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AXIAL FATIGUE OF PRE- AND POST-IRRADIATED
A 302 B AND A 212 B STEELS

C. R. Brinkman and J. M. Beeston

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ABSTRACT

The axial fatigue properties of A 302 B and A 212 B steels in pre- and post-irradiated conditions at a fluence of 4×10^{17} nvt $E > 1$ MeV were investigated. For the A 302 B steel in the test region of 10,000 to 100,000 cycles, the fatigue life of the irradiated samples appeared to be reduced in the high strain range and increased slightly in the low strain range so that a crossover in the two curves occurred. For the A 212 B steel, the fatigue lives of the irradiated samples were within the test scatter. Cyclic plastic strain range was found to be the parameter most sensitive to irradiation. The fatigue toughness (total-energy-to-failure) increased as the number of cycles-to-failure increased. Analysis of the data in terms of semiempirical equations showed the data to be in agreement with other investigations.

SUMMARY

For A 302 B steel in the region tested, the fatigue life of irradiated samples appeared to be reduced in the high strain-range region and increased slightly in the low strain-range region. Cyclic plastic strain range was found to be the parameter most sensitive to irradiation. No effect of irradiation was noticed on the cyclic stress-amplitude or toughness; whereas, a slight effect was noted on the tensile properties.

Within the cycle ranges of 10,000 to 100,000 for plain and irradiated fatigue data, there is no discernable difference in the behavior of A 212 B at the irradiation level tested (approximately 4×10^{17} nvt > 1 MeV).

Analysis of the data according to the semiempirical equations that have been postulated shows that the data are in good agreement with these relations.

The fatigue toughness expressed as total-energy-to-failure increases as the number of cycles-to-failure increases for these steels.

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AXIAL FATIGUE OF PRE- AND POST-IRRADIATED A 302 B AND A 212 B STEELS

I. INTRODUCTION

The fluence at which irradiation begins to influence the fatigue properties of many materials is not known although the mechanical properties of structural metals and alloys are not greatly affected by irradiation until a fluence of at least 10^{18} nvt ($E > 1$ MeV) is exceeded. In fatigue, the usual increase in the yield strength could prove beneficial while the decrease in ductility should have a deleterious effect. The nucleation of a micro-crack, its growth, and its propagation could be influenced by the presence of irradiation-produced defects.

It is the objective of this report to examine the fatigue behavior at a fluence of 4×10^{17} nvt $E > 1$ MeV as irradiation begins to affect the tensile-compressive fatigue properties of two carbon steels, ASTM A 302 B and A 212 B. Future studies would include these and other steels to higher fluence, and they would include the effect of temperatures up to 550°C . Additional work would entail effects of pre-strain on the irradiated and unirradiated fatigue properties of these materials.

Lately there have been several investigations initiated to determine the effects of irradiation on the fatigue properties of metals, particularly on those steels in use or contemplated for use as pressure vessel materials or for other uses within reactors. Hawthorne et al[1] reported that there was no pronounced difference in the room temperature fatigue strength of A 302 B steel in the irradiated (8.5×10^{18} to 1.1×10^{19} n/cm² > 1 MeV) and unirradiated condition. Their data suggested that the strength of the irradiated specimens was higher at the high-cycle (750,000) end of the curve. Gibbons et al[2] investigated the room temperature fatigue properties of A 302 B and A 212 B steels irradiated up to 6×10^{19} nvt ($E > 1$ MeV). They found that irradiation tended to raise the endurance limit and reduce the low-cycle fatigue life.

