.5-gallon-per-minute ($9.4\times10^{-3}$ m$^3$/min) liquid-hydrogen pump capable of 4000 psi ($27.6\times10^6$ N/m$^2$) was used to pressurize the test tank. The rate was 3 cycles per minute (0.05 Hz).

Instrumentation. - Carbon resistor probes were used to determine the liquid level in the cryostats. In all tests, however, the test specimen was submerged in the appropriate cryogenic liquid.

Crack length was measured by use of foil element continuity gages. A complete description of the gage and its use is found in reference 6. The cyclic calibration is described in that reference. Figure 5 shows two continuity gages mounted in tandem at the notch tip.

## Procedure

Static tensile tests. - Tensile tests to determine the ultimate strength and

0.2-percent-offset yield strength were run at approximately 70° F (293° K) in ambient air, -320° F (77° K) in liquid nitrogen, and -423° F (20° K) in liquid hydrogen. Specimens with a 1.0-inch (2.54-cm) notch length were tested at -320° and -423° F (77° and 20° K) to determine the apparent fracture toughness value ($K_c$) for the extruded material when machined to a thickness of 0.060 inch (0.15 cm). The notch length used for the fracture toughness calculations was the critical notch length obtained when the crack propagation velocity approached 0.5 to 1.0 inch (1.3 to 2.5 cm) per second (ref. 7). The validity of this specimen size is also shown in reference 7. A minimum of two specimens was run for each test condition. Average values of these data are listed in table II.

Static tank tests. - One unnotched tank was tested at -320° and -423° F (77° and 20° K) to determine the biaxial 0.2-percent-offset yield strength. Foil strain gages were used to measure the strain in the tank wall. The mounting technique and gage type are described in reference 8.

Cyclic tensile tests. - Axial-tension fatigue tests were conducted on tensile specimens with initial notch lengths $2a_i$ equal to approximately 0.125, 0.300, 0.500, and 1.000 inch (0.318, 0.762, 1.27, and 2.54 cm). The specimen width was 3.00 inches (7.6 cm). At -320° F (77° K) approximately four specimens were tested at each notch length (see table III). The maximum cyclic stress level for each of the four specimens was chosen to give various cyclic lives up to approximately 1000 cycles. The minimum cyclic stress was fixed at 4.6 ksi ($31.7 \times 10^6$ N/m$^2$) due to limitations of the test equipment in the early stages of the program. Due to the fixed minimum stress and varied maximum stress, the $R_i$ ratio varied from approximately 0.07 to 0.23. The cyclic rate was 3 cycles per minute (0.05 Hz).

At -423° F (20° K) similar tests were run but with only one specimen at each notch length because the results were very similar to the -320° F (77° K) data. For these tests the minimum cyclic stress was varied to give particular values for $R_i$ (see tensile data, table IV).

Cyclic tank tests. - Biaxial fatigue tests were conducted on tanks for the same notch lengths and test temperatures as the tensile fatigue tests. The tanks were immersed in and filled with the cryogenic liquid. To have a common factor between the tank and tensile tests, the initial maximum stress intensity factor ($K_{max, i}$) was held equal for a particular tank and corresponding tensile specimen (see BASIS OF DATA ANALYSIS section). The minimum cyclic stress was again held at 4.6 ksi ($31.7 \times 10^6$ N/m$^2$) (see tank data, tables III and IV). The cycle rate was approximately 3 cycles per minute (0.05 Hz).

## BASIS OF DATA ANALYSIS

The Irwin equation (ref. 9) with plastic zone correction was used for calculation of

stress intensity factors K of the tensile specimens. The equation has the form

$$K = \sigma \sqrt{w \tan\left[\frac{\pi}{w}\left(a + \frac{1}{2\pi}\frac{K^2}{\sigma_y^2}\right)\right]} \tag{1}$$

An equation recently developed by M. Isida has been shown to be more accurate than the Irwin tangent equation when the aspect ratio (2a/w) is greater than 0.1 (ref. 10). Therefore equation (1) results in K values that are a maximum of 9 percent low when the final notch length ($2a_L$) was 2.0 inches (5.1 cm), aspect rates equal to 0.67. For most of the test results this error is much less.

For the tank specimens the equation with bulge correction developed by Anderson (ref. 11) was used to determine K. This equation takes the form

$$K = \sigma_H \sqrt{\pi a + \frac{1}{2}\frac{K^2}{\sigma_{yB}^2}\left(1 + \frac{Ca}{r}\right)} \tag{2}$$

As described in the Procedure section (p. 5), the maximum cyclic tensile stresses were chosen to give a range of values for cyclic life. Also, the initial maximum stress intensity factors ($K_{max,\,i}$) were to be equal for a tensile specimen and the corresponding tank specimen. Therefore, to calculate the maximum cyclic hoop stress $\sigma_{H_{max}}$ for the tank specimens, the procedure was as follows:

(1) The initial maximum stress intensity factor $K_{max,\,i}$ was calculated for the tensile specimens by using equation (1), the initial tensile specimen geometry, maximum cyclic stress, and the tensile yield strength.

(2) Substituting the value of $K_{max,\,i}$ into equation (2) along with the tank specimen geometry, biaxial yield strength, and a value for C from reference 11 gives the required maximum cyclic hoop stress $\sigma_{H_{max}}$.

Figure 6 is typical of the curves obtained for crack growth as a function of stress cycles. Data were plotted and a smooth curve drawn to give a good visual fit. Ten points were selected on each curve. At each point the slope d(2a)/dN was determined graphically and $K_{max}$ and $K_{min}$ were calculated using either equation (1) for tensile or equation (2) for tank specimens (tables V, VI, and VII). The crack growth rate da/dN as a function of stress intensity factor range $\Delta K$ is plotted in figures 7(a) to (r). The slope $\gamma$ was determined using a least-square best-fit computer program.

# RESULTS AND DISCUSSION

## Tank and Tensile Correlation

Figures 7(a) to (r) show the crack growth rate da/dN as a function of crack tip stress intensity factor range $\Delta K$ and the calculated slope $\gamma$ for tank and tensile specimens. The $R_i$ ratio ($K_{min,\,i}/K_{max,\,i}$) varies from 0.068 to 0.355. Figures 7(a) to (n) are for -320° F (77° K); figures 7(o) to (r) are for -423° F (20° K). For tests in which the values of $K_{max,\,i}$ and $R_i$ were approximately equal for the tensile and tank specimens, the tank and tensile data are in fairly close agreement. In figures 7(ℓ) to (n), the values of $K_{max,\,i}$ were the same for tank and tensile tests, but the $R_i$ value was considerably different, and the two sets of data are more widely separated. Therefore, it appears that when $R_i$ and $K_{max,\,i}$ are the same for tank and tensile specimens, the crack growth rates da/dN are almost equal for a given stress intensity range $\Delta K$. Similar results were obtained for tests run at -423° F (20° K), figures 7(o) to (r).

In figures 7(e), (f), (i), and (ℓ) the curves of da/dN against $\Delta K$ are initially somewhat flat or have a negative slope. These curves are for the tests that had the highest $K_{max,\,i}$. The flatness or negative slope may be the result of notch blunting or high compressive stresses at the crack tip created during the first cycle; as a result, the crack growth rate was initially reduced. These few points were not included in the least-square curve fit.

## Crack Growth Laws and R Ratio

The crack propagation law proposed by Paris (ref. 1)

$$\frac{da}{dN} = C^* \Delta K^{\gamma} \tag{3}$$

(where $\gamma = 4$) gives good results for moderate- to high-cycle life test conditions. However, it does not appear to adequately account for the effect of R ratio changes on crack growth rate in the low-cycle region as observed in this study. Figure 8 was compiled from figures 7(a) to (r) and shows the effect of $R_i$ ratio on the slope $\gamma$ of the da/dN against $\Delta K$ plots. The value for $\gamma$ ranged from 6 to 13. These values are much higher than the value of 4 proposed by Paris. However, it should be pointed out that the data from which Paris proposed his fourth-power relation were for $N_F$ in the range of $10^4$ to $10^6$ cycles. This is indicative of $K_{max,\,i}$ being at a fairly low percentage of $K_c$. The

data reported here are for cyclic lives primarily less than 1000 cycles and $K_{max,\,i}$ above 0.4 $K_c$.

Carman and Katlin (ref. 12) point out that for their data the fourth-power relation held until the value of K reached 0.7 to 0.8 of $K_c$, then a greatly accelerated growth rate occurred. Clark (ref. 13) shows values of $\gamma = 9$ for some high-strength steels under plane strain conditions. In reference 14, Hudson applied several crack growth laws to data with various R ratios at room temperature and found that a relation developed by Forman, Kearny, and Engle (ref. 15) best fit the data. That equation is

$$\frac{da}{dN} = \frac{C_1(\Delta K)^n}{(1 - R)K_c - \Delta K} \tag{4}$$

This equation was applied to part of the data in this study with some success. However, at higher values of $R_i$, the predicted growth rates were still quite low (up to a factor of 10) with respect to the data. Therefore, it appears that for data in the low-cycle region, a crack growth law might take a form such as

$$\frac{da}{dN} = C_2\,\Delta K^{\gamma} \tag{5}$$

where $\gamma$ is a function of $R_i$ ratio and $C_2$ is a constant depending on material and environment.

## Effect of R Ratio on Crack Growth

In figure 8 as the $R_i$ ratio is increased the slope $\gamma$ generally increased. Therefore, referring to figures 7(a) to (r), an increase in $R_i$ means an increase in $\gamma$ and an increase in crack growth rate da/dN for a given value of $\Delta K$. This is true for specimens tested at both $-320^{\circ}$ and $-423^{\circ}$ F ($77^{\circ}$ and $20^{\circ}$ K). It should be pointed out that since R equals $1 - (\Delta K/K_{max})$ or $(K_{min}/K_{max})$, to increase the R ratio and hold $\Delta K$ constant requires an increase in both $K_{min}$ and $K_{max}$.

## Effect of Stress Intensity on Cycles to Failure

Figures 9(a) and (b) show the effect of $K_{max,\,i}/K_c$ and $R_i$ ratio on cycles to failure for tensile and tank specimens, respectively. Tests with higher values of $R_i$ have

longer lives at a given percent of critical; correspondingly, tests run at -423° F (20° F) had longer lives than those run at -320° F (77° K).

For similar initial conditions for R ratio and $K_{max}$, the cyclic lives of tensile and tank specimens were almost equal, with the tensile specimens generally having longer lives.

## SUMMARY OF RESULTS

An investigation was conducted to determine the cryogenic low-cycle fatigue crack growth behavior and cyclic life of 2014-T6 aluminum through notched tank and tensile specimens. Low-cycle crack growth data were obtained from the notched specimens in liquid nitrogen and liquid hydrogen. Various notch lengths and $R_i$ ratios (minimum to maximum initial stress intensity factors, $K_{min,\,i}/K_{max,\,i}$) were studied. The following results were obtained:

1. The $R_i$ ratio appears to be a useful parameter for relating crack growth rate in tensile specimens to the crack growth rate in tanks. When the $R_i$ ratio and the initial maximum stress intensity factor $K_{max,\,i}$ are the same for the tank and tensile specimens, the crack growth rates da/dN are essentially equal for a given stress intensity factor range $\Delta K$. This is true for specimens run at both -320° and -423° F (77° and 20° K).

2. For the cyclic range studied (less than 1000 cycles and high $K_{max,\,i}$), the relation for crack growth might take a form such as $(da/dN) = C_2 \Delta K^{\gamma}$, where the slope $\gamma$ is a function of the $R_i$ ratio and $C_2$ is a constant accounting for material and environment. The values for $\gamma$ ranged from 6 to 13. These values are much higher than the value of 4.0 that Paris obtained; however, Paris' data were for the $10^4$ to $10^6$ cycle region. Similar results were obtained for both test temperatures.

3. When the stress intensity factor range $\Delta K$ is held constant, the rate of crack growth generally increases with increasing $R_i$ ratio. This is true for tests run at both -320° and -423° F (77° and 20° K).

4. The curves of $K_{max,\,i}/K_c$ against the cycles to failure $N_F$ shows that specimens tested at higher $R_i$ ratios have longer lives than those tested at lower $R_i$ ratios; correspondingly, specimens run at -423° F (20° K) had longer lives than those run at -320° F (77° K). Also, for similar initial conditions, the cyclic lives of tensile and tank specimens were almost equal, with the tensile specimens generally having longer lives.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, December 18, 1967,
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TABLE I. - CHEMICAL ANALYSIS OF TEST MATERIAL

| Composition, wt % | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Cu | Fe | Si | Mn | Mg | Zn | Ni | Cr | Ti | Sn |
| 4.32 | 0.35 | 0.80 | 0.73 | 0.40 | 0.06 | 0.005 | 0.01 | 0.025 | 0.001 |

TABLE II. - MECHANICAL PROPERTIES OF 2014-T6 ALUMINUM ALLOY[a]

| | Ambient air ($70^{\circ}$ F; $293^{\circ}$ K) | Liquid nitrogen ($-320^{\circ}$ F; $77^{\circ}$ K) | Liquid hydrogen ($-423^{\circ}$ F; $20^{\circ}$ K) |
|---|---|---|---|
| Uniaxial yield strength, ksi ($MN/m^2$) | 63.3 (440) | 75.0 (520) | 81.6 (560) |
| Biaxial yield strength, ksi ($MN/m^2$) | --------- | 85.8 (590) | 93.8 (650) |
| Ultimate tensile strength, ksi ($MN/m^2$) | 75.0 (520) | 86.0 (590) | 99.7 (690) |
| Fracture toughness, $K_c$, ksi$\sqrt{in.}$ ($MN/m^{3/2}$) | --------- | 64.6 (71) | 55.1 (61) |

[a]Specimen thickness, 0.060 in. (0.15 cm).

TABLE III. - INITIAL CONDITIONS AND TEST DATA AT -320° F (77° K)

