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REACTOR MATERIALS PROGRAM - Microstructural and Mechanical Response of Types 304, 304L, and 308 Stainless Steels to Low Temperature Neutron Irradiation (U)

Task Number: 89-023-1

R. L. Sindelar

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By

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Title: REACTOR MATERIALS PROGRAM - Microstructural and Mechanical Response of Types 304, 304L, and 308 Stainless Steels to Low Temperature Neutron Irradiation (U)

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Task Title: Measure Mechanical Properties of Irradiated Stainless Steels

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EXECUTIVE SUMMARY

Neutron irradiation of austenitic stainless steels at low temperatures (< 300 °C) causes hardening (increased yield strengths up to several times the initial strengths with reduced work hardenability, the difference between the yield and tensile strengths) and reduces fracture toughness. A database of mechanical properties of irradiated Types 304 and 304L stainless steel piping and plate materials and Type 308 stainless steel weld materials was previously developed under the SRTC Reactor Materials Program (RMP) for the structural and fracture analyses of the SRS reactor tanks.[1] Mechanical testing of specimens from the 12M capsule, the final RMP capsule irradiated in the High Flux Isotope Reactor (HFIR), is complete and the results are added to the database. Several of the 12M tensile, Charpy V-notch, and compact tension specimens contained neutronically-generated helium at levels bounding the reactor tank wall maximum level. The table below shows the irradiation and test conditions of the materials in the mechanical property database.

Irradiation	Irradiation Temperature (°C)	Test Temperature (°C)	Fast Fluence (10^{21} n/cm^2, E_n > 0.1 MeV)	dpa_{NRT} (ASTM E693)	Helium (atomic parts per million)
UBR	120	25 and 125	0.11	0.065	0.066 to 1.4 (measured)
Thermal Shield Materials	119	25	0.29 and 1.2	0.2 and 0.6	9.6 and 168 (estimated)
R-tank Disks	≤ 125	25 and 125	0.1 and 0.7	0.1 and 0.5	10 and 34 (measured)
HFIR 1Q	75 to 150	125	0.36 to 0.92	0.21 to 0.52	3.27 to 8.12 (measured)
HFIR 4M	75 to 150	125	1.8 to 3.8	1.0 to 2.16	12.6 to 39.5 (measured)
HFIR 12M	75 to 150	25 and 125	5.4 to 11.4	3.1 to 6.4	74 to 276 (estimated)
K-Tank Sidewalls	≤ 125	Not Applicable	Max. 1.86	Max. 1.4 (includes He and γ-ray)	Max. 140 (measured August 1986)

The mechanical properties' results of the 12M testing are summarized in the table below. A comparison of the 12M results with the previous results in the database show that the helium build-in does not cause an additional loss of fracture toughness at the test conditions; the materials have high fracture toughness, supporting the demonstration of boundary integrity under all conditions of operation including design basis events and reactor shutdown.

Specimen Type and Mechanical Parameter	Range of Test Results @ 25°C	Range of Test Results @ 125°C
Tensile: Engr. yield; ultimate strengths	s_y: 102.1 to 106.1 ksi; s_u: 111.2 to 112.2 ksi	s_y: 90.1 to 96.3 ksi; s_u: 93.5 to 99.1 ksi
Charpy V-notch: Absorbed energy	69.6 ft-lb	66.8 to 81.1 ft-lb
Compact Tension: Fracture toughness -- J_{IC}; J_{1mm} (for J_{def}, power law)	J_{IC}: 315.9 to 1240.8 in-lb/in^2; J_{1mm}: 686.4 to 1952.4 in-lb/in^2	J_{IC}: 509.1 to 2493.2 in-lb/in^2; J_{1mm}: 589.1 to 3054.1 in-lb/in^2

[1] The database of mechanical properties, developed from irradiation and testing of SRS reactor system materials, is contained in reference 1 to this report.

The piping materials included base, weld, and weld heat-affected-zone (HAZ) weldment components in both the L-C and L-C orientations. The 12M results were consistent with the previous testing of materials in the unirradiated and irradiated conditions showing the C-L specimen orientation to be significantly less tough that the L-C orientation for the base and HAZ weldment components.

The HAZ component materials in the database show an increased sensitivity to irradiation (greater loss of toughness) compared to base component materials. The range of values of residual toughness (defined as the value of the J_{def}-R curve @ 1 mm crack extension in the irradiated condition divided by the unirradiated value for the corresponding material heat and specimen orientation) of the HAZ component is 41 to 54%, whereas the range of residual toughness values of the base component is 65 to 89% for the 0.4T planform specimens for the 25 and 125°C test temperatures. The range of residual toughness values of the weld component is 48 to 66%.

The mechanical properties from each irradiated specimen in the database are plotted as a function of fast fluence to evaluate the sensitivity to irradiation exposure. A monotonical increase in yield strength is observed for the composite results of base, weld, and HAZ components and, for individual specimens of a specific melt of steel, over the entire range of exposures. The absorbed impact energies and elastic-plastic fracture toughness results show only little or no decrease with exposure over the entire range of dpa_{NRT} (0.065 to 6.4).

Small lattice defect complexes are the predominant microstructural features produced during irradiation of the materials causing the change in mechanical properties. The microstructures of selected R-tank, UBR, and 1Q specimens were characterized by Transmission Electron Microscopy by measuring the size and number density of the lattice defect complexes. A summary of the defect cluster size and number density is contained in the table below. Helium bubbles with a mean diameter of 2.5 nm and a number density of approximately 1.5 x 10^{16}/cm^3 were observed in the R-tank specimen, but were not clearly resolvable (> 2 nm) in the UBR and HFIR specimens.

Irradiation: Specimen	Mean Diameter	Density (10^{17}/cm^3)
R-tank: Disk RA3-1D, 3D (Type 304 SS)	1.85 nm	2.9
UBR: 1HA21-1, -2 (Type 304 SS)	1.66 nm	6.0
UBR: 7W7 (Type 308 SS, delta ferrite phase)	5.2 nm	0.020
HFIR 1Q: F50-X1 (Type 304L SS)	2.7 nm	5.5

The defect cluster microstructure is correlated to the change in mechanical properties due to irradiation. The barrier strength of the defects was determined by applying literature models based on Orowan's theory of dislocation bowing to describe the change in shear strength through interaction between the defect complexes and moving dislocations. The barrier strength, calculated to be 0.124 to 0.146, depending on the defect cluster population distribution, is consistent with recent literature results for Type 304 stainless steel.

The mechanical property results are applied to a model from the literature predicting the fracture toughness (K_{JC}) of irradiated materials based on the fracture toughness of unirradiated materials and on unirradiated and irradiated tensile properties. The model does not accurately predict the measured fracture toughness of materials in the database.

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1.0 INTRODUCTION

A database of mechanical properties of Type 304, 304L, and 308 stainless steel materials following low-temperature neutron irradiation is developed to provide input into the structural and fracture analyses of the SRS reactor tanks.† The database previously reported in reference 1 has been supplemented by the final results of the testing of the High Flux Isotope Reactor 12M capsule specimens [4 -6] in this report. With the placement of K Reactor on cold standby, no testing of the specimens irradiated as part of the K-reactor surveillance program [7] will be planned. This report completes the irradiation and testing activities of the SRTC Reactor Materials Program [4].

This database of irradiated materials' properties is applicable in design or evaluation of austenitic stainless steel structures at exposure conditions less than 7 dpa_{NRT} at temperatures less than 200°C. The database also provides information relevant to the material response of candidate austenitic stainless steel materials of the first wall of the International Thermonuclear Experimental Reactor in which exposures of 30 dpa at temperatures from 50 to 350°C would occur.

1.1 Database of Mechanical Properties

Databases of SRS materials were developed from archival piping materials [8] in the unirradiated [9] and irradiated [1] conditions to include base, weld, and weld heat-affected-zone (HAZ) weldment components in both the L-C and L-C orientations. The database of irradiated materials also included reactor tank sidewall materials from the R Reactor, specimens of 1950s vintage stainless steel from a reactor thermal shield mock-up irradiated in the core of P Reactor, and materials from a 1960s vintage plate of Type 304L stainless steel [1]. The fast neutron fluence and displacement damage of these specimens exceeded the lifetime anticipated fast fluence and displacement damage of the SRS production reactor tank sidewalls. The testing generated a database of fracture toughness properties for low irradiation and test temperatures (≤ 200°C) where literature data was scarce.

The 12M specimens were irradiated and tested to provide information on the effect of high thermal neutron fluences producing helium contents at and above the tank sidewall maximum level of 140 atomic parts per million (appm) [2, 5]. It was predicted that the helium bubble microstructure would not further reduce the measured toughness loss at the relevant test temperatures (25 and 125°C) [10]. Nevertheless, the 12M irradiation and testing was performed to provide fracture toughness properties at high thermal fluences and to evaluate the effect of high levels of helium build-in.

The 12M testing was performed as part of the SRTC Reactor Materials Program (RMP) Task 89-023-1 [4] under RMP Specification SRP-SL-1111, Rev. 2 [6]. Attachment 1 is the letter report from Fahmy M. Haggag of the Fracture Mechanics Group of the Metals & Ceramics Division at Oak Ridge National Laboratory which contains the full test results of the 12M tensile (T), Charpy V-Notch (CVN), and compact tension (C(T)) specimen testing including J-R curve analysis for both $J_{deformation}$ and $J_{modified}$ J-integral methods. Reference 1 contains the details of the mechanical specimen design and reference 11 contains the checkout testing of the ORNL testing compared to previous testing of irradiated archival piping materials performed by Materials Engineering Associates [1]. Section 2 of this report contains a summary of the irradiation parameters of the RMP HFIR irradiations and a summary of 12M test results with a comparison to the results from the previous irradiations and testing contained in reference 1. A discussion of the mechanical response with exposure is also provided in Section 2.

† A maximum exposure of 1.86×10^{21} n/cm^2 (E_n > 0.1 MeV) with a maximum thermal neutron fluence of 1.16×10^{22} n/cm^2 at temperatures from approximately 25 to 125°C has occurred in the SRS tank sidewalls [2]. This has produced 1.4 displacements per atom (dpa) [3] with a maximum helium content of 140 atomic parts per million (appm).

1.2 Microstructure of Irradiated Materials

The mechanical response to irradiation was also investigated by characterizing the defect microstructure and applying models from the literature describing the change in mechanical properties. The microstructures of specimens 1HA21 and 7W7 from the UBR irradiation and specimen F50-X1 from the HFIR 1Q irradiation were characterized by quantification of the size and number density of the defect clusters produced during irradiation. Attachment 2 contains the results of the analyses by Dr. S. J. Zinkle of Oak Ridge National Laboratory, Metals & Ceramics Division. Previously, the size and number density of defect clusters and helium bubble observed in specimens from disk RA3 of R-tank were measured and the results were published in references 1 and 12. Section 3 contains a summary of the microstructural analyses along with the application of current literature models predicting the mechanical response.

2.0 MECHANICAL PROPERTIES DATABASE

2.1 HFIR 12M Capsule Specimen Irradiation and Mechanical Test Results

2.1.1 Irradiation Parameters

An overview of the histories of the specimen irradiations in the University of Buffalo Reactor, the R-tank specimens, the P-reactor Thermal Shield specimens, and the High Flux Isotope Reactor 1Q and 4M capsule specimens are described in reference 1. The Savannah River Laboratory irradiations in the HFIR were specified in Reactor Materials Program Specification SRP-SL-1107 [6] and conducted through the Engineering Technology Division at Oak Ridge National Laboratory. The 12M mechanical specimen capsule was irradiated to twelve cycles, each approximately one month in duration, in the HFIR removable beryllium position (RB-7) along with the 4M capsule (RB-5) beginning with HFIR cycle #283 on July 15, 1986. Five of twelve HFIR irradiation cycles (HFIR cycle #283 to #287) at 100 MW power were completed prior to the extended HFIR shutdown which began November 14, 1986. The irradiation recommenced July 17, 1990 at 85 MW power and completed cycles six through nine (#289 to #292) on December 12, 1990. In December 1990, the capsule was being moved for HFIR maintanence and a weldment connecting the upper guide tube to the specimen holder assembly failed. A root cause failure analysis was performed and the capsule was repaired following extensive design reviews. The capsule was reinserted for irradiation on June 20, 1991 and completed cycles ten to twelve (#298 to #300) with the end of irradiation on August 28, 1991.

Analysis of (RDT) #1 from capsule 12M verified that software and data files used for previous SRL analyses in 1988 were operational. In October 1991, ORNL performed a comparison of the results from the SRL Removable Dosimeter Tube (RDT) #1 from the 12M capsule to previous analyses of the 4M and 4C dosimeters performed in 1988. The analysis of the 12M RDT #1 verified the operability of the software and data files used in the 4M and 4C analyses and showed agreement with the 12M results by about 10 and 5%, respectively [13]. The balance of the 12M dosimetry analysis was deleted from the program to allow completion of the remaining workscope objectives [6]. The dosimetry analysis of the 4M specimens [14] are applied to estimate the exposure level of the 12M specimens. The fast ($E_n > 0.1$ MeV) and thermal neutron fluences and the dpa_{NRT} values of the 4M specimens [14] were multiplied by three in ascribing exposure parameters to the 12M specimens. The table below contains the irradiation parameters of the HFIR specimens that were mechanically tested in the as-irradiated condition. [Note nineteen of the 12M specimens and 180 surveillance specimens were not tested and will be offered to interested groups].

Irradiation of austenitic stainless steels produces helium primarily through fast neutron (n, α) reactions with the major alloying components, through a two-step thermal neutron reaction with Ni^{58}, and with fast and thermal neutron reactions with B^{10}, depending on the reactor spectrum.

The fast neutron cross section for the production helium for nickel, chromium, and iron are on the order of 1 mb for neutron energies on the order of 1 MeV [15]. The HFIR is a mixed-spectrum reactor with the thermal flux in the removable beryllium positions calculated to be 1.351 of the fast ($E_n > 0.1$ MeV) flux [14] [note that an error in the thermal-to-fast ratio was made in original calculation in [14]; the thermal fluences values reported in ref. 1 for the 1Q and 4M specimens have been corrected in this report]. The primary source of helium in the HFIR specimens is from the two-step neutron reaction with Ni^{58}. Following the method given in reference 16, the calculation of helium via the two-step neutron reaction with Ni^{58} is shown below. Table 1 shows the results of calculated helium build-in of the HFIR specimens from the RMP.

Calculation of Helium Build-in from Two-Step Thermal Neutron Reaction With Ni-58:

$$n = \frac{\text{no. of He atoms}}{\text{no. of SS atoms}} = p\left[\frac{\text{atoms He}}{\text{atoms Ni}^{58}}\right] \times q\left[\frac{\text{atoms Ni}^{58}}{\text{atoms Ni}}\right] \times r\left[\frac{\text{atoms Ni}}{\text{atoms SS}}\right]$$

$$\text{with } p = \frac{\sigma_\alpha}{\sigma_T} \times \frac{\sigma_T \times (1 - e^{-\sigma_\gamma \times \Phi}) - \sigma_\gamma \times (1 - e^{-\sigma_T \times \Phi})}{\sigma_T - \sigma_\gamma}$$

where σ_γ and σ_T are the capture and total absorption thermal neutron cross sections, respectively, for Ni^{58}; σ_α is the alpha emittance thermal neutron cross section for Ni^{59}; and Φ is the thermal fluence. The values for these cross sections are from reference 17 as shown below.

