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WCAP-3677-9

WCAP-3677-9

FRACTURE MECHANICS EVALUATION
OF REACTOR VESSEL STEELS
QUARTERLY PROGRESS REPORT
FOR THE PERIOD ENDING
SEPTEMBER 30, 1968

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October 1968

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PROGRAM DESCRIPTION

An experimental program is being performed directed towards further development and evaluation of a fracture mechanics approach to the problem of brittle fracture of reactor vessel materials, based upon the use of modified Wedge Opening Loading (WOL) specimens. Experimental testing of a group of reactor vessel steels is being performed to investigate the application of the fracture mechanics technique to these materials in both the unirradiated and irradiated conditions. Because of test reactor dimensional constraints, scaled-up specimens can only be used to obtain pre-irradiation data; therefore, irradiation effects will be determined only on small specimens.

Testing in the unirradiated and irradiated conditions will be conducted to determine the variability in fracture toughness of various materials. Materials being investigated include base metal samples from two different heats of nickel modified, manganese-molybdenum steel and European forging grade material; and weld and heat affected zone samples from one heat of a nickel modified, manganese-molybdenum steel. Tensile, Charpy V-notch and drop weight specimens from those materials are included in the program in order to provide correlation data.

EUFM-100 - Program Management (Summary of Progress)

L. F. Cochrun - Project Engineer

This is the ninth technical progress report on a USAEC-Euratom joint program on fracture mechanics. The previous technical progress reports were:

EURAEC-2044 WCAP-3677-8	"Fracture Mechanics Evaluation of Reactor Vessel Steels Quarterly Progress Report for the Period Ending June 30, 1968"
EURAEC-2007 WCAP-3677-7	"Fracture Mechanics Evaluation of Reactor Vessel Steels Quarterly Progress Report for the Period Ending March 31, 1968"
EURAEC-1953 WCAP-3677-6	"Fracture Mechanics Evaluation of Reactor Vessel Steels Quarterly Progress Report for the Period Ending December 31, 1967"
EURAEC-1924 WCAP-3677-5	"Fracture Mechanics Evaluation of Reactor Vessel Steels Quarterly Progress Report for the Period Ending September 30, 1967"
EURAEC-1879 WCAP-3677-4	"Fracture Mechanics Evaluation of Reactor Vessel Steels Quarterly Progress Report for the Period Ending June 30, 1967"
EURAEC-1829 WCAP-3677-3	"Fracture Mechanics Evaluation of Reactor Vessel Steels Technical Progress Report for the Period Ending March 31, 1967"
EURAEC-1780 WCAP-3677-2	"Fracture Mechanics Evaluation of Reactor Vessel Steels Technical Progress Report for the Period Ending December 31, 1966"
EURAEC-1720 WCAP-3677-1	"Fracture Mechanics Evaluation of Reactor Vessel Steels Technical Progress Report for the Period Ending September 30, 1966"

Progress during the period July 1, 1968 through September 30, 1968 is summarized as follows:

1. The irradiation of the second set of three capsules in the Babcock and Wilcox Test Reactor is continuing. The target exposure has been increased from 140 EFPD to 160 EFPD. Approximately 130 EFPD or about 80% of the target exposure has been accumulated.
2. The pre-irradiation testing of specimens fabricated from the 12-inch thick plate of A533, grade B, class 1 steel was completed this quarter.
3. The post-irradiation testing of the specimens from the first set of capsules was also completed this quarter.

EUFM-200 - Irradiation and Analysis

T. R. Mager, W. S. Hazelton, F. O. Thomas

This task provided for the planning of the irradiation experiment, including the design, manufacture and assembly of the irradiation capsules. Technical direction shall be provided during the capsule irradiation, capsule disassembly and post-irradiation examination of specimens. Analysis and evaluation of the experimental results will be performed under this task.

Irradiation Experiment

The irradiation of the second set of three (3) capsules in the Babcock and Wilcox Test Reactor (BAWTR) is continuing. During September, the BAWTR was down for three weeks due to a malfunction in the reactor and the capsules only accumulated several EFPD of exposure. A decision was made to increase the target exposure from 140 EFPD to approximately 160 EFPD. The second set of three (3) capsules will be removed from the BAWTR sometime in November, 1968. The total exposure accumulated by the capsules to date is approximately 130 EFPD or about 80% of the target exposure.