(a) U.S. customary units

| Symbol | Specimen number | $2a_i$, in. | $2a_L$, in. | $\sigma_{min}$, ksi | $\sigma_{max}$, ksi | $\Delta\sigma$, ksi | $\sigma_F$, ksi | $N_F$, cycles to failure | $K_{min,i}$, ksi$\sqrt{in.}$ | $K_{max,i}$, ksi$\sqrt{in.}$ | $\Delta K_i$, ksi$\sqrt{in.}$ | $\Delta K_i/K_c$ | $K_{max,i}/K_c$ | $R_i$ | $\Delta K_i/K_{max,i}$ | $K_{max,L}$, ksi$\sqrt{in.}$ | $\gamma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tensile | | | | | | | | | | | | | | | | | |
| ○ | 1 | 0.126 | 0.59 | 4.6 | 57.3 | 52.7 | 56.2 | 215 | 2.1 | 30.4 | 28.3 | 0.44 | 0.47 | 0.068 | 0.932 | 69.0 | 7.3 |
| □ | 2 | .126 | .56 | | 54.2 | 49.6 | 52.0 | 277 | 2.0 | 28.1 | 26.1 | .40 | .43 | .073 | .927 | 61.4 | 7.6 |
| ◇ | 3 | .128 | .84 | | 52.5 | 47.9 | 50.7 | 751 | 2.1 | 27.1 | 25.1 | .39 | .42 | .076 | .924 | 76.1 | 6.7 |
| △ | 4 | .128 | .94 | | 47.8 | 43.2 | 46.1 | 1163 | 2.1 | 24.1 | 22.0 | .34 | .37 | .086 | .914 | 71.8 | 6.3 |
| ◺ | 5 | .301 | .74 | | 47.6 | 43.0 | 46.3 | 70 | 3.2 | 36.9 | 33.7 | .52 | .57 | .086 | .914 | 60.7 | 9.8 |
| ◺ | 6 | .300 | .82 | | 44.7 | 40.1 | 43.4 | 133 | | 34.1 | 30.9 | .48 | .53 | .093 | .907 | 59.5 | 7.9 |
| ◻ | 7 | .296 | .92 | | 40.4 | 35.8 | 39.0 | 293 | | 30.0 | 26.8 | .42 | .46 | .105 | .895 | 56.4 | 7.7 |
| ◇ | 8 | .300 | 1.00 | | 37.6 | 33.0 | 37.4 | 560 | | 27.8 | 24.6 | .38 | .43 | .114 | .886 | 54.5 | 7.8 |
| ◇ | 9 | .496 | 1.13 | | 37.6 | 33.0 | 37.0 | 116 | 4.1 | 36.1 | 32.0 | .50 | .56 | .114 | .886 | 59.6 | 8.8 |
| ⏢ | 10 | .495 | 1.29 | | 35.5 | 30.9 | 34.7 | 174 | 4.1 | 33.8 | 29.7 | .46 | .52 | .122 | .878 | 61.6 | 8.3 |
| ▱ | 11 | .496 | 1.64 | | 30.0 | 25.4 | 29.2 | 1447 | 4.1 | 28.0 | 23.9 | .37 | .43 | .147 | .853 | 63.2 | 6.5 |
| ▷ | 12 | 1.001 | 1.67 | | 28.1 | 23.5 | 27.8 | 131 | 6.1 | 38.9 | 32.8 | .51 | .60 | .156 | .844 | 59.2 | 11.2 |
| ◁ | 13 | .999 | 1.79 | | 25.0 | 20.4 | 23.8 | 400 | 6.1 | 34.2 | 28.1 | .44 | .53 | .177 | .823 | 55.8 | 11.1 |
| ◇ | 14 | .992 | 1.82 | | 21.4 | 16.8 | 21.0 | 1088 | 6.0 | 28.8 | 22.8 | .35 | .45 | .209 | .791 | 47.2 | 8.9 |
| ▽ | 15 | .995 | 2.17 | | 19.6 | 15.0 | 19.6 | 1906 | 6.0 | 26.3 | 20.0 | .31 | .41 | .230 | .770 | 57.1 | 7.9 |
| Tank | | | | | | | | | | | | | | | | | |
| ● | 16 | 0.125 | 0.50 | 4.6 | 54.9 | 50.3 | ---- | 180 | 2.2 | 30.0 | 27.8 | 0.43 | 0.46 | 0.073 | 0.927 | 79.3 | 6.0 |
| ■ | 17 | | .51 | | 51.8 | 47.2 | 49.9 | 356 | | 27.8 | 25.6 | .40 | .43 | .079 | .921 | 73.5 | 6.2 |
| ◆ | 18 | | .48 | | 50.1 | 45.5 | ---- | 584 | | 26.7 | 24.5 | .38 | .41 | .082 | .918 | 66.7 | 5.6 |
| ▲ | 19 | | .53 | | 45.4 | 40.8 | 45.4 | 1176 | | 23.6 | 21.4 | .33 | .37 | .093 | .907 | 63.1 | 6.0 |
| ◣ | 20 | .300 | .59 | | 41.2 | 36.6 | 40.5 | 59 | 3.7 | 36.5 | 32.8 | .51 | .57 | .102 | .898 | 61.2 | 7.1 |
| ◭ | 21 | .300 | .68 | | 38.6 | 34.0 | 37.7 | 81 | | 33.8 | 30.1 | .47 | .52 | .111 | .889 | 63.3 | 7.3 |
| ◙ | 22 | .300 | .61 | | 34.8 | 30.2 | 34.4 | 191 | | 30.1 | 26.3 | .41 | .47 | .124 | .876 | 51.0 | 7.2 |
| ◆ | 23 | .300 | .69 | | 32.3 | 27.7 | 31.8 | 358 | | 27.7 | 23.9 | .37 | .43 | .135 | .865 | 51.7 | 9.6 |
| ◆ | 24 | .500 | .90 | | 29.5 | 24.9 | 29.5 | 118 | 5.3 | 36.0 | 30.7 | .48 | .56 | .148 | .852 | 58.8 | 8.6 |
| ◭ | 25 | .500 | .91 | | 27.7 | 23.1 | 27.7 | 246 | 5.3 | 33.6 | 28.2 | .44 | .52 | .159 | .841 | 55.1 | 8.7 |
| ◙ | 26 | .500 | 1.00 | | 23.4 | 18.8 | 22.9 | 983 | 5.3 | 27.9 | 22.6 | .35 | .43 | .191 | .809 | 49.7 | 7.0 |
| ◗ | 27 | 1.00 | 1.40 | | 18.5 | 13.9 | 18.1 | 30 | 9.3 | 38.6 | 29.3 | .45 | .60 | .241 | .759 | 53.2 | 12.8 |
| ● | 28 | 1.00 | ---- | | 14.0 | 9.4 | 14.0 | 492 | 9.3 | 28.8 | 19.5 | .30 | .45 | .323 | .677 | ---- | 9.9 |
| ▼ | 29 | 1.00 | 1.66 | | 12.8 | 8.2 | 12.8 | 1613 | 9.3 | 26.3 | 16.9 | .26 | .41 | .355 | .645 | 42.7 | 11.1 |

(b) SI units

| Symbol | Specimen number | $2a_i$, cm | $2a_L$, cm | $\sigma_{min}$, $MN/m^2$ | $\sigma_{max}$, $MN/m^2$ | $\Delta\sigma$, $MN/m^2$ | $\sigma_F$, $MN/m^2$ | $N_F$, cycles to failure | $K_{min,i}$, $MN/m^{3/2}$ | $K_{max,i}$, $MN/m^{3/2}$ | $\Delta K_i$, $MN/m^{3/2}$ | $\Delta K_i/K_c$ | $K_{min,i}/K_c$ | $R_i$ | $\Delta K_i/K_{max,i}$ | $K_{max,L}$, $MN/m^{3/2}$ | $\gamma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Tensile | | | | | | | | | |
| ○ | 1 | 0.320 | 1.499 | 31.7 | 395 | 364 | 388 | 215 | 2.3 | 33.4 | 31.1 | 0.44 | 0.47 | 0.068 | 0.932 | 75.9 | 7.3 |
| □ | 2 | .320 | 1.422 | | 374 | 342 | 359 | 277 | | 30.9 | 28.7 | .40 | .43 | .073 | .927 | 67.5 | 7.6 |
| ◇ | 3 | .325 | 2.134 | | 362 | 331 | 350 | 751 | | 29.8 | 27.6 | .39 | .42 | .076 | .924 | 83.7 | 6.7 |
| △ | 4 | .325 | 2.388 | | 330 | 298 | 318 | 1163 | | 26.5 | 24.2 | .34 | .37 | .086 | .914 | 79.0 | 6.3 |
| ◺ | 5 | .764 | 1.880 | | 328 | 297 | 319 | 70 | 3.5 | 40.6 | 37.1 | .52 | .57 | .086 | .914 | 66.8 | 9.8 |
| ▱ | 6 | .762 | 2.083 | | 308 | 277 | 299 | 133 | | 37.5 | 34.0 | .48 | .53 | .093 | .907 | 65.4 | 7.9 |
| ▭ | 7 | .752 | 2.337 | | 279 | 247 | 269 | 293 | | 33.0 | 29.5 | .42 | .46 | .105 | .895 | 62.0 | 7.7 |
| ◇ | 8 | .762 | 2.540 | | 259 | 228 | 258 | 560 | | 30.6 | 27.1 | .38 | .43 | .114 | .886 | 60.0 | 7.8 |
| ◇ | 9 | 1.260 | 2.870 | | 259 | 228 | 255 | 116 | 4.5 | 39.7 | 35.2 | .50 | .56 | .114 | .886 | 65.6 | 8.8 |
| △ | 10 | 1.257 | 3.277 | | 245 | 213 | 239 | 174 | 4.5 | 37.2 | 32.7 | .46 | .52 | .122 | .878 | 67.8 | 8.3 |
| ▭ | 11 | 1.260 | 4.166 | | 207 | 175 | 201 | 1447 | 4.5 | 30.8 | 26.3 | .37 | .43 | .147 | .853 | 69.5 | 6.5 |
| ▭ | 12 | 2.543 | 4.242 | | 194 | 162 | 192 | 131 | 6.7 | 42.8 | 36.1 | .51 | .60 | .156 | .844 | 65.1 | 11.2 |
| ◁ | 13 | 2.537 | 4.547 | | 172 | 141 | 164 | 400 | 6.7 | 37.6 | 30.9 | .44 | .53 | .177 | .823 | 61.4 | 11.1 |
| ◇ | 14 | 2.520 | 4.623 | | 148 | 116 | 145 | 1088 | 6.6 | 31.7 | 25.1 | .35 | .45 | .209 | .791 | 51.9 | 8.9 |
| ▽ | 15 | 2.527 | 5.512 | | 135 | 104 | 135 | 1906 | 6.6 | 28.9 | 22.0 | .31 | .41 | .230 | .770 | 62.8 | 7.9 |
| | | | | | | | | Tank | | | | | | | | | |
| ● | 16 | 0.318 | 1.270 | 31.7 | 379 | 347 | ----- | 180 | 2.4 | 33.0 | 30.6 | 0.43 | 0.46 | 0.073 | 0.927 | 87.2 | 6.0 |
| ■ | 17 | | 1.295 | | 357 | 326 | 344 | 356 | | 30.6 | 28.2 | .40 | .43 | .079 | .921 | 80.8 | 6.2 |
| ● | 18 | | 1.219 | | 346 | 314 | ----- | 584 | | 29.4 | 27.0 | .38 | .41 | .082 | .918 | 73.4 | 5.6 |
| ▲ | 19 | | 1.346 | | 313 | 282 | 313 | 1176 | | 26.0 | 23.5 | .33 | .37 | .093 | .907 | 69.4 | 6.0 |
| ◣ | 20 | .762 | 1.499 | | 284 | 253 | 279 | 59 | 4.1 | 40.2 | 36.1 | .51 | .57 | .102 | .898 | 67.3 | 7.1 |
| ◣ | 21 | .762 | 1.727 | | 266 | 235 | 260 | 81 | | 37.2 | 33.1 | .47 | .52 | .111 | .889 | 69.6 | 7.3 |
| ◙ | 22 | .762 | 1.549 | | 240 | 208 | 237 | 191 | | 33.1 | 28.9 | .41 | .47 | .124 | .876 | 56.1 | 7.2 |
| ◆ | 23 | .762 | 1.753 | | 223 | 191 | 219 | 358 | | 30.5 | 26.3 | .37 | .43 | .135 | .865 | 56.9 | 9.6 |
| ◆ | 24 | 1.270 | 2.286 | | 204 | 172 | 204 | 118 | 5.8 | 39.6 | 33.8 | .48 | .56 | .148 | .852 | 64.7 | 8.6 |
| ◙ | 25 | 1.270 | 2.311 | | 191 | 159 | 191 | 246 | 5.8 | 37.0 | 31.0 | .44 | .52 | .159 | .841 | 60.6 | 8.7 |
| ◙ | 26 | 1.270 | 2.540 | | 161 | 130 | 158 | 983 | 5.8 | 30.7 | 24.9 | .35 | .43 | .191 | .809 | 54.7 | 7.0 |
| ◆ | 27 | 2.54 | 3.556 | | 128 | 95.9 | 125 | 30 | 10.2 | 42.5 | 32.2 | .45 | .60 | .241 | .759 | 58.5 | 12.8 |
| ◆ | 28 | 2.54 | 3.708 | | 96.6 | 64.9 | 96.6 | 492 | 10.2 | 31.7 | 21.4 | .30 | .45 | .323 | .677 | ---- | 9.9 |
| ▼ | 29 | 2.54 | 4.216 | | 88.3 | 56.6 | 88.3 | 1613 | 10.2 | 28.9 | 18.6 | .26 | .41 | .355 | .645 | 47.0 | 11.1 |

TABLE IV. - INITIAL CONDITIONS AND TEST DATA AT -423° F (20° K)

(a) U. S. customary units

| Symbol | Specimen number | $2a_i$, in. | $2a_L$, in. | $\sigma_{min}$, ksi | $\sigma_{max}$, ksi | $\Delta\sigma$, ksi | $\sigma_F$, ksi | $N_F$, cycles to failure | $K_{min,i}$, ksi$\sqrt{in.}$ | $K_{max,i}$, ksi$\sqrt{in.}$ | $\Delta K_i$, ksi$\sqrt{in.}$ | $\Delta K_i/K_c$ | $K_{max,i}/K_c$ | $R_i$ | $\Delta K_i/K_{max,i}$ | $K_{max,L}$, ksi$\sqrt{in.}$ | $\gamma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tensile | | | | | | | | | | | | | | | | | |
| ◁ | 30 | 0.128 | 0.60 | 6.0 | 56.0 | 50.0 | 56.0 | 280 | 2.7 | 28.8 | 26.1 | 0.47 | 0.52 | 0.093 | 0.907 | 64.8 | 6.8 |
| ◇ | 31 | .301 | .91 | 4.4 | 41.4 | 37.0 | 40.5 | 277 | 3.0 | 30.7 | 27.6 | .50 | .56 | .099 | .901 | 56.5 | 8.8 |
| ◁ | 32 | .496 | 1.53 | 3.0 | 29.3 | 26.3 | 29.3 | 911 | 2.6 | 27.1 | 24.5 | .44 | .49 | .097 | .903 | 55.7 | 8.0 |
| ◸ | 33 | .996 | 1.84 | 4.0 | 22.5 | 18.5 | 21.6 | 753 | 5.3 | 30.4 | 25.1 | .46 | .55 | .174 | .826 | 50.1 | 9.3 |
| Tank | | | | | | | | | | | | | | | | | |
| ◀ | 34 | 0.125 | 0.33 | 5.5 | 54.6 | 49.1 | 48.4 | 278 | 2.6 | 28.6 | 26.0 | 0.47 | 0.52 | 0.090 | 0.909 | 52.3 | 6.7 |
| ◀ | 35 | .300 | .63 | 3.7 | 36.6 | 32.9 | ----- | 272 | 2.9 | 30.5 | 27.6 | .50 | .55 | .095 | .905 | 51.6 | 7.1 |
| ◀ | 36 | .500 | .99 | 2.4 | 23.8 | 21.4 | 23.3 | 401 | 2.6 | 27.1 | 24.5 | .44 | .49 | .097 | .903 | 46.3 | 9.5 |
| ◸ | 37 | 1.000 | 1.71 | 2.8 | 15.8 | 14.4 | ----- | 415 | 5.3 | 30.4 | 25.1 | .46 | .55 | .174 | .826 | 49.7 | 10.6 |

(b) SI units

| Symbol | Specimen number | $2a_i$, in. | $2a_L$, in. | $\sigma_{min}$, MN/m$^2$ | $\sigma_{max}$, MN/m$^2$ | $\Delta\sigma$, MN/m$^2$ | $\sigma_F$, MN/m$^2$ | $N_F$, cycles to failure | $K_{min,i}$, MN/m$^{3/2}$ | $K_{max,i}$, MN/m$^{3/2}$ | $\Delta K_i$, MN/m$^{3/2}$ | $\Delta K_i/K_c$ | $K_{max,i}/K_c$ | $R_i$ | $\Delta K_i/K_{max,i}$ | $K_{max,L}$, MN/m$^{3/2}$ | $\gamma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tensile | | | | | | | | | | | | | | | | | |
| ◁ | 30 | 0.325 | 1.524 | 41.4 | 386 | 345 | 386 | 280 | 3.0 | 31.7 | 28.7 | 0.47 | 0.52 | 0.093 | 0.907 | 71.3 | 6.8 |
| ◇ | 31 | .765 | 2.311 | 30.4 | 286 | 255 | 279 | 277 | 3.3 | 33.8 | 30.4 | .50 | .56 | .099 | .901 | 62.2 | 8.8 |
| ◁ | 32 | 1.260 | 3.886 | 20.7 | 202 | 181 | 202 | 911 | 2.9 | 29.8 | 27.0 | .44 | .49 | .097 | .903 | 60.6 | 8.0 |
| ◸ | 33 | 2.530 | 4.674 | 27.6 | 155 | 128 | 149 | 753 | 5.8 | 33.4 | 27.6 | .46 | .55 | .174 | .826 | 55.1 | 9.3 |
| Tank | | | | | | | | | | | | | | | | | |
| ◀ | 34 | 0.318 | 0.838 | 38.0 | 377 | 339 | 334 | 278 | 2.9 | 31.5 | 28.6 | 0.47 | 0.52 | 0.090 | 0.909 | 57.5 | 6.7 |
| ◀ | 35 | .762 | 1.600 | 25.5 | 253 | 277 | ----- | 272 | 3.2 | 33.6 | 30.4 | .50 | .55 | .095 | .905 | 56.8 | 7.1 |
| ◀ | 36 | 1.270 | 2.515 | 16.6 | 164 | 148 | 161 | 401 | 2.9 | 29.8 | 27.0 | .44 | .49 | .097 | .903 | 50.9 | 9.5 |
| ◸ | 37 | 2.540 | 4.343 | 19.3 | 109 | 99.4 | ----- | 415 | 5.8 | 33.4 | 27.6 | .46 | .55 | .174 | .826 | 54.7 | 10.6 |

