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PLANE STRAIN FRACTURE TOUGHNESS OF 18 Ni (250) AND 18 Ni (200) MARAGING WELDED STEEL PLATE

by H. E. Romine

Prepared *by*
U.S. NAVAL WEAPONS LABORATORY
Dahlgren, Va.

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • SEPTEMBER 1965

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ABSTRACT

Notched slow bend tests on 3/4 inch thick plate welded experimentally to simulate seam and girth welds in a 260 inch solid propellant rocket motor case are adequate to detect low levels of fracture toughness and indicate that TIG welding is preferable to MIG or shorting arc methods. Critical flaws will be detectable by current inspection methods. A simplified method for determining K_{Ic} was experimentally verified.

CONTENTS

INTRODUCTION

The general plan of the testing program was arranged at meetings in 1963 (reference (b)). An objective was to obtain a practical basis for evaluating the fracture toughness of base metal and of several types of welds in maraging steel plate materials being considered for the rocket casings. As a means of simplifying the calculation of the plane strain fracture toughness value K_{Ic} from bend test data, a study was made of the use of equation 10 described in reference (c).

Appendix A lists the results from all valid bend tests having a starting notch parallel to the plate surface.

DESCRIPTION OF MATERIAL

The 3/4 inch thick plates of maraging steel were from an air-melted 18 Ni (250) grade and from a vacuum remelted 18 Ni (200) grade. Compositions of the heats of plate and of welding wire are listed in Table 2. The main chemical differences between the two grades were in contents of titanium, molybdenum and cobalt. These analyses represented standard material at the time the test was started. Because of short supply of material at the time, several heats were used in testing each grade of plate. Additional variables under test were the effects of plate rolling direction and of four different procedures for welding. Two panels were heat treated to aged strength before welding, otherwise all welds were made on annealed plate. The test conditions are summarized in Table 22.

The welds were made by Excelco Developments Incorporated (reference (d)). This company also made the initial preparation of test bars by sectioning, grinding and machine notching, following a typical test layout shown in Figure 1.

Identification and classification of bar shipments and the tensile testing were carried out by the Mechanics Division of the Naval Research Laboratory. At the Naval Weapons Laboratory the bars were given additional machine notching if required, aged, fatigued in reverse bending to add a natural starting crack, and bend tested. A standard aging heat treatment of four hours at 915°F was used as suggested by Excelco.

Nominal tensile properties in longitudinal and transverse specimens from each heat of plate after aging are shown in Table 3. The 18 Ni (200) grade represented by the last three heats in this table had actual yield strengths in the range of 225,000 to 235,000 psi compared with 250,000 to 270,000 for the 250 grade.

DESCRIPTION OF TEST EQUIPMENT AND PROCEDURE

The method of bend testing has been described in references (c), (e) and (f). In early tests, K_{Ic} was determined by an experimental compliance method using these formulas.

$$G_{Ic} = \frac{1}{2}\left(\frac{P}{B}\right)^2 \frac{d\ (B/M)}{da} \qquad K_{Ic} = \sqrt{\frac{E\ G_{Ic}}{1 - \nu^2}}$$

(Symbols are identified in Tables 4-21 and 23.)

This method required a lengthy calibration procedure conducted on only a few bars of a test lot. It had the merit of avoiding unknown factors which might affect mathematical relations in calculating K_{Ic}. More recently, in equation 10 of reference (c), a formula for K_{Ic} was introduced, based essentially on mathematical considerations and avoiding the use of the parameters E or ν.

$$K_{Ic} = \frac{L_1}{d^{3/2}} R\left(\frac{P}{B}\right) \text{ where } R = 2.060\left\{\frac{1}{\alpha^3} - \alpha^3\right\}^{1/2}$$

$$\text{and} \quad \alpha = 1 - \frac{a}{D}$$

In the present report, both ways of determining K_{Ic} usually were tried on the same test lot in order to examine the correlation between them. A test usually was replicated about twenty times in important areas to facilitate a statistical comparison.

Some compliance testing of 250 grade bars was carried out using a constant load for calibration before this procedure was found unsatisfactory. These test values were omitted from the tables. For accurate work with the compliance method it was found necessary to use a variable calibration load for the d(B/M)/da relation which produced a calculated fiber stress at the bottom of the slot about equal to half of the yield stress (reference (e)).

Approximate locations for the starting notch in the bend tests are identified in Figure 2. A machined V-notch generally extended to 15 percent of bar depth although a few 5 percent notches were tried. For the 250 grade, a 15 percent notch plus about a 0.02 inch depth of fatigue crack proved satisfactory (combined depth of approximately 0.14 inch or 20 percent). The tougher 200 grade of maraging steel required a deeper notch in order to obtain a reasonably sharp end point of the load-deflection curve. A total depth of notch plus fatigue crack near the 28 percent optimum indicated by equation 19 of reference (c) was used. These deeper notches generally were fatigued down from a 15 percent machined notch. This made the fatigued part of the notch somewhat deeper than a proposed 0.02 inch standard extension of a machined notch. However the deeper fatigue crack did not interfere seriously with obtaining a fairly straight crack front and the practice eliminated remachining operations (for future tests, a 20 percent machined notch depth probably would be recommended).

A fatigue load was used which would produce a suitable fatigue crack after reverse bending in the range of 5,000 to 20,000 cycles using a Krouse-type plate fatigue machine adapted to 3/4 inch bars.

The total initial crack depth or "visual a" value was measured to the nearest 0.005 inch except for some early tests reported only to 0.01 inch. The a depth was based on average distance of the fatigue crack front from the surface of the bar.

A reduced test coverage of some plates was caused mainly by withholding of bars for special tests at the Naval Research Laboratory and other laboratories.

Formulas used in calculations are given in Tables 23 and 24.

RESULTS AND DISCUSSION

The individual data and results of the bend tests are listed in Tables 4 through 21 (curve types are identified in Figure 11). Tests with obvious experimental difficulties and special notch tests were not included in this summary. Some test conditions were examined with as many as 20 replicates representing about 15 inches of weld length. This coverage increased probability of finding low values of fracture toughness.

Mean K_{Ic} values calculated by equation 10 are shown graphically in Figures 3 through 6 along with the coefficient of variation and the 95 percent confidence limits for the mean. Sample size must be considered along with the statistical spread since, obviously, a large number of replicates improved accuracy of prediction. In comparing base metal and welds tested in the same direction, it will be noted that testing necessarily was divided between two panels (see test layout in Figure 1) but this should not have materially affected the overall relations.

Using as a criterion the average fracture toughness at the center of the weld it is apparent that, except for TIG welds using 110-140 amperes (little TIG) in 250 grade, the TIG welding procedures look more promising than either MIG or short arc(1) welds. It should be noted that other tests (for example, weld efficiency under tension loading) are needed for fuller evaluation of a welding process. Other procedures such as submerged arc welds remain to be evaluated.

It is of interest to compare MIG weld toughness values in annealed plate and in plate aged before welding. Evidently there was not much difference in effect on toughness between these pretreatments in either the 250 or the 200 grades allowing for possible variability in the base metal.

A 250 grade of weld wire was used for both 250 and 200 types of base plate because this was the only proven weld wire available at the time. In the case of MIG welding, toughness at the weld center was practically the same for both steel grades which suggested a possibility of equivalent deposits of fused weld wire unaffected by

(1) "Short arc" is a conventional expression for shorting arc.

base metal composition. On the other hand, the TIG weld centers showed probability of different base metal effects between the two steel grades welded with the same 250 wire so obviously there are other factors involved besides wire composition.

Another point of interest was the presence of occasional high toughness areas among the generally low results for the center of the short arc weld in 200-grade transverse tests. Conversely the little TIG weld center, tested longitudinally in 250 grade, showed spots of relatively low toughness.

The σ_{nom}/σ_{YS} ratio in Tables 4 through 21 gives a separate check on fracture toughness relations. A general objective of fracture mechanics is to develop a nominal stress equal to 100 percent of yield strength at the notch root of a natural crack, so a ratio of one is desired for an optimum combination of strength and toughness. This value of σ_{nom}/σ_{YS} was reached in many bend tests, especially in the 200 grade steel.

A bend test will demonstrate cracking tendency resulting from banded structure in the base metal. This condition was observed only in the air-melted 250 grade and was variable in extent from practically none to heavy delaminations. Actually the banding associated with delamination has been shown to improve relative resistance to propagation of surface type cracks crossing the plate rolling direction but through-thickness properties may be unsatisfactory (reference (g)). (Recent reports have indicated that the tendency toward delamination has been practically eliminated in current production.)

One of the objectives of this project was a comparison between K_{Ic} values determined by an experimental method and by a mathematical relation. The results are shown in Figures 7 and 8. The correlation between K_{Ic} by equation 10 and K_{Ic} by compliance was close to the perfect 1:1 ratio - if anything the equation method tended to give a slightly more conservative value. Theoretical equations also have been proposed by Buechner, B. Gross and others and these presumably could be evaluated by use of the data in Tables 4 through 21.

A comparison of σ_{nom}/σ_{YS} with K_{Ic} by equation 10 is shown for the two steel grades in Figures 9 and 10. Although a linear relation was noted between K_{Ic} and σ_{nom}/σ_{YS} to high values, this has a practical upper limitation in that the stress analysis assumed is for linear elasticity and is not appropriate for $\sigma_{nom} >> \sigma_{YS}$ (reference (h)).

A number of data points were located above the principal correlation zone in Figure 9. This was a real effect resulting from notch depths which were either substantially smaller or larger than the optimum range of 25 to 30 percent of bar depth indicated in reference (c). This obviously shows that, at notch depths on either side of the optimum range, the maximum nominal fiber stress at fracture in the bend test tends to become larger at a given level of fracture toughness.

The regression lines in Figures 7 through 10 should all pass through zero as a matter of basic principle, however the data were analyzed with a digital computer program which did not impose this condition. Although the regression lines were established only by actual data points, the trend toward a zero intersection is evident.

A list of calibration equations in Table 24 is presented for record. Putting a equal to zero in these equations gives an estimate of the compliance B_o/M_o of the unnotched bar. Mean values of B_o/M_o for the 250 and for the 200 grades of maraging steel are almost identical - 5.19 and 5.21 ($in^2/lb \times 10^{-6}$) - and at a probability of 0.95 there is no significant difference between them. However the range of B_o/M_o values is 4.92 to 5.35 for 250 grade and 5.02 to 5.43 for 200 grade. This considerable variability in spring constant of unnotched bars shows the problem of obtaining representative calibration specimens when using only one or two bars per group to establish a compliance relation. The variations in B_o/M_o may result from local variations in composition or structure or from internal stresses resulting from processing and machining. In a large group of tests, an average compliance basis for K_{Ic} correlations appears satisfactory but between specific test areas a variation in B_o/M_o may cause some experimental error.

A set of typical load-deflection curves is illustrated in Figure 11. The relative occurrence of these general groupings is summarized in Table 25. The distribution differs between the 250 and 200 grades with the latter showing a trend toward E and F curves.

A problem arises sometimes in choosing the exact load point to use for "pop-in" of the fatigue crack in the bend test. In a low-toughness condition the trend was toward a straight load-deflection line ending in a sharp drop-off (curves A, B and D in Figure 11) or there would be a sudden lateral shift in the load-deflection line (curve C). With our deflection magnification (83X) a pop-in by line shift was considered to be established by a minimum 0.0006 inch deflection movement at nearly constant load followed by a reduced slope of the rising load line.

Notably in 200 grade materials, the load-deflection line often showed a gradual bend to lower slope near maximum load but without any pop-in shift of the line (E and F curves in Figure 11). The change in slope was believed caused mainly by slow yielding around the crack tip to form a plastic zone. In these cases maximum load was used in K_{Ic} calculation along with the $\underline{a}$ value for the original fatigue crack front. This neglected any presumably small increase of $\underline{a}$ from slow growth in plastic zone formation. Type E and F curves characteristically occurred with high toughness values (a wider bend specimen, increasing restraint, should reduce the yielding effect if desired).

Figure 12 is a chart made by Tiffany and Lorenz (reference (i)) based on Irwin's equation.

$$a_{cr} = \frac{Q\ K_{Ic}^2}{1.21\ \pi\sigma^2}$$

The chart simplifies prediction of critical sizes of typical crack flaws based on K_{Ic} values. The flaw-size comparisons in Table 26 are based on K_{Ic} data for the important case of stress across the center of a longitudinal seam weld in a motor case. The conditions assumed were a 90 percent weld joint efficiency ($\sigma = 0.9\ \sigma_{YS}$) and a flaw of semicircular shape located at the plate surface (a = c in sketch at top left of Figure 12). Corresponding critical flaw sizes based on mean K_{Ic} values for the four welding procedures are given in the next to last column of Table 26. A more conservative approach would be to use the lowest K_{Ic} value in a series of tests. The last column in the table gives these critical flaw sizes based on minimum K_{Ic} value. Depending somewhat upon location and orientation, it is believed that crack dimensions on the order of 0.02 inch or more could easily be detected by non-destructive inspection provided a good surface finish on the motor case is achieved. In the table some of the weld procedures showed a tolerance for cracks of considerably larger dimensions (on the order of 0.1 inch). Comparing the 250 and 200 grades of steel, it should be noted that any advantage of a larger critical flaw size for TIG welds in the 200 grade might be partially offset by a lower operating stress level.

Another interesting relation brought out in Table 26 is the comparison of base metal hardness with an average of the hardness traverse across the corresponding weld center, these values being approximate criteria of relative strength. The average weld center hardness was indicated to be about the same for both grades of steel (49 to 50.5 Rockwell C). Thus weld hardness apparently was less than base metal for the 250 grade (52 Rc) and more than the base metal in the 200 grade (48.5 Rc).

CONCLUSIONS

At this stage of the investigation it appears that notched slow-bend tests, carried out with a reasonable number of replicates on 3/4 inch square bars, are adequate to detect low levels of fracture toughness in welds and base metal of the 250 and 200 grades of 18 Ni maraging steel plate stock.

Out of four welding methods tested - MIG, short arc and two variations of TIG - the two TIG procedures showed most promise of giving good fracture toughness properties for the critical longitudinal seam construction in the rocket motor case.

The maximum size of flaws which can be tolerated under operating conditions at the center of the better welds was indicated to be in a range detectable by current non-destructive inspection methods.

A recently introduced mathematical formula for determining K_{Ic} with the bend test was found to give results comparable to those obtained by the experimental compliance method.

REFERENCES

(a) NRL Work Request WR-4-0065 of 25 May 1964

(b) Conferences at the Naval Research Laboratory, 9-10 May 1963 attended by representatives of the International Nickel Company, U. S. Steel Corporation, Excelco Developments Incorporated, Mellon Institute, National Aeronautics and Space Administration, Air Force Materials Laboratory, Navy Bureau of Weapons, Naval Research Laboratory and Naval Weapons Laboratory

(c) Kies, J. A., Smith, H. L., Romine, H. E., Bernstein, H. "Fracture Testing of Weldments" presented at the ASTM Symposium on Fracture Toughness Testing and Its Applications, Chicago, 23-24 June 1964. Also issued as NRL Mechanics Division Quarterly Progress Report to NASA for period 1 April 1964 to 30 June 1964

REFERENCES (Continued)

(d) Weld wire was described in ltr Excelco Developments Inc. (W. D. Abbott) to Naval Research Laboratory (H. L. Smith, Code 6212) dated 9 Sept 1964, Reports of the welding procedure used on each plate were sent by Excelco to the Naval Research Laboratory, Code 6212

(e) Smith, H. L., Romine, H. E., "Fracture Toughness Evaluation of Welds in Maraging Steel", presented at the Fourth Maraging Steel Project Review sponsored by the Materials Engineering Branch, Materials Application Division, Air Force Materials Laboratory, Dayton, 9-11 June 1964

(f) Romine, H. E. "Plane Strain Fracture Toughness Measurements of Solid Booster Case Materials", Third Maraging Steel Project Review, Technical Documentary Report No. RTD-TDR-63-4048, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio, November 1963. Also issued as NWL Report No. 1884, September 1963

(g) NWL Report No. 1923, 30 June 1964

(h) Irwin, G. R. "Structural Aspects of Brittle Fracture", Applied Materials Research, Vol. 3, No. 2, p. 65, April 1964

(i) Tiffany, C. F., and Lorenz, P. M., "An Investigation of Low Cycle Fatigue Failures Using Applied Fracture Mechanics," Tec. Doc. Rept. ML, TDR-64-53, May 1964; prepared under Contract AF 33(657)-10251 by the Boeing Company

TABLE I. LIST OF PLATES GIVING DIRECTION AND NOMINAL IDENTIFICATION CODES FOR THE FRACTURE TESTS

The test direction is given in relation to the principal rolling direction of the base plate

			Base Metal Tests		Weld Tests				
Plate Number	18 Ni Maraging Steel Grade (1000 psi)	Heat Number	Test Direction	Code Number	Weld Type	Base Metal Condition Before Weld	Test Direction	Nominal Codes for Weld Center Tests	Nominal Codes for Weld Edge Tests
1	250	X14636	$\perp$	1	Little TIG	Annealed	$\parallel$	IV-AA, IV-AC	IV-AB, IV-AD
2	250	X14636	$\parallel$	2	Little TIG	Annealed	$\perp$	IV-BA, IV-BC	IV-BB, IV-BD
5	250	X14636	$\perp$	5	MIG	Annealed	$\parallel$	II-AA	II-AB
6	250	X53013	$\parallel$	6	MIG	Annealed	$\perp$	II-BA, II-BC	II-BB, II-BD
7	250	X53013	$\parallel$	7	Short Arc	Annealed	$\perp$	V-BA, V-BC	V-BB, V-BD
8	250	X53013	$\parallel$	8	Big TIG	Annealed	$\perp$	III-BA, III-BC	III-BB, III-BD
9	250	X53013	$\parallel$	9	MIG	Aged	$\perp$	VI-BA, VI-BC	VI-BB, VI-BD
10	250	X53013	$\perp$	10	Big TIG	Annealed	$\parallel$	III-AA, III-AC	III-AB, III-AD
11	250	X53013	$\perp$	11	Short Arc	Annealed	$\parallel$	V-AA, V-AC	V-AB, V-AD
14	200	3960819	$\perp$	14	Little TIG	Annealed	$\parallel$	XII-AA, XII-AC	XII-AB, XII-AD
15	200	3951215	$\parallel$	15	Little TIG	Annealed	$\perp$	XII-BA, XII-BC	XII-BB, XII-BD
18	200	3951217	$\perp$	18	MIG	Annealed	$\parallel$	XIII-AA, XIII-AC	XIII-AB, XIII-AD
19	200	3960819	$\parallel$	19	MIG	Annealed	$\perp$	XIII-BA, XIII-BC	XIII-BB, XIII-BD
20	200	3951215	$\parallel$	20	Short Arc	Annealed	$\perp$	XIV-AA, XIV-AC	XIV-AB, XIV-AD
21	200	3951217	$\parallel$	21	Big TIG	Annealed	$\perp$	XIV-BA, XIV-BC	XIV-BB, XIV-BD
22	200	3951215	Notest	(22)	MIG	Aged	$\perp$	XV-BA, XV-BC	XV-BB, XV-BD
23	200	3951215	$\perp$	23	Big TIG	Annealed	$\parallel$	XV-AA, XV-AC	XV-AB, XV-AD
24	200	3951215	$\perp$	24	Short Arc	Annealed	$\parallel$	XVI-AA, XVI-AC	XVI-AB, XVI-AD

TABLE 2. COMPOSITIONS OF HEATS OF MARAGING STEEL USED FOR FRACTURE TOUGHNESS TESTS OF WELDMENTS

Manufacturers' Analyses

ELEMENT	HEAT X14636 AIR MELTED 250 GRADE USED FOR 3/4 INCH PLATES 1, 2 AND 5	HEAT X53015 AIR MELTED 250 GRADE USED FOR 3/4 INCH PLATES 6,7,8,9,10 AND 11	HEAT 3951215 VACUUM REMELTED 200 GRADE USED FOR 3/4 INCH PLATES 15,20, 22,23 AND 24	HEAT 3951217 VACUUM REMELTED 200 GRADE USED FOR 3/4 INCH PLATES 18 AND 21	HEAT 3960819 VACUUM REMELTED 200 GRADE USED FOR 3/4 INCH PLATES 14 AND 19	HEAT 08562 [1] VACUUM REMELTED 250 GRADE USED FOR WELD WIRE IN PLATES 8,10, 21 AND 23	HEAT 08850 [1] VACUUM REMELTED 250 GRADE USED FOR WELD WIRE IN PLATES 1,2, 5,6,7,9,11,14, 15,18,19,20, 22 AND 24
Carbon	0.03	0.02	0.025	0.020	0.016	0.01	0.01
Manganese	0.06	0.02	0.09	0.09	0.07	0.03	0.03
Phosphorus	0.005	0.006	0.007	0.007	0.007	0.002	0.002
Sulfur	0.010	0.009	0.006	0.006	0.007	0.005	0.005
Silicon	0.10	0.04	0.05	0.04	0.06	0.01	0.03
Nickel	18.37	17.59	18.35	18.35	18.35	18.12	18.10
Molybdenum	4.70	4.80	4.07	4.05	3.98	4.70	4.52
Cobalt	8.49	8.06	7.55	7.50	7.50	8.11	8.00
Titanium	0.42	0.49	0.19	0.19	0.20	0.48	0.46
Aluminum	0.13	0.07	0.13	0.14	0.13	0.11	0.10
Copper	---	0.12	---	---	---	---	---
Zirconium	---	---	---	---	---	0.02	0.015
Calcium	---	---	---	---	---	0.02	0.02 added
Oxygen	---	---	---	---	---	10.0 ppm	12.0 ppm
Nitrogen	---	---	---	---	---	13.0 ppm	16.0 ppm
Hydrogen	---	---	---	---	---	1.0 ppm	1.0 ppm

(1) These analyses were furnished by Excelco Developments Inc. on 9 Sept 1964

TABLE 3. MECHANICAL PROPERTIES OF MARAGING STEEL PLATES 3/4 INCH THICK USED FOR FRACTURE TOUGHNESS TESTS

Aged properties (915°F - 4 hrs) measured in typical base material of each heat by the Naval Research Laboratory

Heat Number	Test Direction Related to Plate Rolling Direction	Yield Strength at 0.2% Offset (psi)	Ultimate Tensile Strength (psi)	Elongation in 2 in. (%)	Reduction of Area (%)	Hardness Rc
X14636	$\parallel$	263,000	272,000	4.0	30	50 - 53
	$\perp$	248,000	259,000	4.6	33	
X53013	$\parallel$	258,000	265,000	4.7	35	50 - 53
	$\perp$	268,000	275,000	4.0	27	
3951215	$\parallel$	225,000	233,000	12	52	48 - 49
	$\perp$	228,000	236,000	12	53	
3951217	$\parallel$	230,000	234,000	13	53	48 - 49
	$\perp$	225,000	235,000	12	45	
3960819	$\parallel$	233,000	238,000	13	56	48 - 49
	$\perp$	229,000	235,000	13	55	

TABLE 4. FRACTURE TOUGHNESS TESTS OF PLATE NO. 1, 250 KSI GRADE OF MARAGING STEEL, LITTLE TIG WELD.

Base Metal: 18 Ni(250) maraging steel plate 3/4 inch thick, heat No. X14636, air melted. Mill annealed, aged after welding-915°F, 4 hrs, air cool, yield strengths: 263,000 psi ‖ to R.D.; 248,000 psi ⊥ to R.D.

Weld: Tig weld (110-140 amps) by Excelco Developments Inc.

Notch Condition: Machined V-notch extended by fatigue crack, all notches parallel to plate surface.

Test Conditions: Bar bending length was 6.00 inches, tests were conducted at room temperature.

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-in) (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	σ_{nom}/σ_{YS}	B/M Reciprocal of Spring Constant (in^2/lb)(10^{-6})	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} by Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
I- 1	⊥	BM	.751	.749	6,990	.16	83.5	.73	5.88	.165	94.0	A
I- 2	⊥	BM	.748	.750	6,820	.15	78.0	.69	5.86	.165	92.0	A
I- 3	⊥	BM	.750	.751	7,290	.14	79.5	.71	5.68	.150	92.5	B
I- 4	⊥	BM	.750	.751	7,430	.12	74.0	.68	5.57	.140	90.5	A
I- 5	⊥	BM	.749	.750	7,140	.14	78.0	.70	5.81	.160	94.5	A
I- 6	⊥	BM	.750	.750	6,070	.15	69.5	.61	5.95	.170	83.0	C
I- 7	⊥	BM	.750	.750	7,000	.15	80.0	.71	5.79	.160	92.5	C
I- 8	⊥	BM	.749	.750	6,940	.14	76.0	.68	5.93	.170	95.0	B
I- 9	⊥	BM	.749	.750	7,080	.13	74.5	.67	5.75	.155	91.5	A
I-10	⊥	BM	.749	.751	6,680	.14	73.0	.65	5.86	.165	90.0	A
I-11	⊥	BM	.751	.750	7,350	.13	77.0	.69	5.61	.145	92.0	A
I-12	⊥	BM	.751	.750	6,950	.15	79.5	.70	5.87	.165	93.5	A
I-13	⊥	BM	.750	.750	6,930	.13	73.0	.65	5.62	.145	86.5	A
I-14	⊥	BM	.749	.748	6,880	.14	75.5	.67	5.68	.150	87.0	A
I-17	⊥	BM	.749	.751	6,580	.15	75.0	.66	5.89	.170	90.5	C
I-18	⊥	BM	.751	.752	6,920	.14	75.5	.67	5.79	.160	91.5	C
I-19	⊥	BM	.750	.750	7,470	.14	82.0	.73	5.77	.160	99.0	B
I-20	⊥	BM	.750	.750	7,000	.14	76.5	.68	5.78	.160	92.5	A
I-21	⊥	BM	.750	.750	7,440	.13	78.0	.70	5.60	.145	93.0	A
I-22	⊥	BM	.750	.750	6,930	.14	76.0	.68	5.66	.150	87.5	C
I-25	⊥	BM	.750	.751	7,000	.13	73.5	.66	5.44	.140	85.0	A
I-26	⊥	BM	.751	.750	6,280	.15	71.5	.63	5.71	.155	81.5	A
I-27	⊥	BM	.750	.750	7,270	.14	79.5	.71	5.63	.145	91.0	A
I-28	⊥	BM	.750	.750	7,270	.13	76.0	.69	5.58	.140	88.5	C
I-29	⊥	BM	.751	.751	7,190	.13	75.0	.68	5.42	.125	82.0	A
I-30	⊥	BM	.751	.749	7,000	.13	73.5	.66	5.55	.140	85.0	A
Statistics of K_{Ic} values (Eq. 10): Mean - 76.27, c.v.-.042, 95% conf. limits: 75.0 - 77.6, 90% conf. limits: 75.2 - 77.4.												
IV-AA- 1	‖	CW	.750	.750	7,760	.15	88.5	.74	6.00	---	---	B
IV-AA- 2	‖	CW	.746	.748	7,610	.13	80.5	.68	5.86	---	---	C
IV-AA- 3	‖	CW	.750	.750	7,360	.16	87.5	.72	6.09	---	---	A
IV-AA- 4	‖	CW	.749	.751	7,980	.15	91.0	.76	5.97	---	---	C
IV-AA- 5	‖	CW	.751	.750	8,660	.16	103.0	.85	5.93	---	---	F
IV-AA- 6	‖	CW	.746	.748	8,450	.14	93.5	.78	6.30	---	---	F
IV-AA- 7	‖	CW	.751	.751	6,250	.20	86.0	.70	6.70	---	---	F
IV-AA- 8	‖	CW	.749	.751	7,900	.15	90.0	.75	6.07	---	---	C
IV-AA- 9	‖	CW	.750	.751	5,870	.16	70.0	.58	6.30	---	---	F
IV-AA-10	‖	CW	.750	.750	6,510	.15	74.0	.62	6.03	---	---	D
IV-AA-11	‖	CW	.750	.750	5,270	.15	60.0	.50	6.15	---	---	F
IV-AA-12	‖	CW	.750	.750	7,490	.15	85.5	.71	6.12	---	---	F
IV-AA-13	‖	CW	.751	.749	6,460	.15	74.0	.62	6.18	---	---	-
IV-AA-14	‖	CW	.749	.751	7,080	.15	80.5	.67	5.97	---	---	-
IV-AA-15	‖	CW	.751	.750	6,630	.15	75.5	.63	6.02	---	---	D
IV-AA-16	‖	CW	.751	.751	5,390	.16	64.0	.53	6.14	---	---	-
IV-AA-17	‖	CW	.749	.751	7,080	.19	91.5	.74	6.48	---	---	F
IV-AA-18	‖	CW	.749	.751	8,010	.16	95.5	.79	6.12	---	---	-
IV-AA-19	‖	CW	.751	.751	7,590	.17	93.5	.77	6.24	---	---	F
IV-AA-20	‖	CW	.751	.751	6,660	.16	79.0	.65	6.09	---	---	F
IV-AA-21	‖	CW	.746	.746	7,000	.19	94.5	.77	6.53	---	---	F
Statistics of K_{Ic} values (Eq. 10): Mean - 83.67, c.v.-.133, 95% conf. limits: 78.6 - 88.7, 90% conf. limits: 79.5 - 87.9.												
IV-AD- 4	‖	FZ	.750	.750	7,970	.19	107.0	.87	6.37	---	---	B
IV-AD- 5	‖	FZ	.751	.748	8,120	.16	97.5	.84	6.01	---	---	B
IV-AD- 6	‖	FZ	.749	.749	8,170	.17	102.0	.83	6.05	---	---	F
IV-AD- 7	‖	FZ	.750	.750	8,160	.19	109.0	.89	6.34	---	---	C
IV-AD- 8	‖	FZ	.751	.751	7,920	.15	90.0	.75	5.79	---	---	E
IV-AD- 9	‖	FZ	.750	.748	8,680	.16	104.5	.86	5.94	---	---	C
IV-AD-10	‖	FZ	.749	.751	7,740	.16	92.0	.76	5.95	---	---	C
Statistics of K_{Ic} values (Eq. 10): Mean - 100.29, c.v.-.073, 95% conf. limits: 93.5 - 107.1, 90% conf. limits: 94.9 - 105.7.												
IV-AC- 4	‖	HAZ	.750	.751	7,790	.17	96.0	.79	5.95	---	---	B
IV-AC- 5	‖	HAZ	.750	.751	6,130	.16	73.0	.60	5.99	---	---	C
IV-AC- 6	‖	HAZ	.748	.751	7,010	.15	80.0	.66	6.06	---	---	C
IV-AB- 9	‖	HAZ	.749	.750	9,280	.14	101.5	.85	5.90	---	---	C
IV-AB-10	‖	HAZ	.750	.750	8,070	.14	88.5	.74	5.92	---	---	A
IV-AB-11	‖	HAZ	.750	.749	7,470	.14	82.0	.69	5.82	---	---	A
IV-AB-12	‖	HAZ	.750	.749	7,470	.14	82.0	.69	5.87	---	---	C
IV-AB-13	‖	HAZ	.748	.749	9,060	.15	103.5	.86	6.03	---	---	C
IV-AB-14	‖	HAZ	.749	.750	9,350	.14	102.5	.86	5.91	---	---	A
IV-AB-15	‖	HAZ	.750	.750	10,400	.14	114.0	.96	5.77	---	---	A
IV-AB-16	‖	HAZ	.750	.749	9,670	.14	106.0	.89	5.81	---	---	C
IV-AB-17	‖	HAZ	.751	.750	8,660	.16	103.0	.85	6.09	---	---	A
IV-AB-18	‖	HAZ	.751	.749	7,670	.16	92.0	.76	6.09	---	---	C
Statistics of K_{Ic} values (Eq. 10): Mean - 94.15, c.v.-.130, 95% conf. limits: 86.7 - 101.6, 90% conf. limits: 88.1 - 100.2.												
IV-AC- 7	‖	DB	.750	.751	6,800	.17	83.5	.68	6.19	---	---	C
IV-AC- 8	‖	DB	.750	.750	6,000	.17	74.5	.61	6.02	---	---	E
IV-AC- 9	‖	DB	.750	.752	7,230	.15	82.0	.68	5.81	---	---	B
IV-AB- 1	‖	DB	.749	.750	7,890	.10	90.0	.75	5.90	---	---	A
IV-AB- 2	‖	DB	.750	.750	9,530	.08	99.5	.85	5.76	---	---	A
IV-AB- 3	‖	DB	.749	.751	9,430	.12	116.0	.95	6.12	---	---	C
IV-AB- 4	‖	DB	.749	.750	7,880	.08	82.5	.70	5.76	---	---	C
IV-AB- 5	‖	DB	.749	.750	8,910	.09	97.5	.82	5.85	---	---	A
IV-AB- 6	‖	DB	.748	.750	10,160	.075	106.0	.90	5.75	---	---	A
IV-AB- 7	‖	DB	.750	.750	6,970	.11	83.0	.68	6.04	---	---	A
IV-AB- 8	‖	DB	.750	.750	8,930	.08	102.0	.85	5.78	---	---	A
IV-AB-19	‖	DB	.750	.751	8,670	.14	94.5	.79	5.75	---	---	C
IV-AB-20	‖	DB	.750	.750	8,030	.15	91.5	.76	5.90	---	---	C
Statistics of K_{Ic} values (Eq. 10): Mean - 92.50, c.v.-.125, 95% conf. limits: 85.5 - 99.5, 90% conf. limits: 86.8 - 98.2.												