Post - Irradiation Testing

The testing of the irradiated specimens from the first set of three (3) capsules removed from the Babcock and Wilcox Test Reactor (BAWTR) in February was completed at Westinghouse's Post-Irradiation Laboratory at Waltz Mill during this report period. Testing was started with the Charpy V-notch specimens. The results are illustrated in Figures 200.1 through 200.4 where they are compared with the pre-irradiation results of the same material.

The results of the tensile tests are illustrated in Figures 200.5 through 200.7 where they are compared with results from the irradiation material. The results for the post-irradiated material are summarized in Table 200.1

Figure 200.1. ASTM A533 Grade B Class I Steel From 8" Thick Plate

Figure 200.2. EUROPEAN 1.2 MD07 Forging Grade Steel

Figure 200.3. Weld Metal From ASTM A533 Grade B Class I Steel

Figure 200.4. ASTM A533 Grade B Class I Steel Heat Affected Zone

Figure 200.5. ASTM A533 Grade B Class 1 Steel from 8" Thick Plate

Figure 200.6. EUROPEAN 1.2 MD07 Forging Grade Steel

Figure 200.7. Weld Metal From ASTM A533 Grade B Class I Steel

Table 200.1

POST-IRRADIATION TENSILE PROPERTIES

<u>Specimen Number</u>	<u>Test Temp (°F)</u>	<u>Capsule Number</u>	<u>Yield Strength</u>	<u>Tensile Strength</u>
A 533 grade B, class 1, steel				
L-1	80	1	85,000	102,400
L-3	80	2	93,700	110,800
L-2	200	3	86,600	102,200
L-4	200	2	78,000	98,800
European Forging Grade Steel				
N-2	80	3	105,000	122,500
N-1	80	2	91,800	112,600
N-4	200	1	89,500	106,300
N-5	400	3	82,800	104,700
Weldment (A 533 grade B, class 1, steel)				
PW3	80	2	107,000	119,500
PW1	80	1	104,100	119,000
PW4	200	3	105,800	123,600
PW2	400	1	94,300	112,400

The stress intensity factors (fracture toughness) for the specimens from the first set of three (3) capsules are given in Table 200.2 and in Figures 200.8 through 200.10. Some testing difficulties were encountered with four of the specimens, NOK 16, NOK 21, PW2, and LUK T5. In the case of NOK 16 testing was performed at room temperature but the specimen did not fracture at 10,000 lbs. load. It was subsequently tested at -150°F where fracture occurred. Only the higher temperature value is shown on the graph with an arrow pointing upward indicating absence of fracture. In the case of NOK 21 testing was performed at -50°F but at a load of 9,200 lbs. the threads stripped separating the pull rod from the specimen and terminating the test. After re-tapping the specimen was tested at -150°F where fracture occurred. Again only the fracture toughness determined from the 9,200 lb. load is shown on the graph. Two other specimens, LUK T5 and PW2 did not fracture at the maximum testing capacity of the machine, 15,000 lbs. load. The results obtained with the maximum load imposed are indicated on the graphs, however, with an arrow pointing upward indicating absence of fracture. After failing to fracture LUK T5 at room temperature the test was rerun at 0°F where fracture occurred. PW2, after being tested at 0°F was subsequently tested at -50°F , -100°F , and finally at -150°F where fracture occurred.

As discussed in previous quarterly reports pertaining to fracture mechanics, the requirements of the type of fracture toughness testing employed are unusual in that it is necessary to compare post-test data to specimen pre-test dimensions to determine if the fracture toughness measured (K_Q) is the critical value (K_{IC}) for the material. In other words, validity of the test can be determined only after testing. Two criteria for validity have been proposed:

1. Reference 1 proposes use of the secant offset method to determine that the majority of strain is due to slow crack growth.

