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Fatigue Crack Initiation and Propagation in High-Yield-Strength Steel Weld Metal

Flawed HY-130 butt welds are subjected to fatigue, and their total and crack propagation lives are measured and analyzed on the basis of a fracture mechanics analysis

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ABSTRACT. Full penetration, double-vee butt welds with reinforcement removed have been fabricated using a high-yield-strength steel, HY-130. Various filler metals and welding techniques were used. Most welds contained intentionally incorporated weld discontinuities such as slag, lack of fusion and/or porosity. Fatigue specimens were cut from these welds and tested in zero-to-tension, axial fatigue.

The point at which a fatigue crack began to propagate within the specimen was determined by radiographic measurements. The fatigue life of a specimen could therefore be separated into two parts—that portion spent in initiating a fatigue crack and that spent in fatigue crack propagation. The influence of flaw size and geometry upon the crack propagation portions of the fatigue life was found to be large and to depend upon the thickness of the member.

The results of these studies were found to be in good agreement with the fatigue lives predicted on the basis of a fracture mechanics analysis.

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Introduction

Since the introduction of the new high-yield-strength, heat-treated steels for welded structures, much attention has been given to the problem of designing welds which possess increased fatigue properties equal to those of the base metal. Recent investigations[1-3] have shown that the fatigue life of such welds may be substantially less than that of the base metal and hence restrict the usage of these high-strength materials in applications involving repeated loads, particularly repeated axial loads.

As shown in a companion paper,[4] a very large variation in fatigue life has been observed for welded high-strength steels fatigued at one stress level and failing at internal discontinuities. Attempts to relate this behavior to differences in base metal properties, filler metals, and variations in welding method have not been successful; it seems that these variables exerted little influence upon the fatigue phenomenon in these weldments. No strong correlation between any of these variables and the fatigue life expectancy of a weldment was found within the range of lives considered, i.e., approximately 10^4 to 10^6 cycles to failure.

The sizes of internal discontinuities present in the welds, on the contrary, had a large effect on the measured fatigue life: large defects usually resulted in a foreshortening of the expected fatigue lives, whereas minute defects often had a considerably less significant effect. The most important variable in determining the fatigue life of a flawed weldment would seem to be, therefore, the nature of the internal flaws contained within the weld and the manner in which these flaws interact with the stress field in the weld during its fatigue life.[5]

Fatigue Crack Propagation

The total fatigue life of a specimen can be divided into five phases: cyclic slip, crack nucleation, microcrack growth, macrocrack growth and failure.[6] For the purposes of the present study, the first three phases will be considered as the fraction of the fatigue life spent in crack initiation and

Table 1—Chemical Composition of HY-130 Base Metal (Data Supplied by U. S. Steel Corp.)

Heat number	5P2456	5P2004
Fatigue specimen designation	ND	NE
Chemical composition, %		
C	0.10	0.11
Mn	0.84	0.88
P	0.007	0.003
S	0.004	0.006
Si	0.24	0.35
Ni	4.92	4.95
Cr	0.54	0.53
Mo	0.50	0.50
V	0.08	0.08
Ti	0.04	—
Cu	0.06	0.07

Table 2—Mechanical Properties of HY-130 Base Metal (Data Supplied by U. S. Steel Corp.)

		Properties in Longitudinal Direction				
Heat number	Fatigue specimen designation	Yield strength,[a] ksi	Tensile strength, ksi	Elongation in 2 in., %	Reduction in area, %	Charpy V-notch, ft-lb 0° F
5P2456	ND	140.4	149.2	20.0	64.4	83
5P2004	NE	141.6	152.0	20.0	63.8	90

[a] 0.2% offset.

the latter two phases as the fraction of the fatigue life spent in crack propagation.

In terms of welds containing internal defects, the total fatigue life can be divided into an initiation period in which the defect does not enlarge perceptibly, and a propagation period in which a crack originating at the flaw enlarges until fracture has occured. In high-strength steel weldments tested at high stress levels, a significant portion of the fatigue life may be spent in fatigue crack propagation; consequently, there has been much recent interest in measuring the life spent in crack propagation and relating this life to that predicted using current theories of fracture mechanics.[7-11]

Purpose of the Present Investigation

The purpose of the present investigation was to measure the fatigue life of high-strength steel butt welds subjected to a uniform axial stress and containing various intentionally incorporated internal defects. This was done to determine the manner in which a particular defect influences the crack propagation in and the fatigue life of the weld. The point at which the defect became an active fatigue crack was detected by periodically interrupting testing and radiographing the specimen. In this manner the fraction of the fatigue life spent in crack propagation could be determined and compared with that predicted using fracture mechanics analyses.

Weld Fabrication and Testing Procedures

The specimens for this study were fabricated from a high-yield-strength quenched and tempered steel, HY-130. The chemistry and mechanical properties of the heats used are given in Tables 1 and 2. Two plate segments were cut from 1 in. thick plate stock and joined using a full penetration, multiple pass, double-vee butt weld. Both shielded-metal-arc and gas-metal-arc welding were used. The chemistries of the welding electrodes used are given in Table 3. In most specimens, the welding techniques were intentionally altered in such a way as to produce a specific defect area during a portion of one pass. This area was covered by successive passes in which no defects were intentionally created. Using the appropriate technique, internal defects such as slag, lack of fusion, and porosity of roughly the desired proportions could be created.