TABLE V. - CRACK GROWTH DATA FOR TENSILE TESTS AT -320° F (77° K)

(a) U.S. customary units

| Symbol | Specimen number | 2a, in. | N, cycles | $K_{max}$, ksi$\sqrt{in.}$ | $K_{min}$, ksi$\sqrt{in.}$ | $\Delta K$, ksi$\sqrt{in.}$ | Symbol | Specimen number | 2a, in. | N, cycles | $K_{max}$, ksi$\sqrt{in.}$ | $K_{min}$, ksi$\sqrt{in.}$ | $\Delta K$, ksi$\sqrt{in.}$ | Symbol | Specimen number | 2a, in. | N, cycles | $K_{max}$, ksi$\sqrt{in.}$ | $K_{min}$, ksi$\sqrt{in.}$ | $\Delta K$, ksi$\sqrt{in.}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ○ | 1 | 0.126 | 0 | 30.4 | 2.1 | 28.3 | ▷ | 6 | 0.300 | 0 | 34.1 | 3.2 | 30.9 | ▷ | 11 | 0.496 | 0 | 28.0 | 4.1 | 23.9 |
| | | .192 | 50 | 32.2 | 2.2 | 30.1 | | | .319 | 20 | 35.2 | 3.3 | 31.9 | | | .532 | 200 | 29.1 | 4.3 | 24.8 |
| | | .167 | 100 | 35.0 | 2.4 | 32.6 | | | .341 | 40 | 36.4 | 3.4 | 33.0 | | | .579 | 400 | 30.5 | 4.5 | 26.0 |
| | | .210 | 150 | 39.3 | 2.7 | 36.7 | | | .367 | 60 | 37.8 | 3.5 | 34.3 | | | .634 | 600 | 32.0 | 4.7 | 27.3 |
| | | .232 | 170 | 41.4 | 2.8 | 38.7 | | | .401 | 80 | 39.6 | 3.7 | 36.0 | | | .702 | 800 | 33.9 | 5.0 | 28.9 |
| | | .272 | 190 | 44.9 | 3.0 | 41.9 | | | .450 | 100 | 42.2 | 3.9 | 38.2 | | | .778 | 1000 | 35.9 | 5.2 | 30.7 |
| | | .303 | 200 | 47.6 | 3.2 | 44.4 | | | .488 | 110 | 44.0 | 4.1 | 40.0 | | | .892 | 1200 | 39.0 | 5.7 | 33.3 |
| | | .358 | 210 | 51.9 | 3.5 | 48.5 | | | .551 | 120 | 47.1 | 4.3 | 42.7 | | | .999 | 1300 | 41.8 | 6.1 | 35.8 |
| | | .425 | 213 | 57.0 | 3.8 | 53.2 | | | .678 | 130 | 53.0 | 4.9 | 48.1 | | | 1.197 | 1400 | 47.4 | 6.8 | 40.6 |
| | | .590 | 215 | 69.0 | 4.5 | 64.4 | | | .820 | 133 | 59.5 | 5.4 | 54.1 | | | 1.640 | 1447 | 63.2 | 8.6 | 54.6 |
| □ | 2 | 0.126 | 0 | 28.1 | 2.0 | 26.1 | ▽ | 7 | 0.296 | 0 | 30.0 | 3.2 | 26.8 | ▷ | 12 | 1.001 | 0 | 38.9 | 6.1 | 32.8 |
| | | .131 | 40 | 28.6 | 2.1 | 26.6 | | | .327 | 50 | 31.6 | 3.3 | 28.2 | | | 1.073 | 20 | 40.7 | 6.3 | 34.4 |
| | | .139 | 80 | 29.5 | 2.1 | 27.4 | | | .361 | 100 | 33.2 | 3.5 | 29.7 | | | 1.126 | 40 | 42.1 | 6.5 | 35.5 |
| | | .150 | 120 | 30.7 | 2.2 | 28.4 | | | .400 | 150 | 35.1 | 3.7 | 31.4 | | | 1.171 | 60 | 43.2 | 6.7 | 36.5 |
| | | .170 | 160 | 32.7 | 2.4 | 30.3 | | | .449 | 200 | 37.3 | 3.9 | 33.4 | | | 1.221 | 80 | 44.6 | 6.9 | 37.7 |
| | | .203 | 200 | 35.8 | 2.6 | 33.2 | | | .531 | 250 | 40.8 | 4.3 | 36.5 | | | 1.284 | 100 | 46.4 | 7.1 | 39.3 |
| | | .258 | 240 | 40.4 | 2.9 | 37.5 | | | .600 | 270 | 43.6 | 4.5 | 39.1 | | | 1.336 | 110 | 47.7 | 7.3 | 40.4 |
| | | .308 | 260 | 44.3 | 3.2 | 41.1 | | | .667 | 280 | 46.3 | 4.8 | 41.5 | | | 1.407 | 120 | 49.9 | 7.6 | 42.3 |
| | | .425 | 275 | 52.6 | 3.8 | 48.8 | | | .800 | 290 | 51.6 | 5.3 | 46.2 | | | 1.610 | 130 | 56.8 | 8.5 | 48.3 |
| | | .560 | 277 | 61.4 | 4.4 | 57.1 | | | .920 | 293 | 56.4 | 5.8 | 50.6 | | | 1.670 | 131 | 59.2 | 8.7 | 50.5 |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ◇ | 3 | 0.128 | 0 | 27.1 | 2.1 | 25.1 | ◇ | 8 | 0.300 | 0 | 27.8 | 3.2 | 24.6 | ◿ | 13 | 0.999 | 0 | 34.2 | 6.1 | 28.1 |
| | | .137 | 100 | 28.1 | 2.1 | 26.0 | | | .321 | 100 | 28.8 | 3.3 | 25.5 | | | 1.033 | 30 | 34.9 | 6.2 | 28.7 |
| | | .149 | 200 | 29.3 | 2.2 | 27.1 | | | .345 | 200 | 29.9 | 3.4 | 26.4 | | | 1.100 | 100 | 35.7 | 6.3 | 29.3 |
| | | .163 | 300 | 30.7 | 2.3 | 28.3 | | | .376 | 300 | 31.2 | 3.6 | 27.7 | | | 1.100 | 150 | 36.4 | 6.4 | 30.0 |
| | | .179 | 400 | 32.2 | 2.4 | 29.7 | | | .429 | 400 | 33.4 | 3.8 | 29.6 | | | 1.134 | 200 | 37.2 | 6.6 | 30.6 |
| | | .202 | 500 | 34.2 | 2.6 | 31.6 | | | .476 | 450 | 35.3 | 4.0 | 31.3 | | | 1.172 | 250 | 38.0 | 6.7 | 31.3 |
| | | .247 | 600 | 37.9 | 2.9 | 35.0 | | | .561 | 500 | 38.6 | 4.4 | 34.2 | | | 1.232 | 300 | 39.4 | 6.9 | 32.4 |
| | | .315 | 700 | 47.1 | 3.6 | 43.5 | | | .639 | 525 | 41.5 | 4.7 | 36.8 | | | 1.329 | 350 | 41.7 | 7.3 | 34.4 |
| | | .550 | 743 | 58.2 | 4.3 | 53.8 | | | .795 | 550 | 47.1 | 5.3 | 41.8 | | | 1.493 | 388 | 45.9 | 8.0 | 38.0 |
| | | .840 | 751 | 76.1 | 5.5 | 70.6 | | | 1.000 | 560 | 54.5 | 6.1 | 48.5 | | | 1.790 | 400 | 55.8 | 9.3 | 46.5 |
| △ | 4 | 0.128 | 0 | 24.1 | 2.1 | 22.0 | ◊ | 9 | 0.496 | 0 | 36.1 | 4.1 | 32.0 | ◇ | 14 | 0.942 | 0 | 28.8 | 6.0 | 22.8 |
| | | .138 | 200 | 25.0 | 2.1 | 22.8 | | | .542 | 20 | 37.9 | 4.3 | 33.6 | | | 1.039 | 200 | 29.7 | 6.2 | 23.5 |
| | | .150 | 400 | 26.0 | 2.2 | 23.8 | | | .583 | 40 | 39.4 | 4.5 | 35.0 | | | 1.083 | 400 | 30.7 | 6.4 | 24.3 |
| | | .168 | 600 | 27.6 | 2.4 | 25.2 | | | .628 | 60 | 41.1 | 4.7 | 36.4 | | | 1.159 | 600 | 31.9 | 6.6 | 25.2 |
| | | .201 | 800 | 30.2 | 2.6 | 27.6 | | | .694 | 80 | 43.5 | 4.9 | 38.6 | | | 1.254 | 800 | 33.7 | 7.0 | 26.7 |
| | | .223 | 900 | 31.8 | 2.7 | 29.1 | | | .738 | 90 | 45.0 | 5.1 | 40.0 | | | 1.325 | 900 | 35.1 | 7.3 | 27.8 |
| | | .257 | 1000 | 34.2 | 2.9 | 31.3 | | | .797 | 100 | 47.2 | 5.3 | 41.9 | | | 1.437 | 1000 | 37.4 | 7.7 | 29.6 |
| | | .323 | 1100 | 38.5 | 3.3 | 35.2 | | | .914 | 110 | 51.4 | 5.7 | 45.6 | | | 1.560 | 1050 | 40.1 | 8.2 | 31.9 |
| | | .470 | 1150 | 47.0 | 4.0 | 43.0 | | | 1.000 | 113 | 54.5 | 6.1 | 48.5 | | | 1.705 | 1080 | 43.8 | 8.9 | 34.9 |
| | | .940 | 1163 | 71.8 | 5.8 | 65.9 | | | 1.130 | 116 | 59.6 | 6.5 | 53.0 | | | 1.820 | 1088 | 47.2 | 9.5 | 37.7 |
| ◺ | 5 | 0.301 | 0 | 36.9 | 3.2 | 33.7 | ⌂ | 10 | 0.495 | 0 | 33.8 | 4.1 | 29.7 | ▽ | 15 | 0.995 | 0 | 26.3 | 6.0 | 20.3 |
| | | .327 | 10 | 38.5 | 3.3 | 35.2 | | | .519 | 20 | 34.6 | 4.2 | 30.4 | | | 1.042 | 400 | 27.1 | 6.2 | 20.9 |
| | | .355 | 20 | 40.2 | 3.5 | 36.8 | | | .547 | 40 | 35.6 | 4.3 | 31.3 | | | 1.105 | 800 | 28.1 | 6.4 | 21.7 |
| | | .388 | 30 | 42.1 | 3.6 | 38.5 | | | .573 | 60 | 36.5 | 4.4 | 32.1 | | | 1.211 | 1200 | 29.9 | 6.8 | 23.1 |
| | | .423 | 40 | 44.1 | 3.8 | 40.4 | | | .600 | 80 | 37.5 | 4.5 | 32.9 | | | 1.282 | 1400 | 31.1 | 7.1 | 24.0 |
| | | .470 | 50 | 46.7 | 4.0 | 42.7 | | | .630 | 100 | 38.5 | 4.7 | 33.8 | | | 1.393 | 1600 | 33.1 | 7.5 | 25.6 |
| | | .530 | 60 | 49.9 | 4.3 | 45.6 | | | .678 | 120 | 40.1 | 4.9 | 35.3 | | | 1.594 | 1800 | 37.1 | 8.4 | 28.8 |
| | | .572 | 65 | 52.1 | 4.4 | 47.7 | | | .744 | 140 | 42.3 | 5.1 | 37.2 | | | 1.695 | 1830 | 39.4 | 8.9 | 30.6 |
| | | .640 | 69 | 55.6 | 4.7 | 50.9 | | | .858 | 160 | 46.1 | 5.5 | 40.5 | | | 1.945 | 1900 | 46.5 | 10.2 | 36.3 |
| | | .740 | 70 | 60.7 | 5.1 | 55.6 | | | 1.190 | 174 | 57.6 | 6.8 | 50.9 | | | 2.170 | 1906 | 57.1 | 11.7 | 45.4 |

TABLE V. - Concluded. CRACK GROWTH DATA FOR TENSILE TESTS AT -320° F (77° K)

(b) SI units

| Symbol | Specimen number | 2a, cm | N, cycles | $K_{max}$, $MN/m^{3/2}$ | $K_{min}$, $MN/m^{3/2}$ | $\Delta K$, $MN/m^{3/2}$ | Symbol | Specimen number | 2a, cm | N, cycles | $K_{max}$, $MN/m^{3/2}$ | $K_{min}$, $MN/m^{3/2}$ | $\Delta K$, $MN/m^{3/2}$ | Symbol | Specimen number | 2a, cm | N, cycles | $K_{max}$, $MN/m^{3/2}$ | $K_{min}$, $MN/m^{3/2}$ | $\Delta K$, $MN/m^{3/2}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ○ | 1 | 0.320 | 0 | 33.4 | 2.3 | 31.1 | ▷ | 6 | 0.762 | 0 | 37.5 | 3.5 | 34.0 | ▷ | 11 | 1.260 | 0 | 30.8 | 4.5 | 26.3 |
| | | .361 | 50 | 35.4 | 2.4 | 33.1 | | | .810 | 20 | 38.7 | 3.6 | 35.1 | | | 1.351 | 200 | 32.0 | 4.7 | 27.3 |
| | | .424 | 100 | 38.5 | 2.6 | 35.9 | | | .866 | 40 | 40.0 | 3.7 | 36.3 | | | 1.471 | 400 | 33.6 | 5.0 | 28.6 |
| | | .533 | 150 | 43.2 | 3.0 | 40.4 | | | .932 | 60 | 41.6 | 3.8 | 37.7 | | | 1.610 | 600 | 35.2 | 5.2 | 30.0 |
| | | .589 | 170 | 45.5 | 3.1 | 42.6 | | | 1.019 | 80 | 43.6 | 4.1 | 39.6 | | | 1.783 | 800 | 37.3 | 5.5 | 31.8 |
| | | .691 | 190 | 49.4 | 3.3 | 46.1 | | | 1.143 | 100 | 46.4 | 4.3 | 42.0 | | | 1.976 | 1000 | 39.5 | 5.7 | 33.8 |
| | | .770 | 200 | 52.4 | 3.5 | 48.8 | | | 1.240 | 110 | 48.4 | 4.5 | 44.0 | | | 2.266 | 1200 | 42.9 | 6.3 | 36.6 |
| | | .909 | 210 | 57.1 | 3.8 | 53.4 | | | 1.400 | 120 | 51.8 | 4.7 | 47.0 | | | 2.537 | 1300 | 46.0 | 6.7 | 39.4 |
| | | 1.080 | 213 | 62.7 | 4.2 | 58.5 | | | 1.722 | 130 | 58.3 | 5.4 | 52.9 | | | 3.040 | 1400 | 52.1 | 7.5 | 44.7 |
| | | 1.499 | 215 | 75.9 | 5.0 | 70.8 | | | 2.083 | 133 | 65.4 | 5.9 | 59.5 | | | 4.166 | 1447 | 69.5 | 9.5 | 60.1 |
| □ | 2 | 0.320 | 0 | 30.9 | 2.2 | 28.7 | ▷ | 7 | 0.752 | 0 | 33.0 | 3.5 | 29.5 | ▷ | 12 | 2.543 | 0 | 42.8 | 6.7 | 36.1 |
| | | .333 | 40 | 31.5 | 2.3 | 29.3 | | | .831 | 50 | 34.8 | 3.6 | 31.0 | | | 2.725 | 20 | 44.8 | 6.9 | 37.8 |
| | | .353 | 80 | 32.4 | 2.3 | 30.1 | | | .917 | 100 | 36.5 | 3.8 | 32.7 | | | 2.860 | 40 | 46.3 | 7.2 | 39.0 |
| | | .381 | 120 | 33.8 | 2.4 | 31.2 | | | 1.016 | 150 | 38.6 | 4.1 | 34.5 | | | 2.974 | 60 | 47.5 | 7.4 | 40.2 |
| | | .432 | 160 | 36.0 | 2.6 | 33.3 | | | 1.140 | 200 | 41.0 | 4.3 | 36.7 | | | 3.101 | 80 | 49.1 | 7.6 | 41.5 |
| | | .516 | 200 | 39.4 | 2.9 | 36.5 | | | 1.349 | 250 | 44.9 | 4.7 | 40.2 | | | 3.274 | 100 | 51.0 | 7.8 | 43.2 |
| | | .655 | 240 | 44.4 | 3.2 | 41.2 | | | 1.524 | 270 | 48.0 | 5.0 | 43.0 | | | 3.393 | 110 | 52.5 | 8.0 | 44.4 |
| | | .782 | 260 | 48.7 | 3.5 | 45.2 | | | 1.694 | 280 | 50.9 | 5.3 | 45.6 | | | 3.574 | 120 | 54.9 | 8.4 | 46.5 |
| | | 1.080 | 275 | 57.9 | 4.2 | 53.7 | | | 2.032 | 290 | 56.8 | 5.8 | 50.8 | | | 4.089 | 130 | 62.5 | 9.4 | 53.1 |
| | | 1.422 | 277 | 67.5 | 4.8 | 62.8 | | | 2.337 | 293 | 62.0 | 6.4 | 55.7 | | | 4.242 | 131 | 65.1 | 9.6 | 55.6 |