Thermal Neutron Reaction Cross Sections [17]:

$B^{10}(n, \alpha)Li^7$: σ_α (2200 m/s) = 3837 ± 9 barns (1 barn = 10^{-24} cm^2)
$Ni^{58}(n, \gamma)Ni^{59}$: σ_γ (thermal spectrum-averaged) = 4.6 ± 0.3 barns
$Ni^{59}(n, \alpha)Fe^{56}$: σ_α (thermal spectrum-averaged) = 12.3 ± 0.6 barns
$Ni^{59}(n, T)$ (Total absorption): σ_T (thermal spectrum-averaged) = 92 ± 4 barns

also, q = 0.683, the natural isotope abundance of Ni^{58} in nickel, and

$$r = \frac{\text{wt.\% nickel in specimen}}{100 \text{ wt.\% SS}} \times \frac{8.32 \frac{\text{gm of SS}}{\text{cm}^3}}{58.71 \frac{\text{gm of nickel}}{\text{mole of nickel}}} \times \frac{6.023 \times 10^{23} \frac{\text{atoms of nickel}}{\text{mole of nickel}}}{9.1 \times 10^{22} \frac{\text{atoms of SS}}{\text{cm}^3}}$$

Measurement of Helium in Selected RMP Specimens:

Helium assay chips were cut by Materials Engineering Associates from selected UBR CVN specimens and HFIR 1Q and 4M CVN specimens and were measured by fusion analysis by Dr. B. M. Oliver and Dr. H. Farrar IV from Rockwell International. The results are shown in Table 2. The actual boron content of the piping materials reported to contain contents of 10 to 20 wppm [8], near the reported resolution of ± 10 wppm, is most likely negligible. The helium content of approximately 0.07 appm in the base (and HAZ) of the UBR specimens is close to that expected for the fast neutron reactions and is well below that expected from the boron assay of 10 to 20 wppm [18]. The helium content at approximately 1 appm in the 4W deposit is consistent with the thermal reaction with B^{10} and thus the boron assays at the 50 wppm are expected to be more accurate. Similarly, the helium contents of the 4M specimens listed in Table 2 are close to the predicted content (Table 1) and therefore the actual boron contents are negligible in the base materials. The predicted helium content of the 1Q specimens (Table 1) are, however, less than the measured values listed in Table 2. The actual boron content of the F50 plate material is therefore non-negligible and is close to the reported 10 wppm level. The close agreement of the measured helium content of the 4M specimens with the predicted contents shows that the generation of helium from the two-step thermal neutron reaction with Ni^{58} is the primary source of helium and that the predicted values for the helium content of the 12M specimen materials should be accurate.

The recoil of He^4 and Fe^{56} also produces displacement damage [19]. Greenwood [19] has calculated a value of 1/567 dpa for each appm of helium produced from the two-step thermal reaction with Ni^{58}. This contribution to displacement damage has not been added to the dpa_{NRT} values calculated [14] per ASTM E693 shown in Table 1. Note dpa_{NRT} is the dpa model by Norget, Robinson, and Torrens [20].

Table 1 - HFIR Specimen Irradiation Parameters. The dpa values were calculated in accordance with ASTM E693 -- the contribution to dpa of 1/567 per 1 appm helium has not been added to the dpa results. (***Note that the thermal fluences of the 1Q and 4M specimens, previously reported in ref. 1, have been corrected in this table***).

Specimen ID	Specimen Type, Test Temperature	Orientation	Thermal Fluence, 10^{21} n/cm^2	Fast Fluence, E_n>0.1MeV, 10^{21} n/cm^2	dpa_{NRT} (ASTM E693)	Helium (estimated) (appm)
1Q Capsule						
F50-12	T, 125°C	L-T	0.49	0.36	0.21	0.5
F50-9	T, 125°C	L-T	0.81	0.60	0.34	1.2
F50-1	T, 125°C	L-T	1.04	0.77	0.43	2.0
F50-6	T, 125°C	L-T	1.20	0.89	0.50	2.7
F50-8	T, 125°C	L-T	1.24	0.92	0.52	2.8
F50-13	CVN, 125°C	L-T	0.49	0.36	0.21	0.5
F50-19	CVN, 125°C	L-T	0.81	0.60	0.34	1.2
F50-14	CVN, 125°C	L-T	1.04	0.77	0.43	2.0
F50-23	CVN, 125°C	L-T	1.20	0.89	0.50	2.7
F50-17	CT, 125°C	L-T	0.49	0.36	0.21	0.5
F50-18	CT, 125°C	L-T	0.78	0.58	0.33	1.1
F50-12	CT, 125°C	L-T	0.91	0.67	0.38	1.5
F50-19	CT, 125°C	L-T	1.19	0.88	0.50	2.6
F50-13	CT, 125°C	L-T	1.22	0.90	0.51	2.8
F50-8	CT, 125°C	L-T	1.24	0.92	0.52	2.8
4M Capsule						
3HA8	T, 125°C	L-C	2.43	1.8	1.0	9.3
1BB1	T, 125°C	L-C	3.65	2.7	1.5	20
5BA5	T, 125°C	C-L	4.46	3.3	1.9	30
4BB2	T, 125°C	C-L	5.00	3.7	2.1	37
1BB4	T, 125°C	L-C	5.13	3.8	2.1	37
6W1	CVN, 125°C	L-C	2.43	1.8	1.0	10
6HA6	CVN, 125°C	L-C	3.65	2.7	1.5	21
3HB1	CVN, 125°C	L-C	4.46	3.3	1.9	29
4BB9	CVN, 125°C	C-L	5.00	3.7	2.1	37
1BB5	CVN, 125°C	L-C	5.13	3.8	2.1	37
3HA5	CT, 125°C	L-C	2.43	1.8	1.1	9.3
1BB8	CT, 125°C	L-C	2.97	2.2	1.3	13
1BB16	CT, 125°C	L-C	3.51	2.6	1.5	18
2W2	CT, 125°C	L-C	3.92	2.9	1.7	26
5BA7	CT, 125°C	C-L	4.32	3.2	1.8	28
3HB4	CT, 125°C	L-C	4.59	3.4	1.9	30
7HA5	CT, 125°C	C-L	4.86	3.6	2.1	34
7HA7	CT, 125°C	C-L	4.86	3.6	2.0	34
1BB9	CT, 125°C	L-C	5.00	3.7	2.1	36
4BB10	CT, 125°C	C-L	5.13	3.8	2.1	39
12M Capsule						
4BB1	T, 25°C	C-L	7.3	5.4	3.1	74
5W1	T, 25°C	L-C	10.8	8.0	4.6	155
5W4	T, 125°C	L-C	13.2	9.8	5.6	217
4BB5	T, 125°C	C-L	15.2	11.3	6.4	259
1BB2	T, 125°C	L-C	14.6	10.8	6.1	232
4BB8	CVN, 125°C	C-L	7.3	5.4	3.1	74
6W5	CVN, 25°C	L-C	10.8	8.0	4.6	155
6W2	CVN, 125°C	L-C	15.3	11.3	6.4	276
1HA6	CVN, 125°C	L-C	13.2	9.8	5.6	200
4BB11	CT, 125°C	C-L	7.3	5.4	3.2	74
1BB11	CT, 125°C	L-C	9.0	6.7	3.8	103
7HA6	CT, 125°C	C-L	10.5	7.8	4.4	136
7W4	CT, 125°C	C-L	12.8	9.5	5.4	201
1BB18	CT, 25°C	C-L	13.7	10.2	5.8	209
4BB12	CT, 125°C	C-L	15.2	11.3	6.4	259
7W3	CT, 25°C	C-L	12.2	9.0	5.1	186
7HA8	CT, 25°C	C-L	9.6	7.1	4.1	117

Table 2 - Measured helium concentrations from selected UBR and HFIR 1Q and 4M specimens.

Irradiation: Specimen Identification	Boron (wppm)	Helium (atomic parts per million)
UBR: 3HA34	10 ± 10	0.0673 ± 0.0088
UBR: 3BA20	10 ± 10	0.0769 ± 0.0007
UBR: 1HB16	20 ± 10	0.0684 ± 0.0002
UBR: 4W14	50 ± 10	1.404
UBR: 4W15	50 ± 10	0.996
UBR: 4HA19	20 ± 10	0.0703 ± 0.0001
3BA20	10 ± 10	0.09759
1HB16	20 ±10	0.06579
F50-13	10 ±10	3.27
F50-19	10 ±10	3.75
F50-14	10 ±10	5.24
F50-23	10 ±10	7.61
F50-X1	10 ±10	8.12*
6W1	< 10	12.55
6HA6	10 ± 10	13.7
3HB1	20 ± 10	28.40*
4BB9	20 ± 10	39.5
1BB5	20 ± 10	35.5
*The values for specimens F50-X1 and 3HB1 were reported by Rockwell reversed from that shown in this table. It is assumed that the results were inadvertantly switched.		

2.1.2 12M Mechanical Test Results

The complete results of the 12M specimen testing are contained in Attachment 1. Table 3 below summarizes several of the results from each tested specimen.

Table 3 - Summary of 12M mechanical test results reported by ORNL (compiled from Attachment 1).

Specimen ID	Orientation	Type	Test Temp. (°C)	J_{IC} (def. J, power law) (in-lb/in^2)	T_{ave} (def J, power law) ORNL; Adj.	J @ 1 mm crack ext; (in-lb/in^2)
4BBH11	C-L	CT	125	1122.9	147; 75.5	1862.2
1BBH11	L-C	CT	125	2493.2	179; 96.1	3054.1
7HAH6	C-L	CT	125	509.1	14.7; 7.4	589.1
7WH4	C-L	CT	125	2121.3	235; 104	2686.0
1BBH18	C-L	CT	25	1039.8	71; 58.7	1800.2
4BBH12	C-L	CT	125	1109.8	80; 41.1	1533.9
7WH3	C-L	CT	25	1240.8	71.9; 53.9	1952.4
7HAH8	C-L	CT	25	315.9	32.7; 25.0	686.4

Table 3 - cont'd

Specimen ID	Orientation	Type	Test Temp. (°C)	Absorbed Energy (ft-lb)	Lateral Expansion (mils)
4BBH8	C-L	CVN	125	66.8	41
6WH5	L-C	CVN	22	69.6	44
6WH2	L-C	CVN	125	76.3	35
1HAH6	L-C	CVN	125	81.1	51

Specimen ID	Orientation	Type	Test Temp. (°C)	Engr. Yield (0.2%) (ksi)	Engr. Ult.. (ksi)	Uniform Elongation (% in 0.96 in.)	Total Elongation (% in 0.96 in.)
4BBH1	C-L	T	23	102.1	111.2	31.13	31.85
5WH1	L-C	T	23	106.1	112.2	19.42	31.85
5WH4	L-C	T	125	90.1	93.5	9.77	19.01
4BBH5	C-L	T	125	96.3	99.1	22.57	33.78
1BBH2	L-C	T	125	95.0	96.1	20.92	32.21

The values for the flow stress (average of engineering yield and ultimate strengths) used by ORNL in the analysis of the J-R curves are low with respect to the results from the 12M tensile specimen testing. Table 4 below lists the recommended flow stress for the 12M compact tension specimen analysis. The application of these values for the flow stress would not significantly change the J_{IC} results; however, the results for the average tearing modulus, T_{ave}, are impacted -- the adjusted results, using the values for flow stress given in Table 4, are listed along with the ORNL results in Table 3 above.

Table 4 - 12M Specimen Flow Stress Values

C(T) Specimen	s_y (ksi)	s_u (ksi)	s_f (ksi)	Tensile Specimen
4BB11 (C-L;125°C)	96.3	99.1	97.7	4BB5 (C-L;125°C)
1BB11 (L-C;125°C)	95.0	96.1	95.55	1BB2 (L-C;125°C)
7HA6 (C-L;125°C)	90.1	93.5	91.8	5W4 (L-C;125°C)
7W4 (C-L;125°C)	90.1	93.5	91.8	5W4 (L-C;125°C)
1BB18 (C-L;25°C)	102.1	111.2	106.65	4BB1 (C-L;25°C)
4BB12 (C-L;125°C)	96.3	99.1	97.7	4BB5 (C-L;125°C)
7W3 (C-L;25°C)	106.1	112.2	109.15	5W1 (L-C;25°C)
7HA8 (C-L;25°C)	106.1	112.2	109.15	5W1 (L-C;25°C)

The mechanical property testing of the unirradiated [9] and irradiated [1] archival piping materials involved several experimental variables including irradiation conditions (temperature, exposure level, exposure rate, and neutron energy spectrum), weldment component (base, weld, or HAZ), chemical composition, orientation, and test conditions (temperature, and testing apparatus). From the test parameters of temperature (25 and 125°C), orientation (L-C and C-L), and weldment component (base, weld, and HAZ), twelve different categories of properties were defined in the evaluation of the mechanical response of the archival piping materials in both the unirradiated and irradiated conditions. The categorization aided the assessment of the effect of test conditions on the mechanical property results and the selection of properties for structural and fracture analyses. The results from the unirradiated mechanical property testing [9] show no significant effect of chemical composition on the strength or toughness response; similarly, the irradiated property testing [1] shows no significant effect of composition on the response of the material to the low temperature neutron irradiation conditions.

The mechanical properties from 12M testing (Table 3 above) are compared in the discussion below to the mechanical test results of the previous database of materials in the irradiated condition given in references 1 and 11. A complete discussion on the reduction of toughness due to irradiation and the effect of orientation on mechanical response of the archival piping materials is given in reference 11. The effect of irradiation exposure (level) on the mechanical response is discussed in section 2.2.

Tensile Results. The previous individual test results for the irradiated materials are listed in Appendix 1 and the average results for each test category are given in section 5 of reference 1. Each 12M tensile specimen [4BBH1 (Base, C-L, 23°C), 5WH1 (Weld, L-C, 23°C), 5WH4 (Weld, L-C, 125°C), 4BBH5 (Base, C-L, 125°C), and 1BBH2 (Base, L-C, 125°C)] has both a higher yield and ultimate strength than any of the previous individual specimen results in the corresponding categories, but with reduced work hardening ability. The work hardening ability is defined as the difference between the yield and ultimate strengths. Ductilities of the 12M specimens, however, as measured by total or uniform elongation, are generally within the range of the previous results [1].

The strengths of the 12M specimens tested at 125°C are lower than the strengths for the specimens in the corresponding categories tested at 25°C which is consistent with the previous results [1]. A decrease in ductility with the increase in temperature is observed in the companion weld specimens, 5WH1 and 5WH4. No decrease in ductility was observed, however, in the average results for any category in the previous set of results.

No significant orientation effect on strength or ductility was observed for the L-C and C-L test directions for the 12M specimens, similar to the previous results [11].

Charpy V-Notch Results. The previous individual test results for the irradiated materials are listed in Appendix 1 of reference 1. Each 12M CVN specimen exhibited absorbed energies within the range of the previous results. The lowest absorbed energy, 66.8 ft-lb, occurred in specimen 4BBH8, a specimen in the C-L orientation. The previous irradiated test results show the C-L orientation to yield lower absorbed energies than the L-C orientation for the base and HAZ components with differences of 27 to 39%; no significant effect on orientation, however, is observed for the weld components [11].

