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THE EFFECT OF STRESS RATIO
UPON THE ELEVATED TEMPERATURE
FATIGUE-CRACK GROWTH
BEHAVIOR OF SEVERAL REACTOR
STRUCTURAL MATERIALS

HANFORD ENGINEERING DEVELOPMENT LABORATORY
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Lee A. James

February 1975

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ABSTRACT

Linear-elastic fracture mechanics methods were used to characterize the effect of stress ratio upon several alloys used in reactor structural applications: Types 304 and 316 stainless steels, Inconel 600, Inconel 718, Incoloy 800, and A533-B steel. Tests were conducted at temperatures (depending upon the alloy) ranging between 75°F and 1000°F, and at stress ratios ranging between $R=-0.15$ to $R=0.80$. The "effective stress intensity factor" was used to correlate the results at the different stress ratios into a form that is more useful for structural analyses.

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By

Lee A. James

INTRODUCTION

The use of linear-elastic fracture mechanics techniques in design and safety analyses of reactor structural components⁽¹⁾ is increasing rapidly. In addition, considerable progress is being made in characterizing the effect of various operating parameters (e.g. temperature, cyclic frequency, neutron irradiation, environment, etc.) upon the fatigue-crack growth behavior of these materials in terms of fracture mechanics parameters. Such investigations, however, are generally conducted at a single value of stress ratio (usually close to zero), while in practice, the cyclic stresses imposed upon structural components in service almost invariably have non-zero stress ratios⁽¹⁾ ($R = K_{\min}/K_{\max}$). The objective of the present study was, therefore, to characterize the effect of stress ratio upon the fatigue-crack growth behavior of several reactor structural materials, and to express the results in a form that may be easily utilized in structural analyses.

Fatigue-crack growth rates have been traditionally expressed in terms of the stress intensity factor range (ΔK), generally in the form

$$\frac{da}{dN} = C (\Delta K)^n \quad \text{Eq. [1]}$$

where C and n are constant for a given material/environment combination, and $\Delta K = K_{\max} - K_{\min}$. This expression may also be written in the alternative form

$$\frac{da}{dN} = C (K_{\max} [1-R])^n \quad \text{Eq. [2]}$$

where $R = K_{\min}/K_{\max}$. However, when fatigue-crack growth rates are characterized in terms of ΔK , the crack growth rates generally increase with increasing values of R . Results typifying this behavior may be seen in Figures 1 and 2 for Inconel 600 and Type 304 stainless steel, two materials commonly employed in reactor components.

A more useful crack growth equation which accounts for the effect of stress ratio has been developed by Walker⁽²⁾. Using this treatment, the stress intensity factor range, ΔK , is replaced by a term called the "effective stress intensity factor", K_{eff} , giving a crack growth equation of the form

$$\frac{da}{dN} = C (K_{\text{eff}})^n \quad \text{Eq. [3a]}$$

where

$$K_{\text{eff}} = K_{\max} [1-R]^m \quad \text{Eq. [3b]}$$

It will be seen that Equation [2] is quite similar to Equation [3] except that the exponent m in Equation [2] is assumed to be unity, while in Equation [3] the exponent m is a variable that depends upon the material and test conditions. By using the effective stress intensity factor concept, Walker obtained an excellent correlation of crack growth rates for 1/2-hard Type 301 stainless steel at room temperature for stress ratios ranging between 0.063 and 0.807⁽²⁾. This data is illustrated in Figure 3. This concept has also been successfully applied to describe the crack growth behavior of A533-B steel at 550°F (288°C) for $0 < R < 0.8$ ⁽³⁾ (see Figure 4), of annealed Type 304 stainless steel at 800°F (427°C) for $0.05 < R < 0.50$ ⁽¹⁾, and of Type 304 stainless steel at 1000°F (538°C) for $-0.15 < R < 0.75$ ⁽⁴⁾.

Several other crack growth relationships have been proposed to account for the effect of stress ratio⁽⁵⁻⁷⁾. All of the relationships, including the Walker equation used herein, are completely empirical in nature, and the use of a given relationship is mainly a matter of personal preference. Since the Walker relationship (Equation [3]) gives a correlation that is equal or superior to the other relationships⁽⁵⁻⁷⁾ (see Reference 4), and since it is one of the easiest to use in a structural analysis, it will be employed in the present study.