TABLE 5. FRACTURE TOUGHNESS TESTS OF PLATE NO. 2, 250 KSI GRADE OF MARAGING STEEL, LITTLE TIG WELD.

Base Metal: 18 Ni(250) maraging steel plate 3/4 inch thick, heat No. X14636, air melted. Mill annealed, aged after welding-915°F, 4 hrs, air cool, yield strengths: 263,000 psi $\parallel$ to R.D.; 248,000 psi $\perp$ to R.D.

Weld: Tig Weld (110-140 amps) by Excelco Developments Inc.

Notch Condition: Machined V-notch extended by fatigue crack, all notches parallel to plate surface.

Test Conditions: Bar bending length was 6.00 inches, tests were conducted at room temperature.

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-in (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	σ_{nom}/σ_{YS}	B/M Reciprocal of Spring Constant (in^2/lb)(10^{-6})	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} by Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
2- 1	$\parallel$	BM	.751	.750	12,490	.06	84.0	.92	5.33	---	---	B
2- 2	$\parallel$	BM	.750	.750	12,800	.05	78.5	.89	5.28	---	---	B
2- 4	$\parallel$	BM	.747	.750	10,840	.07	80.0	.80	5.30	---	---	B
2- 5	$\parallel$	BM	.751	.749	14,780	.05	91.0	1.03	5.19	---	---	D
2- 7	$\parallel$	BM	.750	.748	12,530	.06	85.0	.91	5.33	---	---	D
2- 8	$\parallel$	BM	.748	.750	13,290	.05	81.5	.93	5.19	---	---	B
2-10	$\parallel$	BM	.750	.748	14,080	.05	87.0	.99	5.25	---	---	B
2-11	$\parallel$	BM	.750	.749	11,970	.07	88.5	.89	5.34	---	---	B
2-12	$\parallel$	BM	.750	.750	13,730	.05	84.5	.96	5.23	---	---	D
2-14	$\parallel$	BM	.750	.749	11,090	.07	82.0	.82	5.35	---	---	B
2-15	$\parallel$	BM	.750	.749	11,070	.08	88.0	.85	5.24	---	---	A
2-16	$\parallel$	BM	.750	.750	12,190	.07	90.0	.90	5.36	---	---	B
2-17	$\parallel$	BM	.751	.751	11,720	.07	86.5	.86	5.41	---	---	B
2-18	$\parallel$	BM	.751	.750	9,990	.08	79.5	.76	5.41	---	---	A
2-20	$\parallel$	BM	.751	.751	6,100	.20	84.5	.69	6.49	---	---	D
2-21	$\parallel$	BM	.750	.750	7,130	.16	85.0	.70	5.96	---	---	A
2-22	$\parallel$	BM	.751	.751	6,980	.17	86.0	.71	6.12	---	---	A
2-23	$\parallel$	BM	.751	.750	7,660	.15	87.5	.73	5.97	---	---	A
2-24	$\parallel$	BM	.752	.751	7,180	.15	82.0	.68	5.88	---	---	C
2-25	$\parallel$	BM	.751	.750	11,000	.07	81.5	.81	5.30	---	---	B
2-27	$\parallel$	BM	.750	.750	12,190	.05	75.0	.85	5.23	---	---	B
2-28	$\parallel$	BM	.751	.750	7,940	.14	87.0	.73	5.99	---	---	B
2-29	$\parallel$	BM	.750	.750	13,120	.05	80.5	.92	5.18	---	---	D
2-30	$\parallel$	BM	.749	.750	11,540	.07	85.5	.93	5.27	---	---	B
Statistics of K_{Ic} values (Eq. 10): Mean - 84.19, c.v. - .046, 95% conf. limits: 82.6 - 85.8, 90% conf. limits: 82.8 - 85.5.												
IV-BA- 1	$\perp$	CW	.749	.751	5,410	.17	66.5	.58	5.90	---	---	C
IV-BA- 2	$\perp$	CW	.750	.750	4,800	.16	57.0	.50	6.08	---	---	D
IV-BA- 3	$\perp$	CW	.750	.750	5,930	.16	71.0	.62	6.01	---	---	C
IV-BA- 4	$\perp$	CW	.750	.750	5,330	.15	61.0	.54	5.90	---	---	C
IV-BA- 5	$\perp$	CW	.750	.750	5,530	.17	68.0	.60	6.01	---	---	A
IV-BA- 6	$\perp$	CW	.750	.749	4,480	.18	58.0	.50	6.40	---	---	C
IV-BA- 7	$\perp$	CW	.751	.751	5,510	.14	60.0	.54	5.77	---	---	C
IV-BA- 8	$\perp$	CW	.751	.750	5,910	.15	67.5	.60	5.85	---	---	A
IV-BA- 9	$\perp$	CW	.750	.751	7,270	.14	79.5	.71	5.74	---	---	F
IV-BA-10	$\perp$	CW	.751	.750	6,190	.14	67.5	.60	5.80	---	---	F
IV-BA-11	$\perp$	CW	.750	.751	6,470	.16	77.0	.67	5.99	---	---	F
IV-BA-12	$\perp$	CW	.750	.751	7,200	.15	82.0	.72	6.27	---	---	F
IV-BA-13	$\perp$	CW	.750	.750	6,230	.18	80.5	.70	6.43	---	---	F
IV-BA-14	$\perp$	CW	.750	.749	5,400	.14	59.0	.53	5.69	---	---	E
IV-BA-15	$\perp$	CW	.750	.750	6,800	.16	81.0	.71	6.11	---	---	F
IV-BA-16	$\perp$	CW	.751	.750	6,580	.15	75.0	.66	6.00	---	---	D
IV-BA-17	$\perp$	CW	.751	.751	5,730	.16	68.0	.60	6.03	---	---	E
IV-BA-18	$\perp$	CW	.751	.750	6,070	.16	72.5	.63	6.01	---	---	C
IV-BA-19	$\perp$	CW	.751	.751	6,660	.160	79.0	.69	6.38	---	---	F
IV-BA-20	$\perp$	CW	.750	.751	6,470	.170	79.5	.70	5.98	---	---	C
IV-BC- 1	$\perp$	CW	.751	.750	8,390	.07	62.0	.66	5.32	---	---	B
IV-BC- 2	$\perp$	CW	.751	.749	10,520	.06	71.5	.80	5.21	---	---	D
IV-BC- 3	$\perp$	CW	.751	.750	9,790	.06	66.5	.75	5.04	---	---	D
IV-BC- 4	$\perp$	CW	.751	.751	9,480	.06	64.0	.72	5.03	---	---	D
IV-BC- 5	$\perp$	CW	.749	.750	8,890	.07	65.5	.70	5.07	---	---	B
IV-BC-10	$\perp$	CW	.750	.750	6,530	.15	75.5	.66	6.26	---	---	F
Statistics of K_{Ic} values (Eq. 10): Mean - 69.77, c.v. - .112, 95% conf. limits: 66.6 - 72.9, 90% conf. limits: 67.2 - 72.4.												
IV-BB-18	$\perp$	FZ	.749	.751	6,480	.17	79.5	.70	5.87	---	---	A
IV-BD- 4	$\perp$	FZ	.751	.750	6,750	.15	77.0	.68	5.97	---	---	A
IV-BD- 5	$\perp$	FZ	.750	.751	7,600	.15	86.5	.76	5.79	---	---	B
IV-BD- 6	$\perp$	FZ	.751	.750	6,600	.15	75.5	.67	5.50	---	---	C
IV-BD- 7	$\perp$	FZ	.751	.750	6,150	.19	82.5	.71	6.28	---	---	C
IV-BD- 8	$\perp$	FZ	.750	.751	7,830	.15	89.0	.79	5.66	---	---	C
IV-BD- 9	$\perp$	FZ	.751	.750	7,140	.15	81.5	.72	5.80	---	---	-
IV-BD-10	$\perp$	FZ	.750	.750	6,530	.15	74.5	.66	6.26	---	---	
Statistics of K_{Ic} values (Eq. 10): Mean - 80.75, c.v. - .064, 95% conf. limits: 76.4 - 85.1, 90% conf. limits: 77.3 - 84.2.												
IV-BB- 8	$\perp$	HAZ	.750	.749	6,800	.18	88.0	.76	6.05	---	---	A
IV-BB- 9	$\perp$	HAZ	.751	.751	5,190	.18	67.0	.58	6.26	---	---	C
IV-BB-10	$\perp$	HAZ	.750	.750	5,730	.17	71.0	.62	6.01	---	---	C
IV-BB-11	$\perp$	HAZ	.750	.750	5,200	.15	59.5	.52	5.84	---	---	A
IV-BB-12	$\perp$	HAZ	.750	.751	5,470	.19	73.0	.63	5.86	---	---	C
IV-BB-13	$\perp$	HAZ	.751	.750	8,190	.14	89.5	.80	5.69	---	---	D
IV-BB-14	$\perp$	HAZ	.749	.747	4,490	.19	60.5	.53	6.26	---	---	C
IV-BB-15	$\perp$	HAZ	.750	.750	6,670	.15	76.0	.67	5.96	---	---	A
IV-BB-16	$\perp$	HAZ	.751	.751	7,500	.15	85.5	.75	5.75	---	---	B
IV-BB-17	$\perp$	HAZ	.749	.750	6,140	.17	76.5	.66	5.82	---	---	A
IV-BB-19	$\perp$	HAZ	.751	.751	5,860	.170	72.0	.63	6.12	---	---	A
Statistics of K_{Ic} values (Eq. 10): Mean - 74.41, c.v. - .137, 95% conf. limits: 67.6 - 81.2, 90% conf. limits: 68.9 - 80.0.												
IV-BB- 1	$\perp$	DB	.750	.750	5,440	.15	62.0	.55	6.02	---	---	A
IV-BB- 2	$\perp$	DB	.750	.751	5,010	.17	61.5	.54	6.06	---	---	C
IV-BB- 3	$\perp$	DB	.751	.751	5,020	.16	59.5	.52	5.93	---	---	C
IV-BB- 4	$\perp$	DB	.751	.750	5,330	.16	63.5	.56	6.02	---	---	C
IV-BB- 5	$\perp$	DB	.751	.750	6,680	.15	76.0	.67	5.83	---	---	B
IV-BB- 6	$\perp$	DB	.750	.750	6,880	.13	72.0	.65	5.70	---	---	B
IV-BB- 7	$\perp$	DB	.749	.749	6,010	.16	72.0	.63	5.91	---	---	A
IV-BB-20	$\perp$	DB	.751	.749	6,580	.130	69.0	.62	5.71	---	---	B
Statistics of K_{Ic} values (Eq. 10): Mean - 66.94, c.v. - .091, 95% conf. limits: 61.9 - 72.0, 90% conf. limits: 62.9 - 71.0.												

TABLE 6. FRACTURE TOUGHNESS TESTS OF PLATE NO. 5, 250 KSI GRADE OF MARAGING STEEL, MIG WELD.

Base Metal: 18 Ni(250) maraging steel plate 3/4 inch thick, heat No. X14636, air melted. Mill annealed, aged after welding-915°F, 4 hrs, air cool, yield strengths: 263,000 psi $\parallel$ to R. D.; 248,000 psi ⊥ to R.D.

Weld: Mig weld by Excelco Developments Inc.

Notch Condition: Machined V-notch extended by fatigue crack, all notches parallel to plate surface.

Test Conditions: Bar bending length was 6.00 inches, tests were conducted at room temperature.

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-in (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	$\frac{\sigma_{nom}}{\sigma_{YS}}$	B/M Reciprocal of Spring Constant (in^2/lb)(10^{-6})	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} by Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
5- 1	⊥	BM	.749	.749	10,230	.07	75.5	.80	4.95	---	---	C
5- 4	⊥	BM	.751	.750	11,150	.07	82.0	.88	4.89	---	---	D
5- 5	⊥	BM	.750	.750	11,150	.07	82.0	.88	4.87	---	---	D
5- 8	⊥	BM	.750	.749	10,920	.06	74.0	.83	4.98	---	---	D
5-11	⊥	BM	.750	.751	7,870	.13	82.0	.74	5.48	---	---	C
5-12	⊥	BM	.749	.750	7,560	.14	83.0	.74	5.46	---	---	B
5-13	⊥	BM	.750	.750	7,330	.14	80.5	.72	5.58	---	---	C
5-14	⊥	BM	.749	.750	7,610	.13	79.5	.72	5.36	---	---	C
5-16	⊥	BM	.750	.750	6,330	.14	69.5	.62	5.57	---	---	C
5-17	⊥	BM	.751	.746	6,790	.13	72.0	.65	5.44	---	---	C
5-18	⊥	BM	.750	.751	6,880	.14	75.0	.67	5.42	---	---	C
5-19	⊥	BM	.751	.751	6,920	.15	79.0	.69	5.79	---	---	B
5-20	⊥	BM	.751	.749	7,260	.14	79.5	.71	5.52	---	---	C
5-21	⊥	BM	.750	.751	7,330	.14	80.0	.71	5.50	---	---	B
5-22	⊥	BM	.750	.751	7,410	.13	77.0	.70	5.42	---	---	C
5-23	⊥	BM	.751	.751	7,320	.14	79.5	.71	5.55	---	---	F
5-24	⊥	BM	.750	.751	6,830	.13	71.0	.64	5.45	---	---	C
5-25	⊥	BM	.749	.750	7,280	.14	79.5	.71	5.48	---	---	C

Statistics of K_{Ic} values (Eq. 10): Mean - 77.81, c.v. - .052, 95% conf. limits: 75.7 - 79.8, 90% conf. limits: 76.1 - 79.5.

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-in (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	$\frac{\sigma_{nom}}{\sigma_{YS}}$	B/M Reciprocal of Spring Constant (in^2/lb)(10^{-6})	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} by Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
11-AA- 1	$\parallel$	CW	.750	.750	6,560	.14	72.0	.60	5.80	---	---	D
11-AA- 4	$\parallel$	CW	.749	.749	6,810	.13	71.5	.61	5.80	---	---	D
11-AA- 6	$\parallel$	CW	.750	.750	6,750	.13	70.5	.60	5.66	---	---	D
11-AA- 7	$\parallel$	CW	.749	.750	5,870	.14	64.5	.54	5.74	---	---	C
11-AA- 8	$\parallel$	CW	.750	.750	8,200	.13	85.5	.73	5.58	---	---	D
11-AA-10	$\parallel$	CW	.750	.751	7,150	.12	71.0	.61	5.47	---	---	D
11-AA-11	$\parallel$	CW	.750	.750	7,570	.12	75.5	.65	5.55	---	---	D
11-AA-13	$\parallel$	CW	.750	.751	7,010	.15	80.0	.66	5.66	---	---	F
11-AA-16	$\parallel$	CW	.751	.751	6,830	.13	71.0	.60	5.52	---	---	D

Statistics of K_{Ic} values (Eq. 10): Mean - 73.50, c.v. - .083, 95% conf. limits: 68.8 - 78.2, 90% conf. limits: 69.7 - 77.3.

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-in (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	$\frac{\sigma_{nom}}{\sigma_{YS}}$	B/M Reciprocal of Spring Constant (in^2/lb)(10^{-6})	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} by Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
11-AB- 5	$\parallel$	HAZ	.750	.751	9,770	.15	115.0	.93	5.76	---	---	F
11-AB-15	$\parallel$	HAZ	.751	.750	9,120	.15	104.0	.87	5.64	---	---	F
11-AB-16	$\parallel$	HAZ	.750	.750	8,800	.15	100.5	.84	5.79	---	---	F
11-AB-17	$\parallel$	HAZ	.750	.750	10,300	.14	113.0	.95	5.70	---	---	F
11-AB-18	$\parallel$	HAZ	.750	.750	9,590	.14	105.0	.88	5.63	---	---	B
11-AB-19	$\parallel$	HAZ	.750	.750	9,470	.15	108.0	.90	5.74	---	---	F
11-AB-20	$\parallel$	HAZ	.749	.751	9,420	.14	102.5	.86	5.61	---	---	F

Statistics of K_{Ic} values (Eq. 10): Mean - 106.86, c.v. - .051, 95% conf. limits: 101.8 - 111.9, 90% conf. limits: 102.9 - 110.8.

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-in (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	$\frac{\sigma_{nom}}{\sigma_{YS}}$	B/M Reciprocal of Spring Constant (in^2/lb)(10^{-6})	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} by Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
11-AB- 2	$\parallel$	DB	.750	.751	8,130	.16	97.0	.80	5.78	---	---	A
11-AB-12	$\parallel$	DB	.750	.749	7,300	.16	87.0	.72	5.97	---	---	E
11-AB-13	$\parallel$	DB	.750	.750	9,730	.15	111.0	.92	5.74	---	---	F

Statistic of K_{Ic} values (Eq. 10): Mean - 98.33

TABLE 7. FRACTURE TOUGHNESS TESTS OF PLATE NO. 6, 250 KSI GRADE OF MARAGING STEEL, MIG WELD.

Base Metal: 18 Ni(250) maraging steel plate 3/4 inch thick, heat No. X53013, air melted. Mill annealed, aged after welding-915°F, 4 hrs, air cool, yield strengths: 260,000 psi ∥ to R.D.; 254,000 psi ⊥ to R.D.

Weld: Mig weld by Excelco Developments Inc.

Notch Condition: Machined V-notch extended by fatigue crack, all notches parallel to plate surface.

Test Conditions: Bar bending length was 6.00 inches, tests were conducted at room temperature.

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-in (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	σ_{nom}/σ_{YS}	B/M Reciprocal of Spring Constant (in^2/lb)(10^{-6})	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} by Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
6- 1	∥	BM	.750	.750	14,080	.070	103.5	1.06	5.19	---	---	D
6- 2	∥	BM	.750	.750	12,230	.07	90.0	.92	5.10	---	---	D
6- 3	∥	BM	.750	.750	8,110	.145	90.5	.77	5.73	---	---	A
6- 4	∥	BM	.751	.750	7,240	.165	73.0	.73	6.00	---	---	A
6- 6	∥	BM	.749	.750	14,130	.07	104.0	1.06	5.21	---	---	D
6- 7	∥	BM	.750	.750	7,330	.140	80.5	.68	5.87	---	---	B
6- 9	∥	BM	.750	.750	13,760	.07	101.0	1.03	5.17	---	---	D
6-10	∥	BM	.751	.750	7,390	.150	84.5	.71	5.85	---	---	C
6-11	∥	BM	.750	.750	8,370	.140	91.5	.78	5.70	---	---	D
6-12	∥	BM	.749	.751	7,900	.15	90.0	.76	5.89	---	---	B
6-13	∥	BM	.750	.750	7,290	.16	87.0	.72	5.94	---	---	B
6-14	∥	BM	.749	.750	7,720	.15	88.0	.74	5.83	---	---	B
6-15	∥	BM	.750	.750	8,110	.15	92.5	.78	5.86	---	---	D
6-16	∥	BM	.750	.751	7,090	.16	84.5	.70	5.89	---	---	C
6-17	∥	BM	.748	.751	7,420	.15	84.5	.71	5.77	---	---	D
6-18	∥	BM	.749	.750	6,860	.18	88.5	.73	6.14	---	---	B
6-19	∥	BM	.750	.750	6,930	.18	89.5	.74	6.06	---	---	D
6-20	∥	BM	.750	.750	7,810	.15	89.0	.75	5.85	---	---	B
6-21	∥	BM	.748	.750	7,650	.14	84.0	.71	5.68	---	---	B
6-22	∥	BM	.749	.750	7,540	.15	86.0	.73	5.89	---	---	C
6-23	∥	BM	.750	.750	7,320	.15	83.5	.70	5.74	---	---	B
6-24	∥	BM	.750	.751	6,930	.17	85.5	.71	5.85	---	---	F
6-25	∥	BM	.750	.751	7,790	.145	87.0	.75	5.79	---	---	D
6-26	∥	BM	.751	.750	7,780	.140	85.0	.72	5.69	---	---	D
6-27	∥	BM	.750	.750	7,680	.140	84.0	.71	5.77	---	---	F
6-28	∥	BM	.751	.750	8,520	.125	87.0	.75	5.49	---	---	D
6-29	∥	BM	.751	.750	7,890	.135	84.5	.72	5.60	---	---	F
6-30	∥	BM	.750	.750	8,240	.135	88.5	.75	5.50	---	---	D
Statistics of K_{Ic} values (Eq. 10): Mean - 88.64, c.v. - .065, 95% conf. limits: 86.4 - 90.9, 90% conf. limits: 86.8 - 90.5.												
11-BA- 1	⊥	CW	.750	.750	6,130	.15	70.0	.60	5.62	---	---	D
11-BA- 2	⊥	CW	.750	.750	6,480	.15	74.0	.64	5.70	---	---	D
11-BA- 3	⊥	CW	.750	.751	5,470	.15	62.5	.54	5.69	---	---	D
11-BA- 4	⊥	CW	.751	.751	3,930	.20	54.5	.46	6.72	---	---	F
11-BA- 5	⊥	CW	.751	.750	6,420	.14	70.3	.61	5.65	---	---	C
11-BA- 6	⊥	CW	.751	.750	5,530	.15	63.0	.54	5.82	---	---	D
11-BA- 7	⊥	CW	.751	.750	6,420	.14	70.5	.61	5.68	---	---	A
11-BA- 8	⊥	CW	.751	.749	6,520	.14	71.5	.62	5.54	---	---	D
11-BA- 9	⊥	CW	.751	.750	5,860	.15	67.0	.58	5.73	---	---	D
11-BA-10	⊥	CW	.751	.750	8,340	.13	87.0	.77	5.57	---	---	D
11-BA-11	⊥	CW	.750	.751	6,790	.14	74.0	.64	5.43	---	---	F
11-BA-12	⊥	CW	.751	.751	8,310	.13	86.5	.76	5.55	---	---	D
11-BA-13	⊥	CW	.750	.751	7,390	.15	84.0	.72	5.64	---	---	D
11-BA-14	⊥	CW	.750	.750	7,570	.14	83.0	.72	5.61	---	---	F
11-BA-15	⊥	CW	.750	.750	7,150	.15	81.5	.70	5.81	---	---	F
11-BA-16	⊥	CW	.750	.750	7,170	.14	78.5	.68	5.45	---	---	F
11-BA-17	⊥	CW	.750	.751	8,160	.13	85.0	.75	5.47	---	---	F
11-BA-18	⊥	CW	.750	.751	6,810	.14	74.0	.65	5.50	---	---	C
11-BA-19	⊥	CW	.750	.751	6,830	.13	71.0	.63	5.50	---	---	B
11-BA-20	⊥	CW	.750	.750	5,470	.150	62.5	.54	5.84	---	---	D
11-BC- 3	⊥	CW	.751	.750	8,920	.055	57.5	.65	5.00	---	---	D
11-BC- 4	⊥	CW	.750	.751	10,610	.050	65.5	.77	5.26	---	---	D
11-BC- 5	⊥	CW	.750	.751	8,030	.065	56.5	.60	5.05	---	---	D
Statistics of K_{Ic} values (Eq. 10): Mean - 71.73, c.v. - .136, 95% conf. limits: 67.5 - 76.0, 90% conf. limits: 68.2 - 75.2.												
11-BC- 6	⊥	FZ	.750	.751	6,560	.130	68.5	.60	5.49	---	---	C
11-BC- 7	⊥	FZ	.751	.750	9,610	.140	105.0	.92	5.67	---	---	D
11-BC- 8	⊥	FZ	.750	.751	6,530	.185	85.5	.72	6.06	---	---	D
11-BC- 9	⊥	FZ	.750	.749	7,010	.135	75.5	.66	5.51	---	---	C
11-BD- 6	⊥	FZ	.751	.750	6,440	.165	78.5	.67	6.01	---	---	F
11-BD- 7	⊥	FZ	.750	.751	7,360	.125	75.0	.67	5.48	---	---	B
11-BD- 8	⊥	FZ	.751	.750	9,510	.140	104.0	.91	5.67	---	---	F
11-BD- 9	⊥	FZ	.750	.751	7,530	.165	91.5	.78	5.70	---	---	F
11-BD-10	⊥	FZ	.751	.751	7,120	.120	71.0	.63	5.31	---	---	B
Statistics of K_{Ic} values (Eq. 10): Mean - 83.83, c.v. - .163, 95% conf. limits: 73.3 - 94.3, 90% conf. limits: 75.4 - 92.3.												
11-BB- 2	⊥	HAZ	.750	.750	8,670	.13	90.5	.80	5.51	---	---	F
11-BB- 3	⊥	HAZ	.749	.749	8,010	.15	91.5	.79	5.54	---	---	F
11-BB- 4	⊥	HAZ	.751	.750	8,500	.14	93.0	.81	5.53	---	---	D
11-BB- 5	⊥	HAZ	.750	.751	8,600	.13	89.5	.79	5.40	---	---	F
11-BB- 6	⊥	HAZ	.750	.750	9,760	.13	102.0	.90	5.47	---	---	D
11-BB- 7	⊥	HAZ	.750	.750	8,510	.14	93.0	.81	5.44	---	---	F
11-BB-13	⊥	HAZ	.749	.750	8,170	.15	93.0	.80	5.70	---	---	D
11-BB-14	⊥	HAZ	.750	.751	8,440	.14	92.0	.80	5.44	---	---	C
11-BB-15	⊥	HAZ	.749	.751	8,940	.14	98.0	.85	5.50	---	---	F
11-BB-16	⊥	HAZ	.749	.749	8,030	.14	88.0	.77	5.56	---	---	C
11-BB-17	⊥	HAZ	.749	.751	8,760	.15	100.0	.86	5.50	---	---	D
11-BB-18	⊥	HAZ	.750	.750	9,120	.14	100.0	.87	5.55	---	---	D
11-BD- 3	⊥	HAZ	.751	.750	12,950	.065	91.5	.98	5.11	---	---	D
11-BD- 4	⊥	HAZ	.750	.751	13,300	.060	89.5	.99	4.96	---	---	D
11-BD- 5	⊥	HAZ	.750	.750	13,150	.060	88.5	.98	5.15	---	---	D
Statistics of K_{Ic} values (Eq. 10): Mean - 93.33, c.v. - .048, 95% conf. limits: 90.8 - 95.8, 90% conf. limits: 91.3 - 95.4.												
11-BB- 1	⊥	DB	.750	.750	8,830	.14	97.0	.84	5.45	---	---	D
11-BB- 8	⊥	DB	.750	.750	7,170	.14	78.5	.68	5.73	---	---	D
11-BB- 9	⊥	DB	.750	.750	7,200	.15	82.0	.71	5.63	---	---	D
11-BB-10	⊥	DB	.750	.750	7,070	.14	77.5	.67	5.67	---	---	D
11-BB-11	⊥	DB	.749	.750	8,970	.14	98.0	.85	5.58	---	---	D
11-BB-12	⊥	DB	.749	.750	8,100	.16	96.5	.82	5.62	---	---	D
11-BB-19	⊥	DB	.749	.749	7,880	.15	90.0	.78	5.53	---	---	F
11-BB-20	⊥	DB	.749	.750	7,880	.15	90.0	.78	5.66	---	---	D
Statistics of K_{Ic} values (Eq. 10): Mean - 89.61, c.v. - .093, 95% conf. limits: 83.2 - 96.0, 90% conf. limits: 84.5 - 94.8.												

TABLE 8. FRACTURE TOUGHNESS TESTS OF PLATE NO. 7, 250 KSI GRADE OF MARAGING STEEL, SHORT ARC WELD.

Base Metal: 18 Ni(250) maraging steel plate 3/4 inch thick, heat No. X53013, air melted. Mill annealed, aged after welding-915°F, 4 hrs, air cool, yield strengths: 260,000 psi ‖ to R. D.; 254,000 psi ⊥ to R.D.

Weld: Short arc weld by Excelco Developments Inc.

Notch Condition: Machined V-notch extended by fatigue crack, all notches parallel to plate surface.

Test Conditions: Bar bending length was 6.00 inches, tests were conducted at room temperature.