Compact Tension Results. The previous individual test results for the irradiated materials are listed in Appendix 1 of reference 1. No tests of C(T) specimens of archival piping materials were previously performed at 25°C. The 12M specimens 7HAH8 (C-L, 25°C) and 7HAH6 (C-L, 125°C) exhibited the lower bound fracture toughness results (J_{IC}, J_{1mm}, and T_{ave}); similarly, the test results from HAZ specimens 7HAH5 (C-L, 125°C) and 7HAH7 (C-L, 125°C) were lower bound for the 4M specimens.

The previous results [1, 11] did not show a significant dependency of fracture toughness on temperature. The results for the 12M HAZ companion specimens 7HAH8 (25°C) and 7HAH6 (125°C) do not show a significant difference in the J-R curve response (see Attachment 1) between 25 and 125°C. The results for the 12M weld companion specimens 7WH3 (25°C) and 7WH4 (125°C), however, do show a difference with the 25°C weld specimen exhibiting lower fracture toughness.

All the 12M specimens, with the exception of specimen 1BBH11, were in the low toughness or C-L orientation. The previous irradiated test results show the C-L orientation to yield lower J_{IC} values than the L-C orientation for the base and HAZ components with differences of 59 to 79%; no significant difference between the C-L and L-C results occurs in the weld component [11]. The high toughness of 12M specimen 1BBH11 (L-C) compared to the low toughness of 12M specimen 1BBH18 (C-L) is consistent with this trend.

The lower bound fracture toughness of the 4M specimens (i.e., results from specimen 7HAH5) were applied in the elastic-plastic fracture mechanics analysis of the reactor tank for the development of the acceptance criteria [8]. A cutoff at a J value of 646 in-lb/in^2 was selected [8] which corresponds approximately to a cut-off at 3 mm of crack extension (J value of 674 in-lb/in^2 for 7HAH5), recommended after the development of the acceptance criteria [1, 9]. The J_{3mm} (power law fit) results from the 12M specimens 7HAH8 and 7HAH6 are 1252 and 673 in-lb/in^2, respectively, and are therefore consistent with the lower bound value previously selected. Note that the lower bound toughness results from the irradiated C(T) specimens in the low toughness orientation (C-L) were applied in the analysis without regard for orientation of postulated flaws [8]. It is recommended that the orientation of flaw with respect to the rolling direction of the plates used to construct the tank be considered in applying fracture toughness properties in flaw-specific analyses [8] to allow a more accurate evaluation of the safety margins. Flaws oriented parallel to the rolling direction of the plate corresponds to the C-L specimen orientation. The strong dependency of fracture toughness on the orientation with respect to the rolling direction of the austenitic stainless steel plate or pipe axis was correlated to the residual dendritic structure of the plate as reported in reference 11.

2.2 Effect of Irradiation Exposure Level on Property Response

Several data from the mechanical testing of each specimen from the R-Tank sidewall disks, the Thermal Shield Materials irradiation in P Reactor, and the archival piping materials irradiated in the UBR and HFIR irradiations are plotted as a function of fast neutron (E_n > 0.1 MeV) fluence for comparison for early work on austenitic stainless steels reported in the literature. The results could have been plotted as a function of dpa_{NRT} -- the interpretation of the effect of exposure level on the mechanical property response would be the same since the fast fluence causes most of the displacive damage and the mechanical properties are relatively insensitive to exposure. The exposure parameter of dpa_{NRT} should be used for levels below approximately 0.1 dpa_{NRT} since the mechanical properties would be strongly dependent on exposure below this level and the contributions of thermal fluence to displacive damage in the high thermal/fast flux at the SRS reactor tank walls and for the HFIR irradiations are significant. Note also that helium build-in occurs with fluence (see Table 1).

2.2.1 Effect of Fast Fluence on Strength, Absorbed Energy, and Elastic-Plastic Toughness

Figures 1 through 6 show the results of yield (0.2% offset) and tensile (ultimate) strengths, impact absorbed energy, and fracture toughness (J_{def} at 1 mm crack extension) at the test temperatures of 25 and 125°C. Mechanical specimens of identical material (e.g., 1BB) and orientation (e.g., L-C), irradiated to several fast fluences are depicted on the figures to show the response of identical test specimens with fluence.

The general data trend showing increased strengths with fluence is evident at both 25 and 125°C in Figures 1 and 2. The 5W weld material irradiated in the UBR and the 12M capsule to 1.1 x 10^{20} and 8.0 x 10^{21} n/cm^2, respectively, and tested at 25°C shows an increase in strength with fluence. The yield strengths are an average of 85.8 and 106.1 ksi, respectively. Similarly, the set of base, weld, and HAZ specimens from the thermal shield irradiation (same melts of material) increase slightly with fluence. Figure 2 shows that at 125°C, the 1BB and 4BB materials, irradiated in the 12M to approximately 11 x 10^{21} n/cm^2, do not follow the general hardening trend, but show a sharp increase in yield strength from their yield strength following irradiation in the 4M capsule to 3.8 x 10^{21} n/cm^2. The difference in response between the 12M materials tested at 25 and 125°C could be due to the impact of helium bubble contribution to lattice hardening in the 12M specimens; that is, helium bubbles as strengthening barriers could exhibit a higher activation energy, U(stress, temperature), for cutting through the bubbles than the activation energy for defect clusters. A similar response with test temperature was observed in irradiated nickel [21].