Table 200.2

FRAC TURE TOUGHNESS - IRRADIATED SPECIMENS

Specimen Number	Capsule	Size	Temp (°F)	Y.S. Ksi see note	a (in.)	Plastic Zone Size r (in.)	Stress Intensity Factor K_{Ic}, K_Q (Ksi $\sqrt{\text{in.}}$)	Validity see note
LUK-5	1	1X	- 75	102.4(e)	0.495	0.008	36.0	1
LUK-8	1	1X	- 25	97.5(e)	0.489	0.012	44.0	1
LUK-9	3	1X	- 25	97.5(e)	0.515	0.006	33.5	1
LUK-6 (prestressed)	2	1X	0	95.4(e)	0.520	0.007	35.4	1
LUK-2	3	1T	25	93.7(e)	0.926	0.014	48.2	1
LUK-3	1	1T	50	92.2(e)	0.923	0.010	40.3	1
LUK-7	2	1X	80	90.4	0.524	0.024	57.6	2
LUK-10	3	1X	80	90.4	0.562	0.029	57.4	4
*LUK-T5	2	1T	80	90.4	0.924	0.031	70.8	2
NOK-22	2	1X	-100	116.3(e)	0.495	0.006	39.1	1
NOK-15	3	1X	- 75	113.2(e)	0.525	0.012	56.7	1
NOK-18	1	1X	- 75	113.2(e)	0.613	0.013	59.5	2
*NOK-21	2	1X	- 50	110.4(e)	0.531		87.5	2
NOK-5	3	1T	- 50	110.4(e)	0.921	0.013	54.8	1
NOK-B4	2	1T	- 50	110.4(e)	0.894	0.019	65.6	1
NOK-20 (prestressed)	1	1X	- 25	108.2(e)	0.578	0.033	90.4	2
NOK-1	1	1T	- 25	108.2(e)	0.924	0.015	58.0	1
*NOK-16	3	1X	30	100.2	0.512		91.6	2
PW-12	2	1X	- 50	116.4(e)	0.529	0.013	53.2	1
PW-17	1	1X	- 25	114.3(e)	0.518	0.009	43.5	1
PW-1	3	1X	- 25	114.3(e)	0.529	0.008	43.6	1
PW-5	2	1T	- 25	114.3(e)	0.917	0.009	48.0	1
PW-9	2	1X	0	112.4(e)	0.618	0.022	83.8	2
*PW-2	3	1T	0	112.4(e)	0.938	0.019	72.5	1
PW-1	1	1T	0	112.4(e)	0.926	0.009	45.3	1
PW-8	1	1X	25	110.7(e)	0.512	0.042	102.5	2
PW-15	3	1X	80	107.6	0.505	0.020	63.4	2

Notes: (e) Indicates that the yield strength of the material at the given temperature has been estimated

(*) Indicates failure to fracture at temperature shown. For further tests see text.

(1) Meets both criteria: a and B greater than $2.5 (K_{Ic}/Y.S.)^2$ and secant offset.

(2) Fails a and B greater than $2.5 (K_{Ic}/Y.S.)^2$, meets secant offset.

(3) Meets a and B greater than $2.5 (K_{Ic}/Y.S.)^2$, fails secant offset.

(4) Fails both criteria

Figure 200.8. Results of Fracture Toughness (K_{Ic}) Tests. Irradiated ASTM A533 Grade B Class 1 Steel from 8-Inch Thick Plate

Figure 200.9. Results of Fracture Toughness (K_{Ic}) Tests, Irradiated European 1.2MD07 Forging Grade Steel

Figure 200.10. Results of Fracture Toughness (K_{Ic}) Tests. Irradiated Weld Metal from ASTM A533 Grade B Class 1 Steel

2. Reference 2 proposes that both the crack length and specimen thickness exceed $2.5 \times (\text{Fracture Toughness}/\text{Strength})^2$. Fracture toughness measured for specimens meeting these criteria is considered to be the critical value (K_{IC}) for the material. If the criteria are not met, the measured fracture toughness (K_Q) is considered to have been biased by specimen size.

It is interesting to note, that the shift in fracture toughness of the three materials (Figure 200.8, 200.9, and 200.10) after the exposure to a fluence of $3-4 \times 10^{19}$ appears less than the 30 ft. lb. fix Charpy transition temperature shift. The upswing or transition in K_{IC} (fracture toughness) values appears to be several hundred degrees less than the 30 ft lbs fix Charpy temperature after irradiation.

Measurement of the fast neutron fluxes using the neutron monitors (Quarterly Report March 31, 1968) embedded in each capsule was conducted according to ASTM standard procedures developed by ASTM Committee E-10 on Radioisotopes and Radiation Effects. The total integrated neutron exposure or fluence as determined from the flux monitors was $2.73-4.25 \times 10^{19}$ n/cm².