| ◇ | 3 | 0.325 | 0 | 29.8 | 2.3 | 27.6 | ◇ | 8 | 0.762 | 0 | 30.6 | 3.5 | 27.1 | △ | 13 | 2.537 | 0 | 37.6 | 6.7 | 30.9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | .348 | 100 | 30.9 | 2.3 | 28.6 | | | .815 | 100 | 31.7 | 3.6 | 28.0 | | | 2.624 | 50 | 38.4 | 6.8 | 31.6 |
| | | .378 | 200 | 32.2 | 2.4 | 29.8 | | | .876 | 200 | 32.9 | 3.7 | 29.0 | | | 2.708 | 100 | 39.3 | 6.9 | 32.2 |
| | | .414 | 300 | 33.8 | 2.5 | 31.1 | | | .955 | 300 | 34.3 | 4.0 | 30.5 | | | 2.794 | 150 | 40.0 | 7.0 | 33.0 |
| | | .455 | 400 | 35.4 | 2.6 | 32.7 | | | 1.090 | 400 | 36.7 | 4.2 | 32.6 | | | 2.880 | 200 | 40.9 | 7.3 | 33.7 |
| | | .513 | 500 | 37.6 | 2.9 | 34.8 | | | 1.209 | 450 | 38.8 | 4.4 | 34.4 | | | 2.977 | 250 | 41.8 | 7.4 | 34.4 |
| | | .627 | 600 | 41.7 | 3.2 | 38.5 | | | 1.425 | 500 | 37.6 | 4.8 | 37.6 | | | 3.129 | 300 | 43.3 | 7.6 | 35.6 |
| | | .952 | 700 | 51.8 | 4.0 | 47.8 | | | 1.623 | 525 | 45.6 | 5.2 | 40.5 | | | 3.376 | 350 | 45.9 | 8.0 | 37.8 |
| | | 1.397 | 743 | 64.0 | 4.7 | 59.2 | | | 2.019 | 550 | 51.8 | 5.8 | 46.0 | | | 3.792 | 388 | 50.5 | 8.8 | 41.8 |
| | | 2.134 | 751 | 83.7 | 6.0 | 77.7 | | | 2.540 | 560 | 60.0 | 6.7 | 53.4 | | | 4.547 | 400 | 61.4 | 10.2 | 51.2 |
| △ | 4 | 0.325 | 0 | 26.5 | 2.3 | 24.2 | ◊ | 9 | 1.260 | 0 | 39.7 | 4.5 | 35.2 | ◇ | 14 | 2.520 | 0 | 31.7 | 6.6 | 25.1 |
| | | .351 | 200 | 27.5 | 2.3 | 25.1 | | | 1.377 | 20 | 41.7 | 4.7 | 37.0 | | | 2.639 | 200 | 32.7 | 6.8 | 25.8 |
| | | .381 | 400 | 28.6 | 2.4 | 26.2 | | | 1.481 | 40 | 43.3 | 5.0 | 38.5 | | | 2.776 | 400 | 33.8 | 7.0 | 26.7 |
| | | .427 | 600 | 30.4 | 2.6 | 27.7 | | | 1.595 | 60 | 45.2 | 5.2 | 40.0 | | | 2.944 | 600 | 35.1 | 7.3 | 27.7 |
| | | .511 | 800 | 33.2 | 2.9 | 30.4 | | | 1.763 | 80 | 47.8 | 5.4 | 42.5 | | | 3.185 | 800 | 37.1 | 7.7 | 29.4 |
| | | .566 | 900 | 35.0 | 3.0 | 32.0 | | | 1.875 | 90 | 49.5 | 5.6 | 44.0 | | | 3.366 | 900 | 38.6 | 8.0 | 30.6 |
| | | .653 | 1000 | 37.6 | 3.2 | 34.4 | | | 2.024 | 100 | 51.9 | 5.8 | 46.1 | | | 3.650 | 1000 | 41.1 | 8.5 | 32.6 |
| | | .820 | 1100 | 42.4 | 3.6 | 38.7 | | | 2.322 | 110 | 56.5 | 6.3 | 50.2 | | | 3.962 | 1050 | 44.1 | 9.0 | 35.1 |
| | | 1.194 | 1150 | 51.7 | 4.4 | 47.3 | | | 2.540 | 113 | 60.0 | 6.7 | 53.4 | | | 4.331 | 1080 | 48.2 | 9.8 | 38.4 |
| | | 2.388 | 1163 | 79.0 | 6.4 | 72.5 | | | 2.870 | 116 | 65.6 | 7.2 | 58.3 | | | 4.623 | 1088 | 51.9 | 10.4 | 41.5 |
| ◺ | 5 | 0.765 | 0 | 40.6 | 3.5 | 37.1 | ⌂ | 10 | 1.257 | 0 | 37.2 | 4.5 | 32.7 | ▽ | 15 | 2.527 | 0 | 28.9 | 6.6 | 22.3 |
| | | .831 | 10 | 42.4 | 3.6 | 38.7 | | | 1.318 | 20 | 38.1 | 4.6 | 33.4 | | | 2.647 | 400 | 29.8 | 6.8 | 23.0 |
| | | .902 | 20 | 44.2 | 3.8 | 40.5 | | | 1.389 | 40 | 39.2 | 4.7 | 34.4 | | | 2.807 | 800 | 30.9 | 7.0 | 23.9 |
| | | .986 | 30 | 46.3 | 4.0 | 42.4 | | | 1.455 | 60 | 40.2 | 4.8 | 35.3 | | | 3.076 | 1200 | 32.9 | 7.5 | 25.4 |
| | | 1.074 | 40 | 48.5 | 4.2 | 44.4 | | | 1.524 | 80 | 41.2 | 5.0 | 36.2 | | | 3.256 | 1400 | 34.2 | 7.8 | 26.4 |
| | | 1.194 | 50 | 51.4 | 4.4 | 47.0 | | | 1.600 | 100 | 37.2 | 5.2 | 37.2 | | | 3.538 | 1600 | 36.4 | 8.2 | 28.2 |
| | | 1.346 | 60 | 54.9 | 4.7 | 50.2 | | | 1.722 | 120 | 44.1 | 5.4 | 38.8 | | | 4.049 | 1800 | 40.8 | 9.2 | 31.7 |
| | | 1.453 | 65 | 57.3 | 4.8 | 52.5 | | | 1.890 | 140 | 46.5 | 5.6 | 40.9 | | | 4.305 | 1850 | 43.3 | 9.8 | 33.7 |
| | | 1.626 | 69 | 61.2 | 5.2 | 56.0 | | | 2.179 | 160 | 50.7 | 6.0 | 44.6 | | | 4.940 | 1900 | 51.2 | 11.2 | 39.9 |
| | | 1.880 | 70 | 66.8 | 5.6 | 61.2 | | | 3.023 | 174 | 63.4 | 7.5 | 56.0 | | | 5.512 | 1906 | 62.8 | 12.9 | 49.9 |

TABLE VI. - CRACK GROWTH DATA FOR TANK TESTS AT -320° F (77° K)

(a) U.S. customary units

| Symbol | Specimen number | 2a, in. | N, cycles | $K_{max}$, ksi$\sqrt{in.}$ | $K_{min}$, ksi$\sqrt{in.}$ | $\Delta K$, ksi$\sqrt{in.}$ | Symbol | Specimen number | 2a, in. | N, cycles | $K_{max}$, ksi$\sqrt{in.}$ | $K_{min}$, ksi$\sqrt{in.}$ | $\Delta K$, ksi$\sqrt{in.}$ | Symbol | Specimen number | 2a, in. | N, cycles | $K_{max}$, ksi$\sqrt{in.}$ | $K_{min}$, ksi$\sqrt{in.}$ | $\Delta K$, ksi$\sqrt{in.}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ● | 16 | 0.125 | 0 | 30.0 | 2.2 | 27.8 | ◣ | 21 | 0.300 | 0 | 33.8 | 3.7 | 30.1 | ◗ | 26 | 0.500 | 0 | 27.9 | 5.3 | 22.6 |
| | | .143 | 40 | 32.5 | 2.4 | 30.1 | | | .326 | 20 | 35.9 | 4.0 | 31.9 | | | .521 | 200 | 28.8 | 5.5 | 23.3 |
| | | .165 | 80 | 35.5 | 2.6 | 32.9 | | | .356 | 40 | 38.2 | 4.2 | 34.0 | | | .558 | 400 | 30.4 | 5.8 | 24.6 |
| | | .192 | 120 | 39.1 | 2.8 | 36.2 | | | .398 | 60 | 41.3 | 4.5 | 36.8 | | | .618 | 600 | 32.9 | 6.3 | 26.6 |
| | | .210 | 140 | 41.4 | 3.0 | 38.4 | | | .417 | 65 | 42.6 | 4.7 | 38.1 | | | .667 | 700 | 35.0 | 6.6 | 28.4 |
| | | .246 | 160 | 46.0 | 3.3 | 42.7 | | | .494 | 70 | 44.8 | 4.4 | 39.9 | | | .732 | 800 | 37.8 | 7.2 | 30.7 |
| | | .264 | 165 | 48.3 | 3.4 | 44.8 | | | .496 | 75 | 48.8 | 5.3 | 43.5 | | | .770 | 850 | 39.4 | 7.5 | 32.0 |
| | | .287 | 170 | 51.2 | 3.6 | 47.5 | | | .539 | 77.5 | 52.1 | 5.6 | 46.5 | | | .808 | 900 | 41.1 | 7.8 | 33.3 |
| | | .330 | 175 | 56.6 | 4.0 | 52.6 | | | .620 | 80 | 52.2 | 6.3 | 52.2 | | | .863 | 950 | 43.5 | 8.2 | 35.3 |
| | | .504 | 180 | 79.3 | 5.4 | 74.0 | | | .680 | 81 | 63.3 | 6.7 | 56.5 | | | 1.000 | 983 | 49.7 | 9.3 | 40.4 |
| ■ | 17 | 0.125 | 0 | 27.8 | 2.2 | 25.6 | ◖ | 22 | 0.300 | 0 | 30.1 | 3.7 | 26.3 | ◗ | 27 | 1.000 | 0 | 38.6 | 9.3 | 29.3 |
| | | .142 | 100 | 30.0 | 2.4 | 27.7 | | | .316 | 40 | 31.2 | 3.9 | 27.3 | | | 1.074 | 3 | 41.2 | 9.9 | 31.3 |
| | | .166 | 200 | 33.1 | 2.6 | 30.5 | | | .338 | 80 | 32.7 | 4.1 | 28.6 | | | 1.112 | 7 | 42.5 | 10.2 | 32.3 |
| | | .184 | 250 | 35.3 | 2.8 | 32.5 | | | .364 | 120 | 34.4 | 4.3 | 30.1 | | | 1.131 | 10 | 43.2 | 10.4 | 32.8 |
| | | .214 | 300 | 38.8 | 3.0 | 35.8 | | | .384 | 140 | 35.7 | 4.4 | 31.3 | | | 1.147 | 13 | 43.8 | 10.5 | 33.3 |
| | | .239 | 320 | 41.7 | 3.2 | 38.5 | | | .421 | 160 | 38.2 | 4.7 | 33.5 | | | 1.168 | 17 | 44.6 | 10.7 | 33.8 |
| | | .259 | 330 | 44.0 | 3.4 | 40.6 | | | .453 | 170 | 40.3 | 5.0 | 35.4 | | | 1.187 | 20 | 45.2 | 10.9 | 34.4 |
| | | .283 | 340 | 46.8 | 3.6 | 43.2 | | | .506 | 180 | 43.9 | 5.4 | 38.5 | | | 1.215 | 23 | 46.3 | 11.1 | 35.2 |
| | | .326 | 350 | 51.8 | 4.0 | 47.8 | | | .545 | 185 | 46.5 | 5.7 | 40.8 | | | 1.282 | 27 | 48.7 | 11.7 | 37.0 |
| | | .520 | 356 | 74.7 | 5.5 | 69.2 | | | .610 | 191 | 51.0 | 6.2 | 44.8 | | | 1.400 | 30 | 53.2 | 12.7 | 40.5 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ◆ | 18 | 0.125 | 0 | 26.7 | 2.2 | 24.5 | ● | 23 | 0.300 | 0 | 27.7 | 3.7 | 23.9 | ● | 28 | 1.000 | 0 | 28.8 | 9.3 | 19.5 |
| | | .136 | 100 | 28.1 | 2.3 | 25.8 | | | .318 | 100 | 28.7 | 3.9 | 24.9 | | | 1.042 | 100 | 29.9 | 9.7 | 20.2 |
| | | .149 | 200 | 29.7 | 2.4 | 27.2 | | | .356 | 200 | 31.1 | 4.2 | 26.9 | | | 1.073 | 200 | 30.7 | 9.9 | 20.8 |
| | | .166 | 300 | 31.7 | 2.6 | 29.1 | | | .383 | 250 | 32.8 | 4.4 | 28.3 | | | 1.127 | 300 | 32.1 | 10.4 | 21.7 |
| | | .191 | 400 | 34.6 | 2.8 | 31.8 | | | .424 | 300 | 35.3 | 4.7 | 30.5 | | | 1.170 | 350 | 33.2 | 10.7 | 22.5 |
| | | .213 | 450 | 37.1 | 3.0 | 34.1 | | | .452 | 320 | 37.0 | 5.0 | 32.0 | | | 1.242 | 400 | 35.2 | 11.3 | 23.8 |
| | | .249 | 500 | 41.1 | 3.3 | 37.8 | | | .498 | 340 | 39.8 | 5.3 | 34.5 | | | 1.294 | 425 | 36.6 | 11.8 | 24.8 |
| | | .295 | 540 | 46.2 | 3.7 | 42.5 | | | .541 | 350 | 42.4 | 5.7 | 36.8 | | | ----- | ---- | ---- | ---- | ---- |
| | | .370 | 570 | 54.4 | 4.3 | 50.1 | | | .595 | 356 | 45.7 | 6.1 | 39.7 | | | ----- | ---- | ---- | ---- | ---- |
| | | .480 | 584 | 66.7 | 5.2 | 61.5 | | | .690 | 358 | 51.7 | 6.8 | 44.9 | | | ----- | ---- | ---- | ---- | ---- |
| ▲ | 19 | 0.125 | 0 | 23.6 | 2.2 | 21.4 | ♦ | 24 | 0.500 | 0 | 36.0 | 5.3 | 30.7 | ▼ | 29 | 1.000 | 0 | 26.3 | 9.3 | 16.9 |
| | | .135 | 200 | 24.7 | 2.3 | 22.4 | | | .558 | 40 | 39.2 | 5.8 | 33.4 | | | 1.023 | 400 | 26.8 | 9.5 | 17.4 |
| | | .150 | 400 | 26.3 | 2.4 | 23.9 | | | .625 | 80 | 42.9 | 6.3 | 36.6 | | | 1.084 | 800 | 28.3 | 10.0 | 18.2 |
| | | .170 | 600 | 28.4 | 2.6 | 25.8 | | | .636 | 85 | 43.5 | 6.4 | 37.1 | | | 1.162 | 1200 | 30.1 | 10.7 | 19.4 |
| | | .201 | 800 | 31.6 | 2.9 | 28.6 | | | .649 | 90 | 44.3 | 6.5 | 37.8 | | | 1.192 | 1300 | 30.8 | 10.9 | 19.9 |
| | | .222 | 900 | 33.7 | 3.1 | 30.6 | | | .665 | 95 | 45.2 | 6.6 | 38.5 | | | 1.232 | 1400 | 31.8 | 11.3 | 20.6 |
| | | .250 | 1000 | 36.3 | 3.3 | 33.0 | | | .684 | 100 | 46.2 | 6.8 | 39.5 | | | 1.301 | 1500 | 33.5 | 11.8 | 21.7 |
| | | .294 | 1100 | 40.6 | 3.7 | 36.9 | | | .711 | 105 | 47.8 | 7.0 | 40.8 | | | 1.370 | 1550 | 35.2 | 12.4 | 22.8 |
| | | .352 | 1150 | 46.1 | 4.2 | 41.9 | | | .751 | 110 | 50.1 | 7.3 | 42.8 | | | 1.510 | 1600 | 38.8 | 13.7 | 25.1 |
| | | .530 | 1176 | 63.1 | 5.6 | 57.6 | | | .900 | 118 | 58.8 | 8.5 | 50.3 | | | 1.620 | 1613 | 41.6 | 14.7 | 27.0 |
| ◣ | 20 | 0.300 | 0 | 36.5 | 3.7 | 32.8 | ▲ | 25 | 0.500 | 0 | 33.6 | 5.3 | 28.2 | | | | | | | |
| | | .328 | 10 | 38.9 | 4.0 | 34.9 | | | .547 | 100 | 36.0 | 5.7 | 30.3 | | | | | | | |
| | | .358 | 20 | 41.4 | 4.2 | 37.1 | | | .577 | 140 | 37.5 | 5.9 | 31.6 | | | | | | | |
| | | .390 | 30 | 44.0 | 4.5 | 39.5 | | | .623 | 180 | 39.9 | 6.3 | 33.6 | | | | | | | |
| | | .424 | 40 | 46.8 | 4.7 | 42.1 | | | .658 | 200 | 41.6 | 6.6 | 35.1 | | | | | | | |
| | | .446 | 45 | 48.7 | 4.9 | 43.8 | | | .678 | 210 | 42.7 | 6.7 | 36.0 | | | | | | | |
| | | .474 | 50 | 51.0 | 5.1 | 45.9 | | | .705 | 220 | 44.1 | 6.9 | 37.2 | | | | | | | |
| | | .519 | 55 | 54.8 | 5.5 | 49.3 | | | .746 | 230 | 46.3 | 7.3 | 39.0 | | | | | | | |
| | | .556 | 57.5 | 57.9 | 5.8 | 52.2 | | | .814 | 240 | 49.9 | 7.8 | 42.1 | | | | | | | |
| | | .594 | 59 | 61.2 | 6.1 | 55.1 | | | .910 | 246 | 55.1 | 8.6 | 46.6 | | | | | | | |