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-in (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	σ_{nom}/σ_{YS}	B/M Reciprocal of Spring Constant (in^2/lb)(10^{-6})	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} by Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
7- 1	‖	BM	.750	.750	8,530	.145	95.5	.81	5.86	.140	99.0	B
7- 5	‖	BM	.750	.751	7,840	.150	89.5	.75	5.76	.130	87.0	B
7- 8	‖	BM	.751	.751	7,830	.145	87.5	.74	5.67	.120	82.5	F
7-12	‖	BM	.750	.750	7,730	.145	86.0	.73	5.66	.120	81.5	F
7-14	‖	BM	.750	.749	8,050	.145	90.5	.77	5.59	.110	80.0	F
7-17	‖	BM	.750	.750	7,670	.145	86.0	.73	5.67	.120	81.0	F
7-18	‖	BM	.750	.750	8,030	.140	88.0	.75	5.70	.125	86.0	D
7-19	‖	BM	.750	.750	6,830	.160	81.5	.68	5.85	.140	79.5	F
7-20	‖	BM	.750	.750	7,730	.145	86.5	.73	5.69	.125	83.0	C
7-22	‖	BM	.750	.750	12,000	.065	85.0	.88	5.20	M	----	D
7-23	‖	BM	.750	.750	12,000	.070	88.0	.90	5.21	M	----	F
7-28	‖	BM	.750	.751	9,415	.105	87.0	.78	5.42	.080	77.0	D
7-30	‖	BM	.750	.751	8,105	.135	81.0	.74	5.72	.125	87.0	D
Statistics of K_{Ic} values (Eq. 10): Mean - 87.08, c.v. - .043, 95% conf. limits: 84.8 - 89.3, 90% conf. limits: 85.2 - 88.9												
V-BA- 1	⊥	CW	.751	.751	3,820	.150	43.5	.40	6.00	.155	50.5	C
V-BA- 2	⊥	CW	.750	.751	7,570	.120	75.4	.80	5.55	.110	81.0	D
V-BA- 3	⊥	CW	.750	.749	5,120	.155	60.0	.53	5.88	.145	64.5	D
V-BA- 4	⊥	CW	.750	.751	4,430	.140	48.0	.44	5.94	.150	57.0	C
V-BA- 5	⊥	CW	.749	.750	4,590	.155	53.5	.48	5.88	.145	58.0	B
V-BA- 6	⊥	CW	.749	.749	4,380	.160	52.5	.46	5.86	.145	55.0	D
V-BA- 7	⊥	CW	.750	.750	6,190	.145	69.0	.61	5.76	.135	74.5	D
V-BA- 8	⊥	CW	.751	.751	5,190	.150	59.0	.51	5.73	.130	61.5	D
V-BA- 9	⊥	CW	.749	.750	4,410	.155	51.5	.46	5.88	.145	55.5	F
V-BA-10	⊥	CW	.750	.750	4,720	.160	56.5	.50	5.92	.150	61.0	F
V-BC- 2	⊥	CW	.751	.750	5,860	.135	63.0	.55	5.67	.125	68.0	D
V-BC- 3	⊥	CW	.751	.749	8,735	.060	59.0	.65	5.07	M	----	D
V-BC- 4	⊥	CW	.750	.750	9,305	.060	63.0	.69	5.26	.060	71.5	D
Statistics of K_{Ic} values (Eq. 10): Mean - 57.99, c.v. - .148, 95% conf. limits: 52.8 - 63.2, 90% conf. limits: 53.4 - 62.2												
V-BD- 2	⊥	FZ	.750	.749	9,305	.135	100.0	.87	5.84	.150	114.0	D
V-BD- 3	⊥	FZ	.750	.751	8,265	.145	92.0	.80	5.63	.130	92.0	D
V-BD- 4	⊥	FZ	.750	.750	9,335	.135	100.0	.87	5.49	.115	95.5	D
A Statistic of K_{Ic} values (Eq. 10): Mean - 97.33												
V-BB- 2	⊥	HAZ	.750	.750	8,290	.145	92.5	.80	5.54	.120	87.5	D
V-BB- 4	⊥	HAZ	.749	.750	9,240	.130	96.5	.85	5.51	.115	95.5	D
V-BB- 5	⊥	HAZ	.747	.750	8,170	.140	89.5	.78	5.57	.125	89.0	C
V-BB- 7	⊥	HAZ	.750	.750	7,800	.140	85.5	.74	5.54	.120	82.0	F
V-BB- 8	⊥	HAZ	.750	.750	8,270	.130	86.5	.76	5.55	.120	87.5	C
Statistics of K_{Ic} values (Eq. 10): Mean - 90.1, c.v. - .050, 95% conf. limits: 84.5 - 95.7, 90% conf. limits: 85.8 - 94.4												
V-BB- 1	⊥	DB	.750	.750	8,530	.140	93.5	.81	5.68	.135	97.5	D
V-BB- 3	⊥	DB	.751	.750	6,790	.145	76.0	.66	5.62	.130	76.0	D
V-BB- 6	⊥	DB	.749	.750	8,700	.140	95.5	.83	5.58	.125	95.0	D
V-BB- 9	⊥	DB	.750	.750	8,350	.130	87.0	.77	5.49	.115	86.5	C
V-BB-10	⊥	DB	.750	.750	8,270	.135	88.5	.78	5.46	.105	80.5	C
Statistics of K_{Ic} values (Eq. 10): Mean - 88.10, c.v. - .086, 95% conf. limits: 78.7 - 97.6, 90% conf. limits: 80.8 - 95.4												

M = Missed calibration curve

TABLE 9. FRACTURE TOUGHNESS TESTS OF PLATE NO. 8, 250 KSI GRADE OF MARAGING STEEL, BIG TIG WELD

Base Metal: 18 Ni(250) maraging steel plate 3/4 inch thick, heat No. X53013, air melted. Mill annealed, aged after welding-915°F, 4 hrs, air cool, yield strengths: 260,000 psi ∥ to R.D.; 254,000 psi ⊥ to R.D.

Weld: Tig weld (310-350) amps), 1/4 inch tungsten electrode, by Excelco Developments Inc.

Notch Condition: Machined V-notch extended by fatigue crack, all notches parallel to plate surface.

Test Conditions: Bar bending length was 6.00 inches, tests were conducted at room temperature.

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-in (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	σ_{nom}/σ_{YS}	B/M Reciprocal of Spring Constant (in²/lb)(10^{-6})	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} by Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
8- 1	∥	BM	.750	.750	8,400	.140	92.0	.78	5.79	.130	91.0	B
8- 3	∥	BM	.750	.750	9,090	.140	99.5	.85	5.70	.120	92.5	F
8- 4	∥	BM	.750	.751	8,770	.135	93.5	.80	5.73	.125	92.0	F
8- 5	∥	BM	.750	.751	9,630	.125	98.0	.85	5.55	.095	83.5	D
8- 6	∥	BM	.750	.750	7,870	.145	88.0	.75	5.84	.135	87.5	A
8- 7	∥	BM	.750	.750	8,110	.145	90.5	.77	5.76	.125	85.0	F
8- 8	∥	BM	.750	.750	8,160	.145	91.0	.77	5.81	.135	91.0	F
8- 9	∥	BM	.750	.750	8,290	.145	92.5	.78	5.79	.130	89.5	F
8-12	∥	BM	.750	.750	8,690	.140	95.0	.81	5.74	.125	91.0	F
8-13	∥	BM	.750	.750	8,480	.140	93.0	.79	5.84	.135	94.5	A
8-17	∥	BM	.750	.750	8,850	.130	92.5	.80	5.71	.120	90.0	D
8-18	∥	BM	.750	.750	9,490	.130	99.0	.85	5.65	.110	91.5	D
8-19	∥	BM	.750	.750	8,510	.140	93.0	.79	5.71	.120	86.5	D
8-20	∥	BM	.750	.751	8,080	.140	88.5	.75	5.75	.125	84.5	D
8-21	∥	BM	.750	.750	8,400	.140	92.0	.78	5.63	.120	85.5	D
8-22	∥	BM	.750	.749	9,870	.125	101.0	.88	5.58	.100	89.0	D
8-23	∥	BM	.751	.750	7,160	.170	88.5	.74	5.98	.150	86.0	F
8-24	∥	BM	.751	.750	8,310	.135	89.0	.76	5.72	.120	84.5	F
8-25	∥	BM	.751	.750	8,180	.140	89.5	.76	5.74	.125	86.0	D
8-26	∥	BM	.751	.750	7,990	.140	87.5	.74	5.66	.110	77.0	D
Statistics of K_{Ic} values (Eq. 10): Mean - 92.68, c.v. - .043, 95% conf. limits: 90.8 - 94.6, 90% conf. limits: 91.1 - 94.2												
III-BA- 1	⊥	CW	.750	.749	8,430	.135	90.5	.79	5.51	.115	88.5	D
III-BA- 2	⊥	CW	.751	.750	7,620	.135	81.5	.71	5.44	.105	76.0	C
III-BA- 3	⊥	CW	.750	.750	8,930	.140	98.0	.85	5.44	.105	89.0	A
III-BA- 4	⊥	CW	.749	.750	8,170	.130	85.5	.75	5.46	.105	81.5	B
III-BA- 5	⊥	CW	.750	.750	10,030	.130	104.5	.93	5.34	.085	86.5	D
III-BA- 6	⊥	CW	.750	.750	9,120	.130	95.0	.84	5.38	.095	84.5	C
III-BA- 7	⊥	CW	.750	.750	9,870	.130	103.0	.91	5.41	.100	95.5	F
III-BA- 8	⊥	CW	.750	.750	8,930	.125	91.0	.81	5.40	.095	85.0	F
III-BA- 9	⊥	CW	.750	.749	9,170	.125	94.0	.83	5.31	.090	83.0	D
III-BA-10	⊥	CW	.750	.750	9,090	.130	95.0	.84	5.40	.095	84.5	C
III-BA-11	⊥	CW	.750	.750	9,810	.130	102.5	.91	5.40	.095	91.0	F
III-BA-12	⊥	CW	.750	.750	9,970	.130	104.0	.92	5.34	.085	86.0	F
III-BA-13	⊥	CW	.750	.750	9,550	.130	99.5	.88	5.37	.090	86.0	F
III-BA-14	⊥	CW	.750	.749	9,200	.125	99.0	.84	5.44	.105	91.5	C
III-BA-15	⊥	CW	.750	.750	9,090	.140	99.5	.87	5.50	.110	93.0	D
III-BA-16	⊥	CW	.750	.750	8,590	.130	89.5	.79	5.42	.100	85.0	A
III-BA-17	⊥	CW	.750	.750	8,510	.125	87.0	.77	5.37	.090	77.0	C
III-BA-18	⊥	CW	.750	.750	9,330	.135	100.0	.87	5.52	.115	98.0	F
III-BA-19	⊥	CW	.749	.750	9,910	.135	102.0	.93	5.52	.115	104.5	D
III-BA-20	⊥	CW	.749	.750	9,030	.130	94.5	.83	5.56	.120	98.0	F
Statistics of K_{Ic} values (Eq. 10): Mean - 95.53, c.v. - .069, 95% conf. limits: 92.5 - 98.6, 90% conf. limits: 93.0 - 98.1												
III-BD- 4	⊥	FZ	.749	.750	11,800	.135	126.5	1.11	5.55	.115	102.5	D
III-BD- 5	⊥	FZ	.751	.751	9,720	.155	113.0	.97	5.68	.135	99.5	B
III-BD- 6	⊥	FZ	.749	.750	10,250	.145	114.5	.99	5.59	.125	97.5	F
III-BD- 7	⊥	FZ	.749	.749	11,000	.135	118.0	1.04	5.63	.130	109.0	D
III-BD- 8	⊥	FZ	.751	.750	6,660	.150	76.0	.66	5.79	.150	76.0	C
III-BD- 9	⊥	FZ	.750	.750	9,760	.135	104.5	.91	5.70	.140	104.5	E
III-BD-10	⊥	FZ	.747	.749	9,370	.130	98.5	.87	5.58	.120	85.5	A
Statistics of K_{Ic} values (Eq. 10): Mean - 107.29, c.v. - .154, 95% conf. limits: 92.0 - 122.5, 90% conf. limits: 95.2 - 119.4												
III-BB- 1	⊥	DB	.751	.749	6,680	.170	83.0	.70	5.85	.155	85.5	D
III-BB- 2	⊥	DB	.750	.749	7,710	.145	86.5	.75	5.51	.115	80.0	D
III-BB- 3	⊥	DB	.750	.750	6,270	.150	71.5	.62	5.55	.120	67.0	F
III-BB- 4	⊥	DB	.749	.750	7,020	.150	80.0	.69	5.57	.125	77.0	D
III-BB- 5	⊥	DB	.750	.750	7,470	.150	85.0	.74	5.64	.135	86.0	F
III-BB- 6	⊥	DB	.750	.749	8,130	.140	89.5	.78	5.44	.105	79.5	F
III-BB- 7	⊥	DB	.751	.749	10,070	.140	111.0	.96	5.51	.115	105.0	F
III-BB- 8	⊥	DB	.751	.749	8,790	.145	98.5	.85	5.58	.125	96.5	D
III-BB- 9	⊥	DB	.750	.749	7,760	.150	89.0	.77	5.66	.135	89.5	D
III-BB-10	⊥	DB	.750	.749	9,360	.150	107.5	.93	5.58	.125	102.5	F
III-BB-11	⊥	DB	.750	.750	7,150	.160	85.0	.73	5.79	.150	89.0	F
III-BB-12	⊥	DB	.751	.749	7,400	.145	83.0	.72	5.64	.135	85.5	F
III-BB-13	⊥	DB	.749	.750	6,890	.155	80.0	.69	5.61	.130	78.0	F
III-BB-14	⊥	DB	.751	.749	7,990	.145	89.5	.78	5.44	.105	78.0	F
III-BB-15	⊥	DB	.749	.750	7,770	.150	88.5	.76	5.56	.120	83.0	D
III-BB-16	⊥	DB	.751	.750	7,190	.145	80.5	.70	5.47	.110	72.0	F
III-BB-17	⊥	DB	.748	.750	7,990	.140	87.5	.76	5.58	.125	87.5	D
III-BB-18	⊥	DB	.751	.749	9,750	.150	112.0	.96	5.61	.130	110.5	D
III-BB-19	⊥	DB	.751	.749	7,780	.145	87.0	.76	5.65	.135	89.5	D
III-BB-20	⊥	DB	.751	.749	7,720	.145	86.5	.75	5.61	.130	87.0	F
Statistics of K_{Ic} values (Eq. 10): Mean - 89.05, c.v. .118, 95% conf. limits: 84.1 - 94.0, 90% conf. limits: 85.0 - 93.1												

TABLE 10. FRACTURE TOUGHNESS TESTS OF PLATE NO. 9, 250 KSI GRADE OF MARAGING STEEL, MIG WELD.

Base Metal: 18 Ni(250) maraging steel plate 3/4 inch thick, heat No. X53013, air melted. Mill annealed, aged by Excelco before welding, aged after welding-915°F, 4 hrs, air cool, yield strengths: 260,000 psi ∥ to R.D.; 254,000 psi ⊥ to R.D.

Weld: Mig weld by Excelco Developments Inc.

Notch Condition: Machined V-notch extended by fatigue crack, all notches parallel to plate surface.

Test Conditions: Bar bending length was 6.00 inches, tests were conducted at room temperature.

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-in (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	$\frac{\sigma_{nom}}{\sigma_{YS}}$	B/M Reciprocal of Spring Constant $(in^2/lb)(10^{-6})$	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} by Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
9- 1	∥	BM	.751	.751	6,600	.160	78.5	.65	5.85	.155	78.5	A
9- 3	∥	BM	.750	.751	16,700	.055	104.0	1.19	5.08	M	----	D
9- 4	∥	BM	.751	.750	11,400	.070	83.5	.85	5.22	M	----	F
9- 5	∥	BM	.751	.751	6,470	.175	81.5	.67	6.19	.190	90.0	F
9- 6	∥	BM	.751	.751	6,500	.185	85.0	.70	6.24	.195	92.0	F
9- 7	∥	BM	.751	.751	7,590	.150	86.5	.73	5.86	.160	91.5	F
9- 8	∥	BM	.751	.751	8,520	.135	91.0	.78	5.52	.120	82.5	B
9-11	∥	BM	.751	.751	7,110	.170	88.0	.73	5.89	.165	88.0	F
9-13	∥	BM	.748	.750	6,810	.140	74.5	.63	5.70	.145	76.0	F
9-16	∥	BM	.750	.750	6,800	.165	82.5	.60	5.82	.155	80.0	D
9-17	∥	BM	.750	.750	9,270	.125	94.0	.82	5.53	.120	89.5	F
9-19	∥	BM	.751	.750	6,680	.160	79.5	.67	5.85	.155	79.5	F
9-20	∥	BM	.751	.750	6,520	.155	76.0	.64	5.89	.160	78.5	F
9-21	∥	BM	.751	.750	6,740	.165	82.0	.68	5.82	.150	78.5	A
9-22	∥	BM	.751	.751	6,360	.160	75.5	.63	5.86	.155	75.5	B
9-23	∥	BM	.750	.750	6,910	.155	80.5	.68	5.79	.150	80.0	F
9-28	∥	BM	.751	.751	7,360	.150	84.0	.70	5.71	.145	82.0	F
9-29	∥	BM	.751	.751	6,990	.155	80.5	.68	5.79	.140	76.0	F
9-30	∥	BM	.750	.751	7,600	.140	83.0	.70	5.53	.120	73.5	F
Statistics of K_{Ic} values (Eq. 10): Mean - 83.68, c.v. - .084, 95% conf. limits: 80.3 - 87.1, 90% conf. limits: 80.9 - 86.5												
VI-BC- 2	⊥	CW	.751	.751	5,270	.150	60.0	.52	5.85	.140	61.0	D
VI-BC- 4	⊥	CW	.750	.749	9,650	.145	108.0	.94	5.92	.150	118.5	F
VI-BC- 5	⊥	CW	.750	.747	4,770	.155	56.0	.48	6.01	.155	60.5	F
VI-BD- 2	⊥	CW	.750	.750	5,010	.145	56.0	.48	5.84	.140	58.0	C
VI-BD- 3	⊥	CW	.750	.751	5,550	.140	60.5	.53	5.71	.125	59.0	D
VI-BD- 4	⊥	CW	.750	.749	8,990	.160	108.0	.92	5.88	.145	107.5	D
VI-BD- 6	⊥	CW	.751	.750	5,300	.150	60.5	.52	5.77	.130	58.0	F
Statistics of K_{Ic} values (Eq. 10): Mean - 72.71, c.v. - .333, 95% conf. limits: 50.4 - 95.1, 90% conf. limits: 55.0 - 90.5												
VI-BC- 6	⊥	FZ	.750	.751	6,930	.130	72.0	.63	5.59	.105	65.5	C
VI-BC- 7	⊥	FZ	.750	.751	9,010	.125	92.0	.81	5.79	.130	99.5	F
VI-BC- 8	⊥	FZ	.751	.751	6,310	.135	67.0	.59	5.67	.120	65.0	C
VI-BC- 9	⊥	FZ	.751	.750	10,120	.135	108.5	.95	5.81	.135	114.5	D
VI-BD- 7	⊥	FZ	.749	.751	5,820	.140	63.5	.55	5.63	.110	56.5	C
VI-BD- 8	⊥	FZ	.751	.750	6,500	.160	77.5	.66	5.82	.135	73.5	A
VI-BD- 9	⊥	FZ	.750	.751	7,920	.145	88.5	.76	5.74	.130	87.0	D
VI-BD-10	⊥	FZ	.749	.751	7,100	.140	77.5	.67	5.64	.110	69.0	C
Statistics of K_{Ic} values (Eq. 10): Mean - 80.81, c. v. - .184, 95% conf. limits: 68.4 - 93.2, 90% conf. limits: 70.9 - 90.8												

M = Missed calibration curve

TABLE II. **FRACTURE TOUGHNESS TESTS OF PLATE NO. 10, 250 KSI GRADE OF MARAGING STEEL, BIG TIG WELD.**

Base Metal: 18 Ni(250) maraging steel plate 3/4 inch thick, heat No. X53013, air melted. Mill annealed, aged after welding-915°F, 4 hrs, air cool, yield strengths: 260,000 psi $\parallel$ to R.D.; 254,000 psi $\perp$ to R.D.

Weld: Tig weld (310-350 amps), 1/4 inch Tungsten electrode, by Electrode Developments Inc.

Notch Condition: Machined V-notch extended by fatigue crack, all notches parallel to plate surface.

Test Conditions: Bar bending length was 6.00 inches, tests were conducted at room temperature.

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-In (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	σ_{nom}/σ_{YS}	B/M Reciprocal of Spring Constant (in^2/lb)(10^{-6})	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} by Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
10- 9	$\perp$	BM	.751	.750	6,020	.215	88.5	.75	6.64	.220	94.0	F
10-10	$\perp$	BM	.749	.750	5,930	.205	84.0	.71	6.52	.210	89.5	F
10-11	$\perp$	BM	.749	.751	5,660	.220	84.5	.71	6.42	.205	84.5	F
10-12	$\perp$	BM	.750	.749	5,810	.215	86.0	.72	6.50	.210	88.0	F
10-13	$\perp$	BM	.749	.750	5,390	.220	80.5	.68	6.65	.220	84.0	C
10-14	$\perp$	BM	.749	.750	5,230	.220	78.5	.66	6.63	.220	81.5	F
10-15	$\perp$	BM	.749	.750	5,130	.250	85.0	.73	7.02	.240	84.5	F
10-16	$\perp$	BM	.749	.750	5,820	.210	84.0	.70	6.45	.205	87.0	F
10-17	$\perp$	BM	.749	.751	5,420	.240	87.0	.74	6.77	.225	85.5	C
10-18	$\perp$	BM	.749	.750	4,830	.270	86.5	.74	7.25	.255	82.0	A
10-19	$\perp$	BM	.749	.751	5,290	..230	81.5	.69	6.60	.215	81.5	F
10-20	$\perp$	BM	.749	.751	4,590	.240	73.5	.62	6.56	.215	70.5	E
10-22	$\perp$	BM	.751	.750	7,160	.165	87.0	.74	5.75	.150	89.0	F
10-23	$\perp$	BM	.751	.750	8,100	.155	94.5	.81	5.74	.150	101.5	D
10-24	$\perp$	BM	.750	.751	7,810	.160	93.0	.79	5.70	.150	97.5	F
10-25	$\perp$	BM	.749	.751	7,720	.150	88.0	.76	5.68	.145	95.0	C
10-26	$\perp$	BM	.749	.750	7,800	.150	89.0	.77	5.54	.130	90.0	F
10-27	$\perp$	BM	.749	.750	7,960	.155	92.5	.80	5.55	.130	92.0	F
10-28	$\perp$	BM	.750	.751	7,760	.150	88.5	.76	5.61	.140	93.0	A
10-29	$\perp$	BM	.750	.751	6,700	.155	78.5	.67	5.60	.140	81.0	C
Statistics of K_{Ic} values (Eq. 10): Mean - 85.53, c.v. - .061, 95% conf. limits: 83.1 - 87.9, 90% conf. limits: 83.5 - 87.6												
III-AA- 9	$\parallel$	CW	.750	.750	8,370	.180	108.0	.89	6.08	.165	110.5	D
III-AA-10	$\parallel$	CW	.750	.750	7,330	.195	100.0	.82	6.33	.185	103.0	A
III-AA-11	$\parallel$	CW	.751	.751	7,880	.190	105.0	.87	6.29	.180	109.0	F
III-AA-12	$\parallel$	CW	.749	.751	6,300	.215	92.5	.76	6.61	.205	93.5	F
III-AA-13	$\parallel$	CW	.751	.751	9,450	.150	107.5	.90	5.89	.145	115.5	A
III-AA-14	$\parallel$	CW	.751	.750	12,140	.120	121.0	1.06	5.67	.125	138.0	D
III-AA-15	$\parallel$	CW	.751	.750	9,830	.120	98.0	.86	5.65	.125	111.5	F
III-AA-16	$\parallel$	CW	.751	.749	9,270	.135	99.5	.85	5.74	.130	107.0	D
III-AA-17	$\parallel$	CW	.751	.750	9,320	.135	100.0	.85	5.75	.130	107.5	E
III-AA-18	$\parallel$	CW	.751	.751	10,150	.130	106.5	.91	5.74	.130	117.5	D
III-AA-19	$\parallel$	CW	.749	.750	9,750	.115	94.5	.83	5.59	.115	105.5	D
III-AC- 7	$\parallel$	CW	.751	.750	9,590	.125	98.5	.85	5.63	.120	106.5	D
III-AC- 8	$\parallel$	CW	.751	.750	11,530	.135	123.5	1.05	5.70	.125	130.0	D
III-AC- 9	$\parallel$	CW	.751	.750	9,830	.125	100.5	.87	5.54	.105	101.5	F
III-AC-10	$\parallel$	CW	.750	.750	10,610	.125	108.5	.94	5.60	.115	115.0	D
Statistics of K_{Ic} values (Eq. 10): Mean - 104.23, c.v. - .084, 95% conf. limits: 99.4 - 109.1, 90% conf. limits: 100.2 - 108.2												
III-AC- 3	$\parallel$	FZ	.750	.751	10,930	.150	124.5	1.05	5.73	.130	125.5	C
III-AC- 4	$\parallel$	FZ	.750	.750	11,730	.140	128.5	1.09	5.64	.120	128.5	F
III-AC- 5	$\parallel$	FZ	.750	.750	12,210	.155	142.0	1.19	5.85	.140	146.5	F
III-AC- 6	$\parallel$	FZ	.751	.750	9,190	.145	102.5	.87	5.71	.125	103.5	A
III-AD- 4	$\parallel$	FZ	.750	.751	9,810	.170	121.0	1.01	6.08	.165	130.0	F
III-AD- 7	$\parallel$	FZ	.751	.750	9,320	.175	117.5	.98	6.09	.165	123.0	F
III-AD- 8	$\parallel$	FZ	.751	.750	9,930	.130	103.5	.89	5.64	.120	109.0	A
III-AD- 9	$\parallel$	FZ	.750	.750	13,120	.130	137.0	1.18	5.57	.110	137.5	E
III-AD-10	$\parallel$	FZ	.751	.750	10,280	.130	107.5	.93	5.60	.110	107.5	E
Statistics of K_{Ic} values (Eq. 10): Mean - 120.44, c.v. - .118, 95% conf. limits: 110.7 - 131.2, 90% conf. limits: 111.7 - 129.2												
III-AB- 1	$\parallel$	HAZ	.751	.750	10,970	.140	120.0	1.02	5.79	.135	129.0	E
III-AB- 5	$\parallel$	HAZ	.749	.749	13,240	.130	138.5	1.20	5.69	.125	149.0	F
III-AB- 7	$\parallel$	HAZ	.749	.748	14,920	.125	153.5	1.33	5.62	.115	163.5	E
III-AB- 9	$\parallel$	HAZ	.749	.749	9,670	.175	122.0	1.02	5.98	.155	123.5	E
III-AB-10	$\parallel$	HAZ	.749	.748	11,910	.120	119.5	1.05	5.51	.100	118.0	E
III-AB-11	$\parallel$	HAZ	.749	.748	10,470	.130	110.0	.95	5.66	.120	115.0	E
III-AB-13	$\parallel$	HAZ	.749	.750	11,880	.130	124.5	1.07	5.58	.110	124.5	E
III-AB-15	$\parallel$	HAZ	.748	.749	15,480	.115	151.0	1.33	5.56	.110	162.0	E
III-AB-18	$\parallel$	HAZ	.748	.751	12,410	.130	130.0	1.11	5.61	.120	136.0	F
III-AB-19	$\parallel$	HAZ	.749	.748	12,440	.130	130.5	1.13	5.71	.125	140.0	E
III-AB-20	$\parallel$	HAZ	.749	.748	13,080	.125	134.5	1.17	5.71	.125	146.5	E
III-AD- 5	$\parallel$	HAZ	.750	.750	9,330	.150	106.5	.90	5.79	.135	109.5	E
Statistics of K_{Ic} values (Eq. 10): Mean - 128.38, c.v. - .113, 95% conf. limits: 119.2 - 137.6, 90% conf. limits: 120.9 - 135.9												
III-AB- 2	$\parallel$	DB	.749	.749	12,550	.135	135.0	1.15	5.74	.130	144.0	E
III-AB- 3	$\parallel$	DB	.749	.749	10,570	.130	110.5	.95	5.69	.125	118.5	C
III-AB- 4	$\parallel$	DB	.750	.749	8,960	.180	115.5	.95	6.31	.180	124.5	F
III-AB- 6	$\parallel$	DB	.749	.748	7,770	.165	95.0	.79	6.05	.160	101.0	C
III-AB- 8	$\parallel$	DB	.750	.748	11,520	.140	126.5	1.08	5.80	.135	135.5	F
III-AB-12	$\parallel$	DB	.750	.748	12,270	.140	135.0	1.15	5.63	.120	134.5	E
III-AB-14	$\parallel$	DB	.749	.749	8,950	.165	109.0	.91	6.02	.155	114.5	E
III-AB-16	$\parallel$	DB	.749	.748	12,550	.125	129.0	1.12	5.66	.120	137.5	F
III-AB-17	$\parallel$	DB	.750	.749	12,690	.130	132.5	1.15	5.59	.110	133.0	E
III-AD- 6	$\parallel$	DB	.750	.750	9,550	.180	123.0	1.02	6.22	.175	130.5	E
Statistics of K_{Ic} values (Eq. 10): Mean - 121.10, c.v. - .110, 95% conf. limits: 111.6 - 130.6, 90% conf. limits: 113.4 - 128.8												

TABLE 12. FRACTURE TOUGHNESS TESTS OF PLATE NO. 11, 250 KSI GRADE OF MARAGING STEEL, SHORT ARC WELD.

Base Metal: 18 Ni(250) maraging steel plate 3/4 inch thick, heat No. X53013, air melted. Mill annealed, aged after welding-915°F, 4 hrs, air cool, yield strengths: 260,000 psi ∥ to R.D.; 254,000 psi ⊥ to R.D.

Weld: Short arc weld by Excelco Developments Inc.

Notch Condition: Machined V-notch extended by fatigue crack, all notches parallel to plate surface.

Test Conditions: Bar bending length was 6.00 inches, tests were conducted at room temperature.

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-in (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	σ_{nom}/σ_{YS}	B/M Reciprocal of Spring Constant (in²/lb)(10^{-6})	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} by Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
11- 1	⊥	BM	.750	.750	10,910	.070	80.0	.84	5.13	---	---	D
11- 3	⊥	BM	.750	.750	10,720	.070	79.0	.82	5.07	---	---	C
11- 5	⊥	BM	.750	.750	10,720	.070	79.0	.82	5.06	---	---	D
11- 9	⊥	BM	.750	.750	7,440	.150	85.0	.73	5.53	---	---	D
11-11	⊥	BM	.750	.750	6,510	.145	73.0	.63	5.40	---	---	D
11-13	⊥	BM	.750	.747	7,000	.145	79.0	.69	5.55	---	---	C
11-17	⊥	BM	.750	.750	7,710	.145	86.0	.75	5.47	---	---	C
11-18	⊥	BM	.750	.750	7,230	.155	84.5	.72	5.48	---	---	F
11-19	⊥	BM	.750	.751	7,600	.150	86.5	.75	5.61	---	---	F
11-20	⊥	BM	.750	.750	7,710	.160	92.0	.79	5.64	---	---	F
11-25	⊥	BM	.750	.750	7,250	.150	82.5	.71	5.51	---	---	F
11-27	⊥	BM	.750	.750	8,530	.135	91.5	.80	5.26	---	---	F
11-29	⊥	BM	.751	.750	7,320	.145	82.0	.71	5.47	---	---	F

Statistics of K_{Ic} values (Eq. 10): Mean - 83.07, c.v. - .064, 95% conf. limits: 79.9 - 86.3, 90% conf. limits: 80.5 - 85.7

V-AA- 1	∥	CW	.750	.750	5,600	.15	64.0	.54	6.04	---	---	D
V-AA- 2	∥	CW	.749	.750	6,920	.14	76.0	.64	5.80	---	---	D
V-AA- 3	∥	CW	.750	.750	6,670	.14	73.0	.62	5.78	---	---	D
V-AA- 4	∥	CW	.748	.750	6,630	.14	72.5	.62	5.68	---	---	D
V-AA- 5	∥	CW	.751	.750	5,990	.15	68.5	.58	5.81	---	---	D
V-AA- 6	∥	CW	.750	.750	5,600	.14	61.5	.52	5.72	---	---	B
V-AA- 7	∥	CW	.750	.750	6,430	.13	67.5	.58	5.62	---	---	D
V-AA- 8	∥	CW	.750	.750	5,930	.14	65.0	.55	5.74	---	---	A
V-AA- 9	∥	CW	.751	.751	8,520	.13	89.0	.76	5.58	---	---	D
V-AA-10	∥	CW	.750	.749	7,200	.14	79.0	.67	5.65	---	---	D
V-AC- 3	∥	CW	.750	.750	10,030	.055	65.0	.72	5.09	---	---	D
V-AC- 4	∥	CW	.750	.750	8,680	.070	64.0	.65	5.23	---	---	D
V-AC- 5	∥	CW	.749	.750	8,090	.070	59.5	.61	5.20	---	---	B

Statistics of K_{Ic} values (Eq. 10): Mean - 69.58, c.v. - .118, 95% conf. limits: 64.6 - 74.5, 90% conf. limits: 65.5 - 73.6

V-AB- 1	∥	HAZ	.750	.751	11,330	.12	112.5	.99	5.61	---	---	D
V-AB- 2	∥	HAZ	.749	.751	9,210	.13	96.5	.83	5.65	---	---	F
V-AB- 3	∥	HAZ	.751	.744	10,650	.11	102.5	.92	5.70	---	---	D
V-AB- 4	∥	HAZ	.749	.750	11,110	.12	110.5	.97	5.54	---	---	D
V-AB- 5	∥	HAZ	.750	.750	9,200	.14	100.5	.86	5.58	---	---	C
V-AB- 6	∥	HAZ	.750	.749	9,170	.14	100.5	.86	5.59	---	---	C
V-AB- 7	∥	HAZ	.750	.750	10,960	.14	131.0	1.02	5.64	---	---	F
V-AB- 8	∥	HAZ	.751	.751	9,920	.14	108.5	.92	5.66	---	---	C
V-AB- 9	∥	HAZ	.749	.750	10,650	.14	117.0	.99	5.74	---	---	F
V-AB-10	∥	HAZ	.751	.751	8,990	.14	98.0	.83	5.64	---	---	F
V-AD- 3	∥	HAZ	.749	.750	13,620	.060	92.0	.99	5.12	---	---	C
V-AD- 4	∥	HAZ	.750	.751	13,760	.065	97.0	1.01	5.15	---	---	E
V-AD- 5	∥	HAZ	.750	.751	13,960	.060	94.0	1.01	5.11	---	---	E

Statistics of K_{Ic} values (Eq. 10): Mean - 104.65, c.v. - .105, 95% conf. limits: 98.0 - 111.3, 90% conf. limits: 99.3 - 110.1

TABLE 13. FRACTURE TOUGHNESS TESTS OF PLATE NO. 14, 200 KSI GRADE OF MARAGING STEEL, LITTLE TIG WELD

Base Metal: 18 Ni(200) maraging steel plate 3/4 inch thick, heat No. 3960819, vacuum remelted. Mill annealed, aged after welding-915°F, 4 hrs, air cool, yield strengths: 233,000 psi ∥ to R.D.; 228,500 psi ⊥ to R.D.
Weld: Tig weld (110-140 amps) by Excelco Developments Inc.
Notch Condition: Machined V-notch extended by fatigue crack, all notches parallel to plate surface.
Test Conditions: Bar bending length was 6.00 inches, tests were conducted at room temperature.