After welding, the plates were cut to the specimen shape shown in Fig. 1. In order to eliminate the possibility of toe initiated failures, the weld reinforcement was machined off of all specimens tested for this study. Furthermore, removing the reinforcement had the advantage of allowing more precise nondestructive inspection. After removing the reinforcement, the surfaces of all specimens were polished. Following their preparation, the specimens were examined using radiographic and ultrasonic inspection techniques to determine the type, concentration and position of the internal defects apparent within the weld prior to testing.

The specimens were inserted into a 200,000 lb capacity fatigue machine and cycled at a rate of approximately 150 cpm using stress cycles of 0 to 50 ksi, or 0 to 80 ksi axial tension. The tests were interrupted periodically to radiograph the weld to determine the onset of internal fatigue cracking or the extent of fatigue crack growth. Radiographs obtained at 10% intervals of the expected fatigue life permitted the determination of the point at which an internal fatigue crack began to propagate. Crack extensions of 0.02 to 0.05 in. could be detected by this procedure. From this information, the total fatigue life of a specimen could be separated into that spent in crack initiation (or early, undetected growth) and that spent in crack propagation.

All specimens were cycled until complete fatigue fracture occurred. Very little damage was imparted to the fracture surfaces, owing to the zero-to-tension stress cycle used; consequently it was possible to examine the fracture surfaces to determine the exact nature, size and position of the flaws initiating the fatigue crack.

Table 3—Chemical Composition of Electrodes for Welding HY-130 Plates

Manufacturer	U. S. Steel Corp.	Linde Div., Union Carbide Corp.	McKay Co.	
Electrode designation	5Ni-Cr-Mo	Linde 140	McKay 14018	
Electrode type	1/16 in. diam bare wire	1/16 in. diam bare wire	5/32 in. diam covered electrodes	3/16 in. diam covered electrodes
Heat number	50646	106140	1P1375	
Chemical composition, %			5/32 in. diameter	3/16 in. diameter
C	0.11	0.11	0.077	0.081
S	0.006	0.007	0.003	0.004
P	0.004	0.008	0.003	0.003
Mn	0.75	1.72	1.91	1.85
Si	0.38	0.36	0.42	0.39
Ni	5.03	2.49	2.08	1.92
Cr	0.61	0.72	0.71	0.73
Mo	0.47	0.88	0.43	0.43
V	0.01	0.01	—	—
Cu	—	0.08	—	—
Ti	0.015	—	—	—
Al	0.01	—	—	—
N	0.004	—	—	—

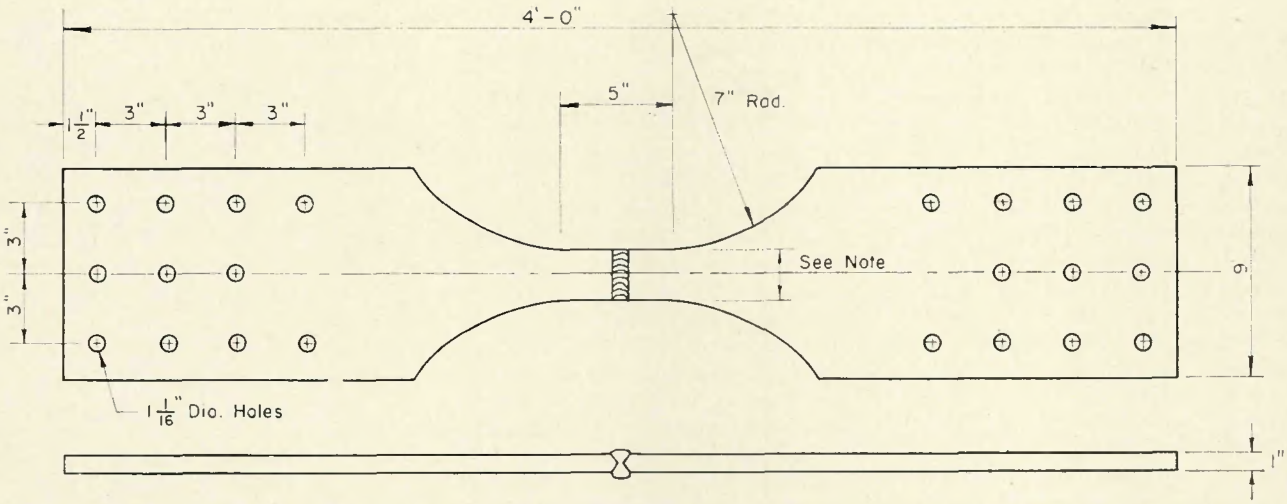

Fig. 1—Details of the butt welded fatigue test specimens. The weld reinforcement was removed prior to testing

Results of the Fatigue Crack Propagation Studies

The results of the fatigue tests of the welded HY-130 specimens are given in Table 4 and Fig. 2.

As can be seen in Fig. 2, there was considerable variation in the total fatigue lives measured at the two stress levels used, 0 to +50 ksi and 0 to +80 ksi. At 0 to +80 ksi, the total fatigue lives ranged from 1,500 cycles to 170,000 cycles or over two orders of magnitude. The spread in the lives at 0 to +50 ksi is almost as great; the lives ranged from 27,500 to 651,900 cycles or well over one order of magnitude in life.

The measured propagation lives, on the other hand, exhibit much less variation. At 0 to +80 ksi the propagation lives ranged from 2,250 to 9,300 cycles, less than one order of magnitude.* At 0 to +50 ksi, the propagation lives ranged from 14,500 cycles to 44,000 cycles, again, less than one order of magnitude.