TABLE VI. - Concluded. CRACK GROWTH DATA FOR TENSILE TESTS AT -320° F (77° K)

(b) SI units

| Symbol | Specimen number | 2a, cm | N, cycles | $K_{max}$, $MN/m^{3/2}$ | $K_{min}$, $MN/m^{3/2}$ | $\Delta K$, $MN/m^{3/2}$ | Symbol | Specimen number | 2a, cm | N, cycles | $K_{max}$, $MN/m^{3/2}$ | $K_{min}$, $MN/m^{3/2}$ | $\Delta K$, $MN/m^{3/2}$ | Symbol | Specimen number | 2a, cm | N, cycles | $K_{max}$, $MN/m^{3/2}$ | $K_{min}$, $MN/m^{3/2}$ | $\Delta K$, $MN/m^{3/2}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ● | 16 | 0.318 | 0 | 33.0 | 2.4 | 30.6 | ◣ | 21 | 0.762 | 0 | 37.2 | 4.1 | 33.1 | ◗ | 26 | 1.270 | 0 | 30.7 | 5.8 | 24.9 |
| | | .363 | 40 | 35.8 | 2.6 | 33.1 | | | .828 | 20 | 39.5 | 4.4 | 35.1 | | | 1.323 | 200 | 39.5 | 6.0 | 25.6 |
| | | .419 | 80 | 39.0 | 2.9 | 36.2 | | | .904 | 40 | 42.0 | 4.6 | 37.4 | | | 1.417 | 400 | 33.4 | 6.4 | 27.1 |
| | | .488 | 120 | 43.0 | 3.1 | 39.8 | | | 1.011 | 60 | 45.4 | 5.0 | 40.5 | | | 1.570 | 600 | 36.2 | 6.9 | 29.3 |
| | | .533 | 140 | 45.5 | 3.3 | 42.2 | | | 1.059 | 65 | 47.1 | 5.2 | 41.9 | | | 1.694 | 700 | 38.5 | 7.3 | 31.2 |
| | | .625 | 160 | 50.6 | 3.6 | 47.8 | | | 1.128 | 70 | 49.3 | 5.4 | 43.9 | | | 1.859 | 800 | 41.6 | 7.9 | 33.8 |
| | | .671 | 165 | 53.1 | 3.7 | 49.3 | | | 1.260 | 75 | 53.7 | 5.8 | 47.8 | | | 1.956 | 850 | 43.3 | 8.2 | 35.2 |
| | | .729 | 170 | 56.3 | 4.0 | 52.2 | | | 1.369 | 77.5 | 57.3 | 6.2 | 51.2 | | | 2.052 | 900 | 45.2 | 8.6 | 36.6 |
| | | .838 | 175 | 62.3 | 4.4 | 57.9 | | | 1.575 | 80 | 64.4 | 6.9 | 57.4 | | | 2.192 | 950 | 47.8 | 9.0 | 38.8 |
| | | 1.280 | 180 | 87.2 | 5.9 | 81.4 | | | 1.727 | 81 | 69.6 | 7.4 | 62.2 | | | 2.540 | 983 | 54.7 | 10.2 | 44.4 |
| ■ | 17 | 0.318 | 0 | 30.6 | 2.4 | 28.2 | ◖ | 22 | 0.762 | 0 | 33.1 | 4.1 | 28.9 | ● | 27 | 2.540 | 0 | 42.5 | 10.2 | 32.2 |
| | | .361 | 100 | 33.0 | 2.6 | 30.5 | | | .803 | 40 | 34.3 | 4.3 | 30.0 | | | 2.728 | 3 | 45.3 | 10.9 | 34.4 |
| | | .422 | 200 | 36.4 | 2.9 | 33.6 | | | .859 | 80 | 36.0 | 4.5 | 31.5 | | | 2.824 | 7 | 46.8 | 11.2 | 35.5 |
| | | .467 | 250 | 38.8 | 3.1 | 35.8 | | | .925 | 120 | 37.8 | 4.7 | 33.1 | | | 2.873 | 10 | 47.5 | 11.4 | 36.1 |
| | | .544 | 300 | 42.7 | 3.3 | 39.4 | | | .975 | 140 | 39.3 | 4.8 | 34.4 | | | 2.913 | 13 | 48.2 | 11.6 | 36.6 |
| | | .607 | 320 | 45.9 | 3.5 | 42.4 | | | 1.069 | 160 | 42.0 | 5.2 | 36.8 | | | 2.767 | 17 | 49.1 | 11.8 | 37.2 |
| | | .658 | 330 | 48.4 | 3.7 | 44.7 | | | 1.151 | 170 | 44.3 | 5.5 | 38.9 | | | 3.015 | 20 | 49.7 | 12.0 | 37.8 |
| | | .719 | 340 | 51.5 | 4.0 | 47.5 | | | 1.285 | 180 | 48.3 | 5.9 | 42.4 | | | 3.086 | 23 | 50.9 | 12.2 | 38.7 |
| | | .828 | 350 | 57.0 | 4.4 | 52.6 | | | 1.384 | 185 | 51.2 | 6.3 | 44.9 | | | 3.256 | 27 | 53.6 | 12.9 | 40.7 |
| | | 1.321 | 356 | 82.2 | 6.0 | 76.1 | | | 1.549 | 191 | 56.1 | 6.8 | 49.3 | | | 3.556 | 30 | 58.5 | 14.0 | 44.6 |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ● | 18 | 0.318 | 0 | 29.4 | 2.4 | 27.0 | ● | 23 | 0.762 | 0 | 30.5 | 4.1 | 26.3 | ◆ | 28 | 2.540 | 0 | 31.7 | 10.2 | 21.4 |
| | | .345 | 100 | 30.9 | 2.5 | 28.4 | | | .808 | 100 | 31.6 | 4.3 | 27.4 | | | 2.647 | 100 | 32.9 | 10.7 | 22.2 |
| | | .378 | 200 | 32.7 | 2.6 | 29.9 | | | .904 | 200 | 34.2 | 4.6 | 29.6 | | | 2.725 | 200 | 33.8 | 10.9 | 22.9 |
| | | .422 | 300 | 34.9 | 2.9 | 32.0 | | | .973 | 250 | 36.1 | 4.8 | 31.1 | | | 2.863 | 300 | 35.3 | 11.4 | 23.9 |
| | | .485 | 400 | 38.1 | 3.1 | 35.0 | | | 1.077 | 300 | 38.8 | 5.2 | 33.6 | | | 2.972 | 350 | 36.5 | 11.8 | 24.8 |
| | | .541 | 450 | 40.8 | 3.3 | 37.5 | | | 1.148 | 320 | 40.7 | 5.5 | 35.2 | | | 3.155 | 400 | 38.7 | 12.4 | 26.2 |
| | | .632 | 500 | 45.2 | 3.6 | 41.6 | | | 1.265 | 340 | 43.8 | 5.8 | 38.0 | | | 3.287 | 425 | 40.3 | 13.0 | 27.3 |
| | | .749 | 540 | 50.8 | 4.1 | 46.8 | | | 1.374 | 350 | 46.6 | 6.3 | 40.5 | | | ----- | --- | ---- | ---- | ---- |
| | | .940 | 570 | 59.8 | 4.7 | 55.1 | | | 1.511 | 356 | 50.3 | 6.7 | 43.7 | | | ----- | --- | ---- | ---- | ---- |
| | | 1.219 | 584 | 73.4 | 5.7 | 67.6 | | | 1.753 | 358 | 56.9 | 7.5 | 49.4 | | | ----- | --- | ---- | ---- | ---- |
| ▲ | 19 | 0.318 | 0 | 26.0 | 2.4 | 23.5 | ♦ | 24 | 1.270 | 0 | 39.6 | 5.8 | 33.8 | ▼ | 29 | 2.540 | 0 | 28.9 | 10.2 | 18.6 |
| | | .343 | 200 | 27.2 | 2.5 | 24.6 | | | 1.417 | 40 | 43.1 | 6.9 | 36.7 | | | 2.598 | 400 | 29.5 | 10.4 | 19.0 |
| | | .381 | 400 | 28.9 | 2.6 | 26.3 | | | 1.588 | 80 | 47.2 | 6.9 | 40.3 | | | 2.753 | 800 | 31.1 | 11.0 | 20.0 |
| | | .432 | 600 | 31.2 | 2.9 | 28.4 | | | 1.615 | 85 | 47.8 | 7.0 | 40.8 | | | 2.951 | 1200 | 33.1 | 11.8 | 21.3 |
| | | .511 | 800 | 34.8 | 3.2 | 31.5 | | | 1.648 | 90 | 48.7 | 7.2 | 41.6 | | | 3.028 | 1300 | 33.9 | 12.0 | 21.9 |
| | | .564 | 900 | 37.1 | 3.4 | 33.7 | | | 1.689 | 95 | 49.7 | 7.3 | 42.4 | | | 3.129 | 1400 | 35.0 | 12.4 | 22.7 |
| | | .635 | 1000 | 39.9 | 3.6 | 36.3 | | | 1.737 | 100 | 50.8 | 7.5 | 43.4 | | | 3.305 | 1500 | 36.8 | 13.0 | 23.9 |
| | | .747 | 1100 | 44.7 | 4.1 | 40.6 | | | 1.806 | 105 | 52.6 | 7.7 | 44.9 | | | 3.480 | 1550 | 38.7 | 13.6 | 25.1 |
| | | .894 | 1150 | 50.7 | 4.6 | 46.1 | | | 1.908 | 110 | 55.1 | 8.0 | 47.1 | | | 3.835 | 1600 | 42.7 | 15.1 | 27.6 |
| | | 1.346 | 1176 | 69.4 | 6.2 | 63.4 | | | 2.286 | 118 | 64.7 | 9.4 | 55.3 | | | 4.115 | 1613 | 45.8 | 16.2 | 29.7 |
| ◣ | 20 | 0.762 | 0 | 40.2 | 4.1 | 36.1 | ⬟ | 25 | 1.270 | 0 | 37.0 | 5.8 | 31.0 | | | | | | | |
| | | .833 | 10 | 42.8 | 4.4 | 38.4 | | | 1.389 | 100 | 39.6 | 6.3 | 33.3 | | | | | | | |
| | | .909 | 20 | 45.5 | 4.6 | 40.3 | | | 1.466 | 140 | 41.2 | 6.5 | 34.8 | | | | | | | |
| | | .991 | 30 | 48.4 | 5.0 | 43.4 | | | 1.582 | 180 | 43.9 | 6.9 | 37.0 | | | | | | | |
| | | 1.077 | 40 | 51.5 | 5.2 | 46.3 | | | 1.659 | 200 | 45.8 | 7.3 | 38.6 | | | | | | | |
| | | 1.133 | 45 | 53.6 | 5.4 | 48.2 | | | 1.722 | 210 | 47.0 | 7.4 | 39.6 | | | | | | | |
| | | 1.204 | 50 | 56.1 | 5.6 | 50.5 | | | 1.791 | 220 | 48.5 | 7.6 | 40.9 | | | | | | | |
| | | 1.318 | 55 | 60.3 | 6.0 | 54.2 | | | 1.895 | 230 | 50.9 | 8.0 | 42.9 | | | | | | | |
| | | 1.412 | 59.5 | 63.7 | 6.4 | 57.4 | | | 2.068 | 240 | 54.9 | 8.6 | 46.3 | | | | | | | |
| | | 1.509 | 59 | 67.3 | 6.7 | 60.6 | | | 2.311 | 246 | 60.6 | 9.5 | 51.3 | | | | | | | |

TABLE VII. - CRACK GROWTH DATA FOR TENSILE AND TANK TESTS AT -423° F (20° K)