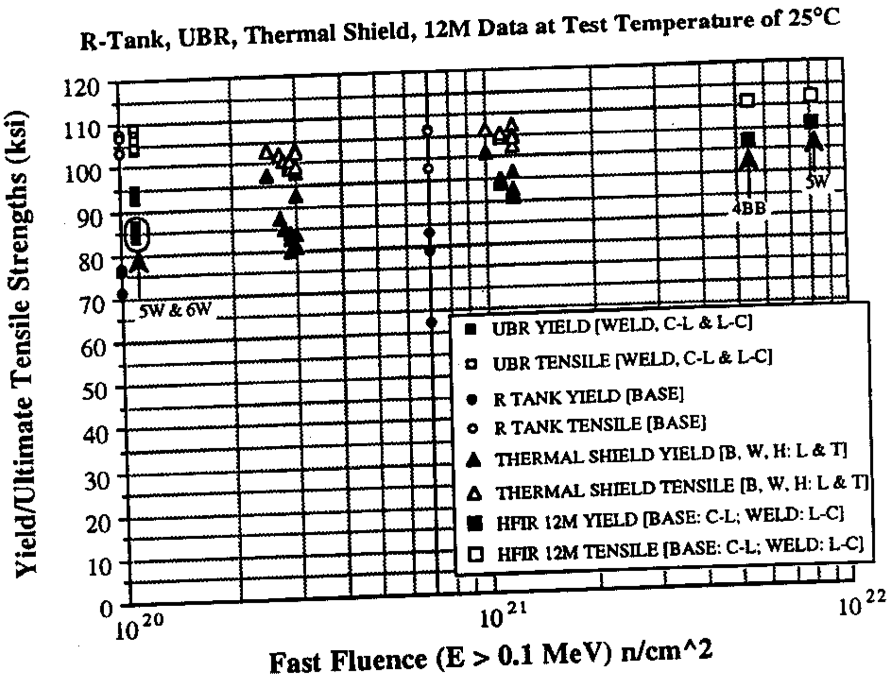


Figure 1 - Strength Results at 25°C

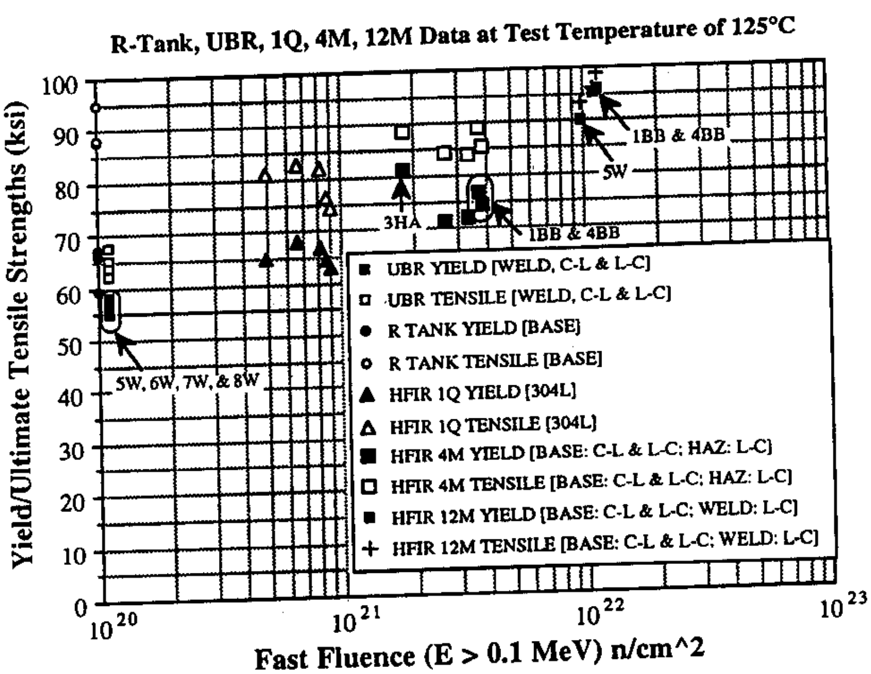


Figure 2 - Strength Results at 125°C

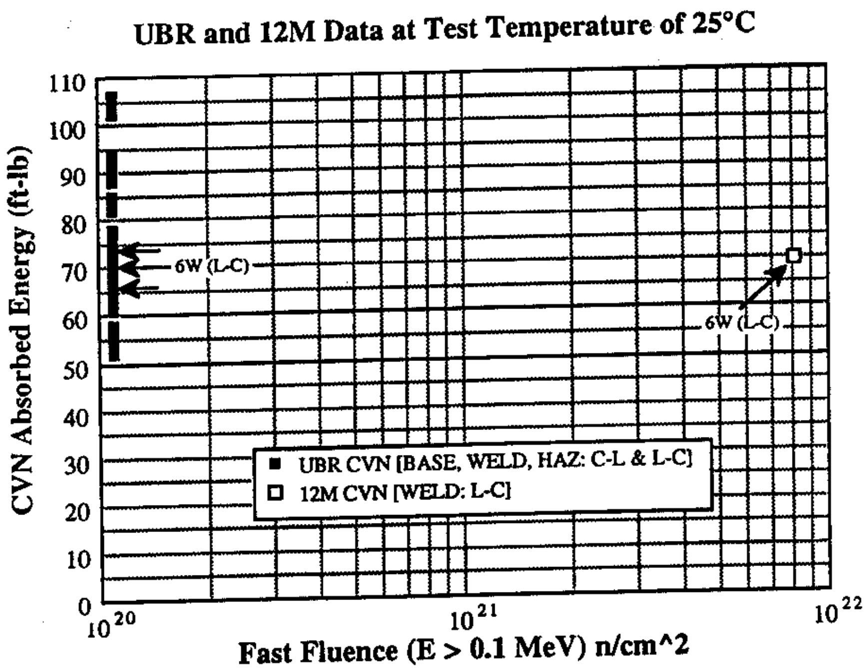


Figure 3 - Absorbed Energy Results at 25°C

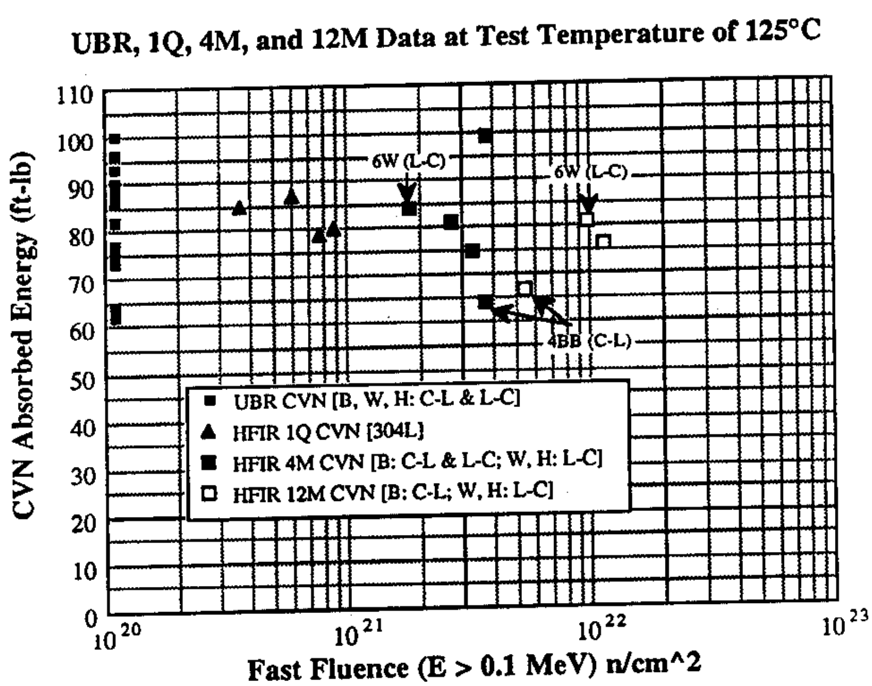


Figure 4 - Absorbed Energy Results at 125°C

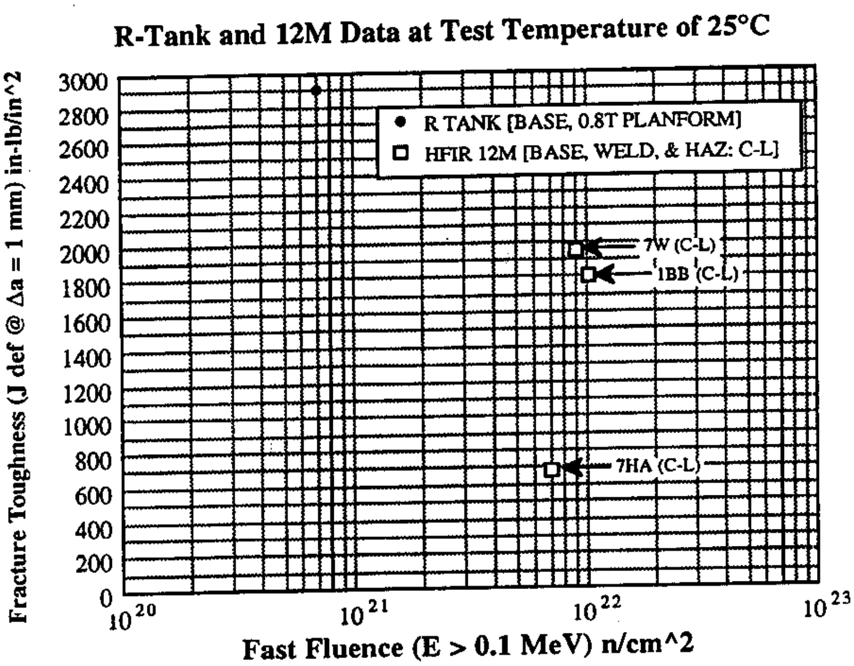


Figure 5 - J_{def} @ 1 mm Crack Extension Results at 25°C

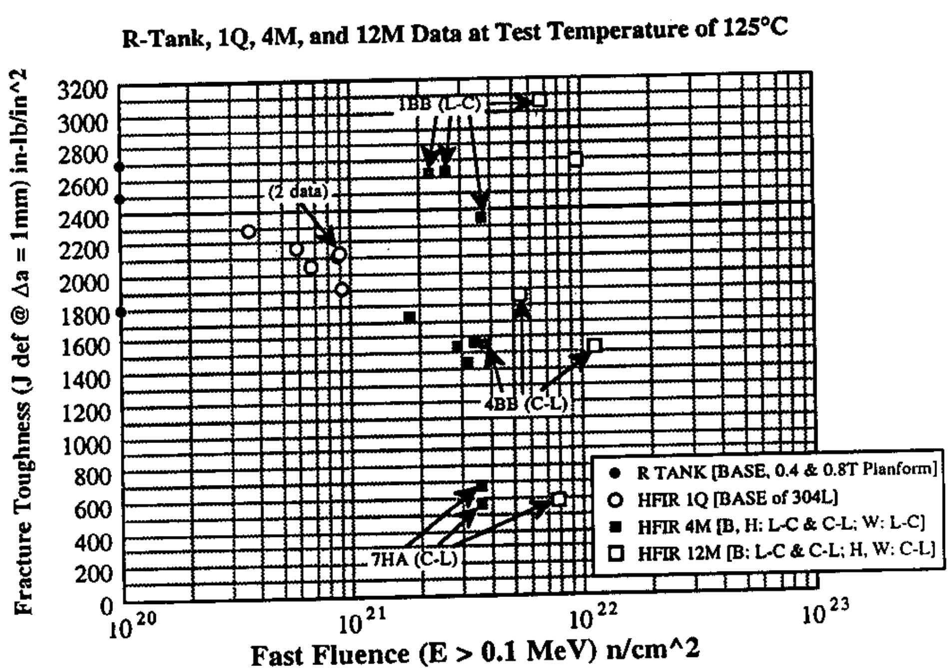


Figure 6 - J_{def} @ 1 mm Crack Extension Results at 125°C

The general trend of data of absorbed energy at 25 and 125°C in Figures 3 and 4 shows no significant decrease with fluence. The absorbed energy of individual materials (melts) irradiated at different fluences also shows no significant decrease of absorbed energy with fluence. The 6W specimen irradiated in the UBR and 12M and tested at 25°C both have an average absorbed energy of approximately 70 ft-lb. Similarly, the 6W and 4BB specimens irradiated in the 4M and 12M capsules show no significant decrease of absorbed energy with fluence over the range 10^{21} to 10^{22} n/cm^2.

As shown in Figures 5 and 6, a large variation exists in the fracture toughness data both, at 25 and 125°C. No individual materials (melts) were tested at more than one fluence at 25°C. Similar melts at several fluences were tested at 125°C. The F50 plate of Type 304L irradiated in the 1Q capsule and the 1BB, 4BB, and 7HA materials irradiated in the 4M and 12M capsule show no significant decrease of fracture toughness with fluence over the range of 10^{21} to 10^{22} n/cm^2.

2.2.2 *Sensitivity of Materials to Irradiation*

The unirradiated and irradiated archival piping materials exhibit a strong dependency of toughness response on orientation [11]. To discriminate the sensitivity of the materials to irradiation from the effects on toughness due to initial or unirradiated condition, the residual fracture toughness (defined as J_{def} -R curve value @ 1 mm crack extension in the irradiated condition divided by the corresponding unirradiated value) is shown as a function of fluence at 25 and 125°C in Figures 7 and 8.

The low carbon materials (F50 @ 0.025 wt.%; 1BB @ 0.035 wt. %; and 5BA @ 0.041 wt.%) have an average residual toughness of 0.78 compared to the high carbon 4BB material (0.083 wt.%) material with an average residual toughness of 0.70 at 125°C.

The toughness of the heat-affected-zone (HAZ) weldment component, containing grain boundary precipitation, shows an increased sensitivity to irradiation (greater loss of toughness) compared to the base component. The range of values of residual toughness (defined as J_{def} -R curve value @ 1 mm crack extension in the irradiated condition divided by the corresponding unirradiated value) of the HAZ component in both the L-C and C-L orientations is 41 to 54%, whereas the range of residual toughness values of the base component is 65 to 89%. The range of residual toughness values of the weld component is 48 to 66%.

The high sensitivity of the HAZ materials to irradiation is interpreted qualitatively by considering the importance of grain boundaries to accommodate shear displacements in irradiated materials. As summarized in reference 22, at low plastic deformations, (≈ 5%), removal of defect clusters by moving dislocations occurs in channels; the spacing of the channels decreases with increasing strain. The channeling process, however, can lead to high stress concentrations and shear displacements at the grain boundaries. The HAZ component contains chromium carbide precipitation, and, the ability to accommodate plastic deformation and thereby absorb energy would be reduced.

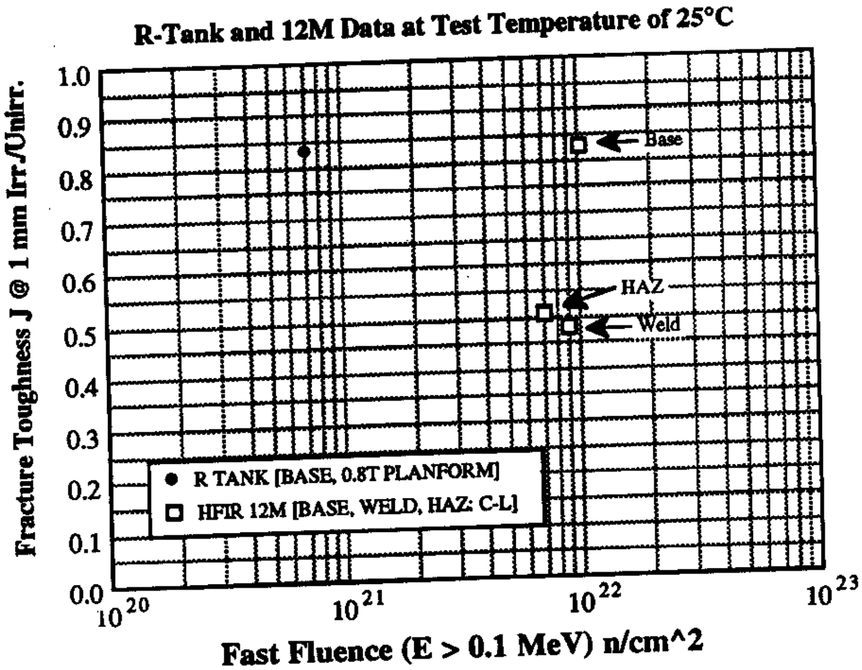


Figure 7 - Normalized J_{def} @ 1 mm Crack Extension Results at 25°C

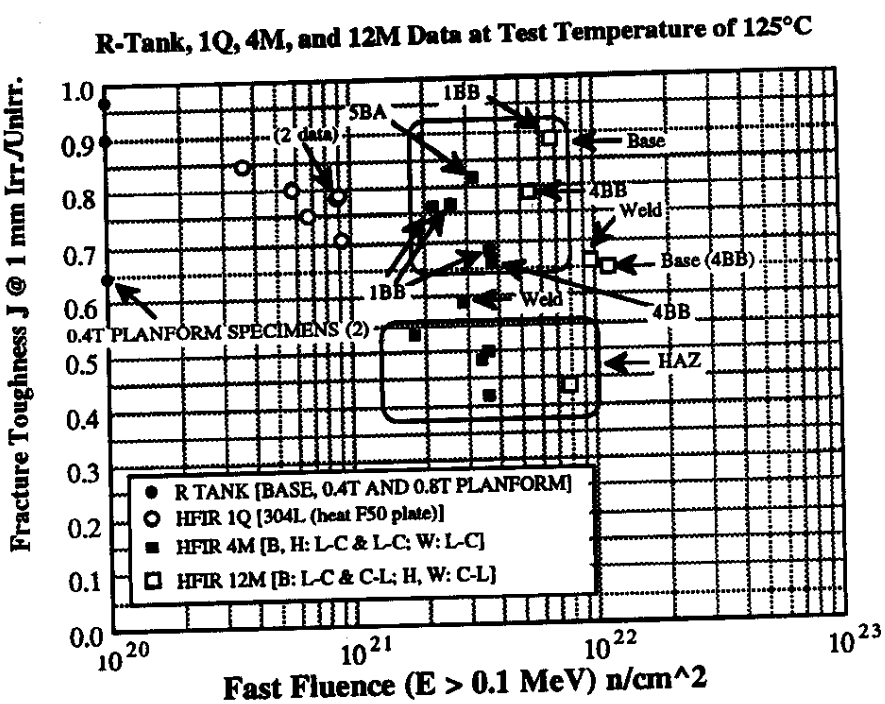


Figure 8 - Normalized J_{def} @ 1 mm Crack Extension Results at 125°C

3.0 MICROSTRUCTURAL ANALYSIS AND MECHANICAL MODELING

3.1 Microstructural Characterization of R-Tank, UBR, and HFIR 1Q Specimens

Characterization of grain size and second phase distribution of RMP materials is discussed in reference 11 and 23. Microstructural analysis of irradiated materials was planned under the RMP [4] and added to Specification SRP-SL-1111, Rev. 2. Attachment 2 is the letter report from Dr. S. J. Zinkle of Oak Ridge National Laboratory containing the results of the Transmission Electron Microscopy analysis of the UBR specimens 7W7 and 1HA21 and HFIR 1Q specimen F50-X1. Analysis of the R-tank RA3 specimen was previously analyzed, and the results were reported in references 1 and 12.

Black spot damage [21], or lattice extended defect clusters, forms under cascade damage conditions in the neutron irradiations of the materials in the database [24]. These defect clusters, produced in the initial cascade/subcascade events, remain stable at low irradiation temperatures; cluster coarsening which increases with time and temperature can also occur. Helium bubble formation, controlled by nucleation and growth processes involving freely migrating point defects, is also possible under these conditions since helium build-in occurs in the irradiation. These defects are responsible for the change in mechanical properties due to irradiation. The investigation of the microstructures from specimens irradiated at increasing exposure levels provides understanding of the mechanical response with exposure.

The defect cluster distribution was investigated with weak beam dark field analysis techniques (Attachment 2). Figure 9 shows the microstructure of defect clusters in the UBR specimen 1HA21. Figure 10 shows the microstructure of defect clusters in the 1Q specimen F50-X1 in comparison to the microstructure of the UBR specimen 1HA21. It is apparent that coarsening has occurred with the increase in fast fluence from 1.1 x 10^{20} n/cm^2 (E_n > 0.1 MeV) to 9.2 x 10^{20} n/cm^2 (note the irradiation conditions of the half CVN F50-X1 are idential with 1Q tensile specimen F50-8). The histograms of the defect clusters for UBR specimen 1HA21, the 1Q specimen F50-X1, and the delta ferrite phase of UBR specimen 7W7 are shown in Figure 11. Helium bubbles with a mean diameter of 2.5 nm and a number density of approximately 1.5 x 10^{16}/cm^3 were observed in the R-tank specimen (Figure 12) but were not clearly resolvable (> 2 nm) in the UBR and HFIR specimens. A summary of the defect cluster size and number density is contained in Table 5 below.

Figure 9 - Weak beam (g, 4g) microstructure of Type 304 stainless steel (specimen 1HA21) irradiated in the UBR at 120°C. The arrow shows the direction of the g = [002] diffraction vector

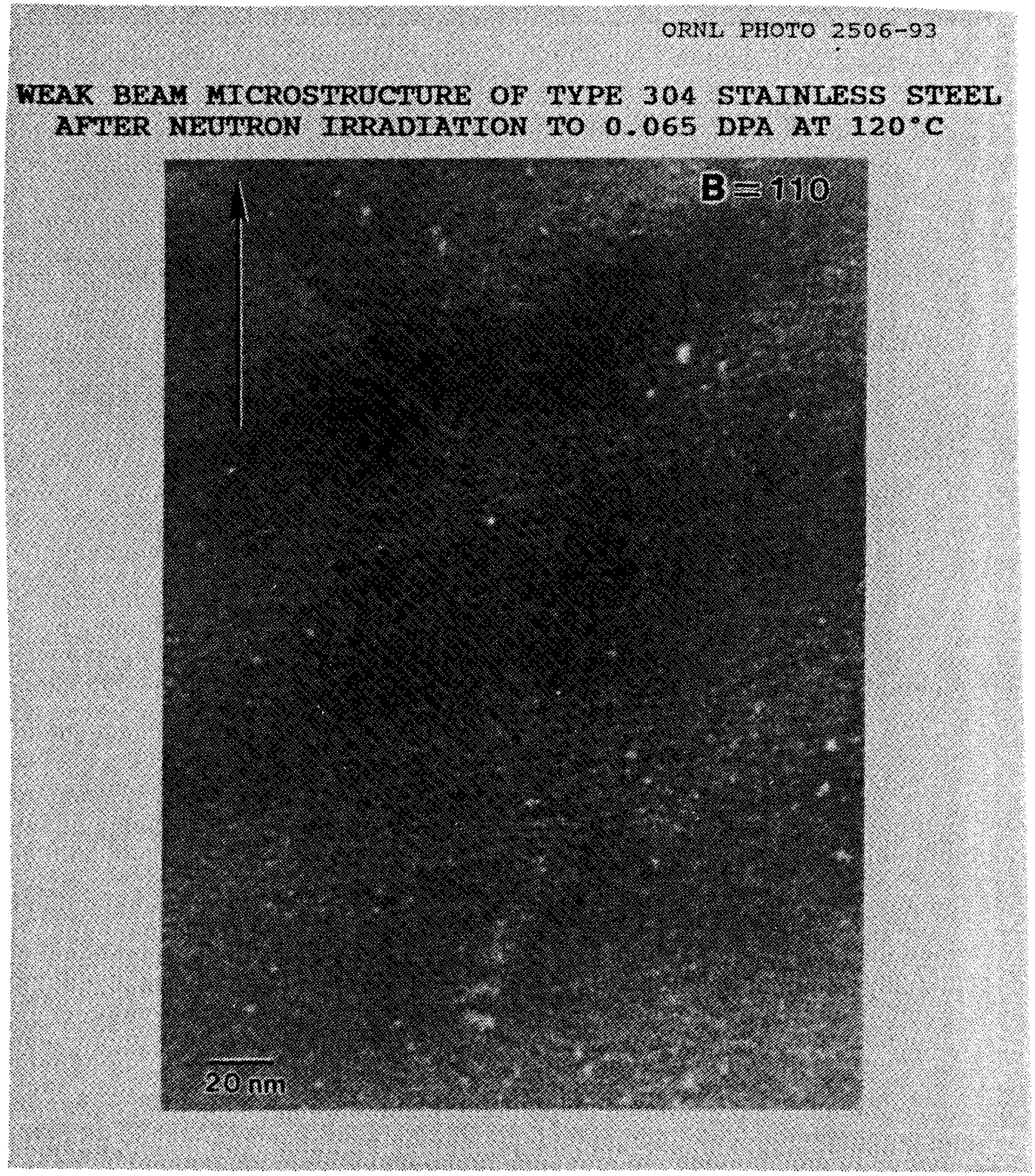


Figure 10 - Weak beam (g, 4g) microstructure of Type 304 and 304L stainless steels irradiated at 120°C in the UBR (top) and the HFIR (bottom). The electron beam direction was near [001] and the arrows show the direction of the g = [200] diffraction vectors