There have been many theories advanced to describe and predict the fatigue characteristics of metals. The Coffin-Manson relation has been found to be generally applicable to axial fatigue data. This relation is

$$N_f^k \Delta\epsilon_p = C \quad (1)$$

where N_f is the number of cycles to failure, $\Delta\epsilon_p$ is the plastic strain range (according to Coffin [3, 4]), C is taken to be equal to $\epsilon_f/2$, and k is a constant equal to $1/2$. The fracture ductility, ϵ_f , is defined as

$$\epsilon_f = \log_e \frac{A_o}{A_f} \quad (2)$$

where A_0 is the initial specimen area and A_f is the fracture area. Thus at $N_f = 1/4$, $\Delta\epsilon_p$ should be equal to ϵ_f . This equation has been found to apply in the low-cycle range and to apply at test temperatures low enough so that time-dependent effects do not occur to any appreciable extent.

Manson[5] expresses Equation (1) in the form

$$\Delta\epsilon_p = M N_f^c \quad (3)$$

where M and c are constants and c is a material constant rather than a universal constant. Similarly, the elastic strain range is expressed by a power law in the form

$$\Delta\epsilon_e = \Delta\sigma/E = (G/E) N_f^b \quad (4)$$

where $\Delta\epsilon_e$ is the cyclic elastic strain range, $\Delta\sigma$ is the stress range, E is the elastic modulus, and G and b are other material constants. Thus, the total strain range (sum of elastic and plastic strain range) can be represented by an equation of the form

$$\Delta\epsilon = \Delta\epsilon_e + \Delta\epsilon_p = L N_f^b + M N_f^c \quad (5)$$

where L , M , b , and c are constants.

A curve may be formed by connecting the tips of the stable hysteresis loops which is described mathematically by adding the elastic strain to the plastic strain. The plastic strain can be expressed as a power function of the form

$$\frac{\Delta\epsilon_p}{2} = \epsilon_f' \left(\frac{\Delta\sigma}{2\sigma_f'} \right)^{1/n'} \quad (6)$$

so that the total strain becomes

$$\frac{\Delta\epsilon}{2} = \frac{\Delta\epsilon_e}{2} + \frac{\Delta\epsilon_p}{2} = \frac{\Delta\sigma}{2E} + \epsilon_f' \left(\frac{\Delta\sigma}{2\sigma_f'} \right)^{1/n'} \quad (7)$$

where $\Delta\epsilon$, $\Delta\epsilon_p$, $\Delta\epsilon_e$, and E have their usual meanings, n' is the cyclic strain hardening constant which has been found to be close to 0.15 for most metals, $\frac{\Delta\sigma}{2}$ is the stress amplitude, and ϵ_f' and σ_f' are constants related to the true ductility, ϵ_f , and true fracture stress, σ_f [6].

By equating Equation (6) to one-half Equation (3) and solving for the stress amplitude, it is seen that

$$\frac{\Delta\sigma}{2} = S (N_f)^b \quad (8)$$

where S and b ($b = n'c$) are material constants. Solving Equation (8) for the stress range and dividing by Young's Modulus results in the elastic strain range similar in form to Equation (4).

Several authors have discussed fatigue life in terms of the plastic energy expended to fracture in steels [7, 8]. After an initial transient increase, the energy per cycle (area under the hysteresis curve) is nearly a constant; hence, the total-energy-to-fracture may be approximated by

$$W_f = \Delta W N_f \quad (9)$$

where ΔW is the stabilized plastic energy per cycle and W_f is the total-energy-to-failure. It can be shown that the plastic hysteresis energy per cycle is related to the cyclic strain hardening constant and the stress and strain range by the expression [8]

$$\Delta W = \frac{1-n'}{1+n'} \Delta \sigma \Delta \epsilon_p \quad (10)$$

Substituting ΔW and the values for $\Delta \sigma$ and $\Delta \epsilon_p$ from Equations (8) and (3), Equation (9) becomes

$$W_f = W' N_f^a \quad (11)$$

where W' is again a material constant and $a = 1 + b + c$. Halford [8] has evaluated the constant "a" for many metals and has found, to a first approximation, that it is equal to 1/3 for most metals.

Using the simple equations presented in this section, the data obtained will be presented.