EXPERIMENTAL PROCEDURE

The effect of stress ratio was determined for several materials frequently employed in reactor structural components: annealed Types 304 and 316 stainless steels, annealed Inconel 600*, annealed Incoloy 800*, and precipitation heat-treated Inconel 718*. The chemical compositions and mechanical properties of each of these materials are given in Tables I and II, respectively. The material heats employed in the present study are the same heats previously used in characterizing the effect of other parameters upon the crack growth behavior of these materials: annealed Type 304 stainless steel^(1,4,8-15), annealed Type 316 stainless steel^(9,14,16), annealed Inconel 600⁽¹⁷⁾, and annealed Incoloy 800⁽¹⁸⁾.

All of the specimens tested in the present study were of the ASTM Compact Specimen design⁽¹⁹⁾. The specimen dimensions and major test parameters are summarized in Table III. Two test temperatures were used for each material, 800°F (427°C) and 1000°F (538°C), and all specimens were tested in an air-circulating furnace which controlled the temperature to within ±2°F (±1°C). Fatigue testing was done on an MTS feed-back controlled electro-hydraulic testing machine. A constant frequency of 400 cpm (6.67 Hz) was employed throughout, and the loading waveforms were either of the sinusoidal or saw-tooth types.

Crack lengths (a) were read periodically during each test using a cathetometer. Fatigue-crack growth rates were determined by dividing each crack growth increment, Δa, by the number of cycles causing that increment, ΔN. The stress intensity factor was based on the average crack length for each increment, and calculations were made using the following relationships:

$$K = \frac{P}{B\sqrt{W}} \left[29.6 \left(\frac{a}{W}\right)^{0.5} - 185.5 \left(\frac{a}{W}\right)^{1.5} + 655.7 \left(\frac{a}{W}\right)^{2.5} - 1017.0 \left(\frac{a}{W}\right)^{3.5} + 638.9 \left(\frac{a}{W}\right)^{4.5} \right] \quad \text{Eq. [4]}$$

* Inconel 600, Inconel 718, and Incoloy 800 are registered trademarks of the International Nickel Company. However, the general specifications for these materials may be found in ASME SB-170, AMS 5597A, and ASME SB-409, respectively.

for $0.3 < \frac{a}{w} < 0.7$ (Ref. 19), and

$$K = \frac{P}{2B} \left[\frac{w + a}{(w-a)^{1.5}} \right] \left[4.0 + \frac{w - a}{w + a} \right] \quad \text{Eq. [5]}$$

for $\frac{a}{w} > 0.7$ (Ref. 20). The results were then plotted as $\log (da/dN)$ versus $\log (K_{\text{eff}})$.

RESULTS AND DISCUSSION

The results of the present study are shown in Figures 5-14. The crack growth data for each of the different stress ratios is plotted together as a function of K_{eff} . Upper and lower scatter bands are drawn through the data and it will be seen that, in general, the data correlates rather well. This should be contrasted with the lack of correlation when the crack growth data for a wide range of R values is plotted as a function of ΔK . For example, compare Figures 1 and 9, and Figures 2 and 6.

The results of this study are also summarized in Table IV. It is interesting to note that the value of m for the materials studied at 800°F (427°C) and 1000°F (538°C) varies between 0.4 and 0.7, with most of the values in the range 0.5 to 0.6. It should be pointed out that no attempt was made to determine statistically the optimum value of m for each case. Instead, various values of m, differing in increments of 0.05 (e.g. m = 0.40, 0.45...0.75), were tried in Equation [3]. The results were then plotted and the value of m selected which appeared to give the best correlation over a wide range of crack growth rates. This approach was completely satisfactory since the value of K_{eff} is not particularly sensitive to small changes in the value of m.

It should be noted in Table IV that there is no general trend in the values of m -- that is, the value of m sometimes increases with increasing temperature and sometimes the opposite is true. The less effect that stress ratio has on crack growth rate, the closer the value of m approaches unity. Although most metals exhibit some stress ratio effects, occasionally one finds a material/temperature combination where stress ratio has little or no effect. For example, Barsom⁽²¹⁾ has shown that A514-B steel at room tempera-

ture exhibited little or no effect of stress ratio over the range $0.05 < R < 0.826$, and for this case m would equal unity.