The difference between the total lives and the measured propagation lives of a specimen is the number of cycles spent prior to crack initiation (or in undetected crack growth). For those specimens in which crack initia-

*The reason that some total lives are shorter than any propagation life shown in Fig. 2 is that the propagation life was not measured in all specimens reported; thus the propagation lives for some short total life specimens are missing.

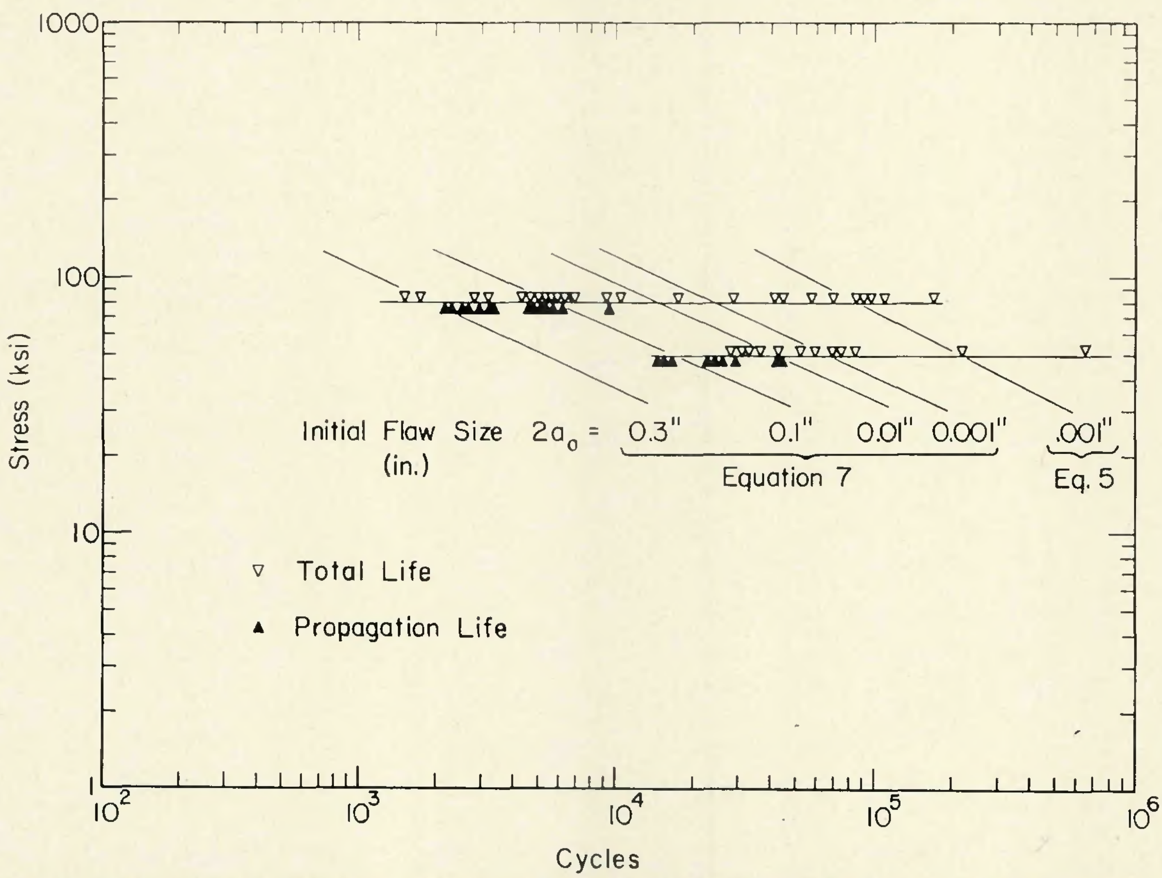

Fig. 2—Total and crack propagation portions of the fatigue life of HY-130 butt welds. The open triangles indicate the total lives while the solid indicate the propagation lives. The diagonal lines represent the predicted S-N curves (propagation) using the expression for a finite plate with a through crack (equation [7]) and the expression for a disc-shaped crack in an infinite body (equation [5])

tion and propagation was studied (see Table 4), the period of life spent in crack initiation varied from essentially zero cycles to over 38,000 cycles at 0 to +80 ksi and from essentially zero to over 74,000 cycles at 0 to +50 ksi.

As would be expected, the total lives and the number of cycles spent in crack initiation and propagation are smaller at the higher stress level than at the lower stress level. Also, there is a general, though not entirely consistent, correlation between large flaws and short fatigue lives as can be verified by inspection of Table 4 in which the dimensions of the flaws as measured on the fracture surface are given. It was found that the critical fatigue crack did not always start at the flaw which appeared to be most severe on the radiographs taken prior to testing. Often the fatal crack would start at a defect not evident upon the initial radiograph. These points are discussed more fully in a companion paper.[4]

Discussion

Fracture Mechanics Analysis

From the foregoing observations and the results of several recent studies,[7–10] it would seem reasonable that the effect of flaws on the fatigue life of welds could be related to the maximum stress experienced in the material adjacent to the defect, i.e., to the stress intensity associated with the defect. Moreover, it would seem that the type of the defect should have little effect upon the advancement of the fatigue crack, once initiated. The variation in the fraction of fatigue life spent in crack propagation shown in Fig. 2 is independent of the initial flaw type. Once an active fatigue crack has formed, the number of cycles to failure at any given stress level depends only upon the rate at which the crack propagates through filler metal and not upon the type of flaw initiating the crack, per se.