II. EXPERIMENTAL PROCEDURE

Axial-tension and compression-fatigue testing was carried out on a Research Incorporated Electrohydraulic Fatigue Tester, Model 7917-18-19 (Figure 1). This piece of equipment allows the precise control of either stress or strain and consists essentially of a load column and sample in series with a hydraulic servomotor and load cell in a load frame. The electronic load-control system allows the application of the load to be programmed to follow a number of functions including square, triangular, sine, or ramp. A sine function was followed in all experimentation reported herein. An environmental control chamber and control system, also parts of this equipment, provide a means for fatigue testing in an evacuated and temperature-controlled environment.

The fatigue specimens (1/8-inch-gauge diameter, 1/2-inch-gauge length as shown in Figure 2) were cut and machined from 4-inch-thick, quenched- and tempered-plate material. The A 302 B material was USS Heat No. N31438, Slab No. 190784, and the A 212 B material was Heat No. 73N573, Slab No. 252697^[9]. Sectioning of the 4-inch plate produced five sections labeled A, B, or C, corresponding to the one-fifth, two-fifths, or center section, respectively. Electron micrographs and photomicrographs of the two-fifths sections of both materials are shown in Figure 3. The carbide particles were finer in the one-fifth sections for A 302 B, and the one-fifth sections of A 212 B showed less ferrite and more pearlite than the two-fifths sections.

After machining, the specimens were stress-relieved at 427°C for two hours, polished to 8 micro-inches, radiographed, and checked for concentricity. Specimens found to be defective were rejected.

Tensile properties of specimens of the same geometry as those used for fatigue studies were determined for the A 302 B and A 212 B carbon steels as given in Appendix Table I.

Specimens that were to be irradiated were placed in the VH-2 position of the MTR for a period of five hours (approximately 4×10^{17} n/cm², $E > 1$ MeV) at 60°C. During this time a negligible amount of corrosion occurred (samples were exposed to process water for cooling). The samples were removed from the water and stored in a water soluble oil to allow the radioactivity to decay.

A great deal of care was exercised when cycling the specimens in the fatigue tester to ensure that axial alignment was maintained. The alignment concentricity of the specimen and column to the load frame was made within a runout of 0.001 inch. The extensometer consisting of a Schaevitz (LVDT type) transducer was fixed to the specimen in such a manner that the cyclic change in longitudinal length between points A and B in Figure 2 was determined. Care was taken to ensure that a mean stress and strain of zero were obtained during startup of the cyclic compression and tension of the specimens. Strain-range controlled testing was carried out at a cyclic rate of 0.5 cycles per second at room temperature in air, and the resultant hysteresis loops were plotted by an X-Y recorder and/or were recorded on magnetic tape for later playback. A photograph of several of the hysteresis loops after various numbers of cycles is shown in Figure 4. The areas of the hysteresis loops were measured with a planimeter.

Fig. 1 A photograph of the Laboratory Fatigue Testing Equipment.

Fig. 2 Fatigue specimen -- solid.

Failure was defined as a reduction of approximately 30 percent in the load signal which corresponds to crack propagation of $1/4$ to $1/2$ through the diameter of the specimen.

M-3676

Photomicrograph - 500X

573-1

Electron micrograph - 4000X

Tempered bainite structure of A 302 B Steel

M-3679

Photomicrograph - 500X

577-5

Electron micrograph - 4000X

Ferrite - pearlite structure of A 212 B Steel

Fig. 3 Typical structures of A 302 B and A 212 B steels.

Fig. 4 Typical hysteresis curves.

III. RESULTS

The following information was obtained directly from hysteresis curves and is defined as follows:

$\Delta\epsilon$ = total strain range, measured from peak to peak along the abscissa

$\Delta\sigma$ = stress range, measured from peak to peak along the ordinate

$\Delta\epsilon_p$ = plastic strain range, width of the hysteresis loop

$\Delta\epsilon_e$ = elastic strain range, difference between total and plastic strain range

ΔW = hysteresis energy per cycle, area under hysteresis loop.