Since there is no apparent trend in the values of m for a given material at different temperatures, and since the value may change fairly dramatically from one temperature to another (see the case of Inconel 600), interpolation or extrapolation of the data to other temperatures may be difficult. This is a disadvantage that the Walker equation (Equation [3]) shares with the other relationships⁽⁵⁻⁷⁾ since they all require empirically-derived coefficients and/or exponents for different material/temperature combinations. It should be reemphasized that all of the relationships that account for stress ratio effects^(2,5-7) are empirical, and their use in structural analyses is justified by the fact that they all satisfactorily account for stress ratio effects.

Some work has been done using different stress ratios in other environments (e.g. liquid sodium⁽¹⁵⁾, vacuum⁽¹⁵⁾, nitrogen⁽²²⁾), and the results to-date indicate that the value of m seems to be dependent upon the material and test temperature, but not upon the environment. The environment itself often has a dramatic effect upon the crack growth behavior, but a single value of m appears to correlate the stress ratio effects regardless of the environment. This behavior is illustrated in Figure 15 for annealed Type 304 stainless steel tested in several environments at 1000°F (538°C).

Table IV lists the ranges of R over which the tabulated values of m have been verified experimentally. This does not imply that the values of m listed in Table IV might not be valid over a wider range of R ; merely that testing was not done over a wider range. Judicious extrapolation of the results beyond the ranges of R investigated in this study is probably justified, but it should be pointed out that there can be limitations to the range of R values that can be described by a single value of m . To illustrate this we will take data for A533-B steel tested at room temperature at $R = 0$ from Reference 23, and combine it with data for the range $0.1 < R < 0.8$ from Reference 24. The data were originally presented in References 23 and 24 in the form $\log (da/dN)$ versus $\log (\Delta K)$, but it has been reworked herein using Equation [3], and is shown in Figure 16. It will be noted in Figure 16 that data at $R = 0.7$ and

$R = 0.8$ above $da/dN = 10^{-7}$ inch/cycle deviates from the rest of the data. Use of a value of m other than 0.55 would merely shift the deviation to another area of the curve. Hence we see that a single value of m can not correlate the data for this material/temperature combination over the range $0 < R < 0.8$, although a single value did work over this range for this material at a different temperature (see Figure 4). For this reason, the range of validity for A533-B steel at room temperature is listed in Table IV as $0 < R < 0.5$.

SUMMARY AND CONCLUSIONS

The effect of stress ratio on the fatigue-crack propagation behavior of annealed Types 304 and 316 stainless steels, annealed Inconel 600, annealed Incoloy 800, and precipitation heat-treated Inconel 718 has been studied at 800°F (427°C) and 1000°F (538°C). It was found that the effect of stress ratio could be accounted for by use of the "effective stress intensity factor" as developed by Walker⁽²⁾. This relationship is quite simple and is easily used in structural analyses.

It was found that there was no apparent pattern or trend in the variation at different temperatures of the exponent m in the effective stress intensity factor relationship. In addition, limited testing in several different environments seems to indicate that the value of m is a function only of the material and test temperature, and is not dependent upon the surrounding environment.

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A P P E N D I X A
T A B L E S

TABLE I

CHEMICAL COMPOSITION (percent by weight)

Alloy	Producer/ Heat No.	C	Mn	P	S	Cr	Ni	Mo	Si	Cu	Al	Ti	Pb	Sn	Co	Ca	Fe	B	Ce	N ₂	Cb&Ta	Total Rare Earths
Type 304	A11.Lud/55697	.053	.87	.019	.010	18.25	9.51	.18	.49	.21	*	<.01	<.001	.006	*	.11	Bal.	*	*	.030	*	<.001
Type 316	A11.Lud/65808	.060	1.72	.012	.007	17.30	13.30	2.33	.40	.065	.012	.003	.0014	.013	.030	*	Bal.	.0005	.0006	.048	*	.0010
Inconel 600	INCO/NX-9929-1A	.05	.32	*	.007	15.24	77.38	*	.28	.01	.06	.17	*	*	.07	*	6.69	*	*	*	*	*
Inconel 718	INCO/52C9EK	.07	.08	.007	.007	18.11	53.44	3.00	.17	.11	.59	1.08	*	*	.03	*	18.19	.003	*	*	5.10	*
Incoloy 800	INCO/HH2531A	.07	.86	*	.007	19.26	30.29	*	.35	.18	.28	.31	*	*	*	*	48.01	*	*	*	*	*

Not determined.