The rate at which a fatigue crack will advance has been studied extensively by Paris,[12] who showed that the rate of crack growth advance per cycle can be related to the range of stress intensity factor by the following equation:

$$\frac{da}{dn} = C\,(\Delta K)^n \tag{1}$$

where:

$\frac{da}{dn}$ = rate of crack advance per cycle
C = material constant
n = material constant
ΔK = range of stress intensity factor.

Paris found that C and n remained constant over a wide range of stress intensity factors; other studies[13] have further shown that these constants vary little from one high-strength steel to another.

The range of stress intensity factor, ΔK, is a function of the crack width and stress level. Therefore, for tests conducted at a constant stress range, ΔK becomes a direct function of instantaneous crack length, and the number of cycles of propagation may be expressed as:

$$N = \int_{a_0}^{a_f} \frac{1}{C\,(\Delta K)^n}\,da \tag{2}$$

where:

N = cycles spent in advancing the crack from a_0 to a_f
a_0 = half initial crack size (defect dimension in direction of subsequent crack growth)
a_f = half final crack size.

The number of cycles of repeated stress necessary to advance the crack from an initial flaw size $2a_0$ to a final crack size $2a_f$ can be calculated using equation (2) if an analytical function for the range of stress intensity factor can be found and integrated. In those cases where the integration of equation (2) is difficult, a finite difference technique can be used and the integration performed numerically with the aid of a computer.

$$N = \sum_{a_0}^{a} \frac{\Delta a}{C\,(\Delta K)^n} \tag{3}$$

where:

Δa = small finite advance of the crack.

Using either equation (2) or (3) and letting a_f equal half the thickness of the specimen, it is possible to estimate the number of cycles spent in crack propagation during the fatigue life of a weld if the initial flaw size in the through-thickness specimen direc-

Table 4—Results of Crack Propagation Studies[a]

Specimen number	Stress cycle, ksi	Crack propagation life, cycles	Total life, cycles	Defect type	Defect length, in.	Defect width, in.	Defect position, in. from surface	Welding procedure and filler metal
ND-8	0–50	14,500	59,500	L	.97	.05	.50	U
ND-21	0–50	16,300	43,800	V	.35	0.2	.40	U
ND-20	0–50	31,000	36,000	LP	.30	.06	.38	U
ND-12	0–50	44,200	219,200	LP	.52	.04	.50	L
ND-28	0–50	+	72,300	L	.50	.125	.28	L
ND-10	0–50	22,500	27,500	L	.65	.05	.37	L
ND-18	0–50	23.800	83,800	S	.55	.05	.46	M
ND-17	0–50	43,800	71,300	S	.95	.10	.36	M
ND-19	0–50	34.500	52.000	S	.70	.07	.36	M
ND-14	0–50	15,000	33,500	P	.175	.175	.27	M
ND-15	0–50	25,400	32,400	P	.08	.08	.26	M
ND-25	0–50	+	651,900	P	.05	.05	.50	M
ND-9	0–80	+	170,000	P	<.001	<.001	.44	U
ND-6	0–80	9,300	95,300	P	<.001	<.001	.50	U
ND-26	0–80	+	95,000	L	.10	.05	.20	U
ND-22	0–80	+	69,000	P	<.001	<.001	.38	U
ND-24	0–80	+	17,800	V	.35	.025	.32	U
ND-13	0–80	+	110,000	P	.03	.03	.35	L
ND-11	0–80	+	4,300	L	1.05	.12	.28	L
ND-16	0–80	+	6,200	S	.30	.02	.40	M
ND-27	0–80	+	86,300	P	<.001	<.001	.50	L
ND-43	0–80	+	28,900	P	.04	.04	.50	L
ND-41	0–80	2,530	9,030	L	.94	.175	.33	L
ND-36	0–80	6,100	6,600	L	.35	.16	.30	L
ND-44	0–80	4,550	5,800	L	.40	.08	.29	L
ND-37	0–80	4,600	5,600	L	.45	.10	.36	L
ND-40	0–80	2,380	5,380	V	.6	.10	.50	L
ND-42	0–80	+	4,450	L	.58	.10	.35	L
NE-10	0–80	2,250	3,250	L	.96	.05	.35	L
NE-9	0–80	+	1,760	L	.74	.08	.29	L
ND-39	0–80	+	1,500	L	1.17	.20	.41	L
ND-46	0–80	4,850	42,850	S	.18	.05	.25	M
ND-47	0–80	4,950	10,400	S	.06	.05	.32	M
ND-45	0–80	5,730	6,750	S	.22	.08	.35	M
ND-38	0–80	5,200	5,700	S	.06	.04	.24	M
NE-8	0–80	3,220	4,970	S	.44	.02	.50	M
NE-7	0–80	2,620	2,870	S	.12	.09	.40	M
NE-11	0–80	3,230	4,830	P	.01	.01	.22	M
NE-12	0–80	2,900	4,400	S	.50	.08	.41	M

[a] Symbols: +—not measured; S—slag; P—porosity; V—void; L—lack of fusion; LP—lack of penetration; U—United States Steel; L—Linde; M—McKay.

tion, $2a_0$, is known, the material constants C and n are known, and if an analytical function for the range of stress-intensity factor can be found which fits the geometry and/or boundary conditions of the physical situation.

Although exact solutions for a generalized flaw in a finite body are not available, solutions for simpler cases which bound or closely model most physical situations do exist.