The total strain range for each specimen is reported as two different values, effective and corrected. The effective strain range, $\Delta\epsilon_{eff}$, is the same as defined above while the corrected strain range, $\Delta\epsilon_c$, is the strain range which corrects for elasticity in the fillets and shoulders of the specimen and is computed as follows:

$$\Delta\epsilon_c = \frac{\Delta l_e}{l_{eff}} + \frac{\Delta l_p}{l_g}$$

where

Δl_e = the elastic displacement range ($\Delta l - \Delta l_p$), where Δl is total displacement

Δl_p = the plastic displacement range (width of hysteresis loop)

l_g = the gage length of uniform diameter (1/2 inch)

l_{eff} = effective length in elastic displacement between transducer brackets.

The effective length for elastic displacement of specimen shoulders and fillet and the uniform gage length were obtained from Instron tensile tests with the extensometer knife edges at equivalent lengths to the fatigue transducer brackets and from the modulus of elasticity (E) obtained in other tests on the uniform section. Thus,

$$l_{eff} = \frac{\Delta l' E}{S}$$

where

$\Delta l'$ = the elastic displacement (linear part of stress-strain curve)

S = corresponding elastic stress.

The effective length of the elastic displacement was determined for the sample geometry shown in Figure 2 and was found to be 0.88 inch for both A 302 B and A 212 B steels.

Appendix Tables II, III, and IV give the fatigue properties of A 302 B and A 212 B steel obtained for both pre- and post-irradiated specimens found to date. As is typical in fatigue testing, the plastic strain range ($\Delta\epsilon_p$), stress range (ΔS), and hysteresis energy per cycle (ΔW) were found to stabilize after a few cycles. An example of this stabilization is shown in Figure 5.

Because the hysteresis energy per cycle rapidly stabilized, a value of ΔW could be selected for, say, one-half the number of cycles-to-failure, which was typical of all the energies per cycle except that of the first few cycles. These values of ΔW are given in Appendix Table IV. In Appendix Tables V and VI, the values of "k" for the Coffin equation are tabulated assuming $C = \epsilon_f/2$ where ϵ_f is the fracture ductility obtained from separate tensile tests.

The total strain ranges (effective and corrected) for both steels are plotted in Figures 6 and 7 as a function of the number of cycles-to-failure. The data of Stout and Pense [10], who used a constant-deflection cantilever beam test, are included for comparison. It should be recognized that we are comparing uniaxial stress fatigue data with bend data.

The data represented in Figures 6 and 8 for A 302 B steel indicate that there is a difference in the fatigue characteristics of the pre- and post-irradiated specimens at less than 8×10^4 cycles-to-failure. The divergence of the two lines drawn through the pre- and post-irradiated data can result from two effects: (a) buckling stresses at the higher strain ranges become significant and responsible for the decrease in fatigue life and (b) the effects of irradiation may be responsible for the apparent decrease. Since both factors come into play, analysis as to the significance of the buckling stresses is based on the following three observations.

- (1) As mentioned previously, the specimen alignment is manually produced on each specimen. The runout (transverse deflection) was measured during cycling for the unirradiated specimens at the lower strain ranges and found to be < 0.001 inch (bending stresses approximately five percent of the total stresses).
- (2) Little evidence for significant buckling was noticed on the recorded hysteresis curves.
- (3) No permanent bending set was present in the specimen after testing. Therefore, separate lines are drawn through the irradiated data in accordance with the condition that the irradiation effect is dominant.