References

1. W. F. Brown, Jr., John E. Scrawley, ASTM STP 410, "Plane Strain Crack Toughness Testing of High-Strength Metallic Materials."
2. "Proposed Recommended Method of Test for Plane-Strain Fracture Toughness of Metallic Materials," ASTM Committee E-24.

EUFM-300 - Pre-Irradiation Testing

T. R. Mager, W. S. Hazelton, F. O. Thomas

Under this task, the material required for the test specimens were procured and the pre- and post-irradiation specimens were manufactured. The testing of the pre-irradiation specimens will be carried out and the results developed for analysis and evaluation under Task EUFM-200.

Specimen Fabrication

The specimens required for the pre-irradiation portion of the program were fabricated from the 12-inch thick plate of A 533, grade B, class 1 (Mn Mo with Ni), steel and have been discussed in the previous quarterly report (June 30, 1968). During this report period additional drop weight specimens were fabricated.

Mechanical Testing

The pre-irradiation testing of specimens fabricated from the 12-inch thick plate of A 533, grade B, class 1 steel was completed this quarter. Additional drop weight specimens were tested in an effort to determine the nil-ductility transition temperature of both the top and bottom surfaces. The test results are given in Table 300.1. The results from the initial determinations are shown in Table 300.2. From Table 300.1, it can be seen that while the results from the bottom surface agree well with the data of Table 300.2, the results from the top surface do not. The behavior of the material in this test suggests that the data of Table 300.1 is doubtful with the respect to that of Table 300.2, and that the tentative data of Table 300.2 is to be preferred, since it was obtained in the same series of experiments as the established data. Furthermore, it would appear that additional drop weight experiments are futile unless they can be conducted through the entire thickness. Such additional testing would involve a prohibitive quantity of material and is not deemed significantly worthwhile at the present time.

Table 300.1

DROP WEIGHT TEST DATA FOR 12" THICK PLATE
ASTM A 533, GRADE B, CLASS 1, STEEL - HEAT NO. 1195-1 PLATE 2

Specimen Length	5 in.
Specimen Width	2 in.
Specimen Thickness	5/8 in.
Support Span	4 in.
Stop Height	0.075 in.
Weight of Head	60 lb
Drop Weight	5 ft

TOP SURFACE

<u>No.</u>	<u>Temp.</u>	<u>Result</u>	<u>N.D.T.</u>
D2-T-9	-80°F	Broken	*
D2-T-10	-60°F	Broken	
D2-T-11	-50°F	Broken	
D2-T-12	-40°F	Broken	

BOTTOM SURFACE

D2-B-9	-60°F	Not Broken	-70°F
D2-B-10	-60°F	Not Broken	

Table 300.2

DROP WEIGHT TEST DATA FOR 12" THICK PLATE
A533 GRADE B CLASS I STEEL - HEAT NO. 1195-1 PLATE 2

Specimen Length	5 in.
Specimen Width	2 in.
Specimen Thickness	5/8 in.
Support Span	4 in.
Stop Height	.075 in.
Weight of Head	60 lb
Drop Weight	5 ft

TOP SURFACE

<u>No.</u>	<u>Temp</u>	<u>Result</u>	<u>N.D.T.</u>
D2-T-1	0°F	Not Broken	
D2-T-2	- 40°F	Not Broken	
D2-T-3	- 80°F	Not Broken	
D2-T-4	-120°F	Broken	
D2-T-5	-100°F	Not Broken	
D2-T-6	-110°F	Broken	
D2-T-7	-100°F	Broken	
D2-T-8	- 90°F	Broken	-90°F*

TOP QUARTER THICKNESS

D1-1Q-1	0°F	Not Broken	
D1-1Q-2	- 20°F	Broken	
D1-1Q-3	- 10°F	Broken	
D1-1Q-4	0°F	Not Broken	-10°F

CENTER THICKNESS

D2-C-1	0°F	Not Broken	
D2-C-2	- 40°F	Broken	
D2-C-3	- 20°F	Broken	
D2-C-4	- 10°F	Broken	
D2-C-5	0°F	Broken	
D2-C-6	+ 10°F	Not Broken	
D2-C-7	+ 10°F	Not Broken	0°F

Table 300.2 (continued)