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-In (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	σ_{nom}/σ_{YS}	B/M Reciprocal of Spring Constant $(in^2/lb)(10^{-6})$	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
14- 2	⊥	BM	.751	.751	9,080	.205	128.0	1.20	6.50	.200	135.5	E
14- 3	⊥	BM	.750	.751	9,120	.210	131.0	1.23	6.57	.205	138.0	F
14- 4	⊥	BM	.751	.750	8,680	.215	128.0	1.19	6.61	.210	133.0	E
14- 5	⊥	BM	.750	.750	9,330	.200	129.0	1.21	6.47	.200	139.0	F
14- 6	⊥	BM	.750	.751	8,370	.220	125.0	1.17	6.92	.225	133.5	F
14- 7	⊥	BM	.751	.751	9,590	.205	135.5	1.27	6.53	.205	145.0	E
14- 8	⊥	BM	.750	.750	11,410	.170	141.0	1.34	6.04	.165	152.0	E
14- 9	⊥	BM	.751	.751	8,580	.215	126.0	1.18	6.63	.210	131.5	F
14-11	⊥	BM	.751	.751	11,320	.175	142.5	1.34	6.01	.165	151.0	E
14-12	⊥	BM	.750	.750	7,330	.245	120.0	1.13	7.31	.250	124.5	F
14-13	⊥	BM	.750	.750	9,170	.215	135.0	1.26	6.59	.205	138.5	F
14-14	⊥	BM	.750	.750	9,070	.210	130.5	1.22	6.67	.210	139.0	E
14-15	⊥	BM	.750	.750	8,480	.225	129.5	1.21	6.88	.225	135.5	F
14-16	⊥	BM	.750	.751	8,690	.215	127.5	1.19	6.54	.205	131.5	F
14-17	⊥	BM	.750	.750	9,070	.205	128.5	1.20	6.37	.190	131.0	E
14-18	⊥	BM	.750	.750	8,850	.220	132.5	1.24	6.60	.210	135.5	E
14-19	⊥	BM	.750	.750	8,800	.205	124.5	1.17	6.42	.195	129.0	E
14-20	⊥	BM	.750	.750	8,930	.215	131.5	1.23	6.57	.205	135.0	E
14-21	⊥	BM	.750	.751	8,350	.230	129.0	1.22	6.80	.220	131.5	F
14-25	⊥	BM	.750	.750	9,200	.210	132.5	1.24	6.44	.195	135.0	F
14-26	⊥	BM	.751	.750	9,030	.215	133.0	1.24	6.53	.205	136.5	E
14-27	⊥	BM	.750	.751	9,070	.215	133.0	1.25	6.47	.200	135.5	E
14-28	⊥	BM	.750	.751	8,800	.215	129.0	1.21	6.52	.205	133.0	E
14-29	⊥	BM	.750	.751	9,070	.210	130.5	1.22	6.49	.200	135.5	F
14-30	⊥	BM	.750	.750	10,000	.190	133.5	1.26	6.28	.185	142.5	E
Statistics of K_{Ic} values (Eq. 10): Mean - 130.76, c.v. - .039, 95% conf. limits: 128.6 - 132.9, 90% conf. limits: 129.0 - 132.5												
XII-AA- 1	∥	CW	.750	.750	8,780	.200	121.5	1.12	6.41	.195	132.0	E
XII-AA- 2	∥	CW	.750	.750	7,030	.210	101.0	.93	6.51	.200	107.5	C
XII-AA- 3	∥	CW	.750	.751	7,540	.205	106.5	.98	6.42	.195	113.5	C
XII-AA- 4	∥	CW	.749	.751	6,730	.225	103.0	.94	6.69	.210	105.5	F
XII-AA- 5	∥	CW	.750	.750	7,070	.235	111.5	1.03	6.88	.220	114.0	C
XII-AA- 6	∥	CW	.750	.750	8,300	.205	117.5	1.08	6.38	.190	123.5	F
XII-AA- 7	∥	CW	.750	.750	8,400	.200	116.5	1.07	6.44	.195	126.5	E
XII-AA- 8	∥	CW	.750	.750	7,870	.210	113.5	1.04	6.50	.200	120.5	F
XII-AA- 9	∥	CW	.751	.750	7,330	.220	109.5	1.00	6.67	.210	115.0	F
XII-AA-10	∥	CW	.750	.750	7,260	.200	100.5	.92	6.52	.200	111.0	F
XII-AA-11	∥	CW	.750	.751	7,550	.200	104.5	.96	6.56	.190	112.5	F
XII-AA-12	∥	CW	.750	.750	7,870	.220	117.5	1.08	6.68	.210	123.5	E
XII-AA-13	∥	CW	.750	.750	7,360	.220	110.0	1.01	6.78	.220	118.5	F
XII-AA-14	∥	CW	.750	.750	7,740	.215	114.0	1.05	6.58	.205	120.0	F
XII-AA-15	∥	CW	.750	.750	8,400	.205	119.0	1.09	6.46	.195	126.5	E
XII-AA-16	∥	CW	.751	.749	7,700	.220	115.5	1.06	6.56	.200	118.0	F
XII-AA-17	∥	CW	.751	.750	7,460	.230	115.5	1.06	6.84	.220	120.0	F
XII-AA-18	∥	CW	.750	.750	9,200	.190	123.5	1.13	6.23	.180	132.5	F
XII-AA-19	∥	CW	.750	.751	5,580	.260	96.5	.89	7.45	.250	97.0	C
XII-AA-20	∥	CW	.750	.750	6,960	.210	100.5	.92	6.60	.205	108.0	F
Statistics of K_{Ic} values (Eq. 10): Mean - 110.88, c.v. - .071, 95% conf. limits: 107.2 - 114.5, 90% conf. limits: 107.9 - 113.9												
XII-AC- 3	∥	FZ	.750	.750	9,680	.195	132.0	1.21	6.40	.185	130.5	F
XII-AC- 4	∥	FZ	.750	.750	6,830	.250	114.0	1.06	7.45	.250	111.5	F
XII-AC- 5	∥	FZ	.750	.751	7,120	.250	119.0	1.10	7.25	.240	114.0	F
XII-AC- 6	∥	FZ	.750	.751	6,130	.290	118.0	1.11	8.18	.285	106.0	E
XII-AC- 7	∥	FZ	.749	.750	6,650	.250	111.0	1.03	7.29	.240	106.0	E
XII-AC- 8	∥	FZ	.751	.751	8,680	.210	125.0	1.14	6.63	.200	127.5	F
XII-AC-10	∥	FZ	.751	.751	7,720	.240	124.5	1.14	6.93	.220	118.5	E
XII-AD- 4	∥	FZ	.749	.749	7,210	.240	116.0	1.07	7.12	.230	113.0	E
XII-AD- 5	∥	FZ	.751	.750	8,630	.210	124.5	1.14	6.65	.200	126.5	F
XII-AD- 6	∥	FZ	.749	.749	7,420	.245	121.5	1.13	7.23	.235	117.5	E
XII-AD- 8	∥	FZ	.749	.749	7,180	.240	115.5	1.07	7.02	.225	111.5	E
XII-AD- 9	∥	FZ	.749	.749	7,800	.220	117.0	1.07	6.76	.210	117.0	F
XII-AD-10	∥	FZ	.751	.750	5,890	.320	127.5	1.23	9.11	---	---	E
Statistics of K_{Ic} values (Eq. 10): Mean - 120.42, c.v. - .050, 95% conf. limits: 116.8 - 124.1, 90% conf. limits: 117.5 - 123.4.												
XII-AB- 3	∥	HAZ	.751	.750	8,840	.205	125.0	1.15	6.57	.195	128.5	E
XII-AB- 4	∥	HAZ	.750	.750	8,400	.215	124.0	1.14	6.76	.210	126.0	E
XII-AB- 9	∥	HAZ	.750	.750	8,240	.220	123.5	1.13	6.55	.195	119.5	E
XII-AB-10	∥	HAZ	.751	.751	7,990	.225	121.5	1.12	6.73	.205	119.0	E
XII-AB-13	∥	HAZ	.750	.750	7,760	.240	125.0	1.15	7.04	.225	120.5	E
XII-AB-18	∥	HAZ	.750	.750	7,590	.235	120.0	1.11	7.18	.235	120.0	F
XII-AB-19	∥	HAZ	.749	.750	7,470	.235	118.0	1.09	7.17	.235	118.5	E
XII-AB-20	∥	HAZ	.745	.751	7,680	.220	114.5	1.05	6.93	.220	117.5	E
Statistics of K_{Ic} values (Eq. 10): Mean - 121.44, c.v. - .031, 95% conf. limits: 118.3 - 124.6, 90% conf. limits: 118.9 - 123.9												
XII-AB- 1	∥	DB	.750	.750	7,680	.235	121.5	1.12	7.09	.230	120.0	E
XII-AB- 2	∥	DB	.750	.750	9,180	.200	127.5	1.17	6.45	.190	131.5	E
XII-AB- 5	∥	DB	.750	.750	8,400	.205	119.0	1.09	6.56	.195	122.0	E
XII-AB- 6	∥	DB	.750	.750	8,230	.215	121.0	1.11	6.68	.205	122.5	E
XII-AB- 7	∥	DB	.751	.751	8,380	.210	120.5	1.10	6.61	.200	123.0	E
XII-AB- 8	∥	DB	.749	.751	7,560	.220	113.0	1.03	6.72	.205	112.5	F
XII-AB-11	∥	DB	.750	.750	8,480	.205	120.0	1.10	6.48	.190	121.5	F
XII-AB-12	∥	DB	.750	.750	8,390	.235	132.5	1.22	6.97	.220	128.5	E
XII-AB-14	∥	DB	.750	.750	7,640	.220	114.5	1.05	6.88	.215	116.0	F
XII-AB-15	∥	DB	.750	.749	7,900	.225	120.5	1.11	6.93	.220	121.0	F
XII-AB-16	∥	DB	.750	.750	8,430	.195	115.0	1.06	6.52	.195	122.5	E
XII-AB-17	∥	DB	.745	.750	6,120	.280	114.0	1.07	7.88	.270	103.5	E
Statistics of K_{Ic} values (Eq. 10): Mean - 119.92, c.v. - .048, 95% conf. limits: 116.3 - 123.5, 90% conf. limits: 117.0 - 122.9												

TABLE 14. FRACTURE TOUGHNESS TESTS OF PLATE NO. 15, 200 KSI GRADE OF MARAGING STEEL, LITTLE TIG WELD.

Base Metal: 18 Ni(200) maraging steel plate 3/4 inch thick, heat No. 3951215, vacuum remelted. Mill annealed, aged after welding-915°F, 4 hrs, air cool, yield strengths: 225,200 psi ∥ to R.D.; 228,400 psi ⊥ to R.D.

Weld: Tig weld (110-140 amps) by Excelco Developments Inc.

Notch Condition: Machined V-notch extended by fatigue crack, all notches parallel to plate surface.

Test Conditions: Bar bending length was 6.00 inches, tests were conducted at room temperature.

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-in (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10) (1000 psi$\sqrt{in}$)	σ_{nom}/σ_{YS}	B/M Reciprocal of Spring Constant $(in^2/lb)(10^{-6})$	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} by Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
15- 1	∥	BM	.750	.750	8,370	.210	120.5	1.14	6.84	.195	129.5	F
15- 2	∥	BM	.750	.750	8,880	.195	121.0	1.15	6.55	.175	128.5	E
15- 3	∥	BM	.751	.750	7,780	.225	118.5	1.13	6.99	.205	124.0	E
15- 4	∥	BM	.751	.750	8,710	.200	121.0	1.15	6.52	.175	126.0	E
15- 6	∥	BM	.750	.751	8,560	.215	125.5	1.19	6.79	.195	132.5	E
15- 7	∥	BM	.750	.750	8,480	.215	125.0	1.19	6.81	.195	131.0	E
15- 8	∥	BM	.750	.750	8,370	.225	127.5	1.21	6.78	.190	127.5	E
15- 9	∥	BM	.750	.750	8,240	.210	118.5	1.13	6.74	.190	125.5	E
15-11	∥	BM	.750	.750	8,080	.215	119.0	1.13	6.97	.205	128.5	E
15-12	∥	BM	.750	.750	8,450	.210	122.0	1.15	6.63	.185	126.5	E
15-13	∥	BM	.750	.750	8,530	.210	123.0	1.17	6.64	.185	127.5	E
15-14	∥	BM	.750	.750	8,030	.225	122.5	1.16	7.03	.205	128.0	E
15-15	∥	BM	.751	.750	8,230	.215	121.5	1.15	6.85	.195	127.0	E
15-16	∥	BM	.750	.750	6,990	.260	121.0	1.16	7.39	.225	118.0	E
15-17	∥	BM	.750	.750	7,470	.240	120.0	1.15	7.22	.220	124.5	E
15-18	∥	BM	.750	.750	8,510	.230	132.0	1.26	7.08	.210	138.0	E
15-19	∥	BM	.748	.751	8,160	.225	124.0	1.18	7.14	.215	134.0	E
15-20	∥	BM	.750	.750	8,610	.205	121.5	1.16	6.81	.195	133.0	E
15-21	∥	BM	.750	.750	9,490	.190	126.5	1.21	6.60	.180	140.0	E
15-22	∥	BM	.749	.751	7,810	.210	112.5	1.07	6.90	.200	131.5	E
15-23	∥	BM	.749	.751	8,010	.235	126.5	1.20	7.13	.215	131.5	E
15-24	∥	BM	.750	.749	7,790	.210	112.5	1.07	6.89	.200	122.5	E
15-25	∥	BM	.750	.751	8,080	.210	116.0	1.10	6.80	.195	125.0	F
15-26	∥	BM	.750	.750	8,050	.210	116.0	1.10	6.84	.195	124.5	E
15-27	∥	BM	.749	.750	8,040	.200	112.0	1.06	6.72	.190	122.5	E
15-28	∥	BM	.750	.750	7,520	.225	114.5	1.09	6.91	.200	118.5	F
15-29	∥	BM	.750	.750	8,160	.210	117.5	1.11	6.78	.190	124.0	F
15-30	∥	BM	.751	.751	6,660	.260	115.0	1.10	7.61	.240	117.0	E
Statistics of K_{Ic} values (Eq. 10): Mean - 120.46, c.v. - .041, 95% conf. limits: 118.6 - 122.4, 90% conf. limits: 118.9 - 122.0												
XII-BA- 1	⊥	CW	.750	.750	5,840	.270	104.5	1.00	7.75	.245	99.5	E
XII-BA- 2	⊥	CW	.750	.750	6,770	.240	109.0	1.02	7.39	.225	111.5	E
XII-BA- 3	⊥	CW	.749	.750	7,530	.235	119.0	1.12	7.51	.235	126.0	E
XII-BA- 4	⊥	CW	.750	.750	7,090	.215	104.5	.98	6.65	.185	107.0	E
XII-BA- 5	⊥	CW	.750	.750	7,330	.210	105.5	.99	6.46	.170	106.5	E
XII-BA- 6	⊥	CW	.750	.750	7,200	.225	109.5	1.03	6.73	.190	110.0	E
XII-BA- 7	⊥	CW	.750	.750	8,000	.220	120.0	1.12	6.80	.195	123.5	E
XII-BA- 8	⊥	CW	.750	.750	7,870	.220	118.0	1.10	6.80	.195	121.5	E
XII-BA- 9	⊥	CW	.750	.750	6,690	.240	107.5	1.02	7.15	.215	108.0	E
XII-BA-10	⊥	CW	.750	.750	6,370	.235	100.5	.95	6.98	.205	100.5	F
XII-BA-11	⊥	CW	.750	.750	8,450	.225	129.0	1.21	6.74	.190	129.0	E
XII-BA-12	⊥	CW	.750	.750	7,680	.225	117.0	1.09	6.69	.185	115.5	E
XII-BA-13	⊥	CW	.750	.750	7,130	.240	114.5	1.08	6.80	.195	110.0	F
XII-BA-14	⊥	CW	.751	.750	6,620	.240	106.5	1.00	7.04	.210	105.5	F
XII-BA-15	⊥	CW	.749	.750	8,330	.225	127.0	1.19	6.84	.195	120.5	E
XII-BA-16	⊥	CW	.750	.751	7,010	.245	114.0	1.08	7.34	.225	115.0	F
XII-BA-17	⊥	CW	.751	.750	7,030	.240	113.0	1.06	7.00	.205	110.0	F
XII-BA-18	⊥	CW	.751	.751	5,850	.260	100.5	.95	7.47	.230	97.0	F
XII-BA-19	⊥	CW	.750	.750	7,520	.220	112.5	1.06	6.81	.195	116.0	E
XII-BA-20	⊥	CW	.741	.750	7,850	.230	122.0	1.15	7.00	.205	124.0	E
XII-BC- 2	⊥	CW	.750	.750	16,300	.070	119.5	1.39	5.20	M	---	F
XII-BC- 3	⊥	CW	.750	.750	14,400	.085	118.5	1.28	5.35	.050	118.0	F
XII-BC- 4	⊥	CW	.751	.750	10,100	.135	108.5	1.05	5.80	.115	122.0	F
XII-BC- 5	⊥	CW	.750	.750	5,680	.270	106.5	.97	7.86	.250	98.0	E
XII-BC- 6	⊥	CW	.750	.750	5,405	.260	93.0	.89	7.54	.235	90.5	E
XII-BC- 7	⊥	CW	.750	.751	7,620	.220	114.0	1.06	6.78	.190	116.5	E
Statistics of K_{Ic} values (Eq. 10): Mean - 112.08, c.v. - .076, 95% conf. limits: 108.7 - 115.5, 90% conf. limits: 109.2 - 114.9												
XII-BC- 8	⊥	FZ	.750	.750	7,600	.220	114.0	1.06	7.03	.215	125.5	E
XII-BC- 9	⊥	FZ	.750	.750	8,345	.220	125.0	1.17	6.72	.195	128.5	F
XII-BD- 2	⊥	FZ	.751	.749	8,650	.225	132.0	1.24	6.92	.205	136.5	E
XII-BD- 3	⊥	FZ	.750	.750	6,935	.235	109.5	1.03	7.20	.225	114.5	E
XII-BD- 4	⊥	FZ	.749	.751	9,320	.220	139.0	1.30	6.82	.200	145.0	E
XII-BD- 6	⊥	FZ	.749	.750	8,410	.220	117.0	1.09	6.53	.180	124.0	E
XII-BD- 7	⊥	FZ	.750	.751	10,105	.205	142.0	1.34	6.55	.185	151.5	E
XII-BD- 8	⊥	FZ	.750	.750	9,120	.225	139.0	1.30	6.71	.195	140.0	E
XII-BD- 9	⊥	FZ	.750	.750	8,130	.220	131.5	1.14	6.89	.205	128.5	E
Statistics of K_{Ic} values (Eq. 10): Mean - 126.56, c.v. - .095, 95% conf. limits: 117.4 - 135.8, 90% conf. limits: 119.1 - 134.0												
XII-BB- 1	⊥	HAZ	.749	.750	8,010	.220	111.5	1.04	6.49	.180	118.0	E
XII-BB- 2	⊥	HAZ	.750	.750	7,920	.200	110.0	1.01	6.53	.180	116.5	E
XII-BB- 3	⊥	HAZ	.750	.750	8,185	.210	118.0	1.11	6.55	.180	120.5	E
XII-BB- 6	⊥	HAZ	.750	.750	7,920	.210	114.0	1.07	6.56	.180	116.5	E
XII-BB- 7	⊥	HAZ	.750	.749	6,775	.235	107.5	1.01	7.67	.245	117.5	F
XII-BB- 9	⊥	HAZ	.751	.751	8,735	.205	128.0	1.16	6.28	.165	122.5	E
XII-BB-11	⊥	HAZ	.750	.751	8,455	.205	120.0	1.12	6.52	.180	124.5	E
XII-BB-12	⊥	HAZ	.750	.750	5,385	.305	108.5	1.07	8.50	.285	101.5	E
XII-BB-13	⊥	HAZ	.750	.750	8,695	.195	118.5	1.11	6.29	.165	122.5	E
XII-BB-16	⊥	HAZ	.751	.750	7,485	.235	118.5	1.11	7.23	.225	123.5	E
XII-BB-18	⊥	HAZ	.750	.750	8,585	.200	119.5	1.12	6.58	.185	128.5	E
Statistics of K_{Ic} values (Eq. 10): Mean - 115.82, c.v. - .053, 95% conf. limits: 111.7 - 119.9, 90% conf. limits: 112.5 - 119.2												
XII-BB- 4	⊥	DB	.750	.750	8,055	.205	114.0	1.07	6.66	.190	122.5	E
XII-BB- 5	⊥	DB	.751	.751	7,800	.215	114.5	1.07	6.81	.200	121.5	E
XII-BB- 8	⊥	DB	.750	.751	8,425	.215	123.5	1.16	6.48	.180	124.0	E
XII-BB-10	⊥	DB	.750	.750	7,760	.225	118.5	1.11	6.80	.200	120.5	E
XII-BB-14	⊥	DB	.750	.749	7,495	.210	108.5	1.02	6.82	.200	116.5	F
XII-BB-15	⊥	DB	.750	.750	7,600	.225	116.0	1.09	6.90	.205	119.5	E
XII-BB-17	⊥	DB	.751	.750	9,160	.190	122.5	1.17	6.39	.170	131.0	E
XII-BB-19	⊥	DB	.750	.750	8,375	.210	120.5	1.13	6.55	.180	123.5	E
XII-BB-20	⊥	DB	.751	.750	9,880	.185	129.5	1.22	6.25	.160	137.5	E
Statistics of K_{Ic} values (Eq. 10): Mean - 118.61, c.v. - .052, 95% conf. limits: 113.8 - 123.4, 90% conf. limits: 114.8 - 122.5												

M = Missed calibration curve

TABLE 15. FRACTURE TOUGHNESS TESTS OF PLATE NO. 18, 200 KSI GRADE OF MARAGING STEEL, MIG WELD

Base Metal: 18 Ni(200) maraging steel plate 3/4 inch thick, heat No. 3951217, vacuum remelted. Mill annealed, aged after welding-915°F, 4 hrs, air cool, yield strengths: 229,500 psi || to R.D.; 224,900 ⊥ to R.D.

Weld: Mig weld by Excelco Developments Inc.

Notch Condition: Machined V-notch extended by fatigue crack, all notches parallel to plate surface.

Test Conditions: Bar bending length was 6.00 inches, tests were conducted at room temperature.

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-in (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	σ_{nom}/σ_{YS}	B/M Reciprocal of Spring Constant (in^2/lb)(10^{-6})	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
18- 2	⊥	BM	.750	.750	7,290	.195	99.5	.95	6.47	.200	109.0	F
18- 3	⊥	BM	.750	.750	6,640	.210	95.5	.91	6.58	.205	100.5	F
18- 4	⊥	BM	.750	.750	6,430	.210	92.5	.88	6.74	.215	100.0	F
18- 5	⊥	BM	.750	.750	7,200	.185	94.5	.90	6.23	.185	103.0	F
18- 6	⊥	BM	.750	.750	6,690	.205	94.5	.90	6.54	.205	101.5	F
18- 7	⊥	BM	.750	.750	8,000	.165	97.0	.93	6.00	.165	107.5	F
18- 8	⊥	BM	.750	.750	6,400	.205	90.5	.86	6.53	.205	96.5	F
18- 9	⊥	BM	.751	.750	7,380	.215	109.0	1.03	6.77	.215	115.0	F
18-11	⊥	BM	.750	.750	7,730	.200	107.0	1.02	6.89	.225	123.0	F
18-12	⊥	BM	.750	.750	8,050	.200	111.5	1.07	6.81	.220	126.5	F
18-13	⊥	BM	.750	.750	7,090	.205	100.0	.96	6.90	.225	113.0	F
18-14	⊥	BM	.750	.750	6,990	.205	99.0	.94	6.97	.230	112.5	F
18-15	⊥	BM	.751	.749	7,190	.200	100.0	.96	6.89	.225	114.5	F
18-16	⊥	BM	.750	.750	7,650	.200	106.0	1.01	6.74	.215	119.0	F
18-17	⊥	BM	.750	.750	7,390	.180	95.5	.91	6.45	.195	109.0	D
18-18	⊥	BM	.750	.750	7,330	.165	89.0	.86	6.30	.185	105.0	F
18-19	⊥	BM	.749	.750	6,060	.195	83.0	.79	6.71	.215	94.5	C
18-20	⊥	BM	.750	.750	6,240	.200	86.5	.83	6.77	.220	98.0	D
18-21	⊥	BM	.750	.750	6,370	.200	88.5	.84	6.72	.215	99.0	D
18-22	⊥	BM	.750	.750	6,690	.195	91.0	.87	6.69	.215	104.0	F
18-23	⊥	BM	.750	.750	7,010	.195	95.5	.91	6.66	.210	107.5	F
18-24	⊥	BM	.749	.750	7,080	.190	94.5	.90	6.55	.205	107.0	F
18-25	⊥	BM	.750	.750	6,000	.205	85.0	.81	6.80	.220	94.5	F
18-26	⊥	BM	.750	.750	6,530	.195	89.0	.85	6.54	.205	98.5	F
18-27	⊥	BM	.750	.749	6,750	.205	95.5	.91	6.67	.210	103.5	F
18-28	⊥	BM	.750	.750	6,270	.210	90.5	.86	6.75	.215	97.5	F
18-29	⊥	BM	.750	.750	6,560	.200	91.0	.87	6.79	.220	103.5	F
18-30	⊥	BM	.750	.750	6,990	.200	97.0	.92	6.65	.210	107.0	F
Statistics of K_{Ic} values (Eq. 10): Mean - 95.29, c.v. - .075, 95% conf. limits: 92.6 - 98.0, 90% conf. limits: 93.0 - 97.6												
XIII-AA- 1	||	CW	.750	.750	5,440	.180	70.1	.65	6.46	.200	82.0	C
XIII-AA- 2	||	CW	.750	.750	5,090	.190	68.0	.64	6.48	.200	77.0	F
XIII-AA- 3	||	CW	.750	.750	5,760	.200	80.0	.75	6.67	.210	89.5	D
XIII-AA- 4	||	CW	.750	.750	4,530	.185	59.5	.56	6.51	.200	68.5	C
XIII-AA- 5	||	CW	.750	.750	4,610	.205	65.0	.61	6.79	.215	73.0	E
XIII-AA- 6	||	CW	.750	.750	5,830	.200	81.0	.75	6.57	.205	89.5	D
XIII-AA- 7	||	CW	.750	.750	4,840	.215	71.5	.66	6.77	.215	76.5	D
XIII-AA- 8	||	CW	.750	.750	5,250	.200	73.0	.68	6.74	.215	83.0	F
XIII-AA- 9	||	CW	.750	.750	4,610	.190	61.5	.58	6.32	.190	67.5	C
XIII-AA-10	||	CW	.742	.750	6,000	.210	86.5	.81	6.80	.220	96.0	D
XIII-AA-11	||	CW	.751	.750	4,730	.185	62.0	.58	6.40	.195	70.5	E
XIII-AA-12	||	CW	.750	.750	5,250	.200	73.0	.68	6.49	.200	79.5	E
XIII-AA-13	||	CW	.750	.750	5,250	.200	73.0	.68	6.56	.205	80.5	E
XIII-AA-14	||	CW	.751	.750	4,860	.210	70.0	.65	6.81	.220	78.0	E
XIII-AA-15	||	CW	.751	.751	5,220	.195	71.0	.66	6.48	.200	79.0	E
XIII-AA-16	||	CW	.751	.750	4,870	.185	64.0	.60	6.40	.195	72.5	E
XIII-AA-17	||	CW	.750	.750	5,200	.195	71.0	.66	6.53	.200	78.5	E
XIII-AA-18	||	CW	.750	.751	5,010	.205	70.5	.66	6.87	.220	80.0	E
XIII-AA-19	||	CW	.750	.750	5,150	.200	71.5	.67	6.69	.210	80.0	E
Statistics of K_{Ic} values (Eq. 10): Mean - 70.64, c.v. - .096, 95% conf. limits: 67.4 - 73.9, 90% conf. limits: 67.9 - 73.3												
XIII-AC- 3	||	FZ	.750	.749	7,150	.225	109.0	1.02	6.83	.215	110.5	C
XIII-AC- 4	||	FZ	.750	.750	8,560	.215	126.0	1.18	6.70	.205	129.0	E
XIII-AC- 5	||	FZ	.750	.750	8,240	.230	128.0	1.19	6.98	.220	128.5	F
XIII-AC- 6	||	FZ	.750	.750	6,030	.280	112.5	1.07	7.87	.270	104.0	E
XIII-AC- 7	||	FZ	.750	.750	8,750	.215	129.0	1.20	6.57	.195	129.0	E
XIII-AD- 4	||	FZ	.750	.750	5,680	.225	96.5	.91	7.44	.250	94.0	F
XIII-AD- 5	||	FZ	.750	.750	9,040	.210	130.5	1.21	6.60	.200	135.0	E
XIII-AD- 6	||	FZ	.750	.751	6,610	.275	120.5	1.14	7.66	.260	111.5	E
XIII-AD- 7	||	FZ	.750	.749	5,890	.310	123.0	1.19	8.61	.305	107.5	E
XIII-AD- 8	||	FZ	.750	.750	8,850	.225	135.0	1.26	6.83	.215	136.5	E
XIII-AD- 9	||	FZ	.750	.751	9,470	.215	139.0	1.29	6.53	.195	139.5	E
Statistics of K_{Ic} values (Eq. 10): Mean - 122.64, c.v. - .101, 95% conf. limits: 114.3 - 131.0, 90% conf. limits: 115.9 - 129.4												
XIII-AC- 8	||	HAZ	.750	.750	9,120	.195	124.5	1.16	6.28	.175	127.0	E
XIII-AC- 9	||	HAZ	.750	.750	8,850	.195	120.5	1.12	6.38	.185	127.0	E
XIII-AB- 1	||	HAZ	.750	.751	7,290	.225	110.5	1.03	6.99	.225	115.0	F
XIII-AB- 2	||	HAZ	.750	.750	6,370	.240	102.5	.96	7.21	.235	102.5	F
XIII-AB- 3	||	HAZ	.750	.751	6,220	.235	98.0	.92	6.99	.220	97.0	E
XIII-AB- 4	||	HAZ	.750	.750	7,470	.210	107.5	1.00	6.65	.200	111.5	F
XIII-AB- 5	||	HAZ	.751	.750	7,620	.205	107.5	1.01	6.63	.200	113.5	F
XIII-AB- 6	||	HAZ	.751	.750	6,370	.240	102.5	.96	7.10	.230	101.5	F
XIII-AB- 7	||	HAZ	.751	.750	6,130	.235	97.0	.91	6.88	.215	94.5	F
XIII-AB- 8	||	HAZ	.750	.751	6,130	.225	93.0	.87	6.94	.220	95.5	F
XIII-AB-10	||	HAZ	.750	.750	7,740	.210	111.5	1.04	6.75	.210	118.0	F
XIII-AB-11	||	HAZ	.750	.751	6,510	.245	106.0	1.00	7.23	.235	105.0	F
XIII-AB-14	||	HAZ	.750	.751	7,200	.225	109.5	1.02	6.77	.210	110.0	F
XIII-AB-17	||	HAZ	.750	.750	6,720	.205	95.0	.89	6.48	.190	97.5	A
XIII-AB-18	||	HAZ	.750	.750	8,350	.220	125.0	1.16	6.89	.215	128.5	E
Statistics of K_{Ic} values (Eq. 10): Mean - 107.37, c.v. - .094, 95% conf. limits: 101.8 - 112.9, 90% conf. limits: 102.8 - 111.9												
XIII-AB- 9	||	DB	.750	.750	6,380	.230	99.0	.93	7.19	.230	101.5	F
XIII-AB-12	||	DB	.750	.750	5,280	.270	94.5	.90	7.75	.265	89.5	F
XIII-AB-13	||	DB	.750	.750	6,830	.215	100.5	.94	6.78	.210	104.0	F
XIII-AB-15	||	DB	.750	.750	7,020	.220	105.0	.98	6.61	.200	105.0	F
XIII-AB-16	||	DB	.750	.750	6,620	.225	101.0	.94	7.23	.235	106.5	F
XIII-AB-19	||	DB	.750	.750	6,940	.210	100.0	.93	6.66	.200	103.5	F
XIII-AB-20	||	DB	.750	.750	6,940	.220	104.0	.97	6.94	.220	108.5	F
Statistics of K_{Ic} values (Eq. 10): Mean - 100.57, c.v. - .034, 95% conf. limits: 97.4 - 103.8, 90% conf. limits: 98.0 - 103.1												

TABLE 16. FRACTURE TOUGHNESS TESTS OF PLATE NO. 19, 200 KSI GRADE OF MARAGING STEEL, MIG WELD

Base Metal: 18 Ni(200) maraging steel plate 3/4 inch thick, heat No. 3960819, vacuum remelted. Mill annealed, aged after welding-915°F, 4 hrs, air cool, yield strengths: 233,000 psi ∥ to R.D.; 228,500 psi ⊥ to R.D.