When the elastic and plastic strain ranges are assumed to obey the form expressed by Equations (3) and (4), then the resultant log-log plots of strain-range versus cycles-to-failure allow determination of the exponent from the slope of the straight lines. The sum of the elastic and plastic strain range is equal to the total strain range so that the sum of the above equations is equal to Equation (5), which expresses the total strain range as a function of cycles-to-failure. The data plotted using these assumptions are shown in Figures 8 and 9. The effective elastic strain range was used in these plots for clarity in the presentation of the data for both elastic and total strain-range curves. The effective elastic data can be converted to corrected data by multiplying the values by $0.5/0.88$, which displaces the elastic curve downward but

VARIAION OF STRESS RANGE AND HYSTERESIS ENERGY DURING CONSTANT TOTAL STRAIN CYCLING

VARIAION OF PLASTIC STRAIN RANGE DURING CONSTANT TOTAL STRAIN CYCLING

(A 302 B STEEL -- SPECIMEN 7-B)

Fig. 5 Variation of plastic strain range, stress range, and hysteresis energy during constant total strain cycling.

Fig. 6 Total strain range versus fatigue life for A 302 B steel.

Fig. 7 Total strain range versus fatigue life for A 212 B steel.

Fig. 8 Total strain range as the sum of elastic and plastic components for A 302 B steel.

does not change the slope of the line. In the case of the A 212 B material, no distinction is made between the A or B specimens since no difference was noticed in their behavior.

Figure 10 shows stable-stress versus stable-strain for the two materials studied; Figure 11 gives the cyclic strain hardening constant for both materials which, by the method of least squares, is 0.07 and 0.15 for A 302 B and A 212 B, respectively. Figure 12 is a log-log plot of stabilized-stress versus cycles-to-failure [Equation (8)].

Figure 13 compares the amount of stress relaxation found to take place in the first few cycles of testing for different strain ranges. Both materials were found to exhibit strain-dependent relaxation, and no difference in behavior was found between pre- and post-irradiated material.

Fig. 9 Total strain range as the sum of elastic and plastic components for A 212 B steel.

Fig. 10 Stable stress-strain curves for A 302 B and A 212 B steels.

Fig. 11 Log-log plots of stable cyclic stress -- strain curves for A 302 B and A 212 B steels.

Fig. 12 Stabilized stress amplitude versus cycles-to-failure for A 302 B and A 212 B steels.

Figures 14 and 15 show stabilized hysteresis energy per cycle, ΔW , as a function of cycles-to-failure for both materials. These curves are similar in form to strain-range versus cycles-to-failure curves, and log-log plots show a linear relation between hysteresis energy per cycle and cycles-to-failure. Since the cyclic hysteresis energy is nearly constant after the first few cycles, $\Delta W \cdot N_f$ (where N_f is the number of cycles-to-failure) represents the total energy-to-failure. Log-log plots of $\Delta W \cdot N_f$ versus N_f give linear relationships as shown in Figure 16.

Fig. 13 Stress range versus number of cycles for several strain ranges showing stress relaxation of A 302 B steel.

Fig. 14 Hysteresis energy versus fatigue life for A 302 B steel.

Fig. 15 Hysteresis energy versus fatigue life for A 212 B steel.

Fig. 16 Total hysteresis energy-to-failure as a function of cycles-to-failure.

IV. DISCUSSION

1. Effect of Irradiation

In examination of the data obtained from the irradiated and unirradiated specimens, it is seen that in the case of A 302 B, irradiation appears to have slightly lowered the fatigue life in the low-cycle region (below $\approx 10^5$ cycles) and raised it in the intermediate region (above 10^5 cycles). It should be noted that strain range, particularly plastic strain range, was the most sensitive to irradiation; whereas stress amplitude and toughness, as shown in Figures 10 and 14, appear the least sensitive at the 4×10^{17} nvt ($E > 1$ MeV) level. Additional tests of unirradiated specimens in the high strain-range region would be needed to further substantiate the conclusion.

In the case of A 212 B, no discernable effect of irradiation was noticed on the fatigue properties. These results are important from the reactor operating standpoint as well as in-reactor testing, since it should be recognized that some cycles are accumulated at low-irradiation exposure.

Both materials showed a slight effect of irradiation on the tensile properties as shown in Appendix Table I.