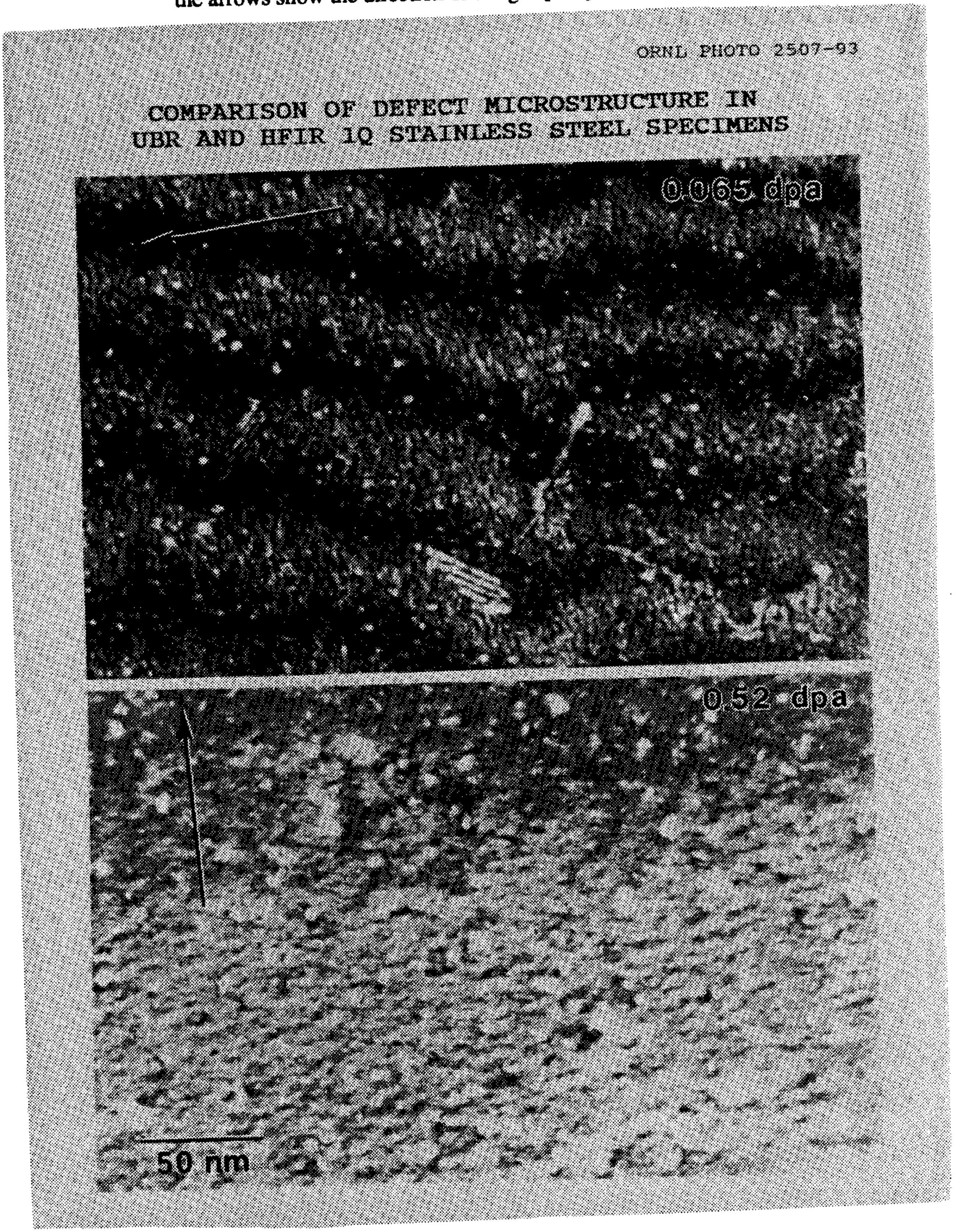


Figure 11 - Size histograms from the microstructural analysis of the UBR specimens 1HA21, 7W7 (delta ferrite phase), and HFIR 1Q specimen F50-X1

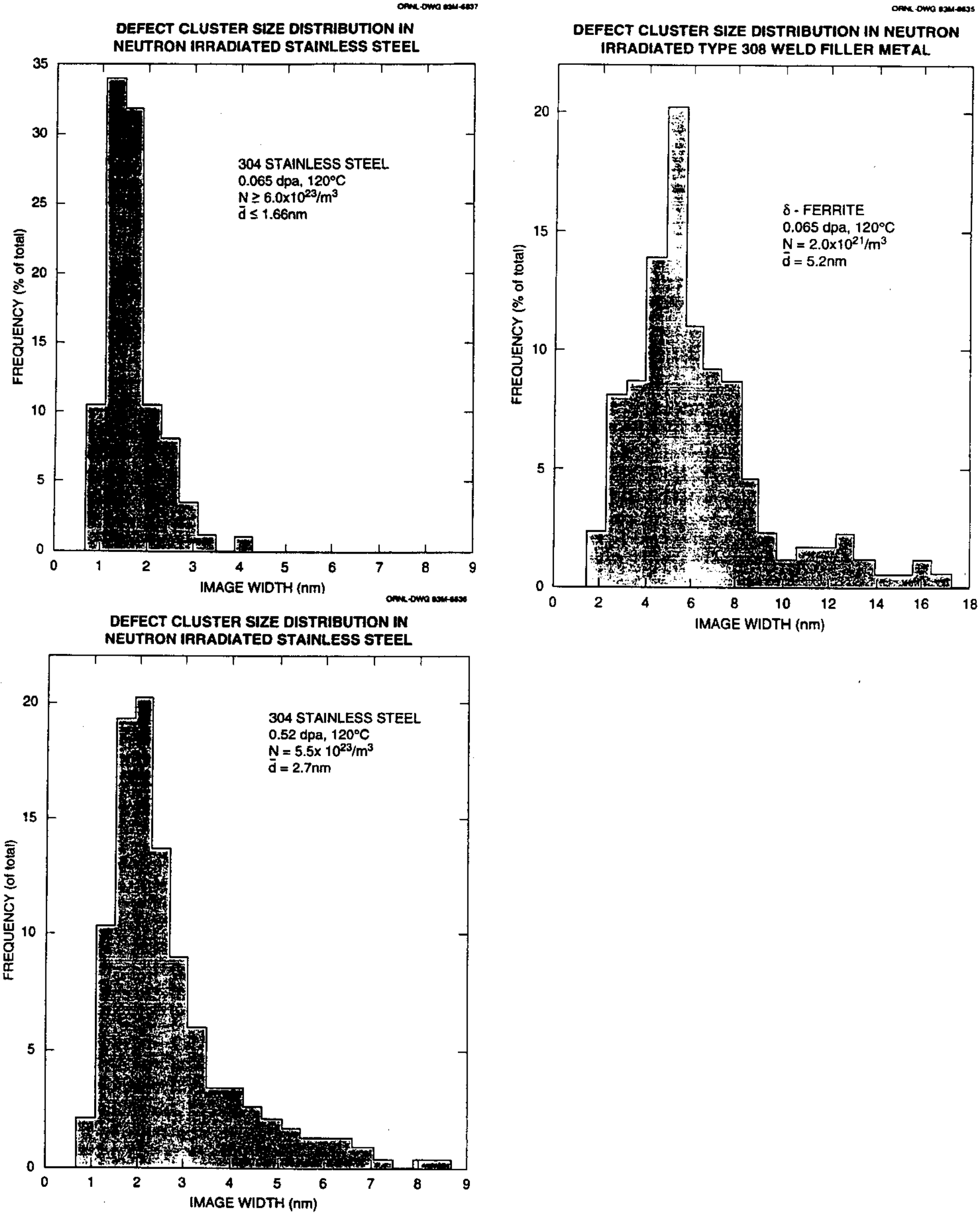


Figure 12 - Helium bubbles in R-tank sidewall material (RA3) irradiated to 0.5 dpa at temperatures less than 130°C. The RA3 disk from R-tank contained a nominal 35 appm (measured) helium [2]. [Note this is corrected from the content reported in reference 1]. The characterization of the defect cluster distribution in this material is reported in references 1 and 12

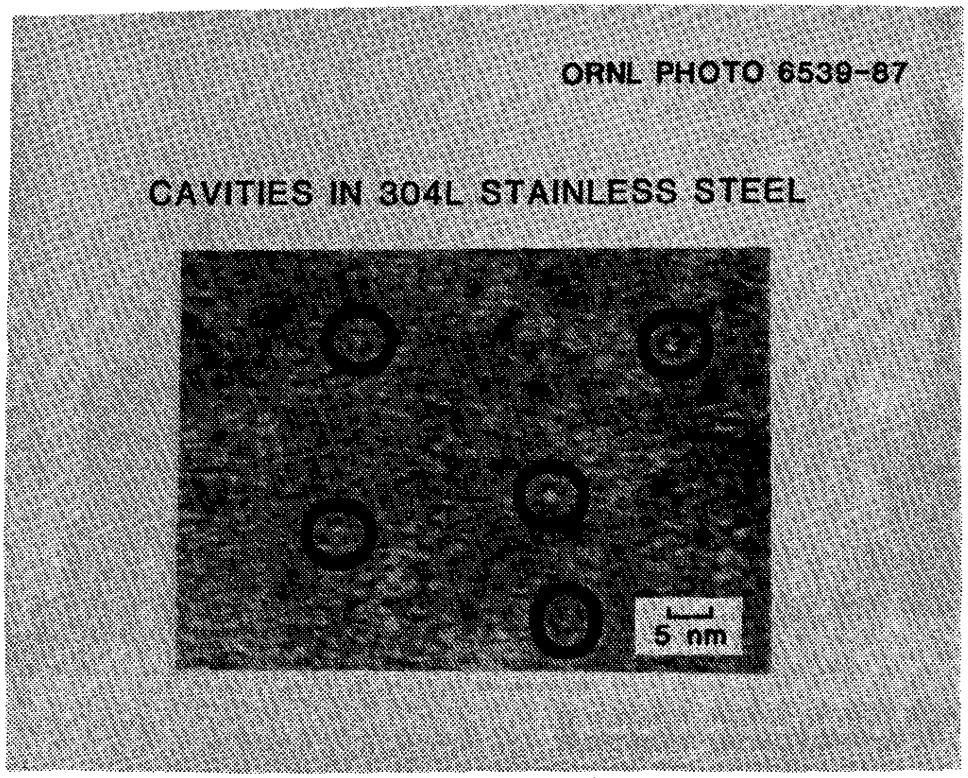


Table 5 - Summary of Defect Cluster Microstructure Results (compiled from Attachment 2)

Irradiation: Specimen	Mean Diameter	Density ($10^{17}/cm^3$)
R-tank: Disk RA3-1D, 3D (Type 304 SS)	1.85 nm	2.9
UBR: 1HA21-1, -2 (Type 304 SS)	1.66 nm	6.0
UBR: 7W7 (Type 308 SS, delta ferrite phase)	5.2 nm	0.020
HFIR 1Q: F50-X1 (Type 304L SS)	2.7 nm	5.5

3.2 Effect of Microstructure on Mechanical Response

3.2.1 Model for Increase in Yield Strength

The irradiation exposures of the materials in the database were at and above levels of saturation of hardening. Austenitic stainless steels irradiated at low temperatures (< 300°C) show "saturation" of radiation hardening or hardening which is regarded as insensitive to exposure [25]. Prior to saturation, the change in yield strength is linear with (fast fluence)$^{\approx 1/2}$ as shown by Higgy and Hammad for Type 304, 316, and 347 stainless steels in a low temperature (< 100°C) irradiation performed in the High Flux Reactor at Petten [26]. Saturation of hardening at a fast fluence of 4 x 10^{19} n/cm^2 (E_n > 1 MeV) was identified [26]. Makin and Minter [21] developed a model describing the functional dependence of the change in the lattice strengthening, $\Delta\sigma_i$, with fluence:

$$\Delta\sigma_i = A[1 - \exp(-B\Phi)]^{0.5}$$

where A and B are constants. The expression reduces to $\Delta\sigma_i \propto \Phi^{0.5}$ at low fluences and approaches A at high fluences (saturation). Note that the lattice strengthening is defined in terms of the lower yield point, σ_y , where:

$\sigma_y = \sigma_i + k_y d^{-0.5}$, where 2d is the grain diameter and k_y is a constant.

The second term is the expression for dislocation hardening based on the stress required to operate dislocation sources. Both σ_i and k_y increase with fluence [27] although the second term is observed to be a small percentage of σ_i in irradiated copper and nickel [21] and in the present results of the stainless steel (see, for example, the stress strain curves given in App. F of Attach. 1).

The derivation for change in lattice strengthening is based on assumptions that include the existence of a volume around each hardening obstacle (defect cluster) in which no new obstacle could be nucleated with additional irradiation. The model ignores the hardening effects of defect cluster coarsening and the production of additional hardening species (e.g. helium bubbles and transmutation species) which would occur more slowly than the initial production and saturation of number of the clusters in the irradiation and are suggested to account for the trend of increased hardening with fluence in the RMP database.

Calculations of lattice strengthening based on models derived from Orowon's theory for athermal bowing of dislocations around obstacles on a slip plane summarized in a review by Bement [22]. The expression for the athermal change in lattice strength is typically cited as the change in yield strength and is [22, 27]:

$$\Delta\sigma_y = M\alpha\mu b(Nd)^{0.5}$$

where M is the Taylor factor [27] and α is the barrier strength, μ is the shear modulus, b is the Burgers vector, and $(Nd)^{0.5}$ is the mean barrier spacing with N given as the total number of barriers, and d as the average barrier diameter.

This model is applied to the microstructural results of the analysis of the F50-X1 specimen with the average yield strength (0.2% offset) test results at 125°C from the F50 materials in the unirradiated condition and the irradiation condition. The average change in yield strength between the 1Q specimens F50-1, -6, -8, -9, and -12 and the unirradiated 1Q specimens F50-113, -101, -86, and -108 is 36.72 ksi (253.2 MPa) (see Appendix 1 of reference 1). With the Taylor factor of 3.06 [26], the shear modulus of 58 x 10^3 MPa, a Burgers vector of 2.544 x 10^{-10} m, and with a total number density of clusters of 5.5 x 10^{23} m^{-3} and an average diameter of 2.7 x 10^{-9} m (Table 5), a value of $\alpha = 0.146$ is obtained. A value of α of 0.2 was obtained in by Yoshida [28] in low-temperature-irradiated Type 316 stainless steel for several defect cluster densities with average dimeters of 1 nm. This value must be adjusted by using the Taylor factor of 3.06 rather than a Tresca factor of 2; however, to correctly relate the shear strengthening to the yield strengthening in a multigrain material. With this correction, the Yoshida result would be $\alpha = 0.131$, in good agreement to the present results.

Two considerations must be noted in deriving a barrier strength and estimating the change in yield strength based on the microstructure. First, Zinkle notes that, in general, α should be considered a function of d (Attachment 2). Second, the barrier hardening model applied in deriving α does not consider the strong temperature dependence of σ_i [21, 22]. If the unirradiated change in lattice strengthening with test temperature has the same dependence as the irradiated change, then the change in yield strength would be temperature insensitive. A comparison of the change in yield strengths at 25 and 125°C, shown in Figures 13 and 14 indicates a slightly higher change in yield at 25 compared to 125°C. The base materials irradiated to approximately 10^{21} n/cm^2 and tested at 25°C show an average change in yield of 57 ksi. In comparison, the base materials irradiated to approximately 3 x 10^{21} n/cm^2 and tested at 125°C show an average change in yield of 47 ksi. Similarly, the F50 materials in the 1Q irradiated to 5 to 9 x 10^{21} n/cm^2 show an average change in yield of 36 ksi; the R-tank materials irradiated to 7 x 10^{21} n/cm^2 have a wide range of change with values from 25 to 45 ksi. Note that a test temperature of 25°C was used in Yoshida's study [28], whereas the test temperature of 125°C was used in this present study in deriving the barrier strength.