(a) U.S. customary units

| Symbol | Specimen number | 2a, in. | N, cycles | $K_{max}$, ksi$\sqrt{in.}$ | $K_{min}$, ksi$\sqrt{in.}$ | $\Delta K$, ksi$\sqrt{in.}$ | Symbol | Specimen number | 2a, in. | N, cycles | $K_{max}$, ksi$\sqrt{in.}$ | $K_{min}$, ksi$\sqrt{in.}$ | $\Delta K$, ksi$\sqrt{in.}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Tensile | | | | | | | | |
| ◁ | 30 | 0.128 | 0 | 28.8 | 2.7 | 26.1 | ◁ | 32 | 0.496 | 0 | 27.1 | 2.6 | 24.5 |
| | | .138 | 40 | 29.9 | 2.8 | 27.1 | | | .549 | 200 | 28.6 | 2.8 | 25.9 |
| | | .149 | 80 | 31.1 | 2.9 | 28.2 | | | .606 | 400 | 30.2 | 2.9 | 27.3 |
| | | .162 | 120 | 32.4 | 3.0 | 29.4 | | | .643 | 500 | 31.2 | 3.0 | 38.2 |
| | | .181 | 160 | 34.3 | 3.2 | 31.1 | | | .694 | 600 | 32.6 | 3.2 | 29.4 |
| | | .209 | 200 | 36.9 | 3.4 | 33.5 | | | .768 | 700 | 34.5 | 3.3 | 31.1 |
| | | .230 | 220 | 38.8 | 3.6 | 35.2 | | | .887 | 800 | 37.5 | 3.6 | 33.9 |
| | | .262 | 240 | 41.4 | 3.8 | 37.6 | | | .984 | 850 | 40.0 | 3.9 | 36.1 |
| | | .326 | 260 | 46.4 | 4.3 | 42.1 | | | 1.210 | 900 | 46 0 | 4.4 | 41.6 |
| | | .600 | 280 | 64.8 | 5.9 | 58.9 | | | 1.530 | 911 | 55.8 | 5.2 | 50.5 |
| ◇ | 31 | 0.301 | 0 | 30.7 | 3.0 | 27.6 | ◸ | 33 | 0.996 | 0 | 30.4 | 5.3 | 25.1 |
| | | .310 | 40 | 31.1 | 3.1 | 28.1 | | | 1.034 | 100 | 31.1 | 5.4 | 25.7 |
| | | .331 | 80 | 32.2 | 3.2 | 29.0 | | | 1.079 | 200 | 32.0 | 5.5 | 26.4 |
| | | .368 | 120 | 34.0 | 3.4 | 30.7 | | | 1.126 | 300 | 32.9 | 5.7 | 27.2 |
| | | .410 | 160 | 36.0 | 3.6 | 32.4 | | | 1.179 | 400 | 33.9 | 5.9 | 28.0 |
| | | .461 | 200 | 38.3 | 3.8 | 34.5 | | | 1.246 | 500 | 35.2 | 6.1 | 29.1 |
| | | .490 | 220 | 39.6 | 3.9 | 35.7 | | | 1.338 | 600 | 37.1 | 6.4 | 30.7 |
| | | .533 | 240 | 41.4 | 4.1 | 37.3 | | | 1.487 | 700 | 40.4 | 6.9 | 33.4 |
| | | .617 | 260 | 44.9 | 4.4 | 40.5 | | | 1.583 | 730 | 42.7 | 7.3 | 35.4 |
| | | .910 | 277 | 56.5 | 5.5 | 51.0 | | | 1.840 | 753 | 50.1 | 8.4 | 41.7 |
| | | | | | Tank | | | | | | | | |
| ◀ | 34 | 0.125 | 0 | 28.6 | 2.6 | 26.0 | ● | 36 | 0.500 | 0 | 27.2 | 2.6 | 24.5 |
| | | .132 | 50 | 29.6 | 2.7 | 26.9 | | | .528 | 100 | 28.2 | 2.8 | 25.5 |
| | | .142 | 100 | 30.8 | 2.8 | 28.0 | | | .562 | 200 | 29.5 | 2.9 | 26.7 |
| | | .156 | 150 | 32.5 | 2.9 | 29.6 | | | .582 | 250 | 30.3 | 3.0 | 27.4 |
| | | .180 | 200 | 35.4 | 3.2 | 32.2 | | | .607 | 300 | 31.3 | 3.0 | 28.2 |
| | | .194 | 220 | 37.1 | 3.3 | 33.7 | | | .628 | 325 | 32.1 | 3.1 | 29.0 |
| | | .211 | 240 | 39.1 | 3.5 | 35.6 | | | .665 | 350 | 33.5 | 3.3 | 30.3 |
| | | .236 | 260 | 42.0 | 3.8 | 38.3 | | | .738 | 375 | 36.4 | 3.5 | 32.8 |
| | | .259 | 270 | 44.5 | 4.0 | 40.6 | | | .808 | 388 | 39.1 | 3.8 | 35.3 |
| | | .330 | 278 | 52.3 | 4.6 | 47.7 | | | .990 | 401 | 46.3 | 4.5 | 41.9 |
| ◆ | 35 | 0.300 | 0 | 30.5 | 2.9 | 27.6 | ◤ | 37 | 1.000 | 0 | 30.4 | 5.3 | 25.1 |
| | | .318 | 50 | 31.7 | 3.0 | 28.7 | | | 1.136 | 250 | 33.9 | 5.9 | 28.0 |
| | | .338 | 100 | 33.0 | 3.1 | 29.9 | | | 1.172 | 300 | 34.9 | 6.0 | 28.8 |
| | | .362 | 150 | 34.6 | 3.3 | 31.3 | | | 1.197 | 325 | 35.5 | 6.2 | 29.3 |
| | | .401 | 200 | 37.1 | 3.5 | 33.6 | | | 1.230 | 350 | 36.4 | 6.3 | 30.1 |
| | | .425 | 220 | 38.6 | 3.6 | 35.0 | | | 1.282 | 375 | 37.8 | 6.5 | 31.2 |
| | | .461 | 240 | 40.9 | 3.8 | 37.0 | | | 1.385 | 400 | 40.6 | 7.0 | 33.5 |
| | | .536 | 260 | 45.6 | 4.3 | 41.4 | | | 1.435 | 405 | 41.9 | 7.2 | 34.7 |
| | | .607 | 270 | 50.1 | 4.7 | 45.5 | | | 1.510 | 410 | 44.0 | 7.6 | 36.4 |
| | | .630 | 272 | 51.6 | 4.8 | 46.8 | | | 1.710 | 415 | 49.7 | 8.6 | 41.1 |

TABLE VII. - Concluded. CRACK GROWTH DATA FOR TENSILE AND TANK TESTS AT -423° F (20° K)

(b) SI units

| Symbol | Specimen number | 2a, cm | N, cycles | $K_{max}$, $MN/m^{3/2}$ | $K_{min}$, $MN/m^{3/2}$ | $\Delta K$, $MN/m^{3/2}$ | Symbol | Specimen number | 2a, cm | N, cycles | $K_{max}$, $MN/m^{3/2}$ | $K_{min}$, $MN/m^{3/2}$ | $\Delta K$, $MN/m^{3/2}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Tensile | | | | | | | | |
| | 30 | 0.325 | 0 | 31.7 | 3.0 | 28.7 | | 32 | 1.260 | 0 | 29.8 | 2.9 | 27.0 |
| | | .351 | 40 | 32.9 | 3.1 | 29.8 | | | 1.394 | 200 | 31.5 | 3.1 | 28.5 |
| | | .378 | 80 | 34.2 | 3.2 | 31.0 | | | 1.539 | 400 | 33.2 | 3.2 | 30.0 |
| | | .411 | 120 | 35.6 | 3.3 | 32.3 | | | 1.633 | 500 | 34.3 | 3.3 | 31.0 |
| | | .460 | 160 | 37.7 | 3.5 | 34.2 | | | 1.763 | 600 | 35.9 | 3.5 | 32.3 |
| | | .531 | 200 | 40.6 | 3.7 | 36.8 | | | 1.951 | 700 | 38.0 | 3.6 | 34.2 |
| | | .584 | 220 | 42.7 | 4.0 | 38.7 | | | 2.253 | 800 | 41.2 | 4.0 | 37.3 |
| | | .655 | 240 | 45.5 | 4.2 | 41.4 | | | 2.499 | 850 | 44.0 | 4.3 | 39.7 |
| | | .828 | 260 | 51.0 | 4.7 | 46.3 | | | 3.073 | 900 | 50.6 | 4.8 | 45.8 |
| | | 1.524 | 280 | 71.3 | 6.5 | 64.8 | | | 3.886 | 911 | 61.4 | 5.7 | 55.6 |
| | 31 | 0.765 | 0 | 33.8 | 3.3 | 30.4 | | 33 | 2.530 | 0 | 33.4 | 5.8 | 27.6 |
| | | .787 | 40 | 34.2 | 3.4 | 30.9 | | | 2.626 | 100 | 34.2 | 5.9 | 28.3 |
| | | .841 | 80 | 35.4 | 3.5 | 31.9 | | | 2.741 | 200 | 35.2 | 6.0 | 29.0 |
| | | .935 | 120 | 37.4 | 3.7 | 33.8 | | | 2.860 | 300 | 36.2 | 6.3 | 29.9 |
| | | 1.041 | 160 | 39.6 | 4.0 | 35.6 | | | 2.995 | 400 | 37.3 | 6.5 | 30.8 |
| | | 1.171 | 200 | 42.1 | 4.2 | 38.0 | | | 3.165 | 500 | 38.7 | 6.7 | 32.0 |
| | | 1.245 | 220 | 43.6 | 4.3 | 39.3 | | | 3.399 | 600 | 40.8 | 7.0 | 33.8 |
| | | 1.354 | 240 | 45.5 | 4.5 | 41.0 | | | 3.777 | 700 | 44.4 | 7.6 | 36.7 |
| | | 1.567 | 260 | 49.4 | 4.8 | 44.6 | | | 4.021 | 730 | 47.0 | 8.0 | 38.9 |
| | | 2.311 | 277 | 62.2 | 6.0 | 56.1 | | | 4.674 | 753 | 55.1 | 9.2 | 45.9 |
| | | | | | Tank | | | | | | | | |
| | 34 | 0.318 | 0 | 31.5 | 2.9 | 28.6 | | 36 | 1.270 | 0 | 29.9 | 2.9 | 27.0 |
| | | .335 | 50 | 32.6 | 3.0 | 39.6 | | | 1.341 | 100 | 31.0 | 3.1 | 28.0 |
| | | .361 | 100 | 33.9 | 3.1 | 30.8 | | | 1.427 | 200 | 32.4 | 3.2 | 29.4 |
| | | .396 | 150 | 35.8 | 3.2 | 32.6 | | | 1.478 | 250 | 33.3 | 3.3 | 30.1 |
| | | .457 | 200 | 38.9 | 3.5 | 35.4 | | | 1.542 | 300 | 34.4 | 3.3 | 31.0 |
| | | .493 | 220 | 40.8 | 3.6 | 37.1 | | | 1.595 | 325 | 35.3 | 3.4 | 31.9 |
| | | .536 | 240 | 43.0 | 3.8 | 39.2 | | | 1.689 | 350 | 36.8 | 3.6 | 33.3 |
| | | .599 | 260 | 46.2 | 4.2 | 42.1 | | | 1.875 | 375 | 40.0 | 3.8 | 36.1 |
| | | .658 | 270 | 49.0 | 4.4 | 44.7 | | | 2.052 | 388 | 43.0 | 4.2 | 38.8 |
| | | .838 | 278 | 57.5 | 5.1 | 52.5 | | | 2.515 | 401 | 50.9 | 5.0 | 46.1 |
| | 35 | 0.762 | 0 | 33.6 | 3.2 | 30.4 | | 37 | 2.540 | 0 | 33.4 | 5.8 | 27.6 |
| | | .808 | 50 | 34.9 | 3.3 | 31.6 | | | 2.885 | 250 | 37.3 | 6.5 | 30.8 |
| | | .859 | 100 | 36.3 | 3.4 | 32.9 | | | 2.977 | 300 | 38.4 | 6.6 | 31.7 |
| | | .919 | 150 | 38.1 | 3.6 | 34.4 | | | 3.040 | 325 | 39.0 | 6.8 | 32.2 |
| | | 1.019 | 200 | 40.8 | 3.8 | 37.0 | | | 3.124 | 350 | 40.0 | 6.9 | 33.1 |
| | | 1.080 | 220 | 42.5 | 4.0 | 38.5 | | | 3.256 | 375 | 41.6 | 7.2 | 34.3 |
| | | 1.171 | 240 | 45.0 | 4.2 | 40.7 | | | 3.518 | 400 | 44.7 | 7.7 | 36.8 |
| | | 1.361 | 260 | 50.2 | 4.7 | 45.5 | | | 3.645 | 405 | 46.1 | 7.9 | 38.2 |
| | | 1.542 | 270 | 55.1 | 5.2 | 50.0 | | | 3.835 | 410 | 48.4 | 8.4 | 40.0 |
| | | 1.600 | 272 | 56.8 | 5.3 | 51.5 | | | 4.343 | 415 | 54.7 | 9.5 | 45.2 |

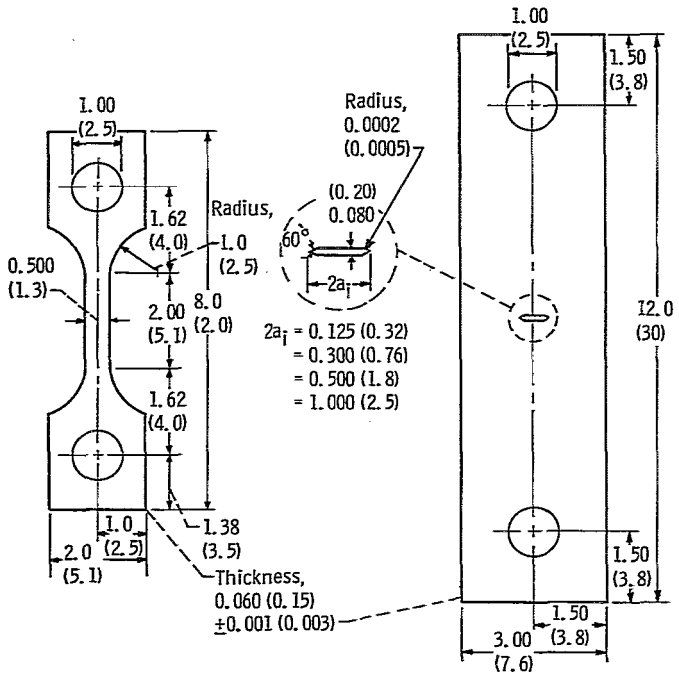



Figure 1. - Smooth and notched tensile specimens. (Dimensions are in inches (cm)).

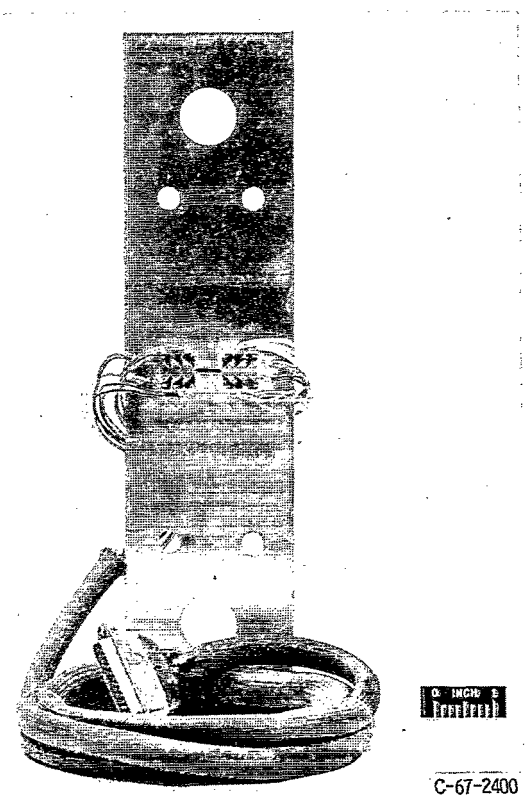



Figure 2. - Notched tensile specimen with continuity gages.

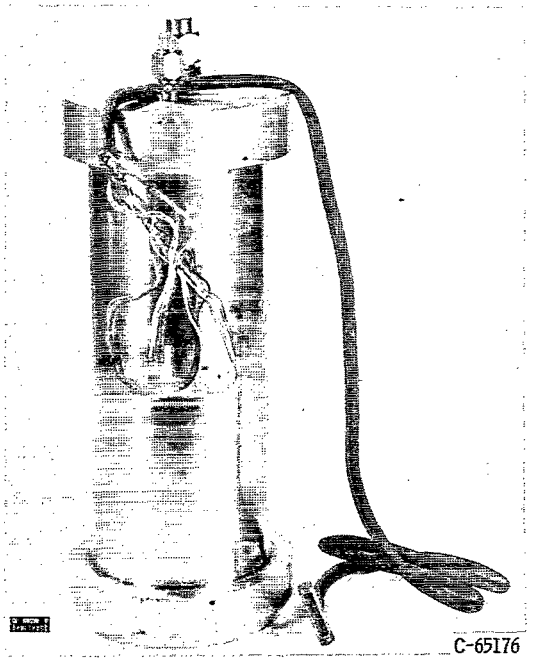



Figure 3. - Notched tank test specimen with continuity gages.


Figure 4. - Tensile fatigue testing machine.

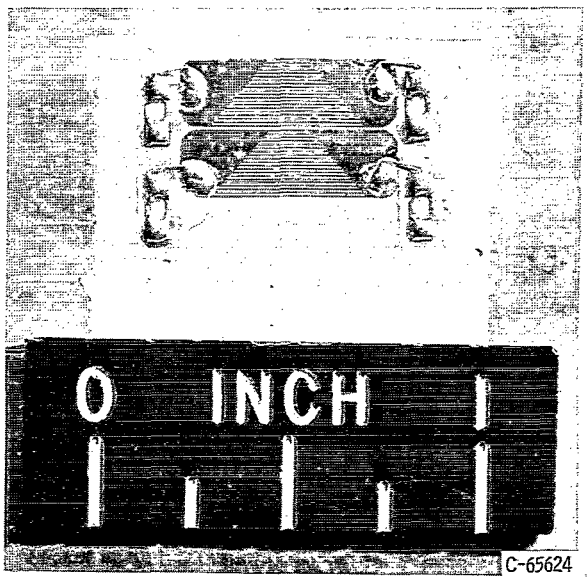



Figure 5. - Two continuity gages mounted in tandem at notch tip.