2. Interpretation of Data According to Given Simple Relations

The exponents in the Coffin equation [Equation (5)] were given in Tables V and VI where C was assumed to be equal to $\epsilon_f/2$. From this preliminary experimentation, our data supports the conclusion that k (the exponent) is not a universal constant but rather a material constant approximately equal to 0.63 and 0.55 for A 302 B and A 212 B steel, respectively, when the value of C is fixed.

The data expressing both the elastic and plastic strain ranges as simple power functions of cycles-to-failure are shown in Figures 8 and 9. The exponents for the elastic (b) and plastic (c) lines are given in Table I. It should be noted

TABLE I
COMPARISON OF EXPERIMENTAL EXPONENTS WITH LITERATURE VALUES

Exponent	Experimental		Literature	
	A 302 B	A 212 B	Average	Range
n'	0.07	0.15	0.14	0.07 to 0.24
a	0.22	0.42	0.33	0.20 to 0.50
b	-0.05	-0.04	-0.083	-0.05 to -0.15
$b[a]$	-0.06	---	---	---
c	-1.1	-0.45	-0.58	-0.45 to -0.70
$c[a]$	-0.75	---	---	---

[a] Irradiated values.

that the values of c for A 302 B are lower than the reported values. This is partially due to the short range of test data.

Figure 10 shows a cyclic stress-strain curve for the two materials -- note that there is no discernable difference in the pre- and post-irradiated specimens for both materials. Morrow [11] points out that the cyclic stress-strain curve will be above the monotonic stress-strain curve for metals that harden and below this curve for those that cyclically soften. The cyclic strain hardening constant determined for A 212 B of 0.15 agrees very well with the published values [6, 8]. The strain hardening constant of 0.07 for A 302 B is in the neighborhood of the values reported for cold-worked materials. These values are compared to the published values in Table I.

According to Equations (4) and (8) [which express elastic strain range and stress amplitude as power functions of cycles-to-failure with the same exponent (b)], log-log plots of plastic strain range versus cycles-to-failure and log-log plots of stress amplitude versus cycles-to-failure should have the same slopes (b). Comparing Figures 8 and 9 with Figure 12, this is seen to be true for A 302 B and, within experimental error, for A 212 B.

3. Stress Relaxation

Both materials studied exhibited some stress relaxation during the first few cycles. Some typical examples are shown in Figure 13. It can be seen that the amount of relaxation increases with increasing strain range within the limits tested. This behavior is typical of metals subjected to cyclic stress. In general, fully annealed metals harden, heavily cold worked metals soften, and partial annealing results in an intermediate behavior. There is, however, a stabilization in all cases after a few cycles to a constant stress level. Benham and Ford [12] found that hot-rolled, mild steel cyclically hardens at high-strain amplitudes and further softens at low amplitudes. Morrow [13] further states that this behavior is typical of metals with an initial yield point that disappears in the cyclic state.

4. Energy Relations

According to Equation (11) (which expresses the total-energy-to-failure as a power function of cycle-to-failure), a log-log plot of the total-energy-to-failure versus cycles-to-failure should produce a straight line whose slope is equal to

$$a = 1 + b + c$$

where b and c are the experimental constants from Table I. The calculated values of a and the slope from Figure 16 are compared as follows:

	<u>A 302 B</u>	<u>A 212 B</u>
a (calculated)	0.19[a]	0.51
a (actual slope)	0.22	0.42

---

[a] Irradiated values of b and c used.

The slopes obtained from Figure 16 are in excellent agreement with the published data as shown in Table I. The calculated slope "a" of 0.51 for A 212 B is very close to that of the actual slope. Similarly, the calculated slope for the irradiated A 302 B is close to the actual slope.