THREE QUARTER THICKNESS

D1-3Q-1	0°F	Broken	
D1-3Q-2	+ 20°F	Not Broken	
D1-3Q-3	+ 10°F	Not Broken	
D1-3Q-4	+ 10°F	Not Broken	0°F

BOTTOM SURFACE

D2-B-1	0°F	Not Broken	
D2-B-2	- 40°F	Not Broken	
D2-B-3	- 80°F	Not Broken	
D2-B-4	-120°F	Broken	
D2-B-5	-100°F	Broken	
D2-B-6	- 90°F	Broken	
D2-B-7	- 80°F	Broken	
D2-B-8	- 70°F	Broken	-60°F*

* Tentative N.D.T. - Additional tests in progress

Fracture toughness testing of the unirradiated 12-inch thick plate was completed utilizing 1X WOL and 1T and 2T Compact K_{IC} specimens. The stress intensity factors (fracture toughness) for the 12-inch thick plate are summarized in Table 300.3 through 300.7 and in Figures 300.1 through 300.10. The information contained in the figures is divided into two (2) sets, those which contain valid data and those with invalid data superimposed upon the band denoting the range of valid data. Estimates can be obtained previous to the test itself of the probability of obtaining valid data. However, the validity of the data can be established only after testing, since the fracture toughness itself is involved in criteria for substantiating the test. The two standards cited under EUFM-200 were also used in determining the validity of the pre-irradiation data.

The material at the top and bottom surfaces of the 12-inch thick plate is considerably tougher than the interior of the plate. This is evident from Figures 300.1 through 300.10, where it is shown that the measuring capacity of the 1X and 1T specimens is exceeded at -150°F for the top and bottom surfaces while for the interior of the plate, 1T Compact K_{IC} specimens gave valid data at -75°F . In comparison, the fracture toughness or K_{IC} value is approximately 60,000 at -150°F versus 45,000 for the interior plate material. The greater toughness of the top and bottom surfaces is reflected in the lower NDTT for these two positions, (Tables 300.1 and 300.2).

Table 300.3

RESULTS OF FRACTURE TOUGHNESS TESTS OF 12" ASTM A 533 GRADE B, CLASS 1, STEEL
HEAT NO. 1195-1 PLATE 2

TOP SURFACE

Specimen Number	Size	Temp (°F)	Y.S. (Ksi)	a (in.)	a/W	Plastic Zone Size r (in.)	Stress Intensity Factor K_{Ic}, K_Q (Ksi√in.)	Validity
W-1T1C	1X	-250	131.0	0.533	0.473	0.005	39.2	1
W-1T7	1X	-250	131.0	0.508	0.460	0.008	52.0	1
K3-1T10	1T	-250	131.0	1.023	0.512	0.002	26.2	1
W-1T11	1X	-200	115.0	0.548	0.487	0.009	48.3	1
W-1T9	1X	-200	115.0	0.533	0.473	0.020	70.1	4
W-1T12	1X	-200	115.0	0.545	0.484	0.010	50.9	1
K3-1T5	1T	-200	115.0	1.022	0.511	0.010	50.1	1
K3-1T8	1T	-200	115.0	0.999	0.500	0.008	40.1	1
W-1T1	1X	-175	107.0	0.558	0.496	0.013	54.3	2
K3-1T9	1T	-175	107.0	1.011	0.505	0.010	47.2	1
W-1T13	1X	-150	104.0	0.539	0.479	0.018	60.1	4
K3-1T11	1T	-150	104.0	1.054	0.527	0.019	62.5	1
K3-1T6	1T	-150	104.0	1.035	0.518	0.015	54.9	1
K2-2T5	2T	-150	104.0	2.041	0.510	0.011	51.0	1
K3-1T7	1T	-125	100.0	1.021	0.510	0.031	76.2	2
K1-2T3	2T	-100	97.0	2.029	0.507	0.028	70.0	1
K1-2T1	2T	-100	97.0	2.050	0.512	0.036	79.4	1
K2-2T8	2T	-100	97.0	2.200	0.550	0.078	117.3	4
K2-2T6	2T	- 50	90.0	2.031	0.508	0.065	99.5	2