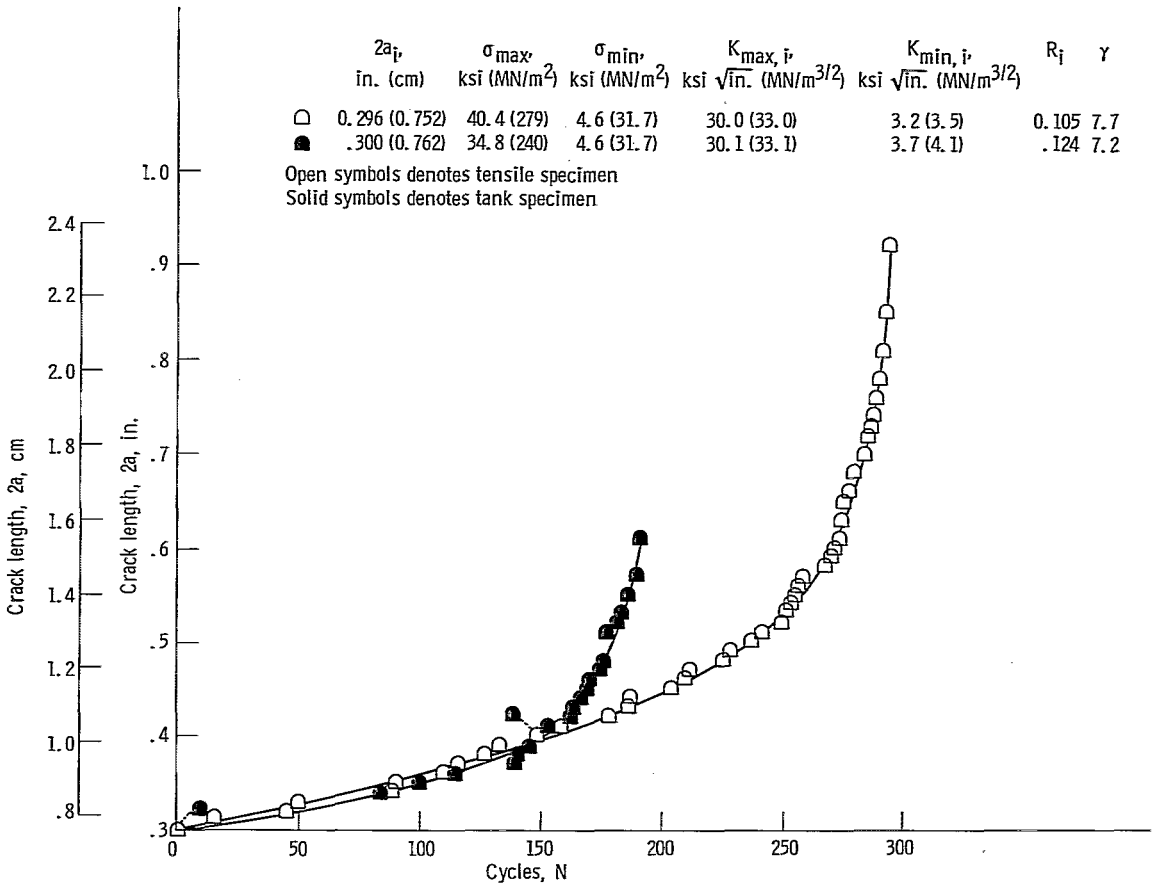
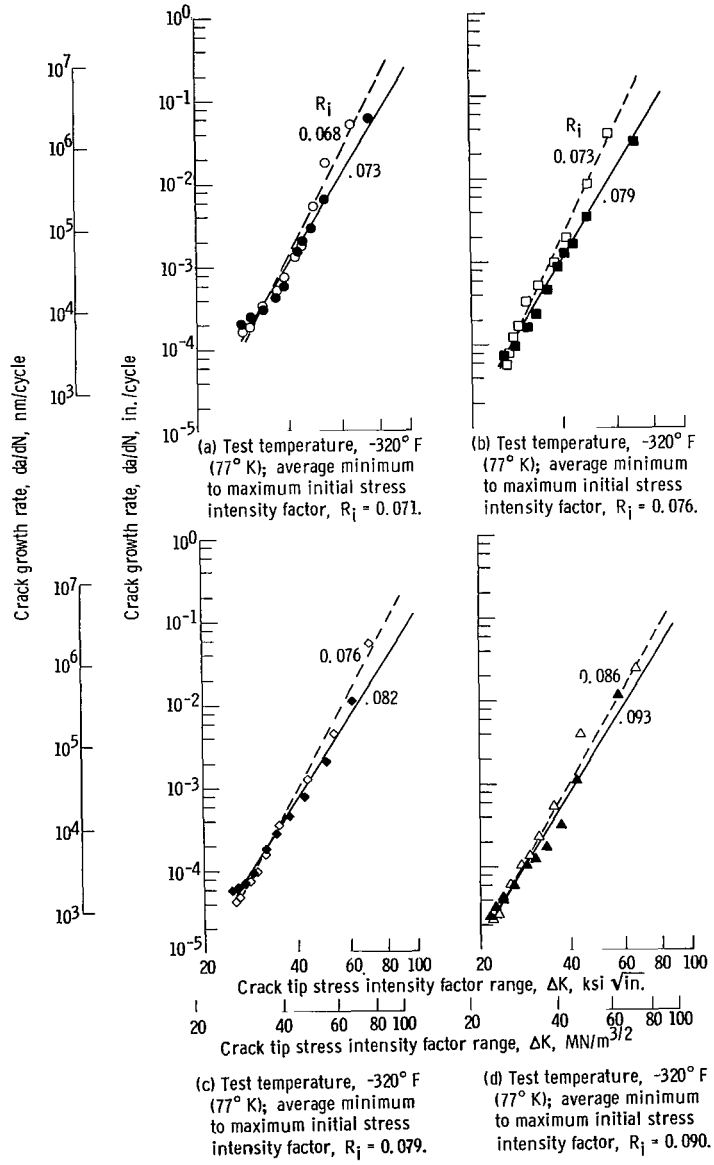



Figure 6. - Typical curve of crack growth as function of stress cycles at -320° F.

| Specimen number | $2a_i$, in. (cm) | $\sigma_{max}$, ksi ($MN/m^2$) | $\sigma_{min}$, ksi ($MN/m^2$) | $K_{max,i}$, ksi $\sqrt{in.}$ ($MN/m^{3/2}$) | $K_{min,i}$, ksi $\sqrt{in.}$ ($MN/m^{3/2}$) | $R_i$ | $\gamma$ | N |
|---|---|---|---|---|---|---|---|---|
| ○ 1 | 0.126 (0.320) | 57.3 (395) | 4.6 (31.7) | 30.4 (33.4) | 2.1 (2.3) | 0.068 | 7.3 | 215 |
| ● 16 | .125 (.318) | 54.9 (379) | | 30.0 (33.0) | 2.2 (2.4) | .073 | 6.0 | 180 |
| □ 2 | .126 (.320) | 54.2 (374) | | 28.1 (30.9) | 2.0 (2.2) | .073 | 7.6 | 277 |
| ■ 17 | .125 (.318) | 51.8 (357) | | 27.8 (30.6) | 2.2 (2.4) | .079 | 6.2 | 356 |
| ◇ 3 | .128 (.325) | 52.5 (362) | | 27.1 (29.8) | 2.1 (2.3) | .076 | 6.7 | 751 |
| ◆ 18 | .125 (.318) | 50.1 (346) | | 26.7 (29.4) | 2.2 (2.4) | .082 | 5.6 | 584 |
| △ 4 | .128 (.325) | 47.8 (330) | | 24.1 (26.5) | 2.1 (2.3) | .086 | 6.3 | 1163 |
| ▲ 19 | .125 (.318) | 45.4 (313) | | 23.6 (26.0) | 2.2 (2.4) | .093 | 6.0 | 1176 |

— — — Tensile specimens.
——— Tank specimens

Open symbols denote tensile specimens
Solid symbols denote tank specimens




(a) Test temperature, -320° F (77° K); average minimum to maximum initial stress intensity factor, $R_i$ = 0.071.

(b) Test temperature, -320° F (77° K); average minimum to maximum initial stress intensity factor, $R_i$ = 0.076.

(c) Test temperature, -320° F (77° K); average minimum to maximum initial stress intensity factor, $R_i$ = 0.079.

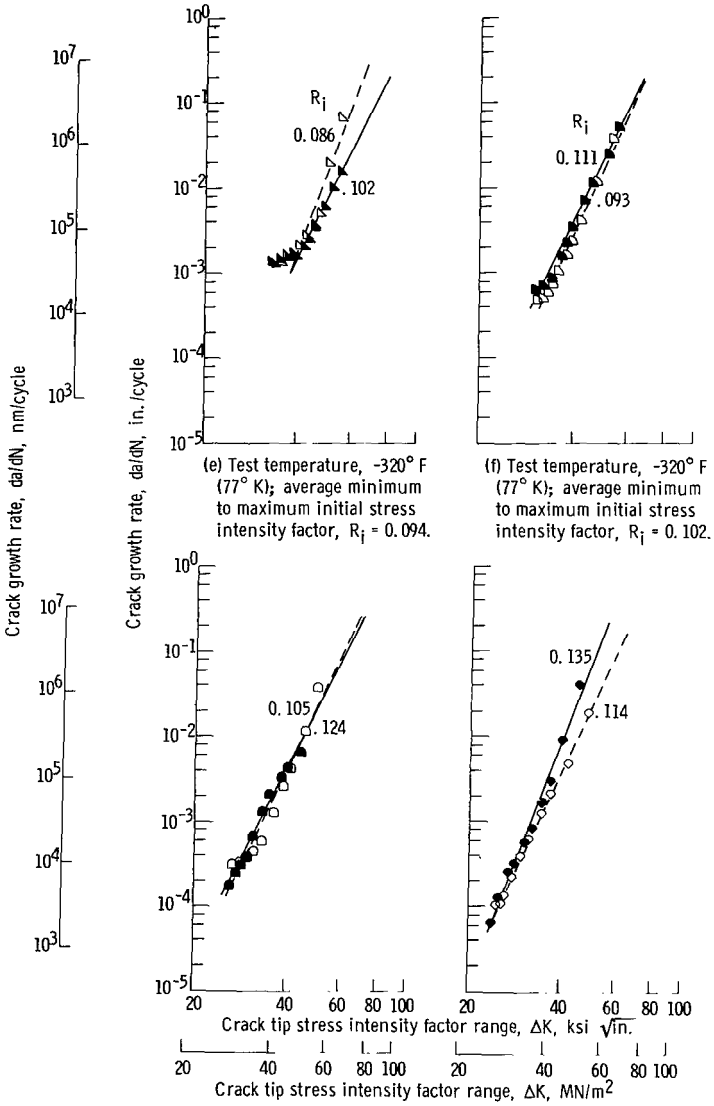
(d) Test temperature, -320° F (77° K); average minimum to maximum initial stress intensity factor, $R_i$ = 0.090.

Figure 7. - Crack growth rate as function of crack tip stress intensity factor range for tensile and tank specimens.

| Specimen number | $2a_i$, in. (cm) | $\sigma_{max}$, ksi ($MN/m^2$) | $\sigma_{min}$, ksi ($MN/m^2$) | $K_{max,i}$, ksi $\sqrt{in.}$ ($MN/m^{3/2}$) | $K_{min,i}$, ksi $\sqrt{in.}$ ($MN/m^{3/2}$) | $R_i$ | $\gamma$ | N |
|---|---|---|---|---|---|---|---|---|
| 5 | 0.301 (0.764) | 47.6 (328) | 4.6 (31.7) | 36.9 (40.6) | 3.2 (3.5) | 0.086 | 9.8 | 70 |
| 20 | .300 (.762) | 41.2 (284) | | 36.5 (40.2) | 3.7 (4.1) | .102 | 7.1 | 59 |
| 6 | .300 (.762) | 44.7 (308) | | 34.1 (37.5) | 3.2 (3.5) | .093 | 7.9 | 133 |
| 21 | .300 (.762) | 38.6 (266) | | 33.8 (37.2) | 3.7 (4.1) | .111 | 7.6 | 81 |
| 7 | .296 (.752) | 40.4 (279) | | 30.0 (33.0) | 3.2 (3.5) | .105 | 7.7 | 293 |
| 22 | .300 (.762) | 34.8 (240) | | 30.1 (33.1) | 3.7 (4.1) | .124 | 7.2 | 191 |
| 8 | .300 (.762) | 37.6 (259) | | 27.8 (30.6) | 3.2 (3.5) | .114 | 7.8 | 560 |
| 23 | .300 (.762) | 32.3 (223) | | 27.7 (30.5) | 3.7 (4.1) | .135 | 9.6 | 358 |

— — — Tensile specimens
——— Tank specimens

Open symbols denote tensile specimens
Solid symbols denote tank specimens




(e) Test temperature, -320° F (77° K); average minimum to maximum initial stress intensity factor, $R_i$ = 0.094.

(f) Test temperature, -320° F (77° K); average minimum to maximum initial stress intensity factor, $R_i$ = 0.102.

(g) Test temperature, -320° F (77° K); average minimum to maximum initial stress intensity factor, $R_i$ = 0.114.

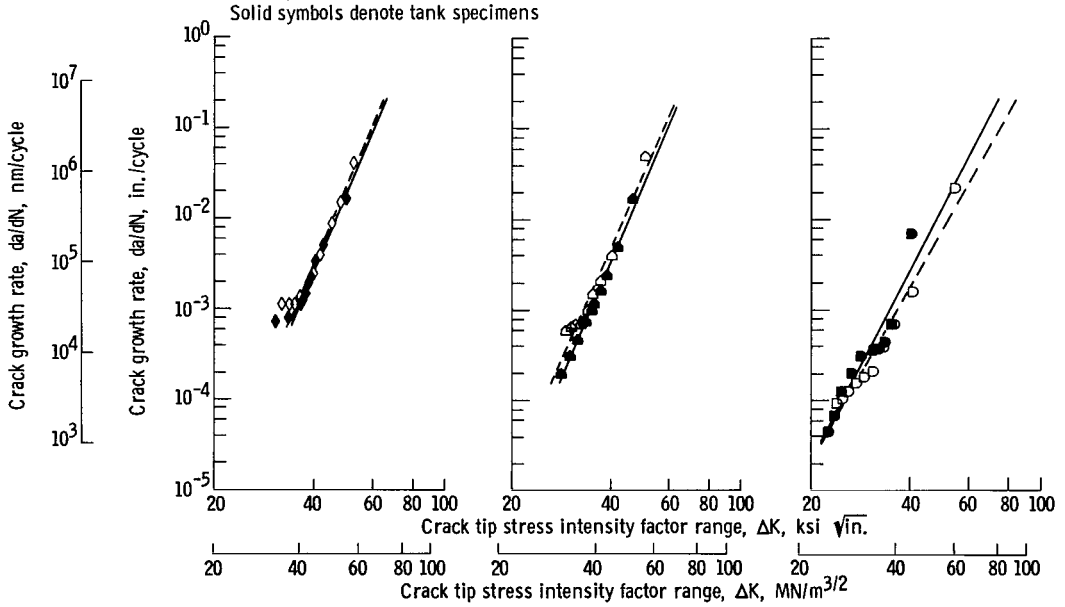
(h) Test temperature, -320° F (77° K); average minimum to maximum initial stress intensity factor, $R_i$ = 0.124.

Figure 7. - Continued.

| Specimen number | $2a_i$, in. (cm) | $\sigma_{max}$, ksi (MN/m$^2$) | $\sigma_{min}$, ksi (MN/m$^2$) | $K_{max,i}$, ksi $\sqrt{in.}$ (MN/m$^{3/2}$) | $K_{min,i}$, ksi $\sqrt{in.}$ (MN/m$^{3/2}$) | $R_i$ | $\gamma$ | N |
|---|---|---|---|---|---|---|---|---|
| ◇ 9 | 0.496 (1.260) | 37.6 (259) | 4.6 (31.7) | 36.1 (39.7) | 4.1 (4.5) | 0.114 | 8.8 | 116 |
| ◆ 24 | .500 (1.270) | 29.5 (204) | ↓ | 36.0 (39.6) | 5.3 (5.8) | .148 | 8.6 | 118 |
| △ 10 | .495 (1.257) | 35.5 (245) | ↓ | 33.8 (37.2) | 4.1 (4.5) | .122 | 8.3 | 174 |
| ▲ 25 | .500 (1.270) | 37.7 (191) | ↓ | 33.6 (37.0) | 5.3 (5.8) | .159 | 8.7 | 246 |
| □ 11 | .496 (1.260) | 30.0 (207) | ↓ | 28.0 (30.8) | 4.1 (4.5) | .147 | 6.5 | 1447 |
| ■ 26 | .500 (1.270) | 23.4 (161) | ↓ | 27.9 (30.7) | 5.3 (5.8) | .191 | 7.0 | 983 |

— — — Tensile specimens
——— Tank specimens

Open symbols denote tensile specimens
Solid symbols denote tank specimens




(i) Test temperature, -320° F (77° K); average minimum to maximum initial stress intensity factor, $R_i$ = 0.131.