Weld: Mig weld by Excelco Developments Inc.

Notch Condition: Machined V-notch extended by fatigue crack, all notches parallel to plate surface.

Test Conditons: Bar bending length was 6.00 inches, tests were conducted at room temperature.

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-In (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	σ_{nom}/σ_{YS}	B/M Reciprocal of Spring Constant (in^2/lb)(10^{-6})	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} by Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
19- 3	∥	BM	.751	.750	20,910	.065	148.0	1.72	5.29	M	---	E
19- 4	∥	BM	.750	.750	8,360	.225	127.5	1.17	7.03	.200	130.0	E
19- 5	∥	BM	.750	.750	8,400	.220	125.5	1.15	7.06	.205	132.5	E
19- 6	∥	BM	.750	.750	8,290	.230	129.0	1.18	7.05	.200	129.0	E
19- 7	∥	BM	.750	.750	8,430	.215	123.5	1.14	6.95	.200	131.0	E
19- 8	∥	BM	.751	.751	8,520	.225	129.5	1.19	6.94	.200	132.5	E
19- 9	∥	BM	.750	.750	8,520	.225	130.0	1.19	6.82	.190	129.0	E
19-10	∥	BM	.751	.750	8,180	.235	129.0	1.19	7.02	.200	127.0	E
19-11	∥	BM	.750	.750	7,790	.225	119.0	1.09	7.20	.215	126.5	E
19-12	∥	BM	.750	.750	12,720	.140	139.5	1.32	6.00	.125	152.5	E
19-13	∥	BM	.750	.751	8,290	.210	119.0	1.09	6.87	.195	127.5	E
19-14	∥	BM	.750	.750	11,950	.145	133.5	1.26	5.96	.120	140.5	E
19-15	∥	BM	.750	.751	11,760	.140	128.0	1.22	5.91	.115	134.5	E
19-16	∥	BM	.751	.750	8,260	.215	122.0	1.12	7.01	.200	128.5	E
19-17	∥	BM	.750	.751	8,320	.225	126.5	1.16	7.07	.205	131.5	E
19-18	∥	BM	.750	.751	7,170	.260	123.5	1.15	7.61	.235	122.5	E
19-19	∥	BM	.750	.750	8,190	.240	131.5	1.21	6.98	.200	127.5	E
19-20	∥	BM	.750	.751	8,110	.235	128.0	1.18	7.00	.200	126.0	E
19-21	∥	BM	.750	.750	7,760	.230	120.5	1.11	6.94	.200	120.5	F
19-22	∥	BM	.750	.751	7,600	.245	124.0	1.15	6.98	.200	118.0	E
19-23	∥	BM	.750	.750	7,810	.225	119.0	1.09	6.98	.195	120.0	E
19-24	∥	BM	.751	.751	7,500	.240	120.5	1.11	7.00	.200	117.0	E
19-28	∥	BM	.751	.751	7,760	.235	122.5	1.12	7.08	.205	122.5	E
19-29	∥	BM	.751	.750	5,330	.335	121.0	1.20	9.08	M	---	F
19-30	∥	BM	.751	.751	4,890	.345	115.0	1.15	9.95	M	---	F
Statistics of K_{Ic} values (Eq. 10): Mean - 126.20, c.v. - .056, 95% conf. limits: 123.3 - 129.1, 90% conf. limits: 123.8 - 128.6												
XIII-BA- 1	⊥	CW	.750	.750	4,120	.200	57.5	.53	6.70	.185	61.0	A
XIII-BA- 2	⊥	CW	.750	.750	4,620	.205	65.5	.61	6.70	.185	68.5	A
XIII-BA- 3	⊥	CW	.750	.750	3,950	.220	59.0	.55	7.02	.205	61.0	A
XIII-BA- 4	⊥	CW	.750	.751	4,270	.215	62.5	.59	6.86	.200	65.5	A
XIII-BA- 5	⊥	CW	.750	.751	4,180	.220	62.0	.58	6.88	.200	64.0	A
XIII-BA- 6	⊥	CW	.750	.750	4,070	.215	60.0	.56	6.90	.200	62.5	A
XIII-BA- 7	⊥	CW	.750	.750	5,100	.195	69.5	.65	6.61	.180	74.5	D
XIII-BA- 8	⊥	CW	.750	.750	4,870	.195	66.5	.62	6.61	.180	71.0	D
XIII-BA- 9	⊥	CW	.751	.750	4,190	.240	67.5	.63	7.41	.230	68.5	A
XIII-BA-10	⊥	CW	.751	.751	4,130	.235	65.0	.61	7.06	.210	65.0	B
XIII-BA-11	⊥	CW	.750	.750	4,400	.200	61.0	.57	6.61	.180	67.5	D
XIII-BA-12	⊥	CW	.750	.750	4,730	.195	64.5	.60	6.45	.170	67.5	D
XIII-BA-13	⊥	CW	.750	.750	4,190	.200	58.5	.55	6.83	.195	63.5	B
XIII-BA-14	⊥	CW	.751	.750	4,060	.205	57.5	.54	6.86	.195	61.5	C
XIII-BA-15	⊥	CW	.750	.750	4,390	.210	63.5	.59	6.81	.195	66.5	A
XIII-BA-16	⊥	CW	.750	.751	4,260	.205	60.0	.56	6.75	.190	63.5	D
XIII-BA-17	⊥	CW	.750	.750	4,380	.210	63.0	.59	6.87	.195	66.5	B
XIII-BA-18	⊥	CW	.750	.750	4,230	.200	59.0	.55	6.64	.185	62.5	B
XIII-BA-19	⊥	CW	.750	.750	4,260	.220	63.5	.60	7.13	.215	67.5	D
XIII-BA-20	⊥	CW	.750	.750	3,730	.215	55.0	.51	7.07	.210	58.5	F
Statistics of K_{Ic} values (Eq. 10): Mean - 62.03, c.v. - .061, 95% conf. limits: 60.3 - 63.8, 90% conf. limits: 60.6 - 63.5												
XIII-BC- 2	⊥	FZ	.750	.750	8,190	.220	122.5	1.15	6.55	.180	120.5	E
XIII-BC- 3	⊥	FZ	.750	.750	8,460	.205	119.5	1.12	6.57	.180	124.5	E
XIII-BC- 4	⊥	FZ	.750	.750	7,710	.225	117.5	1.10	6.93	.205	120.5	E
XIII-BC- 5	⊥	FZ	.750	.749	8,990	.200	125.0	1.18	6.60	.185	134.0	E
XIII-BC- 6	⊥	FZ	.750	.750	9,150	.205	129.5	1.21	6.70	.190	138.0	E
XIII-BC- 7	⊥	FZ	.750	.750	8,880	.200	123.5	1.16	6.55	.180	130.5	E
XIII-BC- 9	⊥	FZ	.750	.750	9,870	.185	129.5	1.22	6.31	.165	136.0	F
XIII-BD- 2	⊥	FZ	.751	.750	7,380	.230	114.5	1.08	7.01	.210	116.5	F
XIII-BD- 3	⊥	FZ	.750	.750	8,960	.200	124.5	1.16	6.43	.170	129.0	E
XIII-BD- 4	⊥	FZ	.749	.750	10,120	.200	140.5	1.32	6.46	.175	146.5	E
XIII-BD-10	⊥	FZ	.750	.751	10,430	.190	139.0	1.30	6.26	.160	142.0	E
Statistics of K_{Ic} values (Eq. 10): Mean - 125.96, c.v. - .065, 95% conf. limits: 120.4 - 131.5, 90% conf. limits: 121.5 - 130.4												
XIII-BB- 1	⊥	HAZ	.751	.749	8,640	.200	120.0	1.13	6.69	.190	130.0	E
XIII-BB- 3	⊥	HAZ	.750	.750	8,400	.210	121.0	1.13	6.71	.190	126.5	E
XIII-BB- 5	⊥	HAZ	.750	.750	8,220	.220	123.0	1.15	6.74	.195	125.5	E
XIII-BB- 7	⊥	HAZ	.750	.750	8,860	.205	125.5	1.17	6.72	.190	133.5	E
XIII-BB- 8	⊥	HAZ	.750	.750	8,880	.220	133.0	1.24	6.76	.195	135.5	E
XIII-BB- 9	⊥	HAZ	.750	.751	9,500	.210	136.5	1.28	6.48	.175	138.0	E
XIII-BB-10	⊥	HAZ	.750	.750	7,760	.220	116.0	1.09	7.11	.215	124.0	E
XIII-BB-11	⊥	HAZ	.751	.750	7,320	.220	109.5	1.02	7.32	.225	119.0	F
XIII-BB-17	⊥	HAZ	.750	.751	9,440	.190	125.5	1.18	6.52	.180	139.0	F
XIII-BB-19	⊥	HAZ	.751	.750	8,950	.195	122.0	1.15	6.66	.185	133.5	E
Statistics of K_{Ic} values (Eq. 10): Mean - 123.20, c.v. - .063, 95% conf. limits: 117.7 - 128.7, 90% conf. limits: 118.7 - 127.7												
XIII-BB- 2	⊥	DB	.750	.751	7,520	.220	112.5	1.05	7.02	.210	118.5	E
XIII-BB- 4	⊥	DB	.750	.751	8,540	.210	123.0	1.15	6.65	.185	127.5	E
XIII-BB- 6	⊥	DB	.750	.751	8,760	.205	123.5	1.16	6.59	.185	130.5	E
XIII-BB-12	⊥	DB	.751	.751	8,520	.195	116.0	1.09	6.77	.195	130.0	F
XIII-BB-13	⊥	DB	.750	.750	7,630	.215	112.5	1.05	6.84	.200	118.0	E
XIII-BB-14	⊥	DB	.751	.751	8,660	.210	124.0	1.16	6.74	.195	132.0	F
XIII-BB-15	⊥	DB	.749	.750	7,980	.200	111.0	1.04	6.73	.190	120.0	E
XIII-BB-16	⊥	DB	.750	.750	7,120	.220	106.5	1.00	7.06	.210	112.5	E
XIII-BB-18	⊥	DB	.750	.750	8,930	.195	121.5	1.14	6.70	.190	134.5	E
XIII-BB-20	⊥	DB	.750	.750	7,310	.220	109.5	1.02	6.91	.205	114.0	F
XIII-BD- 6	⊥	DB	.751	.750	7,010	.245	114.5	1.08	7.43	.235	116.5	E
XIII-BD- 7	⊥	DB	.750	.750	5,280	.310	110.0	1.07	9.06	M	---	F
XIII-BD- 8	⊥	DB	.751	.750	5,060	.305	103.5	1.00	9.23	M	---	F
Statistics of K_{Ic} values (Eq. 10): Mean - 114.46, c.v. - .059, 95% conf. limits: 110.4 - 118.5, 90% conf. limits: 111.1 - 117.8												

TABLE 17. FRACTURE TOUGHNESS TESTS OF PLATE NO. 20, 200 KSI GRADE OF MARAGING STEEL, SHORT ARC WELD

Base Metal: 18 Ni(200) maraging steel plate 3/4 inch thick, heat No. 3951215, vacuum remelted. Mill annealed, aged after welding-915°F, 4 hrs, air cool, yield strengths: 225,200 psi ∥ to R.D.; 228,400 psi ⊥ to R.D.

Weld: Short arc weld by Excelco Developments Inc.

Notch Condition: Machined V-notch extended by fatigue crack, all notches parallel to plate surface.

Test Conditions: Bar bending length was 6.00 inches, tests were conducted at room temperature.

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-In (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	σ_{nom}/σ_{YS}	B/M Reciprocal of Spring Constant $(in^2/lb)(10^{-6})$	Effective a from $\sigma_{YS}/2$ Complinace Curve (in)	K_{Ic} Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
20- 1	∥	BM	.750	.750	9,170	.210	132.0	1.25	6.65	.185	132.5	E
20- 2	∥	BM	.749	.750	8,810	.210	127.0	1.20	6.67	.190	129.0	E
20- 3	∥	BM	.750	.750	9,070	.210	130.5	1.24	6.62	.185	131.0	E
20- 4	∥	BM	.750	.749	9,240	.200	128.5	1.22	6.57	.180	132.0	E
20- 5	∥	BM	.750	.749	8,850	.205	126.0	1.19	6.66	.190	129.5	E
20- 6	∥	BM	.750	.751	8,530	.215	125.0	1.19	6.81	.200	128.0	E
20- 7	∥	BM	.750	.751	8,640	.210	124.0	1.18	6.71	.190	126.5	E
20- 8	∥	BM	.750	.751	7,710	.240	123.5	1.18	7.21	.220	121.5	E
20- 9	∥	BM	.750	.749	8,960	.210	129.5	1.23	6.80	.200	134.5	E
20-10	∥	BM	.750	.750	9,070	.215	133.5	1.27	6.82	.200	136.0	E
20-11	∥	BM	.750	.751	9,200	.215	135.0	1.28	6.76	.195	137.0	E
20-12	∥	BM	.750	.750	9,330	.210	134.5	1.27	6.62	.185	135.0	E
20-13	∥	BM	.750	.750	9,040	.205	128.0	1.22	6.50	.175	127.0	E
20-14	∥	BM	.750	.750	8,770	.215	129.5	1.23	6.63	.185	127.0	E
20-15	∥	BM	.750	.751	9,330	.210	134.0	1.27	6.66	.190	136.5	E
20-16	∥	BM	.750	.750	8,800	.215	129.5	1.23	6.76	.195	131.0	E
20-17	∥	BM	.750	.750	7,840	.210	113.0	1.07	6.78	.195	116.5	F
20-18	∥	BM	.750	.750	7,600	.210	109.5	1.04	6.69	.190	111.0	F
20-19	∥	BM	.750	.750	8,190	.205	116.0	1.10	6.54	.180	117.0	F
20-20	∥	BM	.750	.750	8,000	.205	113.0	1.07	6.59	.180	114.0	F
Statistics of K_{Ic} values (Eq. 10): Mean - 126.08, c.v. - .060, 95% conf. limits: 122.5 - 129.6, 90% conf. limits: 123.1 - 129.0												
XIV-AA- 1	⊥	CW	.750	.750	4,030	.240	65.0	.61	7.48	.235	66.0	C
XIV-AA- 2	⊥	CW	.749	.751	3,930	.220	58.5	.55	7.00	.210	61.0	A
XIV-AA- 3	⊥	CW	.750	.750	4,210	.230	65.5	.61	7.07	.215	66.0	B
XIV-AA- 4	⊥	CW	.750	.751	3,710	.275	67.5	.64	8.09	.270	64.5	F
XIV-AA- 5	⊥	CW	.749	.750	4,210	.230	65.5	.61	7.13	.215	66.0	A
XIV-AA- 6	⊥	CW	.750	.751	2,990	.340	69.0	.70	10.08	M	---	F
XIV-AA- 7	⊥	CW	.750	.745	4,370	.200	61.0	.57	7.02	.210	68.0	E
XIV-AA- 8	⊥	CW	.749	.750	6,800	.300	136.0	1.32	8.26	.275	119.0	E
XIV-AA- 9	⊥	CW	.749	.750	6,430	.305	131.0	1.28	8.53	.290	115.5	E
XIV-AA-10	⊥	CW	.749	.750	3,980	.290	77.0	.74	8.32	.280	70.0	F
XIV-AA-11	⊥	CW	.750	.750	2,830	.300	56.5	.55	8.45	.285	50.5	E
XIV-AA-12	⊥	CW	.750	.750	4,600	.230	71.5	.67	7.15	.220	73.0	C
XIV-AC- 4	⊥	CW	.750	.749	5,440	.170	67.5	.64	6.26	.160	74.0	F
XIV-AC- 5	⊥	CW	.751	.750	4,930	.165	60.0	.57	6.11	.145	64.5	D
Statistics of K_{Ic} values (Eq. 10): Mean - 75.11, c.v. - .337, 95% conf. limits: 60.5 - 89.7, 90% conf. limits: 63.1 - 87.1												
XIV-AC- 6	⊥	FZ	.749	.750	10,550	.200	147.0	1.37	6.53	.180	152.0	E
XIV-AC- 7	⊥	FZ	.750	.750	11,010	.190	133.5	1.25	6.37	.170	154.5	E
XIV-AC- 8	⊥	FZ	.750	.749	11,680	.180	150.0	1.42	6.22	.155	156.5	E
XIV-AC- 9	⊥	FZ	.749	.750	9,350	.205	132.0	1.24	6.59	.185	136.5	E
XIV-AC-10	⊥	FZ	.750	.751	4,990	.225	76.0	.71	6.79	.200	75.5	D
XIV-AD- 3	⊥	FZ	.750	.750	8,880	.235	140.5	1.32	7.05	.215	139.5	E
XIV-AD- 4	⊥	FZ	.751	.751	9,720	.220	145.0	1.36	6.73	.195	145.5	E
XIV-AD- 5	⊥	FZ	.750	.750	10,240	.210	147.5	1.38	6.61	.185	150.0	E
Statistics of K_{Ic} values (Eq. 10): Mean - 133.94, c.v. - .182, 95% conf. limits: 113.6 - 154.3, 90% conf. limits: 117.6 - 150.2												
XIV-AB- 3	⊥	HAZ	.749	.749	7,980	.250	133.5	1.26	7.30	.230	129.5	E
XIV-AD- 6	⊥	HAZ	.750	.751	11,310	.190	150.5	1.41	6.36	.170	159.0	E
XIV-AD- 7	⊥	HAZ	.750	.750	9,520	.235	150.5	1.42	6.91	.205	146.5	E
XIV-AD- 8	⊥	HAZ	.750	.750	11,730	.185	154.0	1.45	6.30	.165	162.5	E
XIV-AD- 9	⊥	HAZ	.750	.750	10,000	.200	139.0	1.30	6.52	.180	144.0	E
XIV-AD-10	⊥	HAZ	.751	.750	10,600	.195	144.5	1.36	6.40	.170	149.0	E
Statistics of K_{Ic} values (Eq. 10): Mean - 145.33, c.v. - .054, 95% conf. limits: 137.1 - 153.6, 90% conf. limits: 138.9 - 151.8												
XIV-AB- 1	⊥	DB	.749	.750	6,940	.240	111.5	1.05	7.12	.220	110.5	F
XIV-AB- 2	⊥	DB	.749	.749	8,280	.220	124.0	1.16	6.86	.200	125.5	E
XIV-AB- 4	⊥	DB	.749	.749	8,220	.220	123.5	1.16	6.84	.200	125.0	E
XIV-AB- 5	⊥	DB	.749	.749	6,380	.255	108.5	1.03	7.33	.230	103.5	F
XIV-AB- 6	⊥	DB	.750	.750	9,330	.200	129.5	1.21	6.60	.185	136.5	E
XIV-AB- 7	⊥	DB	.750	.749	8,090	.210	117.0	1.09	6.86	.205	124.5	E
XIV-AB- 8	⊥	DB	.750	.750	6,530	.245	107.0	1.01	7.51	.240	108.5	F
XIV-AB- 9	⊥	DB	.750	.749	7,470	.235	118.5	1.12	7.28	.230	121.5	E
XIV-AB-10	⊥	DB	.750	.749	7,730	.210	111.5	1.05	6.87	.205	118.5	E
XIV-AB-11	⊥	DB	.749	.751	6,600	.245	107.5	1.02	7.44	.235	108.0	F
XIV-AB-12	⊥	DB	.750	.749	7,810	.215	115.0	1.08	6.97	.210	121.5	E
XIV-AB-13	⊥	DB	.749	.750	7,400	.230	115.0	1.08	7.24	.225	119.0	E
XIV-AB-14	⊥	DB	.749	.749	8,280	.225	126.5	1.19	7.09	.215	130.0	E
XIV-AB-15	⊥	DB	.750	.751	7,230	.225	110.0	1.03	6.94	.205	111.0	E
XIV-AB-16	⊥	DB	.749	.751	8,010	.205	113.0	1.06	6.62	.185	117.0	E
XIV-AB-17	⊥	DB	.750	.751	7,650	.215	112.0	1.05	6.79	.200	116.0	E
XIV-AB-18	⊥	DB	.752	.750	8,240	.195	112.5	1.05	6.61	.185	120.5	E
XIV-AB-19	⊥	DB	.749	.749	8,760	.190	117.5	1.10	6.55	.180	126.5	E
XIV-AB-20	⊥	DB	.750	.751	8,610	.190	114.5	1.08	6.58	.185	126.0	F
Statistics of K_{Ic} values (Eq. 10): Mean - 115.50, c.v. - .056, 95% conf. limits: 112.4 - 118.6, 90% conf. limits: 112.9 - 118.1												

TABLE 18. FRACTURE TOUGHNESS TESTS OF PLATE NO. 21, 200 KSI GRADE OF MARAGING STEEL, BIG TIG WELD.

Base Metal: 18 Ni(200) maraging steel plate 3/4 inch thick, heat No. 3951217, vacuum remelted. Mill annealed, aged after welding-915°F, 4 hrs, air cool, yield strengths: 229,500 psi ∥ to R.D.; 224,900 psi ⊥ to R.D.

Weld: Tig weld (310-350 amps), 1/4 inch tungsten electrode, by Excelco Developments Inc.

Notch Condition: Machined V-notch extended by fatigue crack, all notches parallel to plate surface.

Test Conditions: Bar bending length was 6.00 inches, tests were conducted at room temperature.

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-in (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	σ_{nom}/σ_{YS}	B/M Reciprocal of Spring Constant (in^2/lb)(10^{-6})	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
21- 2	∥	BM	.750	.751	7,600	.210	109.5	1.02	6.77	.210	118.0	F
21- 3	∥	BM	.751	.750	7,620	.215	112.5	1.05	6.82	.215	119.0	F
21- 4	∥	BM	.751	.751	7,800	.210	112.0	1.04	6.77	.210	121.0	E
21- 5	∥	BM	.751	.751	7,000	.220	104.5	.97	6.77	.210	108.5	B
21- 6	∥	BM	.750	.751	7,230	.225	110.0	1.02	6.89	.220	115.0	E
21- 7	∥	BM	.751	.751	7,320	.225	111.5	1.04	6.87	.220	116.0	F
21- 8	∥	BM	.751	.751	7,640	.215	112.0	1.05	6.72	.210	118.5	E
21- 9	∥	BM	.751	.751	7,830	.215	115.0	1.07	6.85	.215	122.5	E
21-11	∥	BM	.750	.750	8,110	.210	117.0	1.09	6.81	.215	127.0	E
21-12	∥	BM	.750	.750	8,030	.215	118.5	1.10	6.79	.215	125.5	E
21-13	∥	BM	.751	.751	7,720	.210	111.0	1.03	6.81	.215	121.0	F
21-14	∥	BM	.750	.750	7,730	.220	115.5	1.08	6.81	.215	121.0	E
21-15	∥	BM	.751	.751	7,480	.215	109.5	1.02	6.88	.220	119.0	E
21-16	∥	BM	.751	.751	7,480	.225	114.0	1.06	6.96	.225	120.0	E
21-17	∥	BM	.751	.750	7,320	.215	108.0	1.01	6.87	.220	116.0	F
21-18	∥	BM	.751	.749	6,740	.230	105.0	.98	7.23	.240	112.5	E
21-19	∥	BM	.750	.750	7,600	.215	112.0	1.04	6.92	.220	120.5	F
21-20	∥	BM	.751	.750	7,590	.210	109.5	1.02	6.81	.215	118.5	F
21-21	∥	BM	.750	.750	7,730	.210	111.5	1.04	6.77	.210	120.0	F
21-22	∥	BM	.750	.750	7,490	.230	116.0	1.08	6.92	.220	119.0	E
21-23	∥	BM	.749	.750	7,820	.215	115.5	1.07	6.78	.215	122.5	E
21-24	∥	BM	.750	.750	7,680	.220	115.0	1.07	6.91	.220	122.0	F
21-25	∥	BM	.751	.750	7,940	.220	119.0	1.11	6.91	.220	126.0	E
21-26	∥	BM	.750	.751	7,680	.235	121.0	1.13	7.08	.230	125.0	E
21-27	∥	BM	.750	.735	7,760	.230	126.5	1.18	7.36	.245	130.5	E
21-28	∥	BM	.750	.751	7,070	.250	116.5	1.11	7.39	.245	119.0	E
21-29	∥	BM	.751	.750	8,070	.220	121.0	1.12	6.83	.215	126.5	E
21-30	∥	BM	.751	.750	8,230	.210	118.5	1.10	6.75	.210	127.5	E

Statistics of K_{Ic} values (Eq. 10): Mean - 113.84, c.v. - .044, 95% conf. limits: 111.9 - 115.8, 90% conf. limits: 112.2 - 115.4

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-in (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	σ_{nom}/σ_{YS}	B/M Reciprocal of Spring Constant (in^2/lb)(10^{-6})	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
XIV-BA- 1	⊥	CW	.751	.751	9,590	.125	97.5	.98	5.71	.140	116.0	C
XIV-BA- 2	⊥	CW	.751	.751	8,960	.125	91.0	.92	5.81	.150	113.0	B
XIV-BA- 3	⊥	CW	.750	.750	7,680	.230	119.5	1.14	7.13	.240	129.5	F
XIV-BA- 4	⊥	CW	.750	.751	7,130	.220	106.5	1.02	6.95	.230	117.5	F
XIV-BA- 5	⊥	CW	.750	.750	4,930	.290	95.0	.93	8.49	.300	97.0	F
XIV-BA- 6	⊥	CW	.750	.751	6,610	.250	110.0	1.05	7.28	.245	112.5	F
XIV-BA- 7	⊥	CW	.749	.750	6,680	.230	104.0	.99	6.97	.230	110.0	F
XIV-BA- 8	⊥	CW	.750	.750	6,610	.230	102.5	.98	7.13	.300	111.5	F
XIV-BA- 9	⊥	CW	.751	.751	7,620	.235	120.0	1.15	7.06	.235	126.5	F
XIV-BA-10	⊥	CW	.751	.751	6,280	.255	106.5	1.02	7.47	.255	110.0	F
XIV-BA-11	⊥	CW	.750	.751	6,090	.245	99.5	..95	7.40	.250	105.5	F
XIV-BA-12	⊥	CW	.751	.751	8,810	.205	124.5	1.18	6.59	.210	136.5	D
XIV-BA-13	⊥	CW	.750	.750	7,470	.220	112.0	1.06	6.89	.225	120.5	F
XIV-BA-14	⊥	CW	.751	.751	8,040	.210	115.5	1.10	6.62	.210	125.0	F
XIV-BA-15	⊥	CW	.751	.751	6,920	.215	101.5	.96	6.69	.215	108.5	F
XIV-BA-16	⊥	CW	.750	.751	7,080	.225	107.5	1.02	6.77	.220	113.0	F
XIV-BA-17	⊥	CW	.750	.751	7,800	.220	116.5	1.11	6.60	.210	121.0	F
XIV-BA-18	⊥	CW	.750	.751	9,550	.200	132.0	1.26	6.32	.190	138.5	E
XIV-BA-19	⊥	CW	.750	.751	9,190	.220	137.5	1.30	6.67	.215	144.0	F

Statistics of K_{Ic} values (Eq. 10): Mean - 110.47, c.v. - .112, 95% conf. limits: 104.5 - 116.4, 90% conf. limits: 105.5 - 115.4