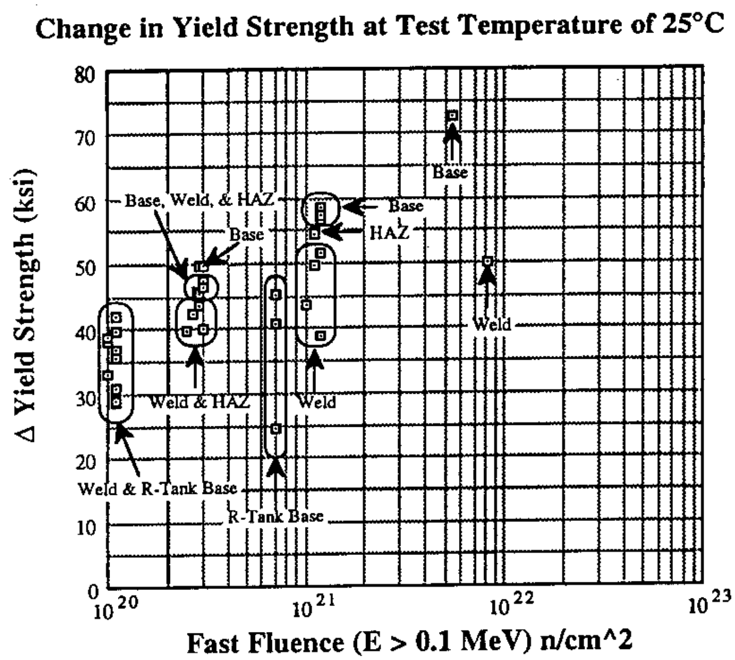


Figure 13 - Change in yield strength at 25°C

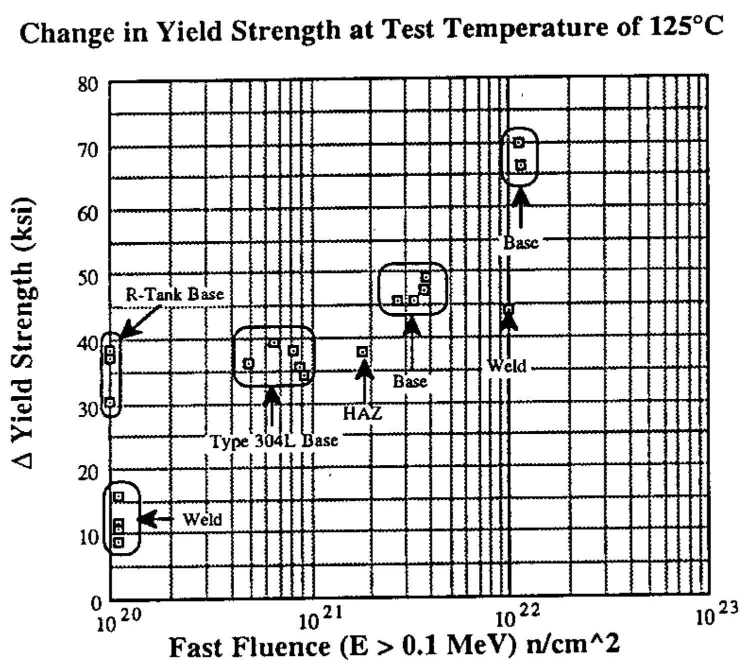


Figure 14 - Change in yield strength at 125°C

3.2.2 Model for Estimating K_{JC}

The process of yielding and plastic deformation for irradiated materials is complex and no models have been developed to predict the change in fracture toughness due to the irradiation-changed microstructure. Models for estimating the fracture toughness, K_{JC}, based on irradiation-induced changes in tensile properties have been proposed [29].

The model is given as [29]:

$$K_{JC}^{irr} = K_{JC}^{unirr}\left(\frac{e_u^{irr}\ \sigma_f^{irr}}{e_u^{unirr}\sigma_f^{unirr}}\right)^{0.5}$$

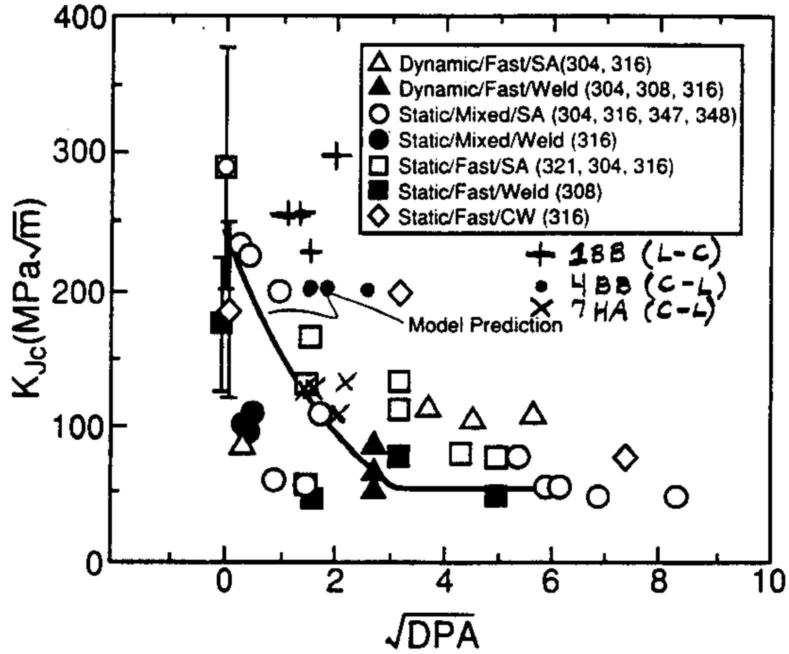
where e_u is the uniform elongation and σ_f is the average of the yield and ultimate strengths. The results from applying the model to a set of C(T) specimens and T specimens of 4BB material are shown below:

Irr. C(T) & T Specimens	K_{JC} unirr MPa√m	e_u unirr	s_f unirr ksi	e_u irr	s_f irr ksi	Measured K_{JC} irr MPa√m	Predicted K_{JC} irr MPa√m
4BBH10 (2.1 dpa) & 4BBH2 (2.1 dpa)	266.1	48%	50	31.91%	82.75	197.0	279.1
4BBH11 (3.2 dpa) & 4BBH2 (2.1 dpa)	266.1	48%	50	31.91%	82.75	194.84	279.1
4BBH12 (6.4 dpa) & 4BBH5 (6.4 dpa)	266.1	48%	50	22.57%	97.7	193.7	255.1
Data for unirradiated fracture toughness and tensile properties are from C(T) and T specimens 4BB113-S and 4BB114, respectively [9]							

A database of fracture toughness properties was also collected in reference 28 for low-temperature neutron irradiation applications, specifically for the International Thermonuclear Experimental Reactor where first wall exposures in the range of 10 to 30 dpa at 50 to 350°C will be considered. The results from the literature for austenitic stainless steel materials irradiated and tested between 205 and 427°C are shown along with selected results from the RMP database in Figure 15 below (note that the model prediction is that given above). The selected results are the results from those specimens exposed to several dpa values. A wide scatter of the data exists up to a √dpa level of 4.

A significant change in the response (yield strength) of Type 304 stainless steel to irradiation occurs at irradiation temperatures near 300°C [30]. Phase decomposition, void and bubble growth, and loop and network dislocation generation are microstructural changes possible at temperatures above 300°C. The scatter in the fracture toughness data may reflect significant differences in the irradiation-induced microstructures of materials irradiated to a common exposure but at different temperatures. Also, helium build-in may affect the fracture toughness at the higher exposures, particularly at the higher test temperatures. In addition, the wide range of results from the RMP database (e.g. Figures 5 and 6 in this report) were attributed to the initial microstructural differences which are not significantly altered in a low-temperature irradiation [11].

Figure 15 - Effect of exposure on fracture toughness (K_{JC}) - literature results [29] with selected HFIR results



4.0 ACKNOWLEDGMENTS

Project support, essential to complete the testing of the 12M specimens, was provided by J. M. Morrison and R. N. Lutz of the Reactor Division, and G. S. Bumgarner of the Equipment and Materials Technology Department. The project manager and task responsible manager, Dr. N. G. Awadalla, provided management guidance and support over the long period of this project. Dr. G. R. Caskey provided many stimulating discussions on microstructure/mechanical property interactions over the course of this work.

R. L. Senn of the Engineering Technology Division of Oak Ridge National Laboratory was the project manager for the Savannah River Technology Center irradiation and testing programs at ORNL. F. M. Haggag of the Fracture Mechanics Group, Metals & Ceramics Division, Oak Ridge National Laboratory performed the mechanical testing of the 12M specimens. Dr. S. J. Zinkle of the Metals & Ceramics Division performed the microstructural analysis and provided the author detailed guidance in the interpretation of microstructural changes and the effects on mechanical strengthening.

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ATTACHMENT 1 TO WSRC-TR-93-196

0512-06-93

OAK RIDGE NATIONAL LABORATORY
MANAGED BY MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE U.S. DEPARTMENT OF ENERGY

BUILDING 4500S MS-6151
POST OFFICE BOX 2008
OAK RIDGE, TENNESSEE 37831-6151
PHONE 615-574-7007
FAX 615-574-5118

May 12, 1993

Mr. Robert L. Sindelar
Westinghouse Savannah River Company
Savannah River Technology Center
Building 773-41A
Aiken, South Carolina 29808

Dear Bob:

I am enclosing a copy of the appendices to be included in my letter report (next week) of all test results from HFIR capsule 12M. The fracture toughness results are for Deformation J-Integral (ASTM E 1152) and Modified Ernst J-Integral. Color photographs are provided for the fracture surfaces of fracture toughness and Charpy impact specimens.

The results are for eight fracture toughness, four Charpy impact, and five tensile test specimens.

If yo have any questions, please call me next week.

Sincerely yours,

Fahmy

Fahmy M. Haggag
Fracture Mechanics Group
Metals and Ceramics Division

FMH:jlb

Enclosures

cc: R. K. Nanstad
R. L. Senn
R. L. Swain
F. M. Haggag - RC

Attachment 1, Appendix A -- Results of 0.4T C(T) Fracture Toughness Specimens Irradiated in the HFIR Capsule 12M (Deformation J-Integral, ASTM E1152

DATA/RESULTS SOURCE: TEST FILE
TEST FILE NAME: 4BBH11
DISK DRIVE SPECIFIER: :,700,1
J-INTEGRAL METHOD: E1152
ANALYSIS ANALYSIS TEMPLATE SOURCE: STANDARD
ANALYZE
4BBH11

SPECIMEN
  IDENTIFICATION: 4BBH11
  MATERIAL
    CODE: 304SS
    YOUNG'S MODULUS: 193.05 (GPA),28000 (KSI)
    POISSON'S RATIO: 0.3
    STRENGTHS
      YIELD: 448.16 (MPA),65 (KSI)
      ULTIMATE: 517.11 (MPA),75 (KSI)
  ORIENTATION: C-L
  GEOMETRY: C-L
  WIDTH: 19.964 (MM),0.786 (IN)
  THICKNESS: 10.008 (MM),0.394 (IN)
  SIDE GROOVE: 20 (PERCENT)
  LOAD PIN CENTER SPAN: 9.804 (MM),0.386 (IN)
  EXTENSOMETER LOCATION: 0 (MM),0 (IN)
  PRECRACK CONDITIONS
    MAXIMUM LOAD: 1.779 (KN),400 (LB)
    FREQUENCY: 30 (HZ)
  FRONT-SURFACE-TO-LOAD-LINE DISTANCE: 4.991 (MM),0.1965 (IN)
  FRONT-SURFACE-TO-INITIAL-CRACK-FRONT DISTANCES
    DISTANCE 1: 15.948 (MM),0.6279 (IN)
    DISTANCE 2: 16.064 (MM),0.6325 (IN)
    DISTANCE 3: 16.023 (MM),0.6308 (IN)
    DISTANCE 4: 16.107 (MM),0.6341 (IN)
    DISTANCE 5: 16.186 (MM),0.6373 (IN)
    DISTANCE 6: 16.11 (MM),0.6343 (IN)
    DISTANCE 7: 16.19 (MM),0.6374 (IN)
    DISTANCE 8: 16.029 (MM),0.6311 (IN)
    DISTANCE 9: 15.969 (MM),0.6287 (IN)
  FRONT-SURFACE-TO-FINAL-CRACK-FRONT DISTANCES
    DISTANCE 1: 20.296 (MM),0.7991 (IN)
    DISTANCE 2: 19.966 (MM),0.7861 (IN)
    DISTANCE 3: 20.009 (MM),0.7877 (IN)
    DISTANCE 4: 19.85 (MM),0.7815 (IN)
    DISTANCE 5: 19.88 (MM),0.7827 (IN)
    DISTANCE 6: 20.033 (MM),0.7887 (IN)
    DISTANCE 7: 20.234 (MM),0.7966 (IN)
    DISTANCE 8: 20.196 (MM),0.7951 (IN)
    DISTANCE 9: 19.894 (MM),0.7833 (IN)
  MEASURED CRACK LENGTHS
    INITIAL: 11.093 (MM),0.4367 (IN)
    FINAL: 15.042 (MM),0.5922 (IN)
TEST
  ROUTINE REVISION: 1.02/07-JUL-88
  TYPE: UCJR
  ENGINEER: FMH
  TECHNICIAN: RLS
  TEST DATE: 04-MAR-93
  ATMOSPHERE: AIR
  TEMPERATURE: 125 (DEG C),257 (DEG F)

```
  REMARK: NONE

  DID SPECIMEN CLEAVE? NO
ANALYSIS
  ROUTINE REVISION: 1.10/06-MAR-90
  CRACK LENGTH PINS
    UC
      INITIAL
        DETERMINATION TEST CYCLE: 4
        EFFECTIVE MODULUS: 192.42 (GPA),27908 (KSI)
        YOUNG'S MODULUS-EFFECTIVE MODULUS: 0.3 (PERCENT)
      FINAL
        PIN NOT APPLIED
  UC RESULTS
    MEASURED FINAL CRACK EXTENSION: 3.949 (MM),0.1555 (IN)
    FINAL CRACK EXTENSION: 3.123 (MM),0.123 (IN)
    FINAL CRACK EXTENSION ERROR:-20.9 (PERCENT)
    PQ: 3.505 (KN),788 (LB)
    KQ: 29.92 (MPA-SQRT(M)),27227 (KSI-SQRT(IN))
    KIC: NO VALID KIC FOR TEST
    PMX: 9.997 (KN),2247 (LB)
    KMX: 85.34 (MPA-SQRT(M)),77.66 (KSI-SQRT(IN))
    E1152 J-INTEGRAL
      PMX J-INTEGRAL: 107.48 (KJ/M^2),613.7 (IN-LB/IN^2)
      FINAL J-INTEGRAL: 475.65 (KJ/M^2),2716 (IN-LB/IN^2)
      FINAL KJ: 303.03 (MPA-SQRT(M)),275.77 (KSI-SQRT(IN))
      POWER-LAW MODEL [J-INTEGRAL=A0*CRACK EXTENSION^A1]
        A0: 326.13 (SI),11319 (ENGLISH)
        A1: 0.55788 (SI),0.55788 (ENGLISH)
        RESULTS EXCLUDED FROM MODEL: CYCLES 1,2,3,4,5,6,7,8,9,10,11,12,13,14,
        15,29 AND 30
      JIC: 196.64 (KJ/M^2),1122.9 (IN-LB/IN^2)
      KJIC: 194.84 (MPA-SQRT(M)),177.31 (KSI-SQRT(IN))
      TEARING MODULUS: 147
```