- Notes:
1. Meets both criteria: a and B greater than $2.5 (K_{Ic}/Y.S.)^2$ and secant offset
 2. Fails a and B greater than $2.5 (K_{Ic}/Y.S.)^2$, meets secant offset
 3. Meets a and B greater than $2.5 (K_{Ic}/Y.S.)^2$, fails secant offset
 4. Fails both criteria

Table 300.4

RESULTS OF FRACTURE TOUGHNESS TESTS OF 12" ASTM A 533 GRADE B, CLASS 1, STEEL
HEAT NO. 1195-1 PLATE 2

TOP QUARTER THICKNESS

Specimen Number	Size	Temp (°F)	Y.S. (Ksi)	a (in.)	a/W	Plastic Zone Size r (in.)	Stress Intensity Factor K_{Ic}, K_Q (Ksi in.)	Validity
W-1Q12	1X	-200	99.0	0.523	0.465	0.008	37.5	1
W-1Q7	1X	-200	99.0	0.514	0.457	0.005	30.5	1
K6-1Q38	1T	-200	99.0	1.011	0.505	0.005	31.2	1
K6-1Q43	1T	-175	95.0	1.081	0.540	0.011	43.5	1
W-1Q2	1X	-150	90.0	0.530	0.470	0.007	31.5	1
W-1Q1C	1X	-150	90.0	0.536	0.476	0.017	52.0	2
W-1Q1	1X	-150	90.0	0.521	0.468	0.011	41.2	1
W-1Q13	1X	-125	88.0	0.506	0.449	0.011	39.1	1
K6-1Q46	1T	-125	88.0	1.034	0.517	0.016	48.3	1
K6-1Q42	1T	-125	88.0	1.025	0.513	0.013	43.4	1
K6-1Q44	1T	-125	88.0	1.008	0.504	0.010	38.1	1
W-1Q11	1X	-100	86.0	0.593	0.527	0.028	61.8	2
K6-1Q45	1T	-100	86.0	1.008	0.504	0.025	58.1	2
K6-1Q41	1T	-100	86.0	1.061	0.530	0.031	65.4	2
K5-1Q16	2T	-100	86.0	2.034	0.508	0.025	59.0	1
K5-1Q17	2T	-100	86.0	2.029	0.507	0.023	56.2	1
K6-1Q20	2T	- 50	81.0	2.010	0.502	0.034	65.0	1
K6-1Q12	2T	- 50	81.0	2.035	0.509	0.037	67.5	1
K5-1Q18	2T	- 10	78.0	2.091	0.523	0.041	68.9	3
K4-1Q13	2T	- 10	78.0	2.169	0.542	0.068	88.3	4

- Notes:
1. Meets both criteria: a and B greater than $2.5 (K_{Ic}/Y.S.)^2$ and secant offset
 2. Fails a and B greater than $2.5 (K_{Ic}/Y.S.)^2$, meets secant offset
 3. Meets a and B greater than $2.5 (K_{Ic}/Y.S.)^2$, fails secant offset
 4. Fails both criteria

Table 300.5

RESULTS OF FRACTURE TOUGHNESS TESTS OF 12" ASTM A 533 GRADE B, CLASS 1, STEEL
HEAT NO. 1195-1 PLATE 2

CENTER

Specimen Number	Size	Temp (°F)	Y.S. (Ksi)	a (in.)	a/W	Plastic Zone Size r (in.)	Stress Intensity Factor K_{Ic}, K_Q (Ksi√in.)	Validity
W-1C7	1X	-250	113.0	0.520	0.462	0.006	37.3	1
W-1C10	1X	-200	93.0	0.555	0.493	0.012	44.0	1
W-1C11	1X	-200	93.0	0.564	0.501	0.007	34.6	1
W-1C1	1X	-200	93.0	0.646	0.573	0.010	39.9	1
W-1C13	1X	-150	84.0	0.541	0.480	0.017	46.8	2
W-1C9	1X	-150	84.0	0.543	0.482	0.014	44.1	2
W-1C12	1X	-150	84.0	0.511	0.453	0.020	52.5	2
K3-1C20	1T	-150	84.0	1.028	0.514	0.013	42.1	1
K3-1C22	1T	-150	84.0	1.025	0.513	0.011	37.7	1
K3-1C23	1T	-100	79.0	1.018	0.509	0.015	42.2	1
K3-1C24	1T	-100	79.0	1.010	0.505	0.020	48.5	1
K3-1C18	1T	-100	79.0	1.010	0.505	0.020	48.5	1
K1-2C4	2T	-100	79.0	2.091	0.523	0.021	50.2	1
K3-1C19	1T	- 75	77.0	1.023	0.512	0.023	50.3	1
K3-1C21	1T	- 75	77.0	1.028	0.514	0.037	64.3	2
K2-2C6	2T	- 50	74.0	2.036	0.509	0.040	65.0	1
K1-2C1	2T	- 50	74.0	2.041	0.510	0.060	79.2	2
K1-2C2	2T	- 50	74.0	2.023	0.506	0.040	65.1	1
K2-2C8	2T	- 25	74.0	2.041	0.510	0.075	88.4	2
K1-2C3	2T	- 25	74.0	2.043	0.511	0.073	87.3	2
K2-2C5	2T	0	73.0	2.024	0.506	0.064	81.0	2