TABLE II
ROOM TEMPERATURE MECHANICAL PROPERTIES

<u>Alloy</u>	<u>0.2% Yield Strength</u>	<u>Ultimate Strength</u>	<u>Percent Elongation</u>	<u>Percent Rad. Area</u>	<u>ASTM Grain Size</u>	<u>Hardness</u>	<u>Condition</u>
Type 304	39,600 psi 273 MPa	77,050 psi 531 MPa	65.0	60.7	4.5	R _B =73.2	Annealed 1 hr. at 2000°F(1093°C)
Type 316	44,100 psi 304 MPa	82,100 psi 566 MPa	68.0	63.4	4	R _B =84.4	Annealed 30 min. at 2000°F(1093°C)
Inconel 600	32,500 psi 224 MPa	93,000 psi 641 MPa	45.0	64.0	7	R _B =78.7	Annealed 45 min. at 1585°F(863°C)
Inconel 718	150,000 psi 1038 MPa	191,300 psi 1319 MPa	18.7	32.1	8	R _C =43.9	Annealed 1750°F(954°C) A.C., Aged 8 hr. at 1325°F(718°C), F.C. to 1150°F(621°C) for total aging time of 18 hr.
Incoloy 800	27,000 psi 186 MPa	76,500 psi 527 MPa	53.0	*	1.5	R _B =69.0	Solution annealed

* Not determined

TABLE III

SPECIMEN DIMENSIONS AND MAJOR TEST PARAMETERS

<u>Material</u>	<u>Specimen Number</u>	<u>Test Temp.</u>	<u>Stress Ratio</u>	<u>Max. Load</u>	<u>"W"</u>	<u>"B"</u>
Type 304	318	800°F	0.050	1100 lb.	2.002 in.	0.492 in.
	323	800	0.333	1200	2.001	0.494
	311	800	0.500	1450	2.002	0.495
	50	1000	-0.150	600	2.001	0.353
	293	1000	0.050	1300	1.996	0.484
	302	1000	0.333	1100	2.001	0.485
	301	1000	0.500	1300	2.002	0.492
	297	1000	0.750	1400	2.000	0.492
Type 316	357	75	0.057/0.50	1400	2.000	0.497
	414	800	0.050	1250	1.998	0.486
	415	800	0.333	1300	2.001	0.481
	416	800	0.600	1300	2.001	0.484
	95	1000	0.050	1150	2.007	0.456
	89	1000	0.333	1100	2.009	0.456
	88	1000	0.500	1200	2.011	0.455
Inconel 600	183	800	0.050	1200	2.002	0.412
	185	800	0.333	1200	2.003	0.413
	184	800	0.600	1200	2.002	0.413
	179	1000	0.050	1200	2.002	0.414
	182	1000	0.333	1200	2.002	0.413
	180	1000	0.500	1250	2.002	0.413
	186	1000	0.667	1300	2.004	0.410
Inconel 718	163	800	0.050	1300	1.997	0.477
	157	800	0.333	1300	1.996	0.477
	161	800	0.500	1200	1.996	0.478
	214	1000	0.050	500	1.151	0.298
	208	1000	0.333	550	1.152	0.298
	215	1000	0.500	600	1.152	0.299
	164	1000	0.667	1700	1.993	0.479
Incoloy 800	176	800	0.050	1200	2.004	0.502
	177	800	0.600	1300	2.003	0.501
	174	1000	0.050	1300	2.001	0.502
	175	1000	0.333	1300	2.003	0.501
	172	1000	0.500	1400	2.002	0.501