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TABLE I
TENSILE PROPERTIES OF STEELS

Steel and Condition	Section	Yield Strength 0.2% Offset (ksi)	Tensile Strength (ksi)	Reduction in Area (percent)	Elongation (1/2 Inch) (percent)	Fracture ^[b] Ductility (ϵ_f)
A 212 B (QT 1175)	1/5	50.0	74.8	70.4	34.8	1.21
A 212 B	2/5	46.4 ^[a]	71.2	68.4	36.2	1.15
A 302 B (QT 1200)	1/5	83.5	99.6	72.7	21.5	1.30
A 302 B	2/5	76.8	95.4	73.5	25.9	1.32
A 302 B (3.6×10^{17} n/cm ²) ^[c]	2/5	82.2	97.9	69.1	----	1.17
A 212 B (4.2×10^{17} n/cm ²)	1/5	53.2	75.6	67.5	----	1.13
A 212 B (4.7×10^{17} n/cm ²)	2/5	51.8	71.9	67.1	----	1.11

[a] At the two-fifths the section A 212 B steel exhibited a yield point jog. The lower yield point was at 42.2 ksi.

[b] Fracture ductility based on reduction in area.

[c] All fluence values are for neutron energies $E > 1$ MeV.

TABLE II
FATIGUE PROPERTIES OF A 302 B STEEL

Material and Specimen Number	Fluence n/cm ² (> 1 MeV $\times 10^{-17}$)	Total Strain Range (percent)		Stabilized Stress Amplitude ($\Delta\sigma/2$) (ksi)	Plastic Strain Range ($\Delta\epsilon_p$) (percent)	Fatigue Life Cycles
		Effective	Corrected			
A 302 B - 5B	0	0.73	0.47	54.0	0.12	42,000
A 302 B - 6B	0	0.70	0.43	56.0	0.08	38,500
A 302 B - 7B	0	0.69	0.42	55.5	0.07	49,400
A 302 B - 8B	0	0.61	0.36	51.5	0.03	87,050
A 302 B - 9B	0	0.72	0.46	53.0	0.12	35,500
A 302 B - 11B	3.7	0.66	0.39	56.0	0.04	60,110
A 302 B - 12B	4.0	0.58	0.34	50.5	0.02	155,210
A 302 B - 14B	4.7	0.78	0.52	56.5	0.17	10,512
A 302 B - 15B	3.11	0.83	0.56	60.1	0.21	6,700
A 302 B - 16B	3.8	0.55	0.33	51.5	0.03	128,630
A 302 B - 17B	4.18	0.68	0.44	54.5	0.13	15,370
A 302 B - 18B	7.42	0.68	0.42	60.0	0.08	8,282
A 302 B - 19B	3.06	0.48	0.28	45.5	0.018	164,576

TABLE III
FATIGUE PROPERTIES OF A 212 B STEEL

Material and Specimen Number	Fluence n/cm ² ($> 1 \text{ MeV} \times 10^{-17}$)	Total Strain Range (percent)		Stabilized Stress Amplitude ($\Delta\sigma/2$) (ksi)	Plastic Strain Range ($\Delta\epsilon_p$) (percent)	Fatigue Life Cycles
		Effective	Corrected			
A 212 B - 10A	4.0	0.54	0.34	31.0	0.08	91,885
A 212 B - 12A	4.2	0.58	0.39	33.5	0.14	49,000
A 212 B - 13A	0	0.75	0.57	38.0	0.32	9,475
A 212 B - 14A	4.46	0.74	0.55	38.0	0.30	9,767
A 212 B - 15A	4.18	0.74	0.55	37.5	0.31	10,308
A 212 B - 16A	3.91	0.69	0.52	38.0	0.29	9,860
A 212 B - 18A	6.98	0.70	0.51	37.5	0.27	11,070
A 212 B - 20A	0	0.58	0.41	33.0	0.10	51,468
A 212 B - 21A	0	0.61	0.43	35.2	0.21	33,073
A 212 B - 22A	0	0.66	----	----	----	45,830
A 212 B - 23A	0	0.69	----	----	----	25,630
A 212 B - 16B	0	0.56	0.39	33.0	0.16	48,000
A 212 B - 17B	0	0.54	0.38	32.5	0.17	62,200
A 212 B - 18B	0	0.56	0.39	33.0	0.17	34,500
A 212 B - 19B	0	0.55	0.39	33.0	0.17	40,600
A 212 B - 20B	4.8	0.54	0.36	32.0	0.13	83,200
A 212 B - 22B	4.25	0.62	0.47	32.3	0.25	27,050
A 212 B - 23B	4.37	0.58	0.41	32.3	0.18	47,180
A 212 B - 24B	4.77	0.52	0.35	32.0	0.15	35,890
A 212 B - 25B	4.09	0.65	0.47	32.6	0.215	20,438
A 212 B - 26B	7.13	0.65	0.46	32.0	0.21	26,977