- Notes:
1. Meets both criteria: a and B greater than $2.5 (K_{Ic}/Y.S.)^2$ and secant offset
 2. Fails a and B greater than $2.5 (K_{Ic}/Y.S.)^2$, meets secant offset
 3. Meets a and B greater than $2.5 (K_{Ic}/Y.S.)^2$, fails secant offset
 4. Fails both criteria

Table 300.6

RESULTS OF FRACTURE TOUGHNESS TESTS OF 12" ASTM A 533 GRADE B, CLASS 1, STEEL
HEAT NO. 1195-1 PLATE 2

BOTTOM QUARTER THICKNESS

Specimen Number	Size	Temp (°F)	Y.S. (Ksi)	a (in.)	a/W	Plastic Zone Size r (in.)	Stress Intensity Factor K_{Ic}, K_Q (Ksi $\sqrt{\text{in.}}$)	Validity
W-3Q4	1X	-200	98.0	0.626	0.556	0.009	41.0	1
W-3Q8	1X	-200	98.0	0.548	0.617	0.008	38.5	1
K6-3Q51	1T	-200	98.0	1.016	0.508	0.005	30.8	1
W-3Q5	1X	-150	92.0	0.529	0.470	0.006	30.5	1
W-3Q3	1X	-150	92.0	0.516	0.458	0.006	29.7	1
W-3Q6	1X	-150	92.0	0.566	0.503	0.015	48.4	2
K6-3Q50	1T	-150	92.0	1.018	0.508	0.010	40.7	1
W-3Q2	1X	-100	87.0	0.608	0.540	0.023	57.3	2
K6-3Q52	1T	-100	87.0	1.049	0.524	0.021	54.8	1
K6-3Q55	1T	-100	87.0	1.030	0.515	0.021	54.4	1
K5-3Q19	2T	-100	87.0	2.065	0.516	0.018	51.4	1
K6-3Q54	1T	- 75	85.0	1.003	0.501	0.016	46.6	1
K6-3Q49	1T	- 50	83.0	1.016	0.508	0.028	61.6	2
K6-3Q53	1T	- 50	83.0	1.044	0.522	0.032	64.5	4
K4-3Q13	2T	- 50	83.0	2.074	0.518	0.025	56.7	1
K4-3Q14	2T	C	79.0	2.026	0.506	0.037	66.4	1
K5-3Q17	2T	C	79.0	2.046	0.511	0.075	93.7	1
K5-3Q18	2T	C	79.0	2.040	0.510	0.060	83.4	1

- Notes:
1. Meets both criteria: a and B greater than $2.5 (K_{Ic}/Y.S.)^2$ and secant offset
 2. Fails a and B greater than $2.5 (K_{Ic}/Y.S.)^2$, meets secant offset
 3. Meets a and B greater than $2.5 (K_{Ic}/Y.S.)^2$, fails secant offset
 4. Fails both criteria