A very simple model for a flaw in a weld, a disc-shaped crack in an infinite body, is shown in Fig. 3a. The range of stress intensity for a zero-to-tension stress condition (stress perpendicular to the plane of the crack) would be:[12]

$$\Delta K = \frac{2}{\pi}\sigma\sqrt{\pi a} \qquad (4)$$

where:
σ = maximum tensile stress
a = crack radius or half width.

Substituting this function into equation (2) and integrating:

$$N = \frac{a_f^{(1-n/2)} - a_0^{(1-n/2)}}{\left(1 - \frac{n}{2}\right) C \left(\frac{2\sigma}{\sqrt{\pi}}\right)^n} \qquad (5)$$

A second model, that of a through crack in a body which is finite in the direction of crack advance is shown in Fig. 3b. The range of stress intensity for a zero-to-tension stress situation can be expressed as:[14]

$$\Delta K = \sigma\sqrt{\pi a}\left(\sec\frac{\pi a}{2b}\right)^{1/2}, \qquad 0 \le a \le 0.8b \quad (6)$$

where b = plate half thickness.

Substituting this function (equation (6)) into equation (3):

$$N = \sum_{a_0}^{a_f}\left[\frac{\cos\frac{\pi a}{2b}}{a\,C^{2/n}\,\sigma^2\,\pi}\right]^{n/2}\Delta a. \qquad (7)$$

In Fig. 4 models of various types of flaws commonly encountered in welds are shown. The through crack of Fig. 3b, for which equations (6) and (7) were developed, models the continuous and intermittent linear flaws shown in Figs. 4a and 4b quite closely; but, it does not adequately model the small, isolated pore. The disc-shaped flaw of Fig. 3a, for which equations (4) and (5) were developed, is more realistic for the latter case. One characteristic of both equations (5) and (7) is that the crack propagation life calculated is very sensitive to the choice of initial flaw size, a_0. A fatigue crack spends the major portion of its propagation life as a very small crack and the accuracy of the solution will therefore depend in large part upon accurately modeling the initial size and geometry of the defect (see Fig. 5).

Comparison with Experimental Results

As reasoned above, the initial size (in the direction of subsequent propagation) and, to a lesser extent, the geometry of a flaw should determine the length of the crack propagation period of the fatigue life. The fatigue lives of Table 4 and Fig. 2 have