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-in (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	σ_{nom}/σ_{YS}	B/M Reciprocal of Spring Constant (in^2/lb)(10^{-6})	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
XIV-BC- 3	⊥	FZ	.751	.750	8,580	.250	143.5	1.37	7.26	.240	141.5	E
XIV-BC- 4	⊥	FZ	.751	.750	10,650	.210	148.5	1.46	6.61	.200	160.0	E
XIV-BC- 5	⊥	FZ	.751	.750	11,080	.195	151.5	1.44	6.36	.185	159.5	E
XIV-BC- 6	⊥	FZ	.750	.751	9,970	.185	130.5	1.24	6.22	.175	140.0	E
XIV-BC- 7	⊥	FZ	.750	.750	9,490	.185	124.5	1.19	6.27	.175	133.5	E
XIV-BD- 4	⊥	FZ	.751	.750	9,480	.230	147.0	1.41	6.97	.220	149.0	E
XIV-BD- 5	⊥	FZ	.750	.750	10,530	.210	151.5	1.44	6.51	.200	158.0	E
XIV-BD- 6	⊥	FZ	.751	.751	11,130	.200	154.0	1.46	6.33	.180	158.5	E
XIV-BD- 7	⊥	FZ	.750	.751	9,840	.215	144.0	1.37	6.43	.190	144.0	E

Statistics of K_{Ic} values (Eq. 10): Mean - 143.89, c.v. - .070, 95% conf. limits: 136.2 - 151.6, 90% conf. limits: 137.7 - 150.1

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-in (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	σ_{nom}/σ_{YS}	B/M Reciprocal of Spring Constant (in^2/lb)(10^{-6})	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
XIV-BC- 8	⊥	HAZ	.750	.751	8,880	.245	144.5	1.39	7.19	.235	144.5	E
XIV-BC- 8	⊥	HAZ	.750	.750	7,410	.260	128.5	1.24	7.35	.245	123.5	E
XIV-BB- 3	⊥	HAZ	.751	.751	8,010	.235	126.5	1.20	6.92	.220	126.5	F
XIV-BD- 8	⊥	HAZ	.750	.751	11,920	.190	159.0	1.52	6.28	.175	167.5	E
XIV-BD- 9	⊥	HAZ	.751	.751	10,200	.215	149.5	1.42	6.76	.210	157.0	E

Statistics of K_{Ic} values (Eq. 10): Mean - 141.60, c.v. - .098, 95% conf. limits: 124.3 - 158.9, 90% conf. limits: 128.3 - 154.9

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-in (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	σ_{nom}/σ_{YS}	B/M Reciprocal of Spring Constant (in^2/lb)(10^{-6})	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
XIV-BB- 1	⊥	DB	.751	.750	9,370	.210	135.0	1.29	6.71	.205	142.5	F
XIV-BB- 2	⊥	DB	.751	.751	8,790	.205	124.0	1.18	6.54	.195	130.0	F
XIV-BB- 4	⊥	DB	.751	.750	8,310	.210	120.0	1.14	6.61	.200	125.0	F
XIV-BB- 5	⊥	DB	.751	.750	8,360	.220	125.0	1.19	6.76	.210	129.0	E
XIV-BB- 6	⊥	DB	.751	.751	9,160	.215	134.5	1.28	6.58	.200	138.5	E
XIV-BB- 7	⊥	DB	.751	.751	8,150	.220	121.5	1.16	6.64	.205	124.0	E
XIV-BB- 8	⊥	DB	.750	.751	9,040	.220	135.0	1.29	6.42	.190	132.0	E
XIV-BB- 9	⊥	DB	.751	.751	9,450	.210	136.0	1.29	6.46	.190	138.0	E
XIV-BB-10	⊥	DB	.750	.751	8,880	.210	127.5	1.21	6.61	.200	133.5	E
XIV-BB-11	⊥	DB	.751	.751	9,210	.210	132.5	1.26	6.56	.195	136.5	E
XIV-BB-12	⊥	DB	.750	.751	8,450	.215	124.0	1.18	6.70	.205	128.5	E
XIV-BB-13	⊥	DB	.750	.750	6,670	.230	103.5	.99	6.84	.215	104.0	E
XIV-BB-14	⊥	DB	.751	.751	8,630	.220	129.0	1.22	6.66	.205	131.5	E
XIV-BB-15	⊥	DB	.750	.751	8,640	.220	129.0	1.23	6.75	.210	133.0	E
XIV-BB-16	⊥	DB	.750	.751	8,530	.215	125.0	1.19	6.66	.205	129.5	E
XIV-BB-17	⊥	DB	.750	.751	8,290	.230	128.0	1.22	6.90	.220	130.5	E
XIV-BB-18	⊥	DB	.751	.751	7,860	.230	121.5	1.16	6.90	.220	123.5	E
XIV-BB-19	⊥	DB	.751	.750	8,390	.215	123.5	1.17	6.69	.205	127.5	E
XIV-BB-20	⊥	DB	.750	.751	8,360	.225	127.0	1.21	6.82	.215	130.5	E

Statistics K_{Ic} values (Eq. 10): Mean - 126.40, c.v. - .059, 95% conf. limits: 122.8 - 130.0, 90% conf. limits: 123.4 - 129.4

TABLE 19. FRACTURE TOUGHNESS TESTS OF PLATE NO. 22, 200 KSI GRADE OF MARAGING STEEL, MIG WELD

Base Metal: 18 Ni (200) maraging steel plate 3/4 inch thick, heat No. 3951215, vacuum remelted. Mill annealed, aged by Excelco before welding, aged after welding-915°F, 4 hrs, air cool, yield strengths: 225,000 psi ‖ to R.D.; 228,400 psi ⊥ to R.D.

Weld: Mig weld by Excelco Developments Inc.

Notch Condition: Machined V-notch extended by fatigue crack, all notches parallel to plate surface.

Test Conditions: Bar bending length was 6.00 inches, tests were conducted at room temperature.

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-in (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	$\frac{\sigma_{nom}}{\sigma_{YS}}$	B/M Reciprocal of Spring Constant (in^2/lb)(10^{-6})	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
XV-BA- 1	⊥	CW	.750	.750	5,630	.205	79.5	.75	6.40	.175	79.5	D
XV-BA- 2	⊥	CW	.750	.750	5,100	.200	71.0	.66	6.29	.165	70.0	F
XV-BA- 3	⊥	CW	.751	.750	5,220	.200	72.5	.68	6.28	.165	71.5	D
XV-BA- 4	⊥	CW	.750	.751	5,520	.195	75.0	.70	5.98	.140	69.0	D
XV-BA- 5	⊥	CW	.748	.751	5,940	.200	82.0	.77	6.17	.155	78.5	D
XV-BA- 6	⊥	CW	.750	.750	5,600	.185	73.5	.69	6.06	.145	71.5	D
XV-BA- 7	⊥	CW	.750	.751	3,860	.325	78.5	.84	8.88	.305	74.0	F
XV-BA- 8	⊥	CW	.750	.751	4,380	.245	71.5	.67	7.02	.215	69.0	D
XV-BA- 9	⊥	CW	.750	.750	4,160	.345	98.5	1.00	9.32	M	----	F
XV-BA-11	⊥	CW	.750	.750	5,040	.200	70.0	.66	6.10	.150	65.0	F
XV-BA-12	⊥	CW	.750	.750	4,940	.210	71.0	.67	6.32	.170	68.5	F
XV-BA-13	⊥	CW	.749	.752	5,740	.205	81.0	.76	6.15	.155	75.5	D
XV-BA-14	⊥	CW	.749	.752	5,800	.195	78.5	.74	6.06	.145	74.0	F
XV-BC- 3	⊥	CW	.750	.751	5,760	.175	72.5	.68	6.17	.155	76.0	F
XV-BC- 4	⊥	CW	.750	.751	5,600	.180	72.0	.68	6.13	.155	73.5	F
XV-BC- 5	⊥	CW	.750	.751	5,600	.185	73.5	.69	6.43	.155	73.5	F
XV-BC- 6	⊥	CW	.750	.750	4,190	.250	70.0	.66	7.22	.225	68.0	C
Statistics of K_{Ic} values (Eq. 10): Mean - 75.91, c.v. - .092, 95% conf. limits: 72.3 - 79.5, 90% conf. limits: 72.9 - 78.9												
XV-BC- 7	⊥	FZ	.750	.750	4,880	.200	68.0	.63	6.32	.170	68.0	C
XV-BC- 8	⊥	FZ	.750	.750	6,450	.235	102.0	.96	6.79	.200	97.5	F
XV-BC- 9	⊥	FZ	.750	.750	9,140	.195	128.5	1.20	6.25	.165	128.0	F
XV-BC-10	⊥	FZ	.750	.750	7,650	.225	116.5	1.09	6.96	.210	118.5	F
XV-BD- 4	⊥	FZ	.750	.751	11,330	.185	148.5	1.39	6.16	.155	150.5	E
XV-BD- 5	⊥	FZ	.750	.749	6,720	.200	93.5	.88	6.50	.180	96.0	A
XV-BD- 6	⊥	FZ	.750	.750	10,800	.190	144.0	1.35	6.10	.150	141.0	F
XV-BD- 7	⊥	FZ	.750	.750	5,390	.255	91.5	.87	7.37	.235	88.5	E
Statistics of K_{Ic} values (Eq. 10): Mean - 111.56, c.v. - .250, 95% conf. limits: 88.2 - 134.9, 90% conf. limits: 92.9 - 130.3												
XV-BB- 1	⊥	HAZ	.750	.751	6,800	.255	115.5	1.09	7.50	.240	113.0	E
XV-BB- 2	⊥	HAZ	.749	.752	7,020	.255	118.5	1.12	7.31	.230	114.0	E
XV-BB- 3	⊥	HAZ	.750	.751	8,350	.235	131.5	1.23	6.96	.210	129.5	E
XV-BB- 9	⊥	HAZ	.751	.750	8,180	.225	124.5	1.17	6.83	.205	125.5	E
XV-BB-13	⊥	HAZ	.751	.750	9,350	.215	138.0	1.29	6.66	.195	139.5	E
XV-BB-16	⊥	HAZ	.750	.751	6,450	.265	113.5	1.08	7.61	.250	109.5	E
XV-BB-17	⊥	HAZ	.751	.751	8,680	.220	129.5	1.21	6.73	.200	131.0	E
XV-BB-18	⊥	HAZ	.750	.749	8,000	.230	124.5	1.17	7.01	.215	125.5	E
XV-BB-19	⊥	HAZ	.750	.751	7,550	.245	123.0	1.16	7.23	.230	122.5	E
XV-BB-21	⊥	HAZ	.749	.751	9,750	.195	132.5	1.24	6.37	.175	137.0	E
XV-BB-24	⊥	HAZ	.750	.750	8,510	.220	127.5	1.19	6.71	.195	127.0	E
Statistics of K_{Ic} values (Eq. 10): Mean - 125.32, c.v. - .060, 95% conf. limits: 120.3 - 130.4, 90% conf. limits: 121.2 - 129.4												
XV-BB- 4	⊥	DB	.749	.752	5,870	.295	114.5	1.11	8.40	.285	106.5	E
XV-BB- 5	⊥	DB	.751	.749	7,380	.230	115.0	1.08	7.08	.220	117.5	E
XV-BB- 6	⊥	DB	.749	.751	7,050	.235	111.0	1.04	7.20	.225	113.5	F
XV-BB- 7	⊥	DB	.750	.751	6,590	.250	110.0	1.04	7.29	.230	107.0	E
XV-BB- 8	⊥	DB	.748	.751	7,380	.230	114.0	1.07	6.96	.210	114.5	F
XV-BB-10	⊥	DB	.749	.749	8,320	.220	125.0	1.17	6.76	.200	126.0	E
XV-BB-11	⊥	DB	.751	.751	6,820	.245	111.0	1.05	7.34	.235	112.0	E
XV-BB-12	⊥	DB	.750	.751	7,570	.230	117.0	1.10	6.77	.200	114.5	E
XV-BB-14	⊥	DB	.750	.749	6,000	.285	114.0	1.10	8.12	.275	107.0	E
XV-BB-15	⊥	DB	.750	.750	7,310	.240	117.5	1.11	7.01	.215	115.0	E
XV-BB-20	⊥	DB	.751	.749	5,810	.300	117.0	1.13	8.45	.290	106.5	E
XV-BB-22	⊥	DB	.750	.751	6,590	.255	112.0	1.06	7.63	.250	112.0	F
XV-BB-23	⊥	DB	.749	.750	6,220	.255	106.0	1.00	7.39	.235	102.5	E
Statistics of K_{Ic} values (Eq. 10): Mean - 114.15, c.v. - .040, 95% conf. limits: 111.4 - 116.9, 90% conf. limits: 111.9 - 116.4												

M = Missed calibration curve

TABLE 20. FRACTURE TOUGHNESS TESTS OF PLATE NO. 23, 200 KSI GRADE OF MARAGING STEEL, BIG TIG WELD.

Base Metal: 18 Ni(200) maraging steel plate 3/4 inch thick, heat No. 3951215, vacuum remelted. Mill annealed, aged after welding-915°F, 4 hrs, air cool, yield strengths: 225,200 psi ∥ to R.D.; 228,400 psi ⊥ to R.D.

Weld: Tig weld (310-350 amps), 1/4 inch tungsten electrode, by Excelco Developments Inc.

Notch Condtion: Machined V-notch extended by fatigue crack, all notches parallel to plate surface.

Test Conditions: Bar bending length was 6.00 inches, tests were conducted at room temperature.

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-In (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	σ_{nom}/σ_{YS}	B/M Reciprocal of Spring Constant (in²/lb)(10⁻⁶)	Effective a from $\sigma_{YS}/2$ Compliance Curve (in)	K_{Ic} Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
23- 9	⊥	BM	.751	.750	8,520	.210	123.0	1.15	6.66	.200	126.0	E
23-10	⊥	BM	.751	.751	8,280	.230	128.0	1.20	6.82	.210	125.5	E
23-11	⊥	BM	.750	.751	7,710	.240	123.5	1.16	6.94	.215	118.5	F
23-12	⊥	BM	.751	.751	8,520	.220	127.5	1.19	6.66	.200	126.0	E
23-13	⊥	BM	.751	.750	8,890	.210	128.0	1.20	6.49	.185	126.0	E
23-14	⊥	BM	.751	.750	8,310	.230	129.0	1.21	6.72	.200	123.0	E
23-15	⊥	BM	.751	.751	8,790	.210	126.5	1.18	6.64	.200	130.0	F
23-16	⊥	BM	.750	.750	7,310	.270	131.0	1.25	7.72	.260	125.0	E
23-17	⊥	BM	.751	.750	8,520	.220	127.5	1.20	6.77	.205	127.5	E
23-18	⊥	BM	.751	.751	9,040	.200	125.0	1.17	6.58	.190	130.0	E
23-19	⊥	BM	.750	.750	8,400	.210	121.0	1.13	6.81	.205	126.0	E
23-20	⊥	BM	.751	.750	9,240	.200	128.5	1.20	6.51	.185	130.5	E
23-22	⊥	BM	.750	.751	9,090	.200	125.5	1.18	6.49	.185	128.5	F
23-23	⊥	BM	.750	.751	8,370	.220	125.0	1.17	6.78	.205	125.5	E
23-24	⊥	BM	.750	.751	9,120	.200	126.0	1.18	6.50	.185	129.0	E
23-25	⊥	BM	.750	.751	9,570	.195	130.0	1.22	6.53	.190	137.5	E
23-26	⊥	BM	.750	.751	8,850	.210	127.5	1.19	6.72	.200	130.5	E
23-27	⊥	BM	.750	.751	9,090	.210	130.5	1.22	6.52	.190	130.5	E
23-28	⊥	BM	.750	.751	8,450	.230	130.5	1.23	6.87	.210	128.0	E
23-29	⊥	BM	.750	.751	9,230	.200	127.5	1.20	6.44	.180	128.5	E
Statistics of K_{Ic} values (Eq. 10): Mean - 127.05, c.v. - .021, 95% conf. limits: 125.8 - 128.3, 90% conf. limits: 126.1 - 128.1												
XV-AA- 1	∥	CW	.751	.751	6,520	.240	104.5	1.00	7.18	.230	103.5	A
XV-AA- 2	∥	CW	.751	.751	7,400	.220	110.5	1.03	6.72	.205	110.5	A
XV-AA- 3	∥	CW	.751	.751	7,400	.225	112.5	1.07	6.64	.200	109.0	E
XV-AA- 4	∥	CW	.751	.750	8,190	.200	114.0	1.08	6.34	.175	112.5	C
XV-AA- 5	∥	CW	.752	.751	5,900	.215	86.5	.82	6.66	.200	87.0	C
XV-AA- 6	∥	CW	.750	.751	6,610	.270	118.0	1.15	7.53	.250	109.5	E
XV-AA- 7	∥	CW	.750	.750	8,920	.200	124.0	1.18	6.44	.185	126.5	F
XV-AA- 8	∥	CW	.751	.750	7,910	.260	136.5	1.32	7.46	.250	131.0	F
XV-AA- 9	∥	CW	.750	.750	6,670	.210	96.0	.91	6.57	.195	97.0	E
XV-AA-10	∥	CW	.750	.750	6,110	.255	103.5	.99	7.29	.240	99.0	C
XV-AA-11	∥	CW	.751	.750	7,950	.230	123.5	1.18	6.73	.205	118.5	F
XV-AA-12	∥	CW	.750	.751	9,200	.205	130.0	1.23	6.47	.185	130.0	E
XV-AA-13	∥	CW	.751	.750	9,990	.185	131.0	1.25	6.19	.165	133.0	F
XV-AA-14	∥	CW	.750	.750	6,240	.210	90.0	.85	6.69	.200	91.5	B
XV-AA-15	∥	CW	.750	.751	6,910	.215	101.5	.96	6.69	.200	102.0	C
XV-AA-16	∥	CW	.750	.751	7,600	.195	103.5	.98	6.27	.170	102.5	A
XV-AA-17	∥	CW	.751	.751	8,470	.205	119.5	1.14	6.44	.185	120.0	E
XV-AA-18	∥	CW	.751	.750	9,130	.210	131.5	1.25	6.46	.185	129.5	C
XV-AA-20	∥	CW	.750	.751	9,330	.170	115.0	1.11	6.15	.160	122.5	C
Statistics of K_{Ic} values (Eq. 10): Mean - 113.24, c.v. - .127, 95% conf. limits: 106.3 - 120.2, 90% conf. limits: 107.5 - 119.0												
XV-AC- 3	∥	FZ	.750	.751	8,690	.220	130.0	1.23	6.65	.200	128.5	F
XV-AC- 4	∥	FZ	.750	.750	10,750	.210	155.0	1.47	6.43	.185	151.5	C
XV-AC- 5	∥	FZ	.750	.751	10,510	.200	145.5	1.38	6.38	.180	145.5	E
XV-AC- 6	∥	FZ	.751	.750	12,440	.175	157.0	1.50	6.10	.160	161.0	E
XV-AC- 7	∥	FZ	.750	.751	7,730	.260	133.5	1.28	7.36	.245	130.5	E
XV-AC- 8	∥	FZ	.751	.750	9,530	.215	140.5	1.33	6.48	.190	136.5	C
XV-AC- 9	∥	FZ	.750	.750	10,000	.185	131.0	1.25	6.17	.165	132.0	C
XV-AC-10	∥	FZ	.751	.751	9,930	.215	145.5	1.39	6.58	.200	146.5	E
Statistics of K_{Ic} values (Eq. 10): Mean - 142.25, c.v. - .073, 95% conf. limits: 133.6 - 150.9, 90% conf. limits: 135.3 - 149.2												
XV-AB- 1	∥	HAZ	.751	.750	8,630	.240	139.0	1.33	7.16	.230	139.5	E
XV-AB- 2	∥	HAZ	.751	.751	9,910	.220	148.0	1.40	6.83	.210	151.5	E
XV-AB- 4	∥	HAZ	.750	.751	9,770	.230	151.0	1.44	6.75	.210	149.0	E
XV-AB- 5	∥	HAZ	.750	.751	9,360	.230	144.5	1.38	6.79	.210	143.0	E
XV-AB- 6	∥	HAZ	.751	.751	9,130	.240	146.5	1.41	7.04	.225	146.0	E
XV-AB- 7	∥	HAZ	.750	.751	10,000	.220	149.5	1.42	6.85	.215	154.5	E
XV-AB- 8	∥	HAZ	.749	.751	9,370	.240	150.5	1.43	6.90	.215	145.0	E
XV-AB- 9	∥	HAZ	.751	.751	10,080	.230	155.5	1.49	6.81	.210	154.0	E
XV-AB-10	∥	HAZ	.751	.751	11,160	.210	160.5	1.52	6.49	.190	159.5	E
XV-AB-11	∥	HAZ	.750	.751	9,440	.225	143,5	1.36	6.83	.215	146.0	E
XV-AB-12	∥	HAZ	.751	.751	9,240	.230	142.5	1.36	6.86	.215	143.0	E
XV-AB-13	∥	HAZ	.751	.750	9,920	.225	151.0	1.43	6.85	.215	153.0	E
XV-AB-14	∥	HAZ	.751	.750	9,880	.230	153.5	1.46	6.81	.210	151.0	E
XV-AB-15	∥	HAZ	.751	.751	10,710	.200	148.0	1.41	6.33	.180	149.0	E
XV-AB-16	∥	HAZ	.750	.750	10,160	.225	155.0	1.47	6.75	.205	152.0	E
XV-AB-17	∥	HAZ	.751	.751	9,560	.225	145.5	1.38	6.79	.210	146.0	E
XV-AB-18	∥	HAZ	.751	.750	10,200	.220	152.5	1.45	6.74	.205	152.5	E
XV-AB-19	∥	HAZ	.751	.751	10,450	.225	159.0	1.51	6.73	.205	156.5	E
Statistics of K_{Ic} values (Eq. 10): Mean - 149.75, c.v. - .038, 95% conf. limits: 146.9 - 152.6, 90% conf. limits: 147.4 - 152.1												

TABLE 21. FRACTURE TOUGHNESS TESTS OF PLATE NO. 24, 200 KSI GRADE OF MARAGING STEEL, SHORT ARC WELD

Base Metal: 18 Ni(200) maraging steel plate 3/4 inch thick, heat No. 3951215, vacuum remelted. Mill annealed, aged after welding-915°F, 4 hrs, air cool, yield strengths: 225,200 psi ∥ to R.D.; 228,400 psi ⊥ to R.D.

Weld: Short arc weld by Excelco Developments Inc.

Notch Condition: Machined V-notch extended by fatigue crack, all notches parallel to plate surface.

Test Conditions: Bar bending length was 6.00 inches, tests were conducted at room temperature.

Bar No.	Bar Length Related to Plate Rolling Direction	Notch Location	B Bar Width (in)	d Bar Depth (in)	P/B Unit Load at Pop-In (lb-in)	Visual a Fatigue Notch Depth (in)	K_{Ic} by NRL Equation 10 (1000 psi$\sqrt{in}$)	σ_{nom}/σ_{YS}	B/M Reciprocal of Spring Constant (in^2/lb)(10^{-6})	Effective a from σ_{YS}/2 Compliance Curve (in)	K_{Ic} by Compliance Method (1000 psi$\sqrt{in}$)	Type of Load-Deflection Curve
24-10	⊥	BM	.749	.745	8,170	.235	128.5	1.24	7.30	.230	134.5	E
24-11	⊥	BM	.750	.750	8,960	.210	129.0	1.21	6.68	.195	133.0	E
24-12	⊥	BM	.750	.750	7,310	.250	122.0	1.15	7.34	.235	122.0	E
24-13	⊥	BM	.750	.751	9,330	.195	127.0	1.19	6.48	.180	131.5	E
24-14	⊥	BM	.750	.750	8,800	.205	124.5	1.17	6.63	.190	128.5	E
24-15	⊥	BM	.750	.750	8,050	.240	129.5	1.22	7.26	.230	132.5	E
24-16	⊥	BM	.750	.750	8,110	.230	126.0	1.18	7.13	.220	129.5	E
24-17	⊥	BM	.749	.745	9,350	.200	132.0	1.24	6.66	.195	138.5	E
24-18	⊥	BM	.745	.749	8,380	.230	130.5	1.23	6.96	.215	132.0	E
24-19	⊥	BM	.749	.751	9,400	.205	132.5	1.24	6.55	.185	134.5	E
24-21	⊥	BM	.749	.750	9,400	.200	131.0	1.22	6.56	.185	134.5	F
24-22	⊥	BM	.749	.750	9,430	.190	126.0	1.19	6.48	.180	133.0	F
24-23	⊥	BM	.749	.750	6,880	.275	125.5	1.20	7.91	.260	122.5	E
24-24	⊥	BM	.749	.745	9,270	.195	128.0	1.20	6.68	.195	137.5	F
24-25	⊥	BM	.750	.750	9,170	.200	127.5	1.19	6.58	.190	133.5	F
24-26	⊥	BM	.750	.750	9,630	.195	131.5	1.23	6.53	.185	138.0	F
24-27	⊥	BM	.750	.750	9,170	.190	129.5	1.22	6.48	.180	137.0	F
24-28	⊥	BM	.750	.749	9,200	.205	130.5	1.23	6.72	.200	138.0	E
24-29	⊥	BM	.749	.750	8,700	.210	125.5	1.17	6.85	.205	133.0	F
Statistics of K_{Ic} values (Eq. 10): Mean - 128.24, c.v. - .022, 95% conf. limits: 126.9 - 129.6, 90% conf. limits: 127.1 - 129.4												
XVI-AA- 9	∥	CW	.750	.750	4,200	.205	59.5	.56	6.71	.205	63.5	C
XVI-AA-10	∥	CW	.749	.750	4,070	.210	58.5	.56	6.84	.210	62.5	C
XVI-AA-11	∥	CW	.749	.750	4,390	.205	62.0	.59	6.75	.210	67.0	F
XVI-AA-12	∥	CW	.751	.750	4,480	.175	56.5	.54	6.40	.180	62.0	D
XVI-AA-13	∥	CW	.750	.750	3,600	.210	52.0	.49	6.93	.220	56.5	A
XVI-AA-14	∥	CW	.750	.750	4,210	.190	56.0	.54	6.56	.195	61.0	F
XVI-AA-15	∥	CW	.750	.750	4,530	.180	58.5	.56	6.46	.185	63.5	D
XVI-AA-16	∥	CW	.751	.750	4,110	.195	56.0	.53	6.53	.195	59.5	F
XVI-AA-17	∥	CW	.750	.751	4,050	.200	56.0	.53	6.75	.205	61.0	F
XVI-AA-18	∥	CW	.750	.751	4,510	.225	68.5	.65	6.98	.220	71.0	F
XVI-AA-19	∥	CW	.750	.751	4,930	.180	63.5	.60	6.28	.175	67.0	F
XVI-AA-20	∥	CW	.750	.751	4,240	.205	60.0	.57	6.79'	.210	65.0	F
XVI-AC- 3	∥	CW	.745	.749	2,820	.350	68.0	.71	10.30	M	---	E
XVI-AC- 4	∥	CW	.750	.750	3,730	.190	50.0	.48	6.53	.190	53.5	B
XVI-AC- 5	∥	CW	.749	.751	7,050	.180	90.5	.87	6.35	.180	97.5	F
XVI-AD- 7	∥	CW	.750	.750	3,490	.245	57.0	.55	7.35	.240	58.0	A
Statistics of K_{Ic} values (Eq. 10): Mean - 60.78, c.v. - .154, 95% conf. limits: 55.8 - 65.8, 90% conf. limits: 56.7 - 64.9												
XVI-AC- 7	∥	FZ	.750	.751	9,170	.185	120.0	1.15	6.42	.185	130.5	F
XVI-AC- 8	∥	FZ	.750	.750	8,210	.185	107.5	1.03	6.37	.180	115.0	F
XVI-AD- 4	∥	FZ	.751	750	7,510	.220	112.5	1.07	6.95	.220	120.5	E
XVI-AD- 6	∥	FZ	.750	.750	8,090	.205	114.5	1.09	6.70	.205	123.5	E
XVI-AD- 8	∥	FZ	.749	.748	7,290	.225	111.5	1.06	7.13	.230	121.0	E
XVI-AD- 9	∥	FZ	.750	.750	6,930	.240	111.5	1.07	7.20	.235	116.5	E
XVI-AD-10	∥	FZ	.750	.751	7,950	.205	112.0	1.07	6.58	.200	119.5	E
Statistics of K_{Ic} values (Eq. 10): Mean - 112.79, c.v. - .034, 95% conf. limits: 109.3 - 116.3, 90% conf. limits: 110.0 - 115.6												
XVI-AB- 5	∥	HAZ	.750	.750	7,310	.240	117.5	1.12	7.13	.230	121.0	E
XVI-AB- 6	∥	HAZ	.750	.749	8,160	.195	111.5	1.06	6.41	.185	116.5	E
XVI-AB- 8	∥	HAZ	.750	.750	8,190	.210	118.0	1.12	6.70	.205	125.0	E
XVI-AB- 9	∥	HAZ	.751	.750	8,390	.200	116.5	1.11	6.48	.190	122.0	E
XVI-AB-10	∥	HAZ	.749	.750	8,180	.215	120.5	1.15	6.73	.210	127.0	E
XVI-AB-16	∥	HAZ	.749	.751	8,200	.215	120.0	1.14	6.78	.210	127.0	E
XVI-AB-19	∥	HAZ	.749	.750	8,730	.200	121.5	1.15	6.56	.195	129.0	E
XVI-AB-20	∥	HAZ	.750	.750	7,890	.190	105.5	1.00	6.54	.195	116.5	E
Statistics of K_{Ic} values (Eq. 10): Mean - 116.38, c.v. - .046, 95% conf. limits: 111.9 - 120.9, 90% conf. limits: 112.8 - 120.0												
XVI-AB- 1	∥	DB	.750	.750	8,560	.200	119.0	1.13	6.52	.195	126.5	E
XVI-AB- 2	∥	DB	.750	.749	7,890	.200	109.5	1.04	6.48	.190	114.5	F
XVI-AB- 3	∥	DB	.749	.749	7,770	.190	104.5	.99	6.38	.185	111.0	E
XVI-AB- 4	∥	DB	.751	.751	7,990	.210	115.0	1.09	6.53	.195	118.0	F
XVI-AB- 7	∥	DB	.749	.751	7,480	.200	103.0	.98	6.64	.200	112.5	F
XVI-AB-11	∥	DB	.750	.750	8,800	.190	117.5	1.12	6.31	.180	123.0	F
XVI-AB-13	∥	DB	.750	.750	6,960	.220	104.0	.99	7.00	.220	111.5	F
XVI-AB-14	∥	DB	.749	.750	6,970	.220	104.5	.99	6.94	.220	111.5	E
XVI-AB-15	∥	DB	.750	.750	8,510	.195	116.0	1.10	6.49	.190	123.5	E
XVI-AB-17	∥	DB	.751	.750	6,920	.210	99.5	.95	6.79	.210	107.5	C
XVI-AB-18	∥	DB	.750	.751	7,520	.200	104.0	.99	6.67	.205	115.0	C
Statisitcs of K_{Ic} values (Eq. 10): Mean - 108.82, c.v. - .063, 95% conf. limits: 104.2 - 113.4, 90% conf. limits: 105.1 - 112.6												

TABLE 22. AVERAGE K_{Ic} FRACTURE TOUGHNESS IN PLATES WELDED BY EXCELCO DEVELOPMENTS INC.