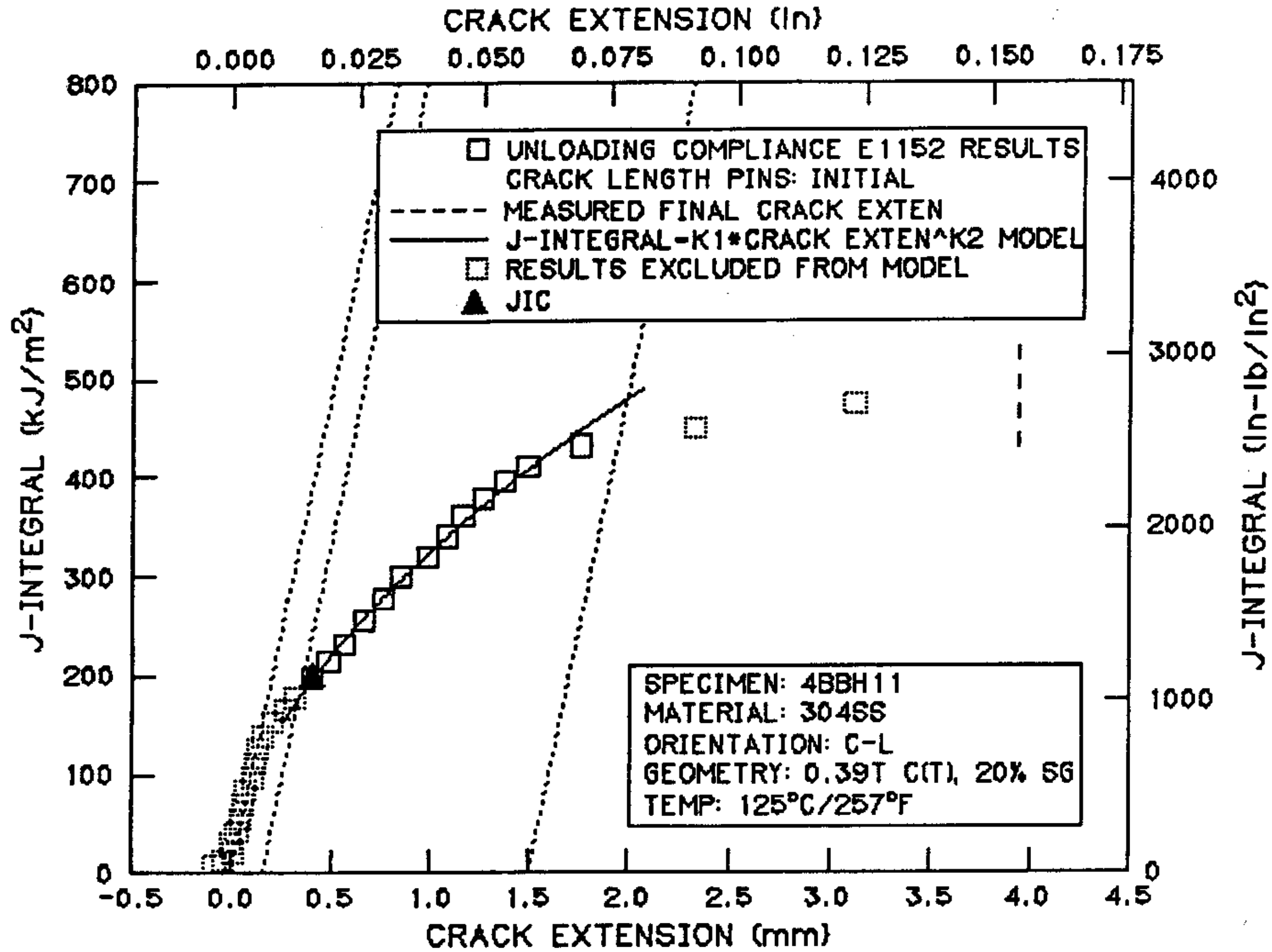
SPECIMEN
  IDENTIFICATION: 4BBH11
  MATERIAL CODE: 304SS
  ORIENTATION: C-L
  GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
  INITIAL CRACK LENGTH: 11.093 (MM),0.4367 (IN)
TEST
  ATMOSPHERE: AIR
  TEMPERATURE: 125 (DEG C),257 (DEG F)
ANALYSIS
  CRACK LENGTH PINS: INITIAL
  CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
  J-INTEGRAL METHOD: E1152

CYCLE	LOAD (KN)	DISPL (MM)	ENERGY (J)	CRACK EXTN (MM)	J-INTEGRAL (KJ/M^2)	KJ (MPA-SQRT(M))
1	4.646	0.115	0.285	-0.086	8.45	40.39
2	5.432	0.14	0.409	-0.037	11.99	48.11
3	6.755	0.186	0.693	0.006	20.33	62.65
4	7.852	0.233	1.039	0	30.83	77.15
5	8.627	0.28	1.434	0.026	42.52	90.6
6	9.136	0.326	1.856	0.046	55.19	103.22
7	9.471	0.374	2.305	0.059	68.78	115.23
8	9.645	0.421	2.762	0.072	82.67	126.33
9	9.725	0.468	3.227	0.109	96.48	136.47
10	9.747	0.514	3.692	0.116	110.87	146.3
11	9.728	0.561	4.159	0.134	124.98	155.33
12	9.69	0.608	4.624	0.159	138.97	163.8
13	9.614	0.655	5.089	0.202	152.44	171.55
14	9.475	0.702	5.547	0.27	165.05	178.5
15	9.309	0.749	5.994	0.315	177.97	185.36
16	9.121	0.819	6.656	0.405	196.31	194.68
17	8.994	0.89	7.313	0.483	214.61	203.55
18	8.845	0.96	7.954	0.566	232.26	211.75
19	8.67	1.054	8.797	0.659	255.91	222.27
20	8.503	1.147	9.619	0.76	278.53	231.88
21	8.282	1.241	10.427	0.848	301.09	241.09
22	7.977	1.335	11.214	0.981	320.51	248.75
23	7.715	1.429	11.97	1.08	340.72	256.47
24	7.521	1.522	12.7	1.162	361.01	264
25	7.284	1.615	13.411	1.263	379.36	270.62
26	7.059	1.709	14.108	1.376	396.22	276.57
27	6.755	1.803	14.775	1.493	411.56	281.87
28	6.24	1.972	15.905	1.761	431.91	288.76
29	5.327	2.276	17.699	2.328	449.82	294.68
30	4.319	2.826	20.386	3.123	475.65	303.03

ANALYZE
4BBH11

SPECIMEN
IDENTIFICATION: 4BBH11
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 11.093 (MM),0.4367 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 125 (DEG C),257 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: E1152

CYCLE	LOAD (LB)	DISPL (IN)	ENERGY (IN-LB)	CRACK EXTN (IN)	J-INTEGRAL (IN-LB/IN^2)	KJ (KSI-SQRT(IN))
1	1045	0.0045	2.52	-0.0034	48.3	36.76
2	1221	0.0055	3.62	-0.0015	68.5	43.78
3	1519	0.0073	6.13	0.0002	116.1	57.02
4	1765	0.0092	9.2	0	176	70.21
5	1939	0.011	12.69	0.001	242.8	82.45
6	2054	0.0129	16.42	0.0018	315.1	93.93
7	2129	0.0147	20.4	0.0023	392.8	104.87
8	2168	0.0166	24.44	0.0028	472	114.97
9	2186	0.0184	28.56	0.0043	550.9	124.2
10	2191	0.0203	32.68	0.0046	633.1	133.14
11	2187	0.0221	36.81	0.0053	713.7	141.36
12	2178	0.0239	40.92	0.0063	793.6	149.06
13	2161	0.0258	45.04	0.0079	870.5	156.12
14	2130	0.0276	49.1	0.0106	942.5	162.45
15	2093	0.0295	53.05	0.0124	1016.2	168.68
16	2050	0.0322	58.91	0.0159	1121	177.16
17	2022	0.035	64.72	0.019	1225.5	185.24
18	1988	0.0378	70.4	0.0223	1326.2	192.7
19	1949	0.0415	77.86	0.0259	1461.3	202.28
20	1912	0.0452	85.14	0.0299	1590.4	211.03
21	1862	0.0488	92.29	0.0334	1719.3	219.41
22	1793	0.0526	99.26	0.0386	1830.2	226.37
23	1734	0.0562	105.94	0.0425	1945.6	233.4
24	1691	0.0599	112.4	0.0458	2061.4	240.25
25	1638	0.0636	118.7	0.0497	2166.2	246.28
26	1587	0.0673	124.86	0.0542	2262.5	251.69
27	1519	0.071	130.77	0.0588	2350	256.52
28	1403	0.0776	140.77	0.0693	2466.3	262.78
29	1198	0.0896	156.65	0.0916	2568.5	268.18
30	971	0.1113	180.43	0.123	2716	275.77


CRACK EXTENSION (in)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
800
700
600
500
400
300
200
100
0
J-INTEGRAL (kJ/m2)
4000
3000
2000
1000
0
J-INTEGRAL (in-lb/in2)
UNLOADING COMPLIANCE E1152 RESULTS
CRACK LENGTH PINS: INITIAL
MEASURED FINAL CRACK EXTEN
J-INTEGRAL=K1*CRACK EXTEN^K2 MODEL
RESULTS EXCLUDED FROM MODEL
JIC
SPECIMEN: 4BBH11
MATERIAL: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T), 20% SG
TEMP: 125°C/257°F
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
CRACK EXTENSION (mm)

DATA/RESULTS SOURCE: TEST FILE
TEST FILE NAME: 1BBH11
DISK DRIVE SPECIFIER: :,700,1
J-INTEGRAL METHOD: E1152
ANALYSIS ANALYSIS TEMPLATE SOURCE: STANDARD
ANALYZE
1BBH11

SPECIMEN
IDENTIFICATION: 1BBH11
MATERIAL
CODE: 304SS
YOUNG'S MODULUS: 193.05 (GPA),28000 (KSI)
POISSON'S RATIO: 0.3
STRENGTHS
YIELD: 448.16 (MPA),65 (KSI)
ULTIMATE: 517.11 (MPA),75 (KSI)
ORIENTATION: L-C
GEOMETRY: L-C
WIDTH: 19.964 (MM),0.786 (IN)
THICKNESS: 10.008 (MM),0.394 (IN)
SIDE GROOVE: 20 (PERCENT)
LOAD PIN CENTER SPAN: 9.804 (MM),0.386 (IN)
EXTENSOMETER LOCATION: 0 (MM),0 (IN)
PRECRACK CONDITIONS
MAXIMUM LOAD: 1.779 (KN),400 (LB)
FREQUENCY: 30 (HZ)
FRONT-SURFACE-TO-LOAD-LINE DISTANCE: 4.991 (MM),0.1965 (IN)

USE GRAPHIC TABLET KEY 1 TO DELETE LAST DIGITIZED POINT
REFERENCE VALUES
LEFT DISTANCE: 0 (IN)
RIGHT DISTANCE: 0.9825 (IN)
BOTTOM THICKNESS: 0.394 (IN)
TOP THICKNESS: 0 (IN)

POINT	DISTANCE (IN)	THICKNESS (IN)
1	0.64853	0.033753
2	0.65167	0.053483
3	0.64674	0.074961
4	0.64342	0.094656
5	0.64174	0.10898
6	0.64007	0.12331
7	0.63514	0.143
8	0.63829	0.16094
9	0.63819	0.18244
10	0.63812	0.19857
11	0.63481	0.21826
12	0.63794	0.23979
13	0.63459	0.26665
14	0.63453	0.28099
15	0.6328	0.30607
16	0.62788	0.32575

WAS THERE CRACK EXTENSION DURING TEST? YES

POINT	DISTANCE (IN)	THICKNESS (IN)
1	0.76962	0.01291

2	0.75013	0.041477
3	0.75485	0.070177
4	0.74828	0.09523
5	0.75304	0.11497
6	0.74968	0.14362
7	0.74955	0.1723
8	0.7446	0.19915
9	0.73962	0.22959
10	0.73305	0.25644
11	0.72165	0.27967
12	0.71835	0.29578
13	0.70534	0.31901

```
  -----------------------------------------------------------------------------
  MEASURED CRACK LENGTHS
    INITIAL: 11.223 (MM),0.4419 (IN)
    FINAL: 13.874 (MM),0.5462 (IN)
TEST
  ROUTINE REVISION: 1.02/07-JUL-88
  TYPE: UCJR
  ENGINEER: FMH
  TECHNICIAN: RLS
  TEST DATE: 05-MAR-93
  ATMOSPHERE: AIR
  TEMPERATURE: 125 (DEG C),257 (DEG F)
  REMARK: NONE

  DID SPECIMEN CLEAVE? NO
FILE NAME: 1BBH11
DISK DRIVE SPECIFIER: :,700,1

OVERWRITE EXISTING 1BBH11:,700,1 FILE? YES
EXISTING FILE PURGED
UCJR TEST FILE CREATED
TEST SET SAVED
ANALYSIS
  ROUTINE REVISION: 1.10/06-MAR-90
  CRACK LENGTH PINS
    UC
      INITIAL
        DETERMINATION TEST CYCLE: 1
        EFFECTIVE MODULUS: 207.72 (GPA),30128 (KSI)
        YOUNG'S MODULUS-EFFECTIVE MODULUS:-7.6 (PERCENT)
      FINAL
        PIN NOT APPLIED
  UC RESULTS
    MEASURED FINAL CRACK EXTENSION: 2.651 (MM),0.1044 (IN)
    FINAL CRACK EXTENSION: 2.361 (MM),0.093 (IN)
    FINAL CRACK EXTENSION ERROR:-10.9 (PERCENT)
    PQ: 5.592 (KN),1257 (LB)
    KQ: 48.84 (MPA-SQRT(M)),44452 (KSI-SQRT(IN))
    KIC: NO VALID KIC FOR TEST
    PMX: 9.826 (KN),2209 (LB)
    KMX: 85.83 (MPA-SQRT(M)),78.11 (KSI-SQRT(IN))
    E1152 J-INTEGRAL
      PMX J-INTEGRAL: 153.12 (KJ/M^2),874.3 (IN-LB/IN^2)
      FINAL J-INTEGRAL: 783.33 (KJ/M^2),4472.9 (IN-LB/IN^2)
```