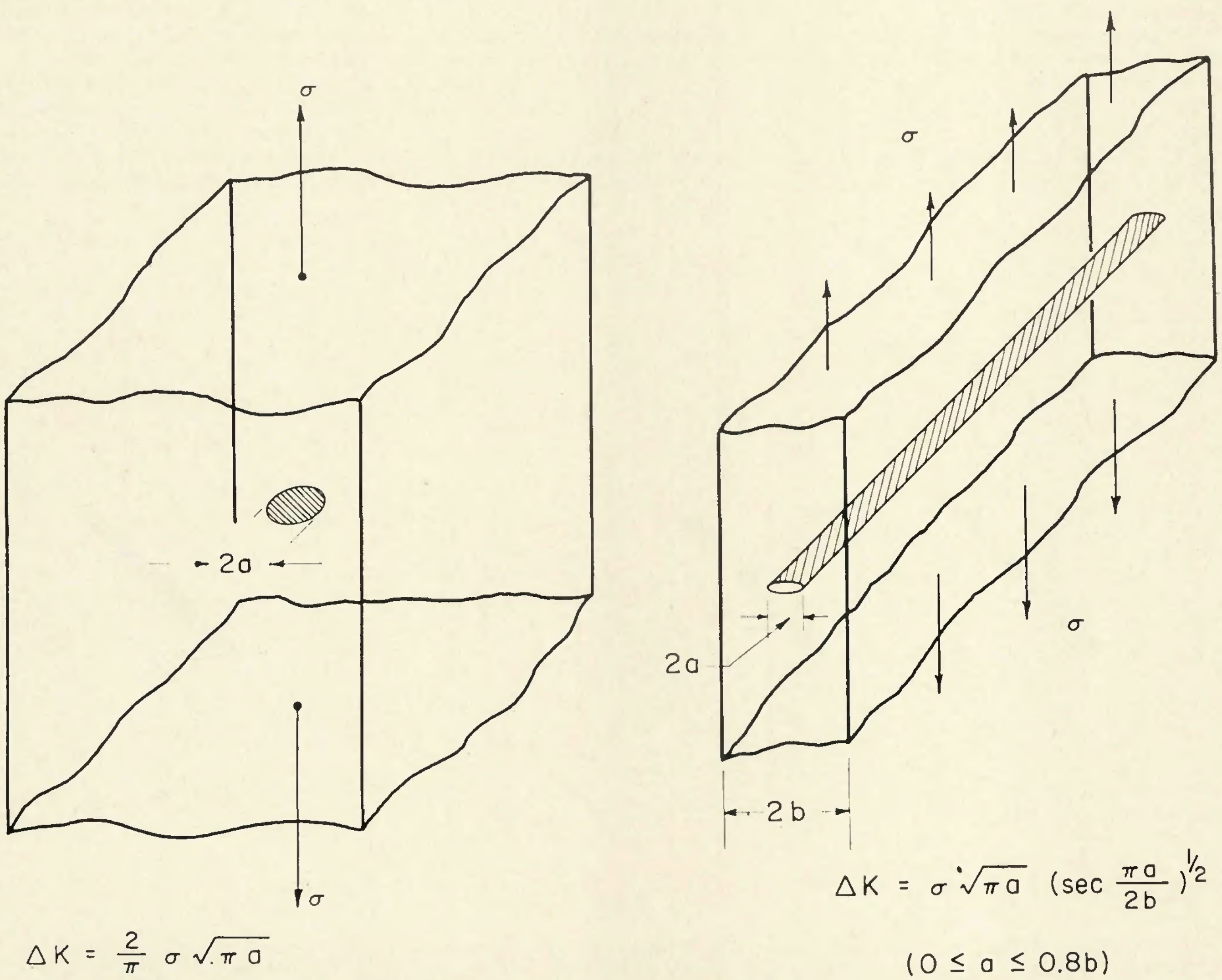

Fig. 3—Two models for flawed weldments: left (a)—a disc-shaped crack in an infinite body; right (b)—a through crack in a finite plate. The stress intensity factors are given for each

therefore been replotted as a function of initial flaw size for the two stress levels of 0 to +80 ksi and 0 to +50 ksi in Figs. 6 and 7. The initial flaw size $2a_o$ in these plots is the initial width of the largest flaw seen on the fracture surface of each specimen. This dimension has been plotted against the total fatigue life, and, for those specimens in which propagation measurements were taken, against the life spent in crack propagation as determined experimentally by radiography. The propagation and total lives measured for a specimen have been connected by a horizontal line, the length of which is the life apparently spent in initiating an active fatigue crack (or in undetected, early crack growth).

Also appearing in Figs. 6 and 7 are three curves for the life spent in crack propagation, N, which have been calculated using equations (5) and (7). The values of C and n used in these calculations are those determined by Barsom, Imhof and Rolfe[13] for HY-130 steel using a zero-to-tension stress cycle and 1 in. thick wedge-opening-loading (WOL) specimens, conditions which are, with the exception of specimen geometry, similar to those used in the present study.

At 0 to +80 ksi the total lives and, particularly, the propagation lives, lie within a band that straddles the predicted results calculated using the through crack in a finite plate model, equation (7). This model represents a condition of severity at least equal to that of the most critical flaw encountered in this study (continuous lack of fusion, etc., see Fig. 4). The fact that some of the specimens exhibited propagation lives less than those predicted by equation (7) may be explained in part by the limitations of the nondestructive testing techniques used to detect crack initiation; i.e., crack extensions of less than about 0.03 in. were generally undetectable on a radiograph, which could result in appreciable error in the estimation of life spent in propagation. It is more difficult to explain why the *total* lives of some of the test specimens were less than the propagation lives predicted by equation (7).

A possible explanation for the shorter lives may be that most flaws were not positioned along the center-line of the weld as assumed for equation (7), but were actually asymmetrically located. The position of the center of the flaw relative to the surface of the specimen is given in Table 4. The centers of some flaws are more nearly at the quarter-points of the specimen. With such flaws, the stress intensity factor for the edge nearest the surface of the specimen is greater than that assumed in the calculation of equation (7) for a 1 in. thick plate. Consequently, a fatigue life shorter than that predicted above could result. The magnitude of this effect can be assessed by bounding the problem with the solution of equation (7) for a $^1/_2$ in. thick plate, the assumption being that a flaw of $2a_o$ initial width with its center at 0.25 in. from the surface of a 1 in. plate could be similar to but not worse than a flaw of $2a_o$ initial width at the center-line of a $^1/_2$ in. plate.

Curves for this latter condition are also plotted in Figs. 6 and 7; it can be seen that the differences between the solution for a 1 in. thick and $^1/_2$ in. thick plate are most pronounced at the larger flaw sizes. For very small flaw sizes the solutions are essentially identical because the effect of the boundary conditions upon the flaw's initial behavior is small. The solution for the $^1/_2$ in. plate very nearly bounds all the data.

The smallest defects which have been observed to initiate fatigue cracks were very small pores. The initial geometry of and the boundary conditions for these flaws may be conservatively approximated by the disc-shaped crack in an infinite body model assumed in equation (5). The difference between the curves for equations (7) and (5) (in Fig. 6) at small flaw sizes reflects the effect of the difference in geometry between point and line flaws. Consequently, the curve for equation (5) should rep-