18 Ni Steel Type	Heat Number Used for Weld Zone Tests	Test Plate Nos.	Welding Method	Tests Bar Axis[1] in Relation to Plate Rolling Direction	Average K_{Ic} Values Based on Visual <u>a</u> and NRL Equation 10. (1000 psi$\sqrt{in}$)				
					BM	CW	FZ	HAZ	DB
250	X14636	2, 1	Little TIG	$\parallel$	84.5	83.5	100.5	94.0	92.5
250	X14636	1, 2	Little TIG	$\perp$	76.5	69.5	81.0	74.5	67.0
250	X53013	8,10	Big TIG	$\parallel$	92.5	104.0	120.5	128.5	121.0
250	X53013	10, 8	Big TIG	$\perp$	85.5	95.5	107.5	-----	89.0
250	X14636	6, 5	MIG	$\parallel$	88.0	78.0	-----	107.0	98.5
250	X53013	5, 6	MIG	$\perp$	78.0	71.5	84.0	93.5	89.5
250		9	MIG on heat	$\parallel$	83.5	----	----	----	----
250	X53013	9	treated on plate	$\perp$	----	72.5	81.0	----	----
250	X53013	7,11	Short Arc	$\parallel$	87.0	69.5	----	104.5	----
250	X53013	11, 7	Short Arc	$\perp$	83.0	58.0	97.5	90.0	88.0
200	3960819	15,14	Little TIG	$\parallel$	120.5	111.0	121.0	121.5	121.5
200	3951215	14,15	Little TIG	$\perp$	130.5	112.0	126.5	116.0	118.5
200	3951215	21,23	Big TIG	$\parallel$	114.0	113.0	142.5	150.0	-----
200	3951217	23,21	Big TIG	$\perp$	127.0	110.5	144.0	141.5	126.5
200	3951217	19,18	MIG	$\parallel$	126.0	70.5	122.5	107.5	100.5
200	3960819	18,19	MIG	$\perp$	95.5	62.0	115.5	113.5	109.5
200			MIG on heat	$\parallel$	----	----	-----	-----	-----
200	3951215	22	treated plate	$\perp$	----	76.0	111.5	125.5	114.0
200	3951215	20,24	Short Arc	$\parallel$	126.0	61.0	113.0	116.5	109.0
200	3951215	24,20	Short Arc	$\perp$	128.0	75.0	134.0	145.5	115.5

(1) $\parallel$ tests simulate a longitudinal seam weld in the rocket casing.
$\perp$ tests simulate a girth weld.

TABLE 23. FORMULAS USED IN CALCULATIONS

Fracture Toughness

By NRL equation 10:

$$K_{Ic} = \frac{L_1}{d^{3/2}} R \left(\frac{P}{B}\right) \quad \text{where } R = 2.060\left\{\frac{1}{\alpha^3} - \alpha^3\right\}^{\frac{1}{2}}$$

and $\alpha = 1 - \frac{a}{d}$. L_1 is the distance between outer and next inner load points of the test bar.

By compliance method:

$$K_{Ic} = \sqrt{\frac{E\,\mathscr{G}_{Ic}}{1-\nu^2}} \quad \text{where } \mathscr{G}_{Ic} = \frac{1}{2}\left(\frac{P}{B}\right)^2 \frac{d\,(B/M)}{d\,a}$$

In tests of maraging steel it is assumed that $E = 27 \times 10^6$ psi and $\nu = 0.3$.

$\frac{d(B/M)}{da}$ is the derivative of a compliance relation $B/M = Q + R_a{}^2 + Sa^3$ where the coefficients were computed from experimental values for B/M as a function of increasing slot depth $\underline{a}$ in a calibration bar loaded to produce a calculated maximum fiber stress of $\sigma_{YS/2}$ (see Table 24). Load F for calibration fiber stress was calculated from the formula

$$F = \frac{2\,B\,(\sigma_{YS/2})(d-a)^2}{3\,L}$$

Calibration $B/M = \frac{Be}{F}$ where e is the beam deflection in three-point loading.

Statistics

Coefficient of variation:

$$\text{c.v.} = \frac{s}{\bar{X}} \quad \text{where } s = \sqrt{\frac{\sum_{i=1}^{N}(X_i - \bar{X})^2}{N-1}}$$

Confidence limits:

95% C. L.: $\alpha = .05$

$$1-\alpha = P\left[\bar{X} - \frac{s}{\sqrt{N}}\, t_{(N-1),\ 1-\alpha/2} < \mu < \bar{X} + \frac{s}{\sqrt{N}}\, t_{(N-1),\ 1-\alpha/2}\right]$$

90% C. L.: same formula as above except $\alpha = .10$

Fiber Stress

The maximum nominal fiber stress σ_{nom} in an unbroken ligament at the tip of the fatigue crack at pop-in was calculated by the formula

$$\sigma_{nom} = \frac{3\,L}{2(d-a)^2}\left(\frac{P}{B}\right)$$

TABLE 24. LIST OF EQUATIONS USED IN CALCULATING K_{Ic} BY COMPLIANCE

Plate No.	Notch Location	Calibration Equation Used for Compliance Calculation of K_{Ic} (1)
1	BM	$B/M = 4.92 + 28.68a^2 + 33.39a^3$ $(\times 10^{-6})$
7	BM	$B/M = 5.27 + 21.55a^2 + 51.65a^3$ $(\times 10^{-6})$
7	CW	$B/M = 5.14 + 29.81a^2 + 32.46a^3$ $(\times 10^{-6})$
7	FZ + HAZ	$B/M = 5.15 + 20.49a^2 + 58.51a^3$ $(\times 10^{-6})$
8	BM	$B/M = 5.35 + 16.05a^2 + 73.69a^3$ $(\times 10^{-6})$
8	CW	$B/M = 5.13 + 21.76a^2 + 64.07a^3$ $(\times 10^{-6})$
8	FZ	$B/M = 5.35 - 0.39a^2 + 131.37a^3$ $(\times 10^{-6})$
8	DB	$B/M = 5.14 + 19.83a^2 + 65.35a^3$ $(\times 10^{-6})$
9	BM	$B/M = 5.23 + 12.22a^2 + 76.41a^3$ $(\times 10^{-6})$
9	CW	$B/M = 5.33 + 11.99a^2 + 99.48a^3$ $(\times 10^{-6})$
9	FZ	$B/M = 5.33 + 14.83a^2 + 84.23a^3$ $(\times 10^{-6})$
10	BM	$B/M = 4.97 + 30.65a^2 + 19.66a^3$ $(\times 10^{-6})$
10	CW	$B/M = 5.17 + 31.90a^2 + 13.96a^3$ $(\times 10^{-6})$
10	FZ + HAZ + DB	$B/M = 5.19 + 29.33a^2 + 25.31a^3$ $(\times 10^{-6})$
14	BM	$B/M = 5.08 + 31.50a^2 + 18.94a^3$ $(\times 10^{-6})$
14	CW	$B/M = 5.02 + 33.18a^2 + 20.00a^3$ $(\times 10^{-6})$
14	FZ + HAZ + DB	$B/M = 5.10 + 38.14a^2 - 6.31a^3$ $(\times 10^{-6})$
15	BM	$B/M = 5.37 + 32.26a^2 + 30.66a^3$ $(\times 10^{-6})$
15	CW	$B/M = 5.23 + 45.22a^2 - 13.96a^3$ $(\times 10^{-6})$
15	FZ + HAZ + DB	$B/M = 5.22 + 38.09a^2 + 8.76a^3$ $(\times 10^{-6})$
18	BM	$B/M = 5.03 + 34.11a^2 + 11.23a^3$ $(\times 10^{-6})$
18	CW	$B/M = 5.07 + 29.85a^2 + 29.02a^3$ $(\times 10^{-6})$
18	FZ + HAZ + DB	$B/M = 5.11 + 38.27a^2 - 2.10a^3$ $(\times 10^{-6})$
19	BM	$B/M = 5.43 + 35.04a^2 + 19.36a^3$ $(\times 10^{-6})$
19	CW	$B/M = 5.26 + 43.12a^2 - 11.43a^3$ $(\times 10^{-6})$
19	FZ + HAZ + DB	$B/M = 5.20 + 43.56a^2 - 11.29a^3$ $(\times 10^{-6})$
20	BM	$B/M = 5.33 + 36.66a^2 + 5.29a^3$ $(\times 10^{-6})$
20	CW	$B/M = 5.25 + 41.95a^2 - 10.29a^3$ $(\times 10^{-6})$
20	FZ + HAZ + DB	$B/M = 5.26 + 39.55a^2 - 2.39a^3$ $(\times 10^{-6})$
21	BM	$B/M = 5.09 + 34.75a^2 + 11.53a^3$ $(\times 10^{-6})$
21	CW	$B/M = 5.05 + 29.05a^2 + 29.89a^3$ $(\times 10^{-6})$
21	FZ + HAZ + DB	$B/M = 5.08 + 37.90a^2 + 0.27a^3$ $(\times 10^{-6})$
22	CW	$B/M = 5.28 + 35.10a^2 + 11.58a^3$ $(\times 10^{-6})$
22	FZ + HAZ + DB	$B/M = 5.25 + 37.05a^2 + 4.63a^3$ $(\times 10^{-6})$
23	BM	$B/M = 5.28 + 32.94a^2 + 12.60a^3$ $(\times 10^{-6})$
23	CW	$B/M = 5.24 + 34.38a^2 + 6.78a^3$ $(\times 10^{-6})$
23	FZ + HAZ + DB	$B/M = 5.27 + 27.72a^2 + 30.67a^3$ $(\times 10^{-6})$
24	BM	$B/M = 5.36 + 27.83a^2 + 34.07a^3$ $(\times 10^{-6})$
24	CW	$B/M = 5.30 + 26.22a^2 + 35.44a^3$ $(\times 10^{-6})$
24	FZ + HAZ + DB	$B/M = 5.28 + 24.08a^2 + 46.05a^3$ $(\times 10^{-6})$

(1) Equations were a least squares fit to B/M compliance values as a function of slot depth $\underline{a}$ in one or more calibration bars from each test lot. The calibration load was adjusted according to slot depth to produce a calculated maximum fiber stress of $\sigma_{YS}/2$ in the unnotched section. The upper linear portion of the load-deflection curve was used to calculate B/M.

TABLE 25. DISTRIBUTION OF TYPES OF LOAD-DEFLECTION CURVES

Types are illustrated in Figure 11. Distribution below is given as parts of one hundred percent.
Values of 50 per cent or over are under lined.

Plate Number	18 Ni Maraging Steel Grade (1000 psi)	Weld Type	Base Metal						Center of Weld						Fusion Zone						Heat-Affected Zone						Dark Band Area					
			A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
1	250	Little TIG	65	12	23	0	0	0	6	6	18	12	0	58	0	29	43	0	14	14	38	8	54	0	0	0	46	8	38	0	8	0
2	250	Little TIG	24	52	4	20	0	0	8	8	27	19	8	30	33	17	50	0	0	0	45	9	36	9	0	0	24	38	38	0	0	0
5	250	MIG	0	17	60	17	0	6	0	0	11	78	0	11	--	--	--	--	--	--	0	14	0	0	0	86	33	0	0	0	33	33
6	250	MIG	7	29	11	42	0	11	4	4	9	57	0	26	0	22	22	22	0	34	0	0	13	54	0	33	0	0	0	89	0	11
7	250	Short Arc	0	15	8	31	0	46	0	10	20	50	0	20	0	0	0	100	0	0	0	8	15	62	0	15	0	0	40	60	0	0
8	250	Big TIG	10	5	0	45	0	40	10	5	25	25	0	35	14	14	14	30	14	14	--	--	--	--	--	--	0	0	0	45	0	55
9	250	MIG	10	10	0	10	0	70	0	0	14	43	0	43	13	0	50	24	0	13	--	--	--	--	--	--	--	--	--	--	--	--
10	250	Big TIG	10	0	20	5	5	60	13	0	0	53	7	27	22	0	11	0	22	45	0	0	0	0	82	18	0	0	20	0	50	30
11	250	Short Arc	0	0	23	31	0	46	8	15	0	77	0	0	--	--	--	--	--	--	0	0	31	23	15	31	--	--	--	--	--	--
14	200	Little TIG	0	0	0	0	56	44	0	0	20	0	20	60	0	0	0	0	54	46	0	0	0	0	100	0	0	0	0	0	60	40
15	200	Little TIG	0	0	0	0	86	14	0	0	0	0	65	35	0	0	0	0	89	11	0	0	0	0	91	9	0	0	0	0	89	11
18	200	MIG	0	0	4	11	0	85	0	0	16	21	52	11	0	0	9	0	73	18	7	0	0	0	27	66	0	0	0	0	0	100
19	200	MIG	0	0	0	0	88	12	40	20	5	30	0	5	0	0	0	0	82	18	0	0	0	0	80	20	0	0	0	0	62	38
20	200	Short Arc	0	0	0	0	80	20	14	7	14	7	29	29	0	13	0	0	87	0	0	0	0	0	100	0	0	0	0	0	74	26
21	200	Big TIG	0	4	0	0	64	32	0	5	5	5	5	80	0	0	0	0	100	0	0	0	0	0	80	20	0	0	0	0	84	16
22	200	MIG	--	--	--	--	--	--	0	0	6	41	0	53	13	0	13	0	24	50	0	0	0	0	100	0	0	0	0	0	77	23
23	200	Big TIG	0	0	0	0	85	15	16	5	21	0	37	21	0	0	0	0	88	12	0	0	0	0	100	0	--	--	--	--	--	--
24	200	Short Arc	0	0	0	0	63	37	13	6	13	13	5	50	0	0	0	0	71	29	0	0	0	0	100	0	0	0	18	0	36	46

TABLE 26. CRITICAL FLAW TOLERANCE AT CENTER OF WELDS SIMULATING A LONGITUDINAL SEAM WELD IN THE ROCKET MOTOR CASE

Plate Number	18 Ni Maraging Steel Grade (1000 psi)	Nominal Hardness of Base Metal (Rc)	Weld Type	Test Direction	Average Hardness of Center of Weld (Rc)	Center of Weld		Calculated Radius of Semi-circular Surface Crack (a=c) Tolerated at 0.9 σ_{YS} Based on Mean K_{Ic} (in)	Calculated Radius of Semi-circular Surface Crack (a=c) Tolerated at 0.9 σ_{YS} Based on Minimum K_{Ic} (in)
						Mean K_{Ic} Value (1000 psi$\sqrt{in}$)	Minimum K_{Ic} Value (1000 psi$\sqrt{in}$)		
1	250	52	Little TIG	II	50.5	83.5	60.0	.074	0.038
5	250	52	MIG	II	49.0	73.5	64.5	.057	0.044
10	250	52	Big TIG	II	49.0	104.0	92.5	.115	0.091
11	250	52	Short Arc	II	50.0	69.5	59.5	.051	0.038
14	200	48.5	Little TIG	II	50.0	111.0	96.5	.175	0.132
18	200	48.5	MIG	II	49.5	70.5	61.5	.070	0.054
23	200	48.5	Big TIG	II	49.5	113.0	86.5	.181	0.106
24	200	48.5	Short Arc	II	50.0	61.0	50.0	.053	0.035

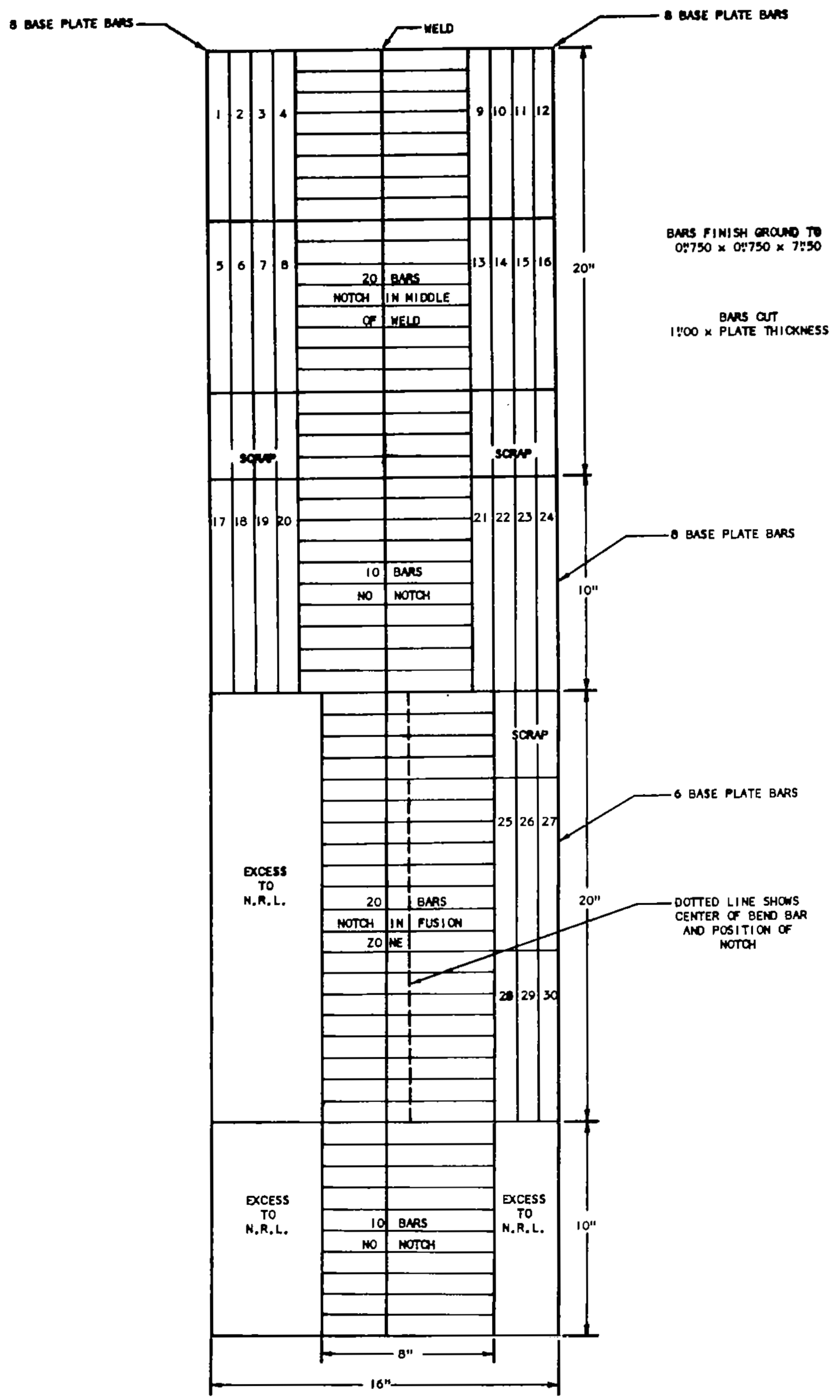
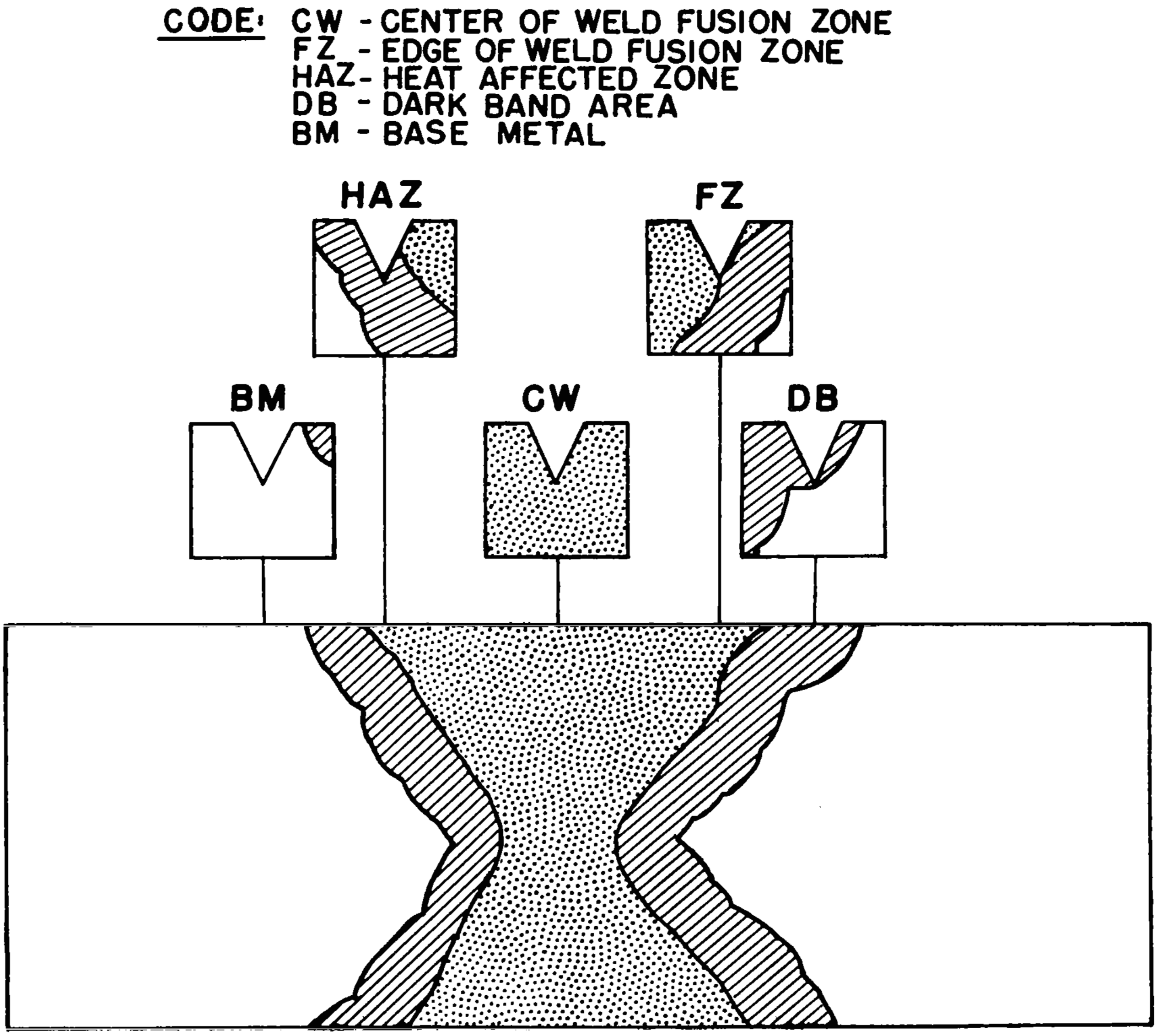


FIGURE I

TYPICAL LAYOUT OF BEND TEST BARS

The welds were made either perpendicular or parallel to the principal rolling direction of the base plate as indicated in Table I.



CROSS SECTION OF WELD AREA SHOWING DIFFERENT LOCATIONS OF STARTING NOTCH TIPPED WITH FATIGUE CRACK

FIGURE 2

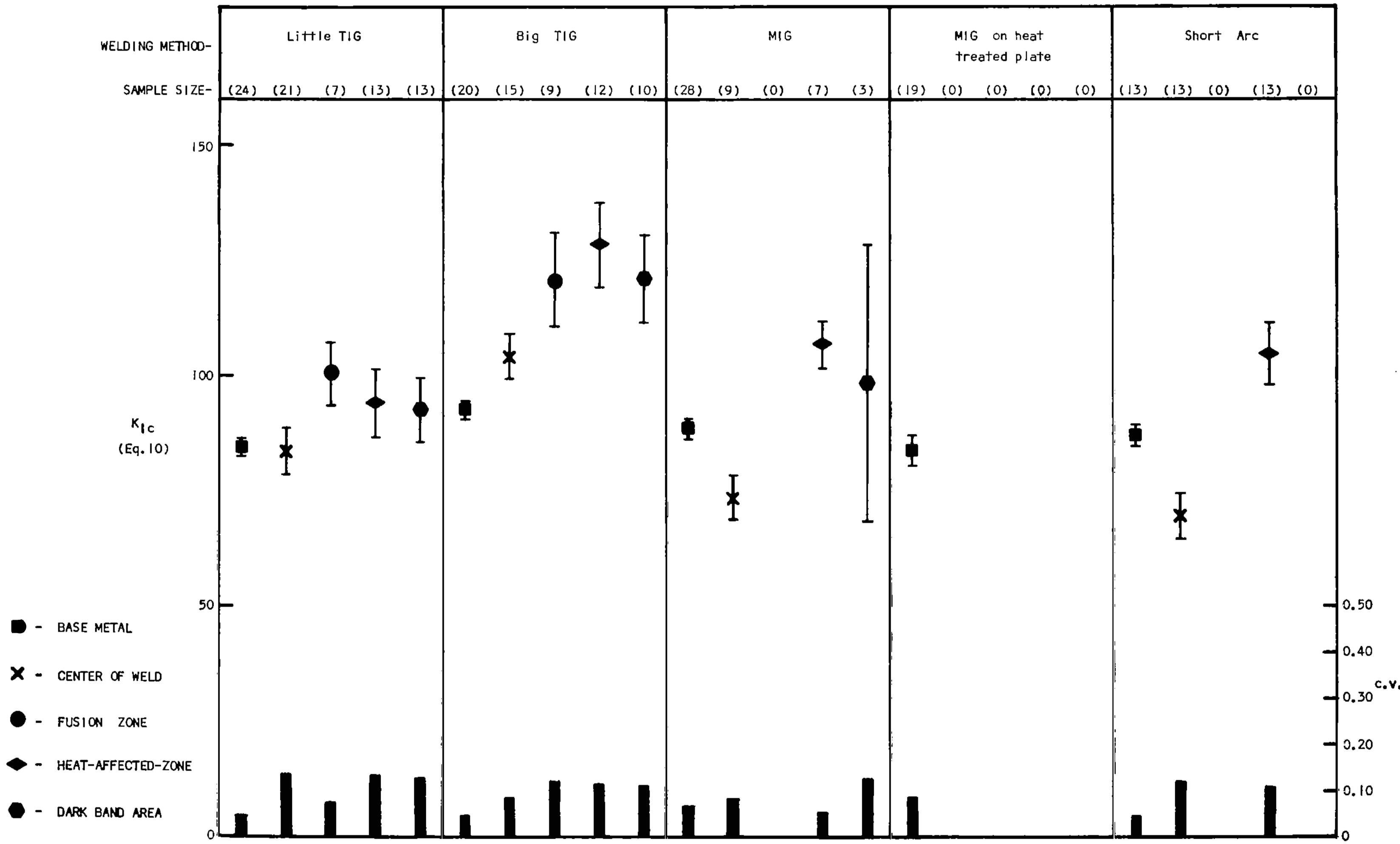


FIGURE 3

STATISTCAL CHART OF FRACTURE TOUGHNESS TESTS MADE ON 18 Ni (250) MARAGING STEEL PLATE 3/4 INCH THICK WELDED TO SIMULATE A LONGITUDINAL SEAM WELD IN A ROCKET MOTOR CASE.

The 95 percent confidence limits are shown attached to the symbol for mean K_{Ic} value. The solid bar at the bottom gives the coefficient of variation for the sample group.

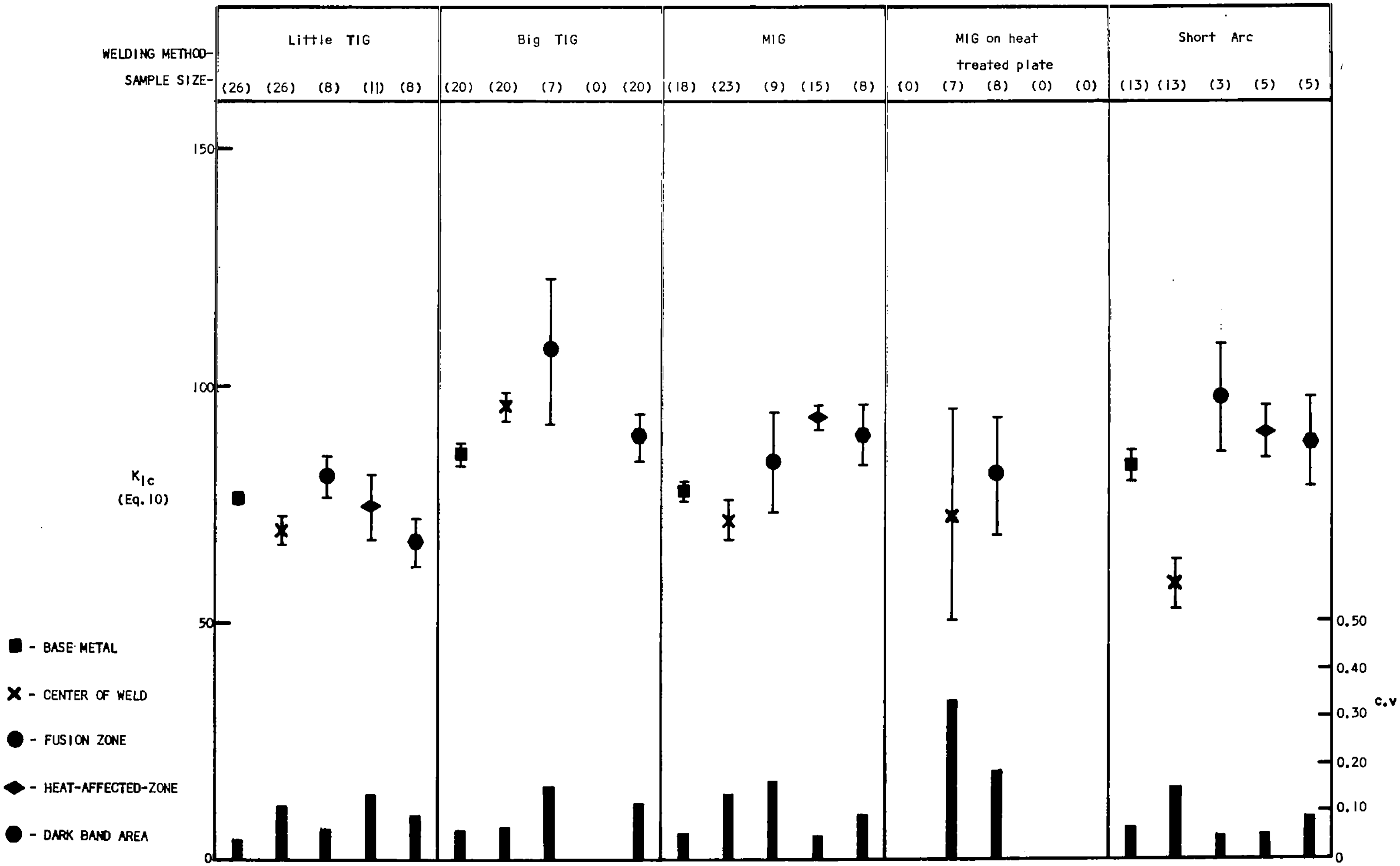


FIGURE 4

STATISTICAL CHART OF FRACTURE TOUGHNESS TESTS MADE ON 18 Ni (250) MARAGING STEEL PLATE 3/4 INCH THICK WELDED TO SIMULATE A GIRTH WELD IN A ROCKET MOTOR CASE.

The 95 percent confidence limits are shown attached to the symbol for mean K_{Ic} value. The solid bar at the bottom gives the coefficient of variation for the sample group.