(j) Test temperature, -320° F (77° K); average minimum to maximum initial stress intensity factor, $R_i$ = 0.140.

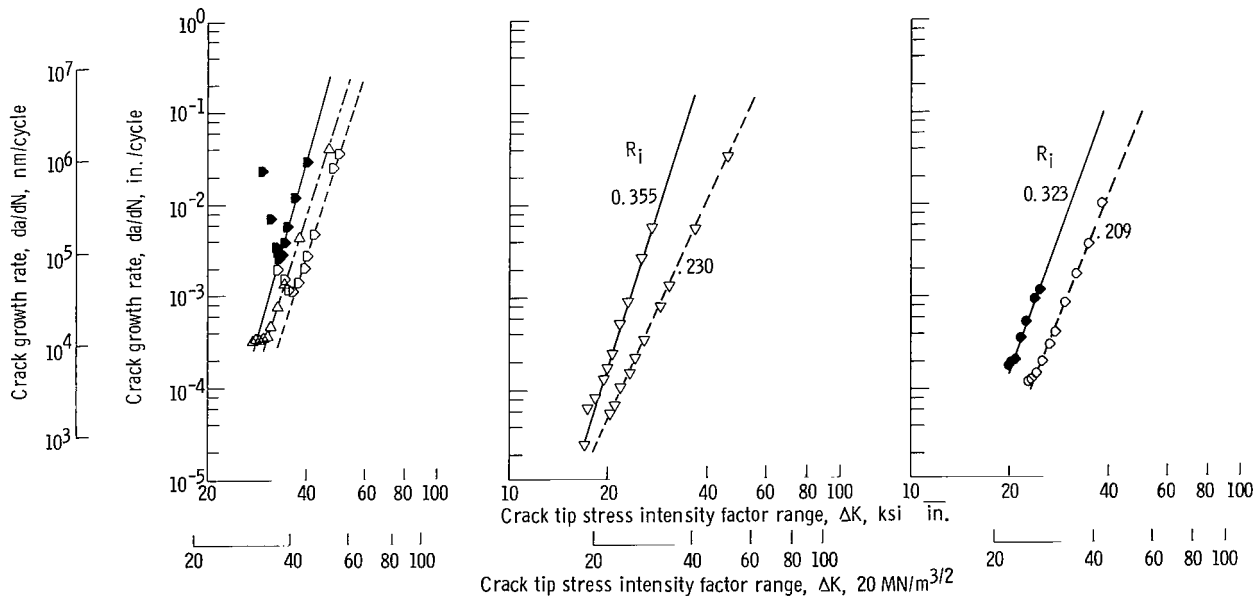
(k) Test temperature, -320° F (77° K); average minimum to maximum initial stress intensity factor, $R_i$ = 0.169.

Figure 7. - Continued.

| Specimen number | $2a_i$, in. (cm) | $\sigma_{max}$, ksi (MN/m$^2$) | $\sigma_{min}$, ksi (MN/m$^2$) | $K_{max,i}$, ksi $\sqrt{in.}$ (MN/m$^{3/2}$) | $K_{min,i}$, ksi $\sqrt{in.}$ (MN/m$^{3/2}$) | $R_i$ | $\gamma$ | N |
|---|---|---|---|---|---|---|---|---|
| 12 | 1.001 (2.543) | 28.1 (194) | 4.6 (31.7) | 38.9 (42.8) | 6.1 (6.7) | 0.156 | 11.2 | 131 |
| 27 | 1.000 (2.54) | 18.5 (128) | | 38.6 (42.5) | 9.3 (10.2) | .241 | 12.8 | 30 |
| 13 | .999 (2.537) | 25.0 (172) | | 34.2 (37.6) | 6.1 (6.7) | .177 | 11.1 | 400 |
| 14 | 0.992 (2.520) | 21.4 (148) | | 28.8 (31.7) | 6.0 (6.6) | .209 | 8.9 | 1088 |
| 28 | 1.000 (2.54) | 14.0 (96.6) | | 28.8 (31.7) | 9.3 (10.2) | .323 | 9.9 | 492 |
| 15 | .995 (2.572) | 19.6 (135) | | 26.3 (28.9) | 6.0 (6.6) | .230 | 7.9 | 1906 |
| 29 | 1.000 (2.54) | 12.8 (88.3) | | 26.3 (28.9) | 9.3 (10.2) | .355 | 11.1 | 1613 |

— — — Tensile specimens
——— Tank specimens

Open symbols denote tensile specimens
Solid symbols denote tank specimens




(l) Test temperature, -320° F (77° K); average minimum to maximum initial stress intensity factor, $R_i$ = 0.199.

(m) Test temperature, -320° F (77° K); average minimum to maximum initial stress intensity factor, $R_i$ = 0.266.

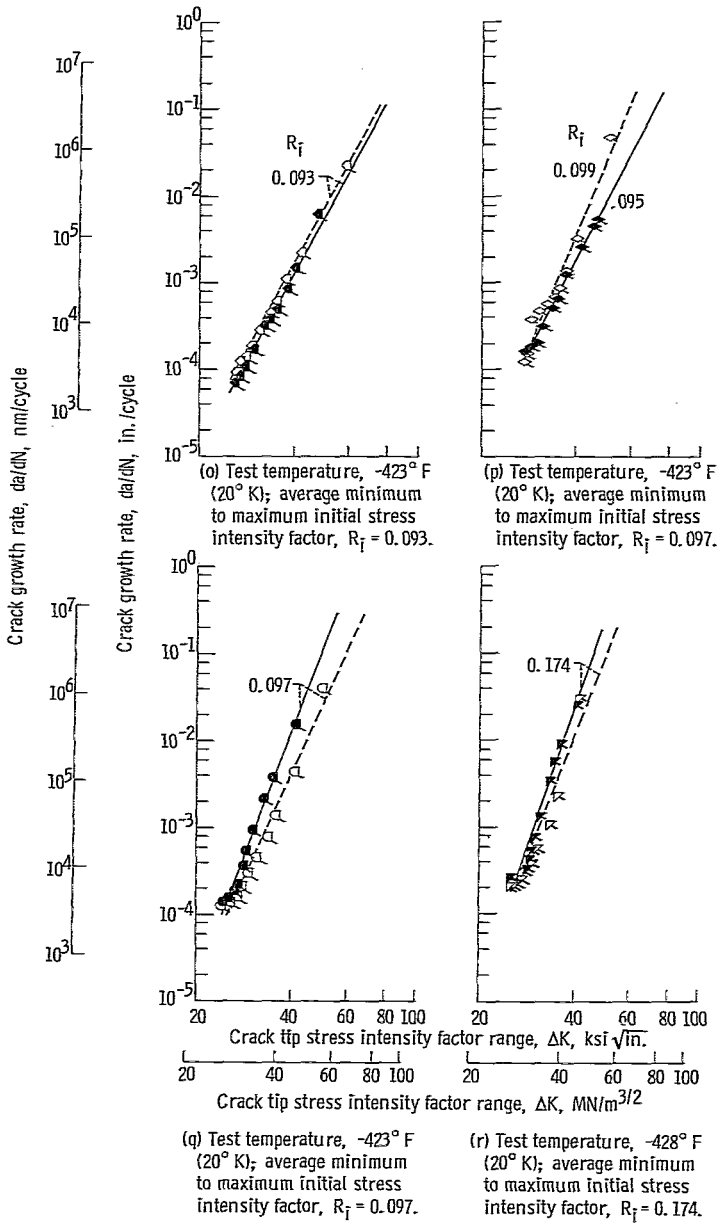
(n) Test temperature, -320° F (77° K); average minimum to maximum initial stress intensity factor, $R_i$ = 0.293.

Figure 7. - Continued.

| Specimen number | $2a_i$, in. (cm) | $\sigma_{max}$, ksi ($MN/m^2$) | $\sigma_{min}$, ksi ($MN/m^2$) | $K_{max,i}$, ksi $\sqrt{in.}$ ($MN/m^{3/2}$) | $K_{min,i}$, ksi $\sqrt{in.}$ ($MN/m^{3/2}$) | $R_i$ | Y | N |
|---|---|---|---|---|---|---|---|---|
| 30 | 0.125 (0.325) | 56.0 (386) | 6.0 (41.4) | 28.8 (31.7) | 2.7 (3.0) | 0.093 | 6.8 | 280 |
| 34 | .125 (.318) | 54.6 (377) | 5.5 (38.0) | 28.6 (31.5) | 2.6 (2.9) | .093 | 6.7 | 278 |
| 31 | .301 (.765) | 41.4 (286) | 4.0 (30.4) | 30.7 (33.8) | 3.0 (3.3) | .099 | 8.8 | 277 |
| 35 | .300 (.762) | 36.6 (253) | 3.7 (25.5) | 30.5 (33.6) | 2.9 (3.2) | .095 | 7.1 | 272 |
| 32 | .496 (1.260) | 29.3 (202) | 3.0 (20.7) | 27.1 (29.8) | 2.6 (2.9) | .097 | 8.0 | 911 |
| 36 | .500 (1.270) | 23.8 (164) | 2.4 (16.6) | 27.1 (29.8) | 2.6 (2.9) | .097 | 9.5 | 401 |
| 33 | .996 (2.530) | 22.5 (155) | 4.0 (27.6) | 30.4 (33.4) | 5.3 (5.8) | .174 | 9.3 | 753 |
| 37 | 1.000 (2.540) | 15.8 (109) | 2.8 (19.3) | 30.4 (33.4) | 5.3 (5.8) | .174 | 10.6 | 415 |

— — — Tensile specimens
——— Tank specimens

Open symbols denote tensile specimens
Solid symbols denote tank specimens




(o) Test temperature, -423° F (20° K); average minimum to maximum initial stress intensity factor, $R_i$ = 0.093.

(p) Test temperature, -423° F (20° K); average minimum to maximum initial stress intensity factor, $R_i$ = 0.097.

(q) Test temperature, -423° F (20° K); average minimum to maximum initial stress intensity factor, $R_i$ = 0.097.

(r) Test temperature, -428° F (20° K); average minimum to maximum initial stress intensity factor, $R_i$ = 0.174.

Figure 7. - Concluded.

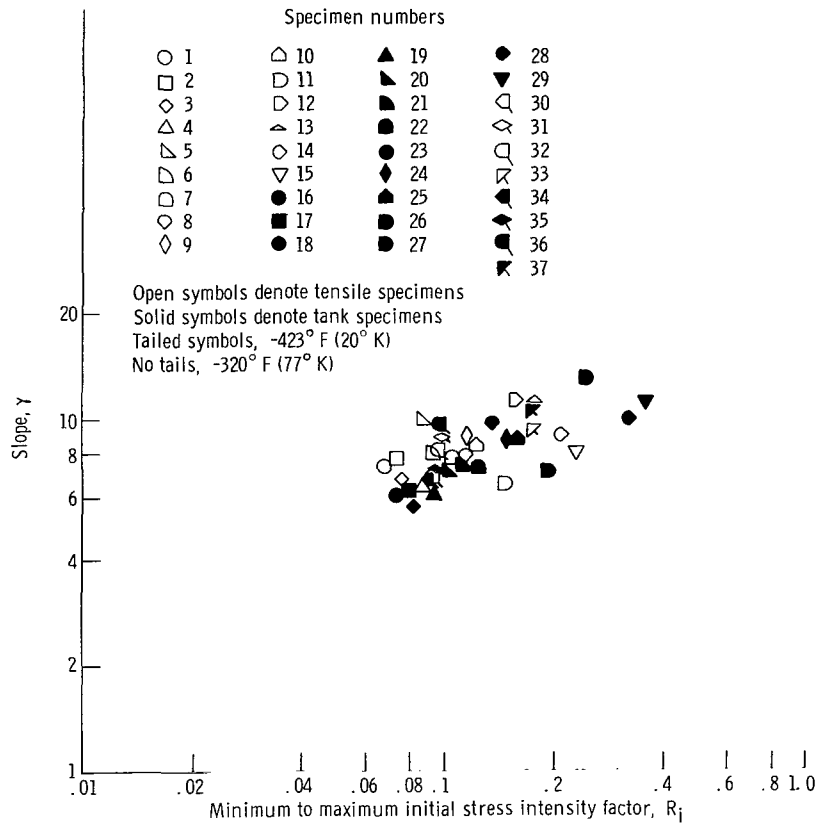



Figure 8. - Relation of minimum to maximum initial stress intensity factor to slope.

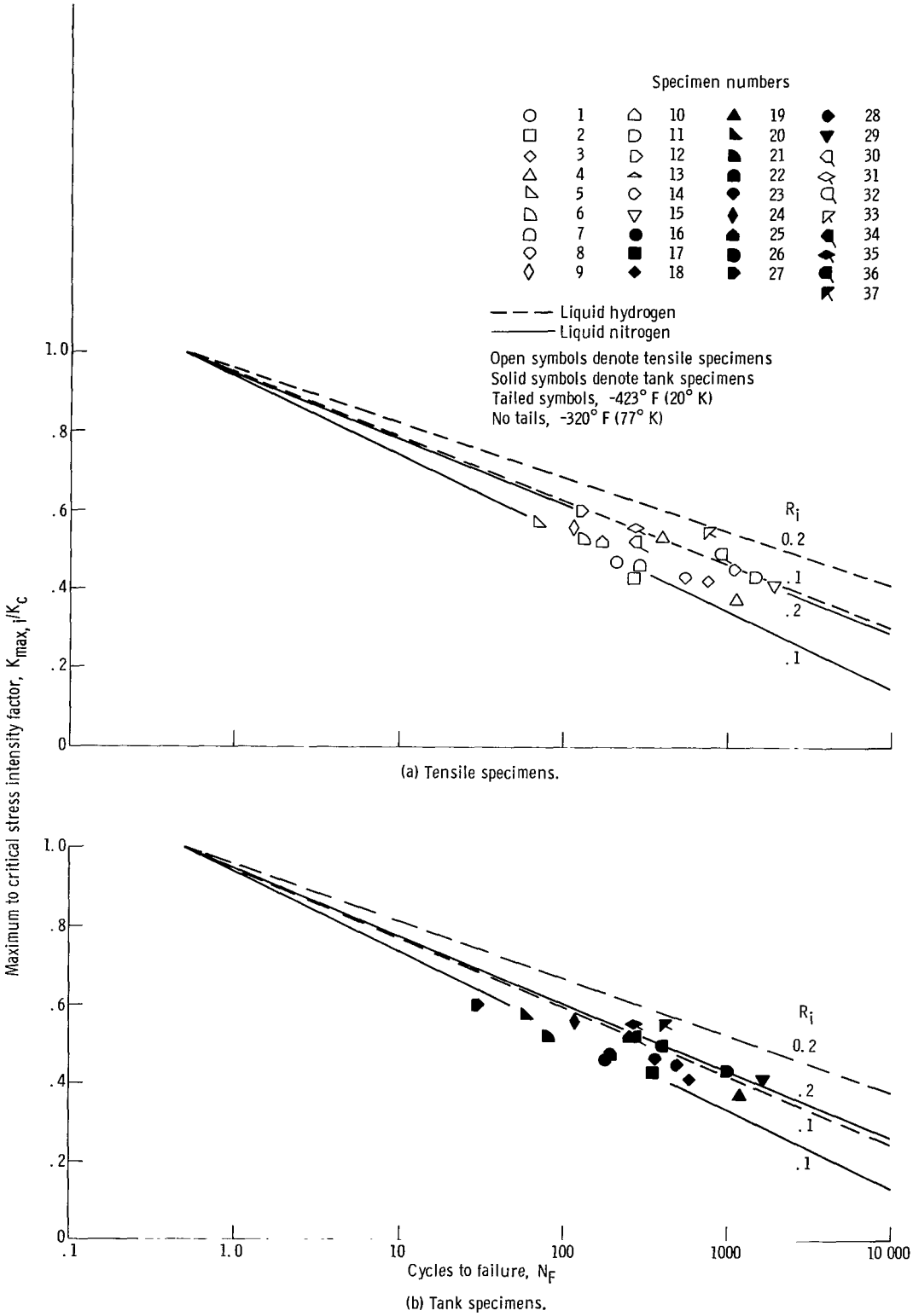



Figure 9. - Effect of $K_{max,i}/K_c$ and $R_i$ ratio on cycles to failure. (See tables II and III for test conditions.)

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