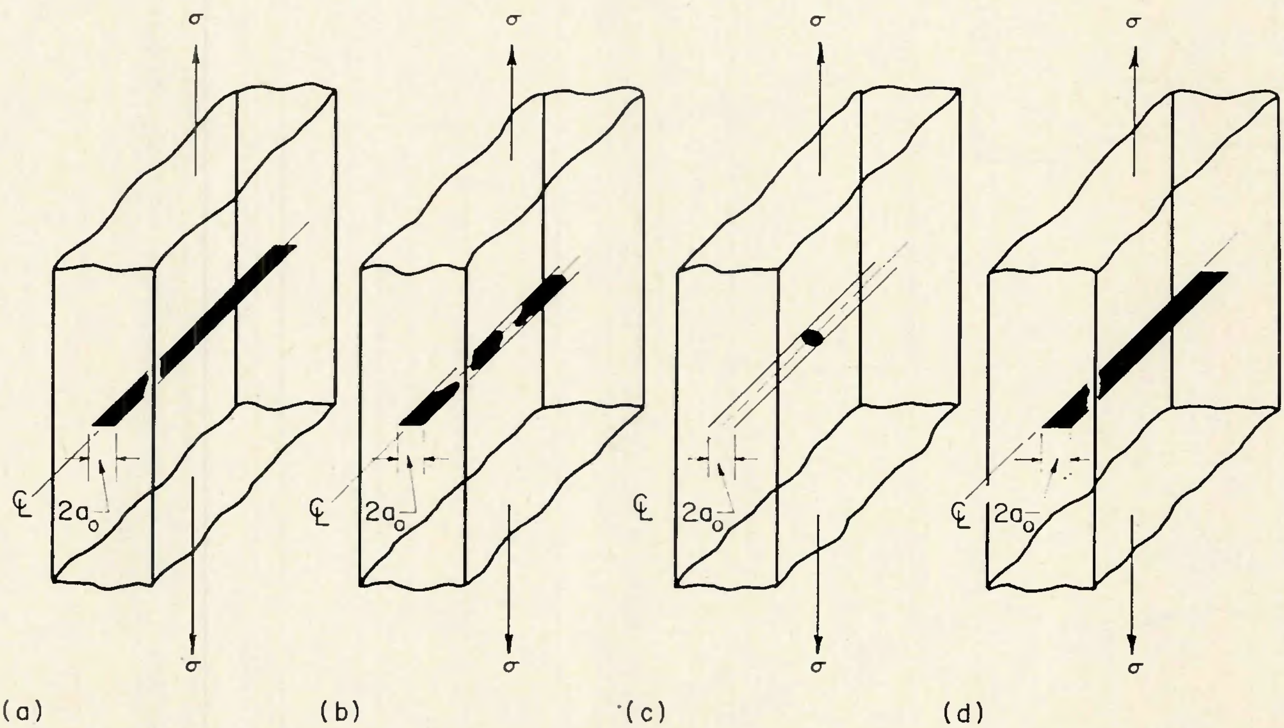

Fig. 4—Types of flaws found in weldments: (a) continuous linear defects at the center of the weldment, e.g., lack of fusion, continuous slag; (b) intermittent linear defects at the center of the weldment, e.g., intermittent lack of fusion, intermittent slag, elongated porosity; (c) isolated pores at the center of the weldment, e.g., small voids, pores, very small defects of all kinds; (d) continuous linear defects located off center in the weldment

resent the propagation life of very small isolated pores better than should equation (7). As can be seen in Fig. 6 the plot of equation (5) bounds most of the fatigue data and agrees particularly well with the fatigue lives of the smallest (spheroidal) defects initiating fatigue fracture.

The same general remarks apply to the data presented in Fig. 7 for tests conducted at 0 to +50 ksi. Few lives were recorded less than that predicted by equation (7) for a 1 in. thick plate. The data for the most part lie between the curves for equations (7) and (5).

The two models used in the fracture mechanics analysis can be seen to bound the data measured at both stress levels, as shown in Fig. 2. S-N curves based on various initial flaw widths have been plotted using the results of equations (5) and (7). Most of the measured fatigue data lie between the solution of equation (7) for an initial flaw size $2a_0$ of 0.3 in. and equation (5) for an initial flaw size $2a_0$ of .001 in.

Conclusion

The results of this study show the large effect internal weld defects may have upon the fatigue life of high-yield-strength steel welds cycled under axial loads. Their fatigue lives have been shown to be insensitive to the welding technique and filler metal used, but highly sensitive to the size and geometry of the flaw initiating fracture.

Measurements of the point at which an observable fatigue crack began to propagate within the specimen have confirmed that a large fraction of the fatigue life is spent in crack propagation—and, particularly at higher stress levels and for larger defect sizes, the crack propagation period may in fact constitute almost the entire fatigue life of the specimen.