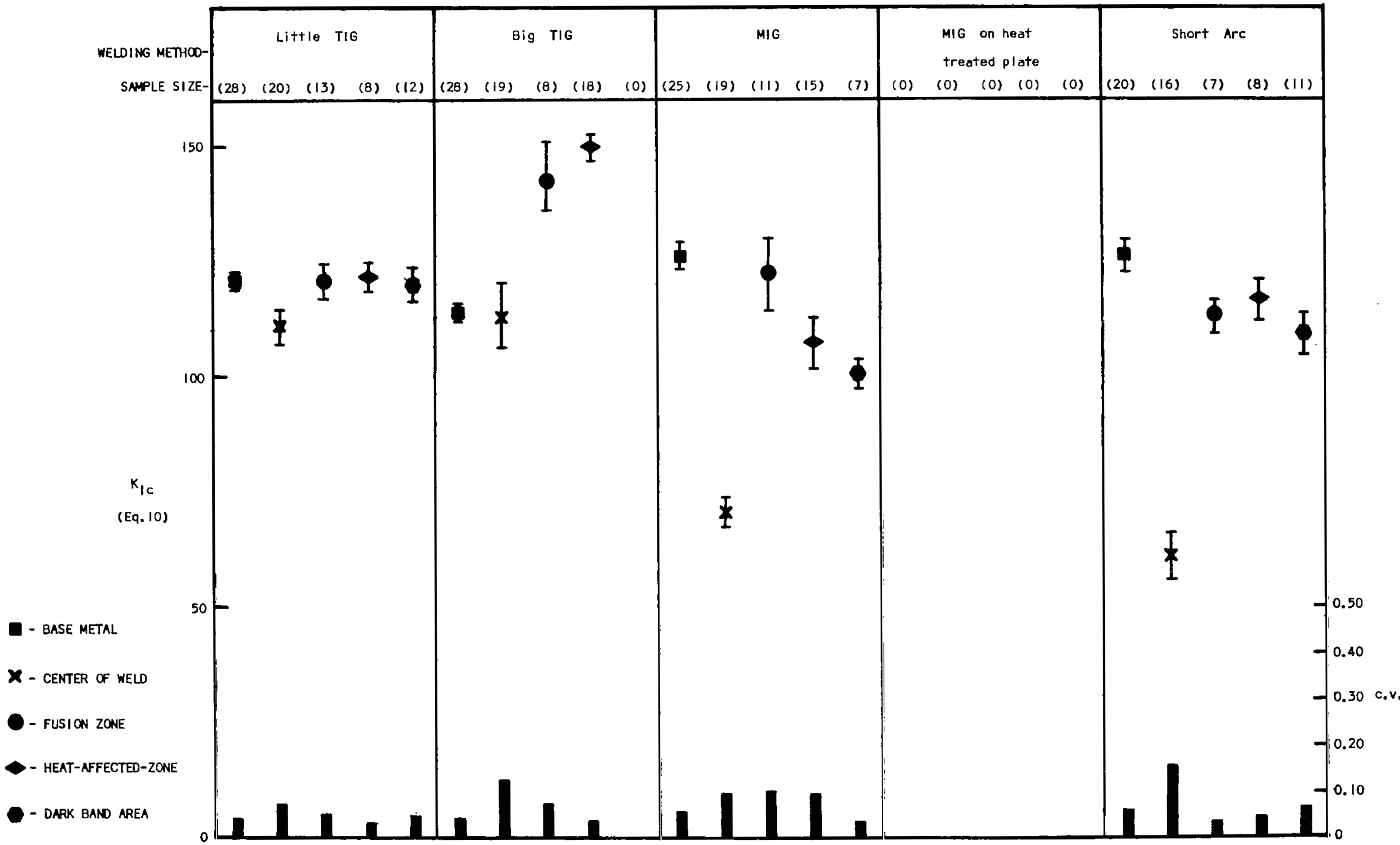


FIGURE 5

STATISTICAL CHART OF FRACTURE TOUGHNESS TESTS MADE ON 18 Ni (200) MARAGING STEEL PLATE 3/4 INCH THICK WELDED TO SIMULATE A LONGITUDINAL SEAM WELD IN A ROCKET MOTOR CASE.

The 95 percent confidence limits are shown attached to the symbol for mean K_{Ic} value. The solid bar at the bottom gives the coefficient of variation for the sample group.

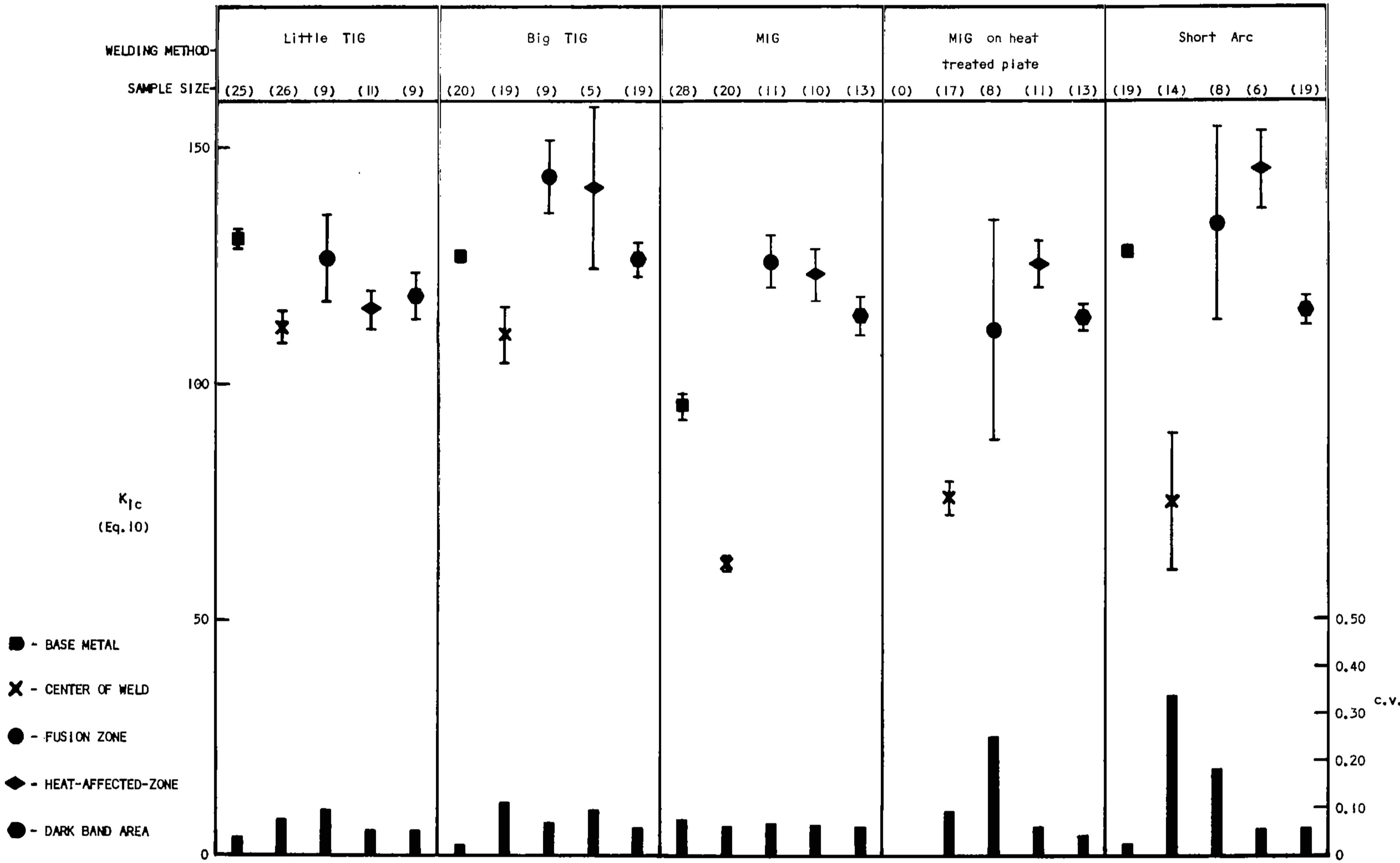


FIGURE 6

STATISTICAL CHART OF FRACTURE TOUGHNESS TESTS MADE ON 18 Ni (200) MARAGING STEEL PLATE 3/4 INCH THICK WELDED TO SIMULATE A GIRTH WELD IN A ROCKET MOTOR CASE.

The 95 percent confidence limits are shown attached to the symbol for mean K_{Ic} value. The solid bar at the bottom gives the coefficient of variation for the sample group.

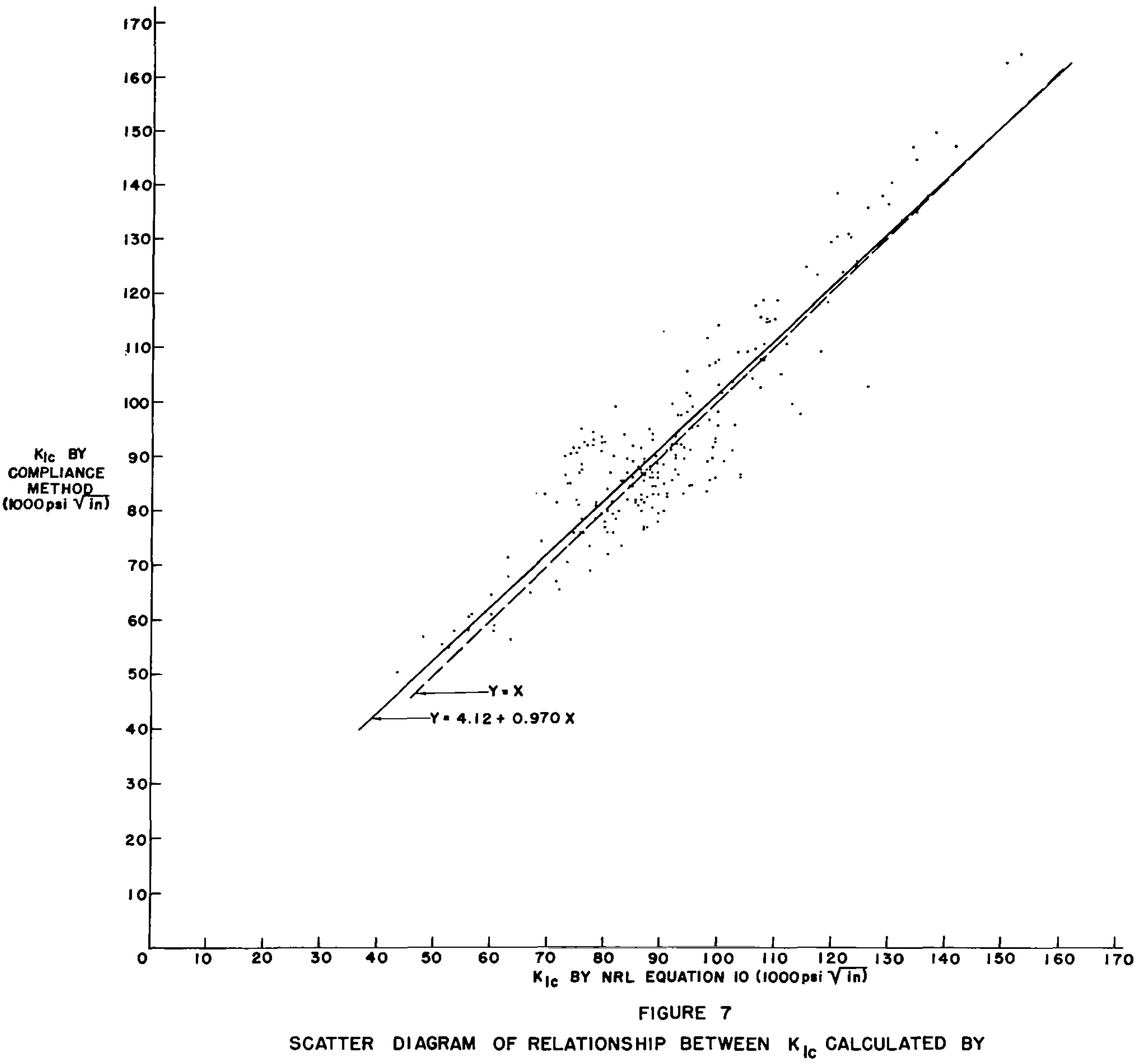


FIGURE 7

SCATTER DIAGRAM OF RELATIONSHIP BETWEEN K_{Ic} CALCULATED BY EQUATION 10 AND K_{Ic} CALCULATED BY THE COMPLIANCE METHOD IN TESTS OF WELDED 18 Ni (250) MARAGING STEEL PLATES 3/4 INCH THICK

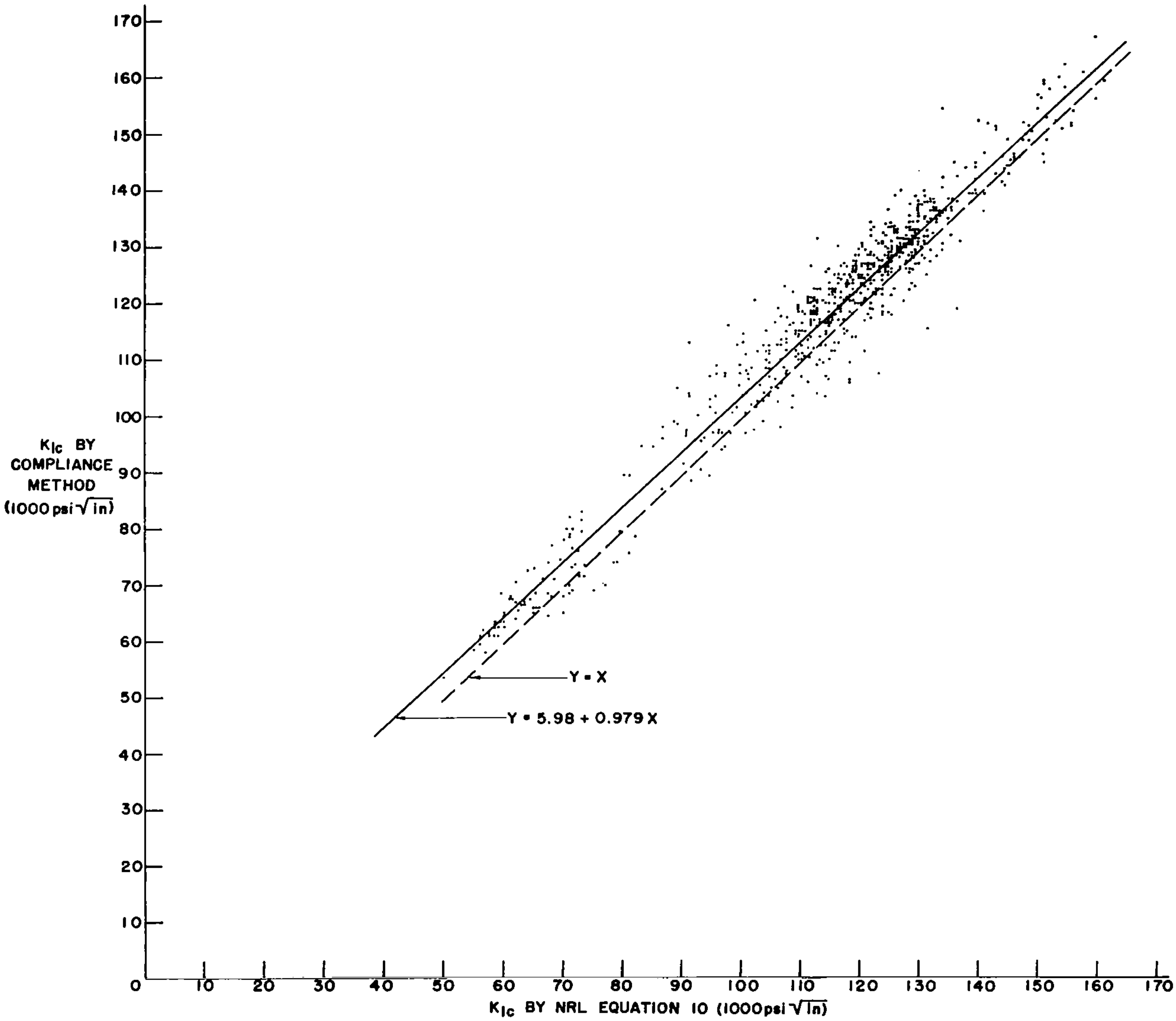


FIGURE 8

SCATTER DIAGRAM OF RELATIONSHIP BETWEEN K_{Ic} CALCULATED BY EQUATION 10 AND K_{Ic} CALCULATED BY THE COMPLIANCE METHOD IN TESTS OF WELDED 18 Ni(200) MARAGING STEEL PLATES 3/4 INCH THICK

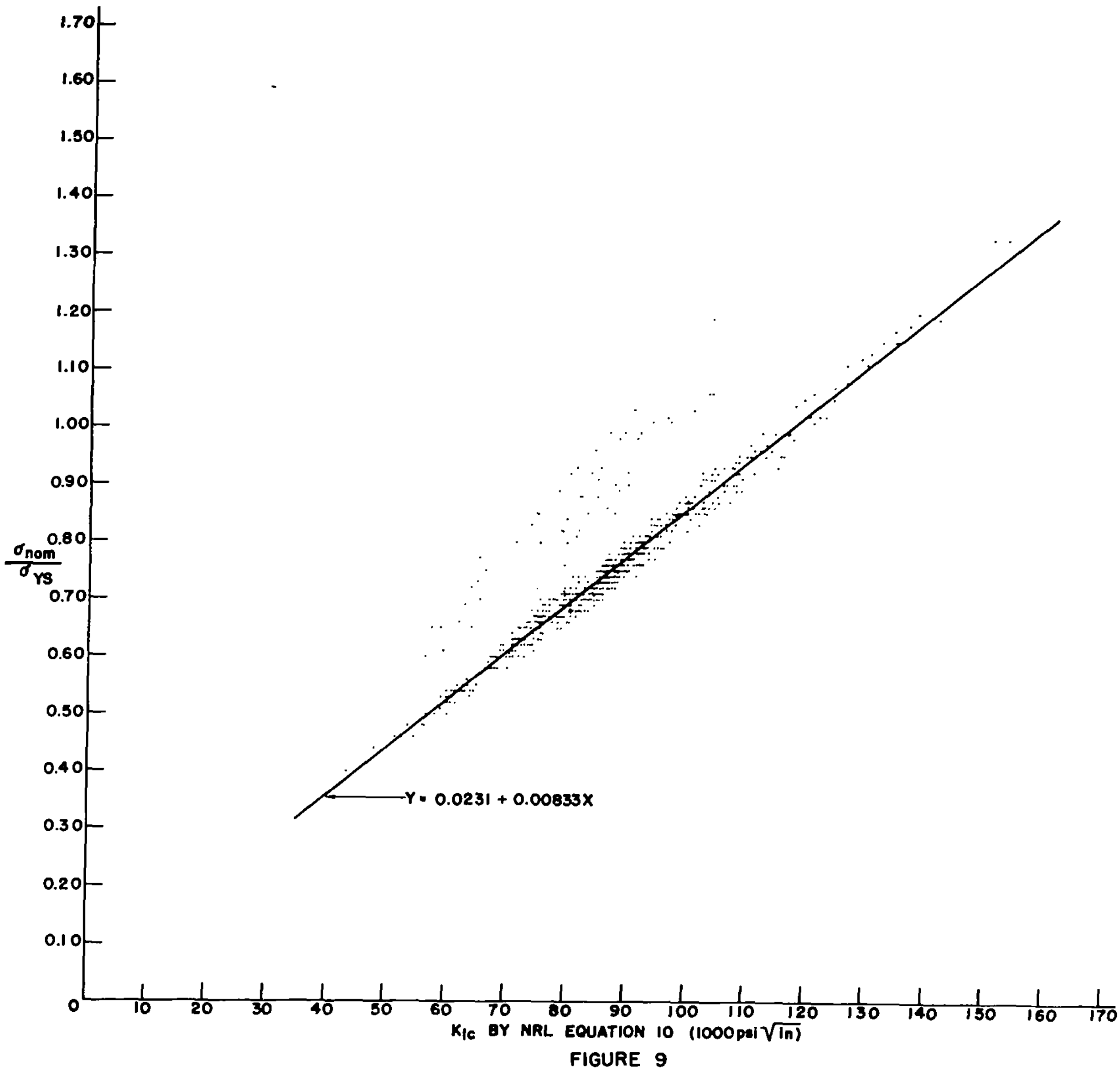


FIGURE 9

SCATTER DIAGRAM OF RELATION BETWEEN K_{Ic} CALCULATED BY EQUATION 10 AND THE CALCULATED RATIO σ_{nom}/σ_{YS} IN TESTS OF WELDED 18 Ni (250) MARAGING STEEL PLATES 3/4 INCH THICK

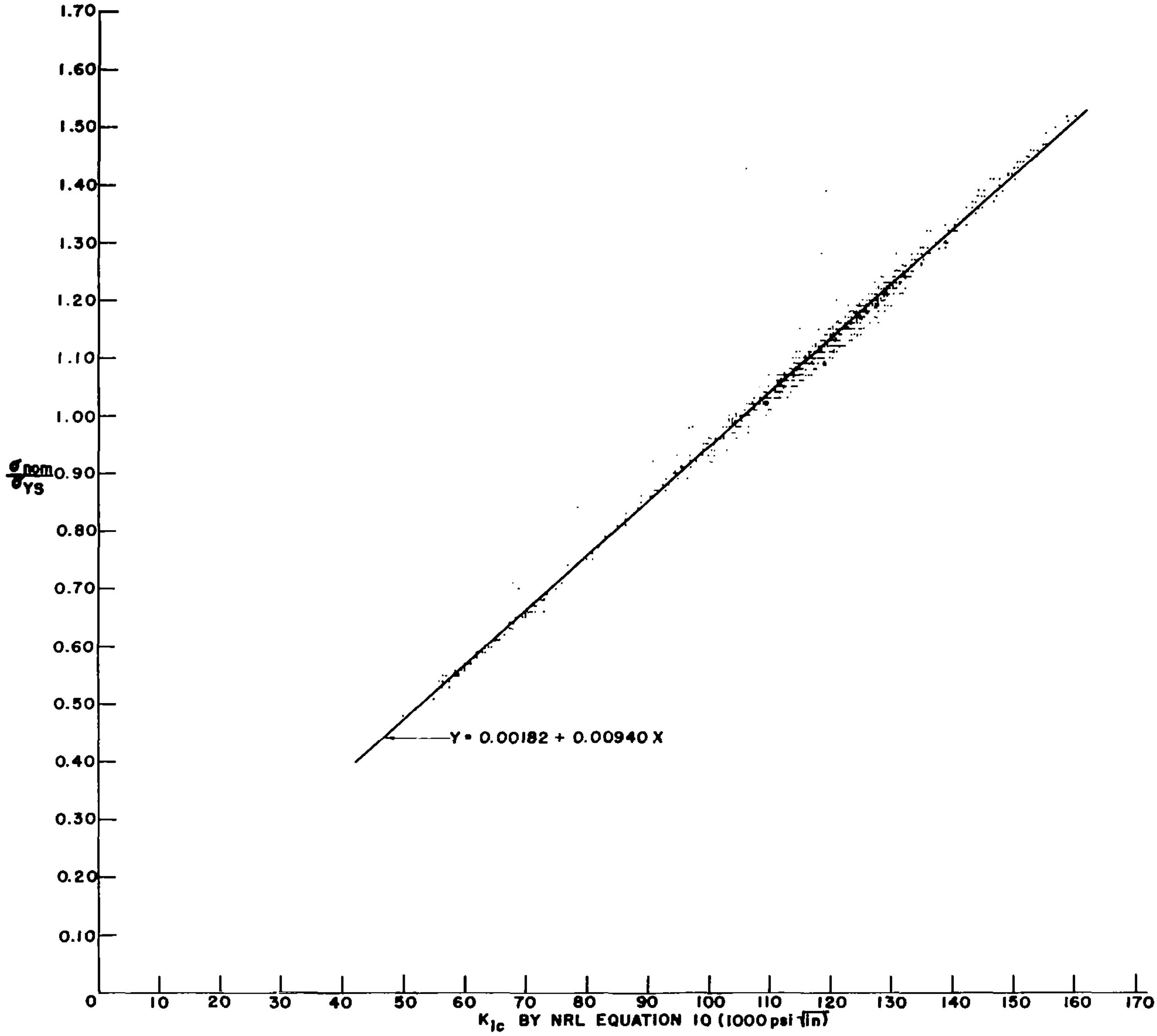


FIGURE 10

SCATTER DIAGRAM OF RELATION BETWEEN K_{Ic} CALCULATED BY EQUATION 10 AND THE CALCULATED RATIO σ_{nom}/σ_{YS} IN TESTS OF WELDED 18 Ni(200) MARAGING STEEL PLATES 3/4 INCH THICK

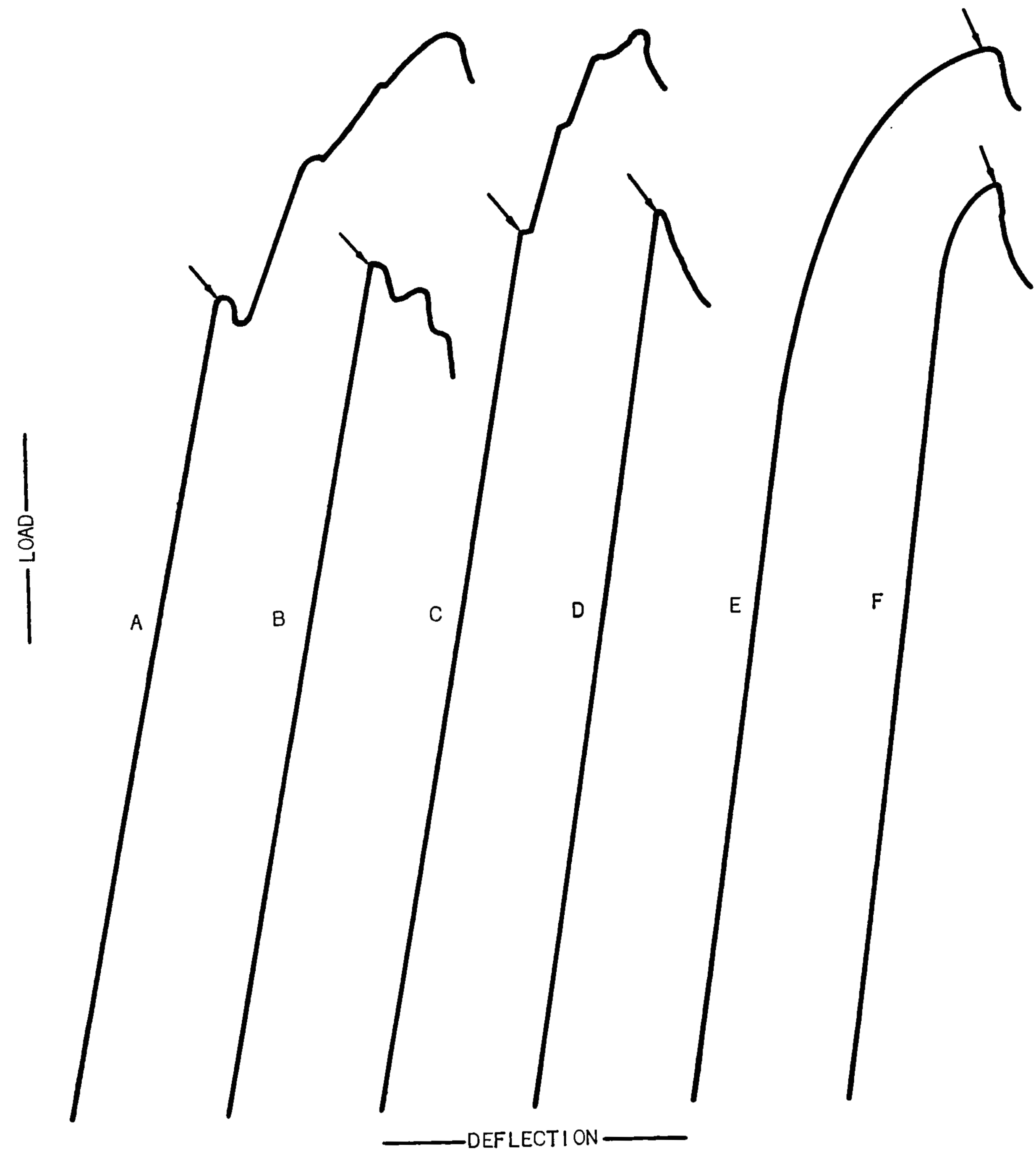


FIGURE 11

TYPICAL LOAD-DEFLECTION CURVES OBSERVED IN THE SLOW BEND TESTS

Arrow indicates pop-in load used in K_{Ic} calculations

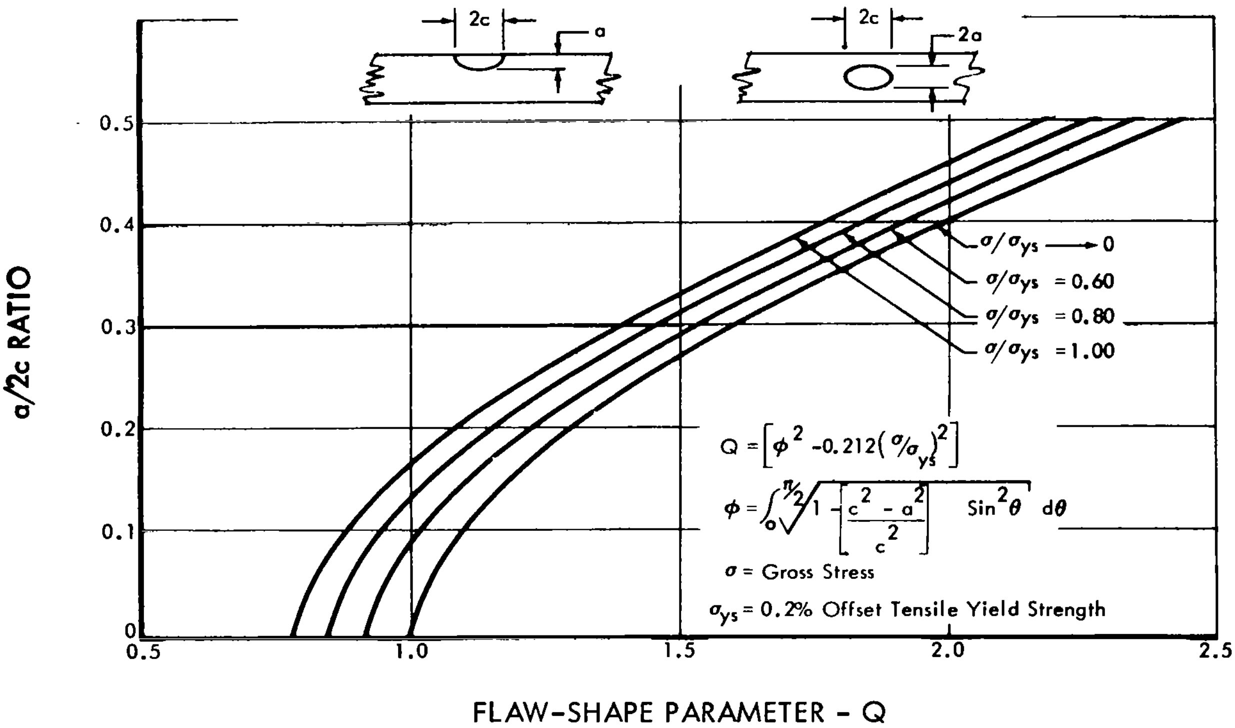


FIGURE 12

(Reproduced from report by C.F. Tiffany and P.M. Lorenz, The Boeing Company)

NASA-Langley, 1965 CR-302