Table 300.7

RESULTS OF FRACTURE TOUGHNESS TESTS OF 12" ASTM A 533 GRADE B, CLASS 1, STEEL
HEAT NO. 1195-1 PLATE 2

BOTTOM SURFACE

Specimen Number	Size	Temp (°F)	Y.S. (Ksi)	a (in.)	a/W	Plastic Zone Size r (in.)	Stress Intensity Factor K_{Ic}, K_Q (Ksi $\sqrt{\text{in.}}$)	Validity
W-1B2	1X	-250	128.0	0.534	0.474	0.006	44.3	1
W-1B3	1X	-250	128.0	0.570	0.506	0.006	41.4	1
W-1B9	1X	-200	109.0	0.534	0.474	0.012	51.0	1
W-1B8	1X	-200	109.0	0.546	0.485	0.007	38.3	1
W-1B4	1X	-200	109.0	0.561	0.498	0.018	63.9	2
K3-1B28	1T	-200	109.0	1.023	0.511	0.016	59.5	1
K3-1B31	1T	-200	109.0	1.060	0.530	0.011	50.4	1
K3-1B29	1T	-200	109.0	1.015	0.507	0.014	56.0	1
W-1B6	1X	-150	102.0	0.583	0.518	0.026	71.3	4
W-1B5	1X	-150	102.0	0.541	0.480	0.023	67.3	2
K3-1B32	1T	-150	102.0	1.020	0.510	0.014	51.4	1
K3-1B25	1T	-150	102.0	1.024	0.512	0.027	73.0	2
K3-1B33	1T	-150	102.0	1.015	0.507	0.022	66.5	2
K3-2B11	2T	-150	102.0	2.031	0.508	0.018	60.2	1
K3-1B30	1T	-125	101.0	1.015	0.507	0.048	96.0	4
K3-1B27	1T	-100	98.0	1.009	0.504	0.046	90.8	4
K1-2B2	2T	-100	98.0	2.005	0.501	0.021	61.5	1
K1-2B4	2T	-100	98.0	2.024	0.506	0.036	80.5	1
K2-2B7	2T	-100	98.0	2.023	0.506	0.017	55.2	1
K1-2B3	2T	-100	98.0	2.028	0.507	0.024	66.3	1
K2-2B5	2T	- 50	94.0	2.045	0.511	0.058	98.1	1
K2-2B8	2T	- 50	94.0	2.530	0.632	0.082	116.9	2

- Notes:
1. Meets both criteria: a and B greater than $2.5 (K_{Ic}/Y.S.)^2$ and secant offset
 2. Fails a and B greater than $2.5 (K_{Ic}/Y.S.)^2$, meets secant offset
 3. Meets a and B greater than $2.5 (K_{Ic}/Y.S.)^2$, fails secant offset
 4. Fails both criteria

Figure 300.1. Result of Compact K_{Ic} Fracture Toughness Tests 12" ASTM A533 Grade B Class I Steel Heat No. 1195-1, Plate 2 Top Surface

Figure 300.2. Result of Compact K_{Ic} Fracture Toughness Tests 12" ASTM A533 Grade B Class I Steel Heat No. 1195-1, Plate 2 Top Surface

Figure 300.3. Results of Compact K_{Ic} Fracture Toughness Tests 12" ASTM A533 Grade B Class I Steel Heat No. 1195-1. Plate 2 Top Quarter Thickness

Figure 300.4. Results of Compact K_{Ic} Fracture Toughness Tests 12" ASTM A533 Grade B Class I Steel Heat No. 1195-1, Plate 2 Top Quarter Thickness

Figure 300.5. Results of Compact K_{Ic} Fracture Toughness Tests 12" ASTM A533 Grade B Class 1 Steel
Heat No. 1195-1 Plate 2 Center

Figure 300.6. Results of Compact K_{Ic} Fracture Tests 12" ASTM A533 Grade B Class 1 Steel Heat No. 1195-1. Plate 2 Center

Figure 300.7. Results of Compact K_{Ic} Fracture Toughness Tests 12" ASTM A533 Grade B Class I Steel Heat No. 1195-1. Plate 2 Bottom Quarter Thickness

Figure 300.8. Results of Compact K_{Ic} Fracture Toughness Tests 12" ASTM A533 Grade B Class 1 Steel Heat No. 1195-1, Plate 2 Bottom Quarter Thickness

Figure 300.9. Results of Compact K_{Ic} Fracture Toughness Tests 12" ASTM A533 Grade B Class 1 Steel Heat No. 1195-1. Plate 2 Bottom Surface

Figure 300-10: Results of Compact K_{Ic} Fracture Toughness Tests 12" ASTM A533 Grade B Class I Steel Heat No. 1195-1; Plate 2 Bottom Surface