The results of the experimental por-

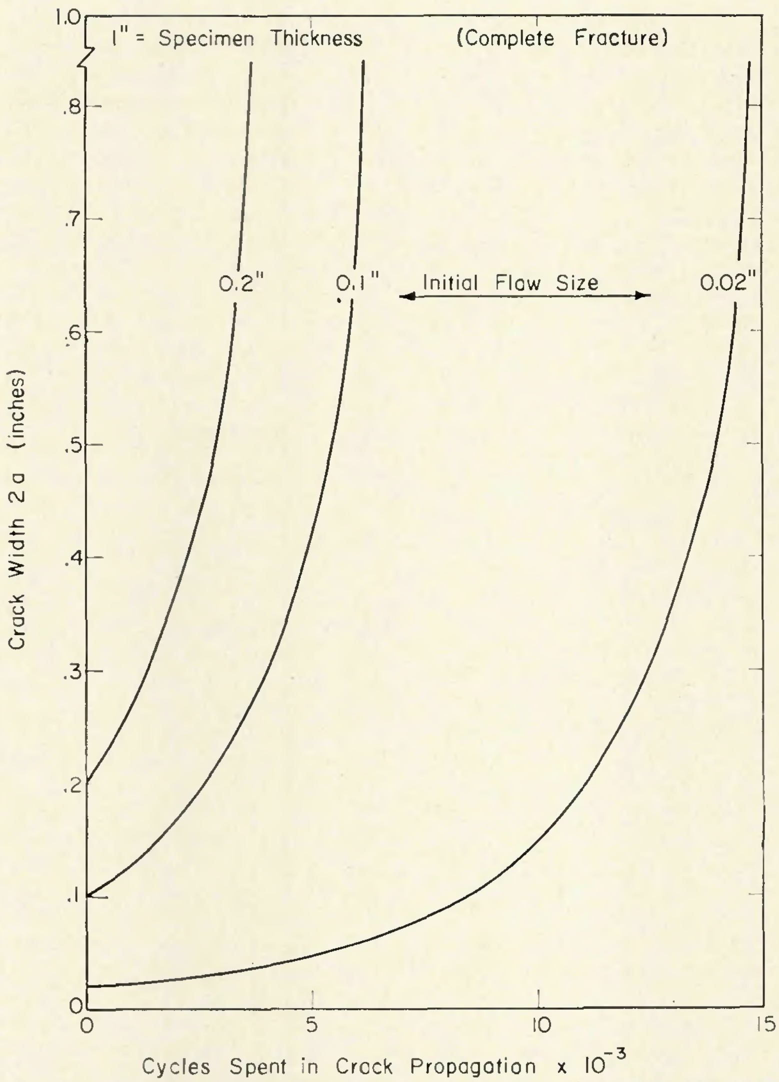

Fig. 5—Effect of initial flaw size on the crack propagation life of a flawed 1 in. thick HY-130 weldment

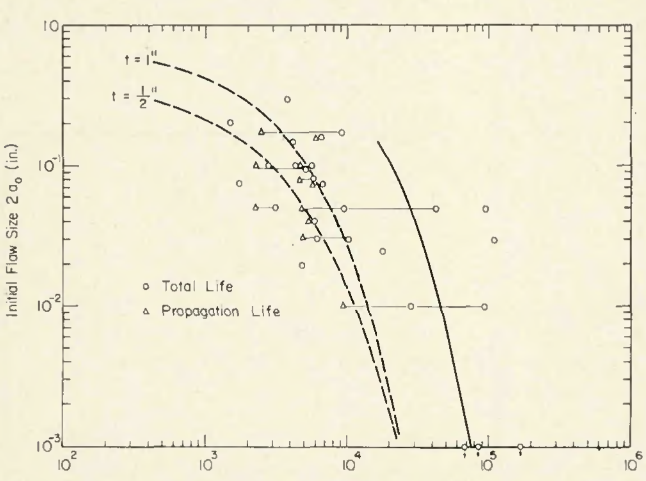

Fig. 6—Crack propagation and total fatigue lives as a function of initial flaw size (width) $2a_0$ at 80 ksi stress level. The dashed lines are solutions of equation (7) (finite plate-through crack) for 1 and ½ in. plate thicknesses. The solid line is a solution for equation (5) (infinite body-disc shaped crack). The horizontal lines connect the propagation and total lives of one specimen

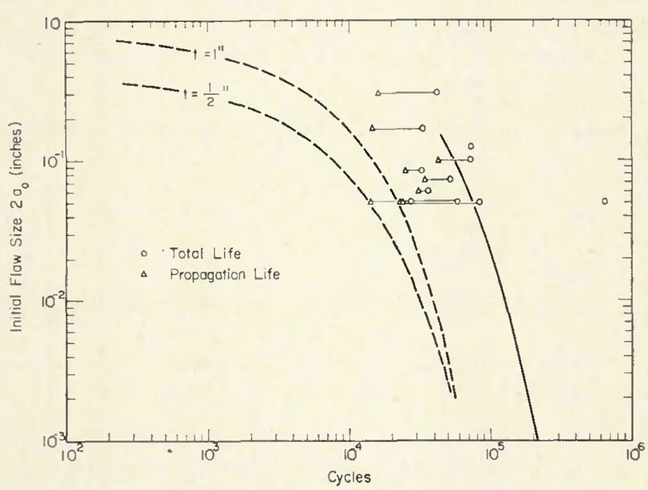

Fig. 7—Crack propagation and total fatigue lives as a function of initial flaw size (width) $2a_0$ at 50 ksi stress level. The dashed lines are solutions of equation (7) (finite plate-through crack) for 1 and ½ in. plate thicknesses. The solid line is a solution of equation (5) (infinite body-disc shaped crack). The horizontal lines connect the propagation and total lives of one specimen

tions of this study have been compared with the propagation lives calculated using the concepts and equations of fracture mechanics. The data agree well with these theories and several conclusions may be drawn from the theoretical and experimental results:

1. The effect of flaw width and the ratio of flaw width to plate thickness are dominant in controlling the length of the period spent in crack propagation.

2. The position of the flaw relative to the center-line of the weld is an important parameter in determining the propagation life. Larger flaws positioned off the center-line of the weld should propagate to failure more rapidly than ones located in exactly the middle of the plate. For very small flaws this is not as important an effect.

3. At very small flaws, where the finiteness of the plate does not affect the flaw during its early stages of crack propagation, the actual geometry of the flaw, i.e., whether it is elongated or spherical, is influential in determining the propagation life. For flaws which are large relative to the plate thickness, the geometry of the flaws influences the propagation life only to a minor extent.

Further study and more refined experimental techniques will be required to determine accurately the period of life spent in initiating an active fatigue crack and the role of flaw size, flaw geometry and stress level in determining that life.

Until such time as the factors controlling this initiation period are better understood and permit the length of that period to be predicted, the fatigue lives of high-strength steel weldments failing at internal flaws may be estimated by neglecting the crack initiation period and using the concepts of fracture mechanics to (empirically) predict the number of cycles spent in crack propagation and hence the minimum expected total life. Furthermore, from the demonstrated sensitivity of the propagation life to initial width of the flaw, it would seem that the fatigue life of a weldment in service should be assumed to be no better than that resulting from the largest flaw (through-thickness dimension) which may be permitted or remain undetected by the post fabrication nondestructive inspection standards used.

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