TABLE IV
VALUES OF EXPONENT "m" IN EFFECTIVE STRESS
INTENSITY FACTOR EQUATION

$$\frac{da}{dN} = C (K_{max} [1-R]^m)^n$$

Material	Temperature (°F)	Range of Stress Ratios Experimentally Verified	"m"
Type 301 1/2-hard	75°F (24°C)	0.063 ≤ R ≤ 0.807	0.667 (Ref. 2)
Type 304 L	75°F (24°C)	0 ≤ R ≤ 0.475	0.50 (Appendix C)
Type 304 S.H.T.	800°F (427°C)	0.050 ≤ R ≤ 0.500	0.60
Type 304 S.H.T.	1000°F (538°C)	-0.150 ≤ R ≤ 0.750	0.50 (Ref. 4)
Types 316L & 316 S.H.T.	75°F (24°C)	0 ≤ R ≤ 0.440	0.35 (Appendix C)
Type 316 S.H.T.	800°F (427°C)	0.050 ≤ R ≤ 0.600	0.65
Type 316 S.H.T.	1000°F (538°C)	0.050 ≤ R ≤ 0.500	0.50
Inconel 600 S.H.T.	800°F (427°C)	0.050 ≤ R ≤ 0.600	0.40
Inconel 600 S.H.T.	1000°F (538°C)	0.050 ≤ R ≤ 0.667	0.70
Inconel 718 P.H.T.	800°F (427°C)	0.050 ≤ R ≤ 0.500	0.50
Inconel 718 P.H.T.	1000°F (538°C)	0.050 ≤ R ≤ 0.667	0.60
Incoloy 800 S.H.T.	800°F (427°C)	0.500 ≤ R ≤ 0.600	0.60
Incoloy 800 S.H.T.	1000°F (538°C)	0.050 ≤ R ≤ 0.500	0.50
A533, Gr.B, C1.1, Q.T.	75°F (24°C)	0 ≤ R ≤ 0.500	0.55
A533, Gr.B, C1.1, Q.T.	550°F (288°C)	0 ≤ R ≤ 0.800	0.75 (Ref. 3)

S.H.T. = Solution Heat Treated
P.H.T. = Precipitation Heat Treated
Q.T. = Quenched and Tempered

A P P E N D I X B

F I G U R E S

Figure 1. The effect of stress ratio upon the fatigue-crack growth behavior of annealed Inconel 600 at 800°F(427°C). [Neg. L-260-12]

Figure 2. The effect of stress ratio upon the fatigue-crack growth behavior of annealed Type 304 stainless steel at 1000°F (538°C).
 (From Reference 4). [Neg. L-260-8]

Figure 3. Use of the effective stress intensity factor to correlate the crack growth behavior of 1/2-hard Type 301 stainless steel at 75°F (24°C). (From Reference 2) [Neg. L-260-10]

Figure 4. Use of the effective stress intensity factor to correlate the crack growth behavior of A533-B steel at 550°F (288°C).
(From Reference 3). [Neg. L-260-6]

Figure 5. Use of the effective stress intensity factor to correlate the crack growth behavior of annealed Type 304 stainless steel at 800°F (427°C).

[Neg. L-260-2]

Figure 6. Use of the effective stress intensity factor to correlate the crack growth behavior of annealed Type 304 stainless steel at 1000°F (538°C). (From Reference 4). [Neg. L-260-9]

Figure 7. Use of the effective stress intensity factor to correlate the crack growth behavior of annealed Type 316 stainless steel at 800°F(427°C).

[Neg. L-302-1]

Figure 8. Use of the effective stress intensity factor to correlate the crack growth behavior of annealed Type 316 stainless steel at 1000°F(538°C).

[Neg. L-260-1]

Figure 9. Use of the effective stress intensity factor to correlate the crack growth behavior of annealed Inconel 600 at 800°F (427°C).

[Neg. L-260-7]

Figure 10. Use of the effective stress intensity factor to correlate the crack growth behavior of annealed Inconel 600 at 1000°F (538°C).

[Neg. L-260-5]

Figure 11. Use of the effective stress intensity factor to correlate the crack growth behavior of precipitation-heat-treated Inconel 718 at 800°F (427°C). [Neg. L-260-13]

Figure 12. Use of the effective stress intensity factor to correlate the crack growth behavior of precipitation-heat-treated Inconel 718 at 1000°F (538°C). [Neg. L-302-2]

Figure 13. Use of the effective stress intensity factor to correlate the crack growth behavior of annealed Incoloy 800 at 800°F (427°C).

[Neg. L-263-1]

Figure 14. Use of the effective stress intensity factor to correlate the crack growth behavior of annealed Incoloy 800 at 1000°F (538°C).

[Neg. L-260-3]

Figure 15. Use of the effective stress intensity factor to correlate the crack growth behavior of annealed Type 304 stainless steel in several environments at 1000°F (538°C). [Neg. L-253-2]

Figure 16. Use of the effective stress intensity factor to correlate the crack growth behavior of A533-B steel at 75°F (24°C). Note the deviation of R=0.7 and R=0.8 data above $da/dN = 10^{-7}$ inch/cycle.
[Neg. L-260-11]

Figure 17. The results of Yahiaoui and Petrequin (25) for Type 304L stainless steel at room temperature, replotted in terms of the effective stress intensity factor. Tests conducted at a constant stress range. [Neg. L-283-4]