TABLE IV
STABILIZED HYSTERESIS ENERGIES
FOR A 302 B AND A 212 B STEELS

Specimen Number	ΔW (in-lb/in. ³)/Cycle	Specimen Number	ΔW (in-lb/in. ³)/Cycle
A 302 B - 5B	85	A 212 B - 10A	32
A 302 B - 6B	68	A 212 B - 12A	73
A 302 B - 7B	58	A 212 B - 13A	176
A 302 B - 8B	28	A 212 B - 14A	167
A 302 B - 9B	80	A 212 B - 15A	175
A 302 B - 14B	142	A 212 B - 16A	165
A 302 B - 15B	175	A 212 B - 18A	150
A 302 B - 16B	20	A 212 B - 20A	91
A 302 B - 17B	105	A 212 B - 21A	112
A 302 B - 18B	70	A 212 B - 16B	77
A 302 B - 19B	20	A 212 B - 17B	77
		A 212 B - 18B	83
		A 212 B - 19B	80
		A 212 B - 20B	64
		A 212 B - 22B	86
		A 212 B - 23B	86
		A 212 B - 24B	122
		A 212 B - 25B	105
		A 212 B - 26B	103

TABLE V
FATIGUE PROPERTIES OF A 302 B STEEL

<u>Material and Specimen Number</u>	<u>Fracture Ductility</u>	<u>Exponent k, $k = \frac{\log \epsilon_f / 2\Delta \epsilon_p}{\log N}$</u>
A 302 B - 5B	1.32	0.59
A 302 B - 6B	1.32	0.64
A 302 B - 7B	1.32	0.63
A 302 B - 8B	1.32	0.68
A 302 B - 9B	1.32	0.60
A 302 B - 11B (irradiated)	1.17	0.66
A 302 B - 12B (irradiated)	1.17	0.67
A 302 B - 14B (irradiated)	1.17	0.63
A 302 B - 15B (irradiated)	1.17	0.64
A 302 B - 16B (irradiated)	1.17	0.63
A 302 B - 17B (irradiated)	1.17	0.63
A 302 B - 19B (irradiated)	1.17	0.51
Average Value Irradiated = 0.63		
Average Value Nonirradiated = 0.63		

TABLE VI
FATIGUE PROPERTIES OF A 212 B STEEL

Material and Specimen Number	Fracture Ductility	Exponent k, $k = \frac{\log \epsilon_f / 2\Delta\epsilon_p}{\log N}$
A 212 B - 10A	1.13	0.58
A 212 B - 12A	1.13	0.56
A 212 B - 13A	1.21	0.58
A 212 B - 14A	1.13	0.57
A 212 B - 15A	1.13	0.56
A 212 B - 16A	1.13	0.57
A 212 B - 18A	1.13	0.57
A 212 B - 20A	1.21	0.54
A 212 B - 21A	1.21	0.55
A 212 B - 16B	1.15	0.55
A 212 B - 17B	1.15	0.53
A 212 B - 18B	1.15	0.56
A 212 B - 19B	1.15	0.55
A 212 B - 20B	1.11	0.54
A 212 B - 22B	1.11	0.53
A 212 B - 23B	1.11	0.53
A 212 B - 24B	1.11	0.56
A 212 B - 25B	1.11	0.56
A 212 B - 26B	1.11	0.55
Average Value = 0.55		