Figure 18. The results of Yahiaoui and Petrequin⁽²⁵⁾ for Type 304L stainless steel at room temperature, replotted in terms of the effective stress intensity factor. Tests conducted at a constant mean stress. [Neg. L-283-3]

Figure 19. The results of Yahiaoui and Petrequin⁽²⁵⁾ for Type 316L stainless steel at room temperature, replotted in terms of the effective stress intensity factor. [Neg. L-283-2]

Figure 20. Use of the effective stress intensity factor to correlate the crack growth behavior of annealed Type 316 stainless steel at room temperature: comparison of HEDL results with those from Figure 19.
[Neg. L-283-1]

Figure 21. Comparison of the crack growth behavior observed by Yahiaoui and Petrequin for Type 316L stainless steel with that observed in similar investigations. [Neg. L-283-5]

A P P E N D I X C

RESULTS FROM OTHER LABORATORIES

APPENDIX C

RESULTS FROM OTHER LABORATORIES

Yahiaoui and Petrequin⁽²⁵⁾ have conducted investigations of the effect of stress ratio upon the fatigue-crack growth behavior of Types 304L and 316L at room temperature. They expressed their experimental results as plots of $\log (d2a/dN)$ versus $\log (\Delta K)$. The present author reworked the data of Reference 25 into the form $\log (da/dN)$ as a function of $\log (K_{eff})$, and the results are plotted in Figures 17-19.

Yahiaoui and Petrequin noted the definition $R = \sigma_{min}/\sigma_{max}$ could be restated in the form

$$R = \frac{\sigma_{min}}{\sigma_{max}} = \frac{\sigma_{mean} - \frac{\Delta\sigma}{2}}{\sigma_{mean} + \frac{\Delta\sigma}{2}} \quad \text{Eq. [6]}$$

where $\Delta\sigma$ is the stress range ($\sigma_{max} - \sigma_{min}$) and $\sigma_{mean} = \frac{\sigma_{max} + \sigma_{min}}{2}$.

For the tests conducted on Type 304L material, they conducted one series of experiments where $\Delta\sigma$ was held constant and they varied σ_{mean} , and another series where they held σ_{mean} constant and varied $\Delta\sigma$. They concluded that when $\log (d2a/dN)$ was plotted in terms of $\log (\Delta K)$, the effect of stress ratio was greater for those tests where σ_{mean} had been held constant than for those tests where $\Delta\sigma$ had been held constant. They therefore proposed that the traditional crack growth law (Eq. [1]) should be modified to the form

$$\frac{da}{dN} = C (\Delta K)^n (a)^p \quad \text{Eq. [7]}$$

However, in the series of tests conducted at a constant value of σ_{mean} , one of the tests (at $R = 0$) was actually conducted at a mean stress of 7110 psi rather than the value of 9960 psi for the other specimens. This particular specimen exhibited an unusual amount of scatter relative to the other specimens in this series, and probably accounted for the observation that a greater effect of stress ratio was achieved when holding σ_{mean} constant. The results from this one test were therefore not included in the present analysis of the

data from Reference 25. As may be seen in Figures 17 and 18, the results from the two series of tests correlate quite well with one another when expressed in terms of K_{eff} , and agree fairly well with previous results on Type 304 S.S. from HEDL⁽⁸⁾. The present author therefore concludes that results obtained from holding σ_{mean} constant do not differ greatly from tests where $\Delta\sigma$ was held constant, and that expressing crack growth behavior in terms of Equation [7] is neither necessary nor desirable.

Yahiaoui and Petrequin⁽²⁵⁾ also examined the effect of stress ratio upon the crack growth behavior of Type 316L S.S. over the range $0 < R < 0.44$. Neither $\Delta\sigma$ nor σ_{mean} was systematically held constant in the tests on Type 316L S.S. The results are shown in Figure 19. Limited testing was done at HEDL on Type 316 at room temperature, and these results are given in Figure 20. It will be noted that the same value of m (see Eq.[3b]) correlates the data for Type 316 (Figure 20) and for Type 316L (Figure 19), although the data from Yahiaoui and Petrequin does fall somewhat below the HEDL data. This same tendency is noted when the data of Yahiaoui and Petrequin is compared to data for Type 316 S.S. from References 9, 16 and 26 for tests conducted at $R \approx 0$. The reason for the lower growth rates observed by Yahiaoui and Petrequin for Type 316L S.S. is not known.

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