FINAL KJ: 388.87 (MPA-SQRT(M)),353.89 (KSI-SQRT(IN))
POWER-LAW MODEL [J-INTEGRAL=A0*CRACK EXTENSION^A1]
A0: 534.86 (SI),14200 (ENGLISH)
A1: 0.47507 (SI),0.47507 (ENGLISH)
RESULTS EXCLUDED FROM MODEL: CYCLES 1,2,3,4,5,6,7,8,9,10,11,12,13,14,
15,16,17,18 AND 28
JIC: 436.63 (KJ/M^2),2493.2 (IN-LB/IN^2)
KJIC: 290.33 (MPA-SQRT(M)),264.22 (KSI-SQRT(IN))
TEARING MODULUS: 179
FILE NAME: 1BBH11
DISK DRIVE SPECIFIER: :,700,1
DISK FORMATTED

VOLUME LABEL: SRLANA
DIRECTORY LENGTH (MAX NUMBER OF FILES): 112
ANALYSIS SET SAVED

ANALYSIS FILE NAME: 1BBH11

ANALYZE
1BBH11

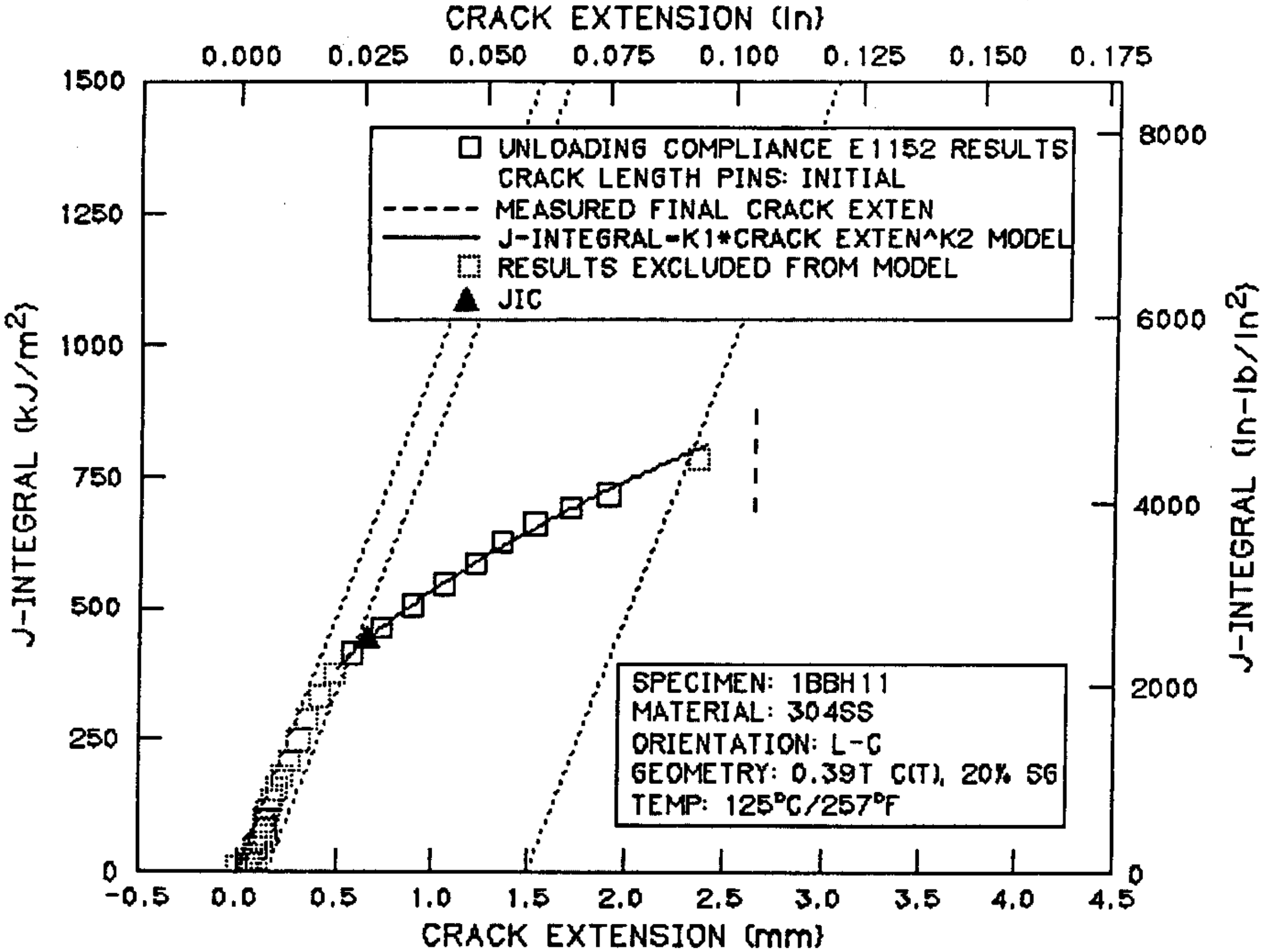
SPECIMEN
IDENTIFICATION: 1BBH11
MATERIAL CODE: 304SS
ORIENTATION: L-C
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 11.223 (MM),0.4419 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 125 (DEG C),257 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: E1152

CYCLE	LOAD (KN)	DISPL (MM)	ENERGY (J)	CRACK EXTN (MM)	J-INTEGRAL (KJ/M^2)	KJ (MPA-SQRT(M))
1	4.329	0.115	0.26	-0.001	7.7	38.57
2	5.747	0.159	0.484	0.062	14.35	52.63
3	6.974	0.203	0.768	0.082	22.86	66.43
4	7.919	0.247	1.103	0.102	33.03	79.85
5	8.592	0.292	1.474	0.098	44.45	92.64
6	8.996	0.335	1.863	0.124	56.4	104.35
7	9.241	0.379	2.271	0.148	68.99	115.4
8	9.406	0.423	2.696	0.149	82.2	125.97
9	9.466	0.467	3.118	0.143	95.6	135.85
10	9.53	0.533	3.759	0.162	115.44	149.28
11	9.539	0.599	4.4	0.181	135.36	161.65
12	9.537	0.664	5.043	0.207	155.16	173.07
13	9.528	0.753	5.907	0.228	181.89	187.39
14	9.491	0.841	6.767	0.27	207.89	200.34
15	9.428	0.972	8.039	0.313	246.95	218.34
16	9.355	1.104	9.311	0.36	285.76	234.88
17	9.241	1.257	10.775	0.419	330.19	252.48
18	9.11	1.411	12.228	0.497	372.66	268.22
19	8.861	1.564	13.65	0.585	413.56	282.56
20	8.594	1.763	15.428	0.733	461.39	298.45
21	8.282	1.96	17.139	0.895	505.64	312.44
22	7.972	2.157	18.787	1.06	547.27	325.04
23	7.739	2.355	20.386	1.225	586.73	336.56
24	7.511	2.552	21.935	1.364	626.93	347.89
25	7.197	2.75	23.439	1.529	661.92	357.47
26	6.852	2.948	24.865	1.708	692.49	365.63
27	6.455	3.145	26.216	1.907	717.29	372.12
28	5.753	3.703	29.677	2.361	783.33	388.87

ANALYZE
1BBH11

SPECIMEN
IDENTIFICATION: 1BBH11
MATERIAL CODE: 304SS
ORIENTATION: L-C
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 11.223 (MM),0.4419 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 125 (DEG C),257 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: E1152

CYCLE	LOAD (LB)	DISPL (IN)	ENERGY (IN-LB)	CRACK EXTN (IN)	J-INTEGRAL (IN-LB/IN^2)	KJ (KSI-SQRT(IN))
1	973	0.0045	2.3	0	44	35.1
2	1292	0.0063	4.29	0.0025	81.9	47.89
3	1568	0.008	6.8	0.0032	130.5	60.46
4	1780	0.0097	9.76	0.004	188.6	72.67
5	1932	0.0115	13.05	0.0039	253.8	84.3
6	2022	0.0132	16.49	0.0049	322.1	94.96
7	2077	0.0149	20.1	0.0058	393.9	105.02
8	2114	0.0167	23.86	0.0059	469.4	114.64
9	2128	0.0184	27.59	0.0056	545.9	123.63
10	2142	0.021	33.27	0.0064	659.2	135.86
11	2144	0.0236	38.94	0.0071	772.9	147.11
12	2144	0.0262	44.63	0.0082	886	157.51
13	2142	0.0296	52.28	0.009	1038.6	170.53
14	2134	0.0331	59.89	0.0106	1187.1	182.32
15	2120	0.0383	71.15	0.0123	1410.1	198.7
16	2103	0.0435	82.41	0.0142	1631.7	213.75
17	2077	0.0495	95.36	0.0165	1885.4	229.77
18	2048	0.0555	108.23	0.0196	2127.9	244.09
19	1992	0.0616	120.81	0.023	2361.5	257.14
20	1932	0.0694	136.55	0.0289	2634.6	271.61
21	1862	0.0772	151.69	0.0352	2887.3	284.33
22	1792	0.0849	166.28	0.0417	3125	295.8
23	1740	0.0927	180.43	0.0482	3350.3	306.28
24	1688	0.1005	194.14	0.0537	3579.8	316.6
25	1618	0.1083	207.45	0.0602	3779.7	325.32
26	1540	0.1161	220.07	0.0672	3954.2	332.74
27	1451	0.1238	232.04	0.0751	4095.8	338.65
28	1293	0.1458	262.66	0.093	4472.9	353.89


CRACK EXTENSION (In)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
UNLOADING COMPLIANCE E1152 RESULTS
CRACK LENGTH PINS: INITIAL
MEASURED FINAL CRACK EXTEN
J-INTEGRAL=K1*CRACK EXTEN^K2 MODEL
RESULTS EXCLUDED FROM MODEL
JIC
J-INTEGRAL (kJ/m2)
1500
1250
1000
750
500
250
0
J-INTEGRAL (In-lb/In2)
8000
6000
4000
2000
0
SPECIMEN: 1BBH11
MATERIAL: 304SS
ORIENTATION: L-C
GEOMETRY: 0.39T C(T), 20% SG
TEMP: 125°C/257°F
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
CRACK EXTENSION (mm)

DATA/RESULTS SOURCE: TEST FILE
TEST FILE NAME: 7HAH6
DISK DRIVE SPECIFIER: :,700,1
J-INTEGRAL METHOD: E1152
ANALYSIS ANALYSIS TEMPLATE SOURCE: STANDARD
ANALYZE
7HAH6

SPECIMEN
  IDENTIFICATION: 7HAH6
  MATERIAL
    CODE: 304SS
    YOUNG'S MODULUS: 193.05 (GPA),28000 (KSI)
    POISSON'S RATIO: 0.3
    STRENGTHS
      YIELD: 413.69 (MPA),60 (KSI)
      ULTIMATE: 482.63 (MPA),70 (KSI)
  ORIENTATION: C-L
  GEOMETRY: C-L
  WIDTH: 19.964 (MM),0.786 (IN)
  THICKNESS: 10.008 (MM),0.394 (IN)
  SIDE GROOVE: 20 (PERCENT)
  LOAD PIN CENTER SPAN: 9.804 (MM),0.386 (IN)
  EXTENSOMETER LOCATION: 0 (MM),0 (IN)
  PRECRACK CONDITIONS
    MAXIMUM LOAD: 1.779 (KN),400 (LB)
    FREQUENCY: 30 (HZ)
  FRONT-SURFACE-TO-LOAD-LINE DISTANCE: 4.991 (MM),0.1965 (IN)

USE GRAPHIC TABLET KEY 1 TO DELETE LAST DIGITIZED POINT
REFERENCE VALUES
  LEFT DISTANCE: 0 (IN)
  RIGHT DISTANCE: 0.9825 (IN)
  BOTTOM THICKNESS: 0.394 (IN)
  TOP THICKNESS: 0 (IN)

POINT	DISTANCE (IN)	THICKNESS (IN)
1	0.62358	0.075786
2	0.62503	0.085654
3	0.62235	0.10401
4	0.62243	0.11812
5	0.62392	0.13645
6	0.62126	0.15904
7	0.62138	0.1788
8	0.61454	0.2
9	0.61607	0.22397
10	0.61481	0.24797
11	0.61494	0.27054
12	0.61365	0.28889
13	0.61378	0.31287
14	0.61944	0.32977
15	0.62509	0.34667
16	0.61959	0.35658

WAS THERE CRACK EXTENSION DURING TEST? YES

POINT	DISTANCE (IN)	THICKNESS (IN)
1	0.75702	0.082074

2	0.77654	0.093249
3	0.78217	0.10592
4	0.78918	0.11716
5	0.78788	0.13269
6	0.78658	0.14822
7	0.79362	0.16511
8	0.7965	0.18343
9	0.79796	0.19612
10	0.79806	0.21446
11	0.79674	0.22717
12	0.79269	0.24836
13	0.78584	0.26533
14	0.77483	0.28514
15	0.76794	0.29506
16	0.75971	0.31486
17	0.75145	0.32901
18	0.74041	0.34178
19	0.73213	0.35311
20	0.72936	0.35454

MEASURED CRACK LENGTHS
INITIAL: 10.72 (MM),0.422 (IN)
FINAL: 14.805 (MM),0.5828 (IN)
TEST
ROUTINE REVISION: 1.02/07-JUL-88
TYPE: UCJR
ENGINEER: FMH
TECHNICIAN: RLS
TEST DATE: 05-MAR-93
ATMOSPHERE: AIR
TEMPERATURE: 125 (DEG C),257 (DEG F)
REMARK: NONE

DID SPECIMEN CLEAVE? NO
FILE NAME: 7HAH6
DISK DRIVE SPECIFIER: :,700,1

OVERWRITE EXISTING 7HAH6:,700,1 FILE? YES
EXISTING FILE PURGED
UCJR TEST FILE CREATED
TEST SET SAVED
ANALYSIS
ROUTINE REVISION: 1.10/06-MAR-90
CRACK LENGTH PINS
UC
INITIAL
DETERMINATION TEST CYCLE: 1
EFFECTIVE MODULUS: 192.73 (GPA),27952 (KSI)
YOUNG'S MODULUS-EFFECTIVE MODULUS: 0.2 (PERCENT)
FINAL
PIN NOT APPLIED
UC RESULTS
MEASURED FINAL CRACK EXTENSION: 4.085 (MM),0.1608 (IN)
FINAL CRACK EXTENSION: 2.51 (MM),0.0988 (IN)
FINAL CRACK EXTENSION ERROR:-38.6 (PERCENT)
PQ: 5.334 (KN),1199 (LB)

```
    KQ: 42.72 (MPA-SQRT(M)),38879 (KSI-SQRT(IN))
    KIC: NO VALID KIC FOR TEST
    PMX: 11.204 (KN),2519 (LB)
    KMX: 89.73 (MPA-SQRT(M)),81.66 (KSI-SQRT(IN))
    E1152 J-INTEGRAL
      PMX J-INTEGRAL: 74.12 (KJ/M^2),423.2 (IN-LB/IN^2)
      FINAL J-INTEGRAL: 118.76 (KJ/M^2),678.2 (IN-LB/IN^2)
      FINAL KJ: 151.42 (MPA-SQRT(M)),137.8 (KSI-SQRT(IN))
      POWER-LAW MODEL [J-INTEGRAL=A0*CRACK EXTENSION^A1]
        A0: 103.17 (SI),872 (ENGLISH)
        A1: 0.12113 (SI),0.12113 (ENGLISH)
        RESULTS EXCLUDED FROM MODEL: CYCLES 1,2,3,4,5,6,12,13 AND 14
      JIC: 89.15 (KJ/M^2),509.1 (IN-LB/IN^2)
      KJIC: 131.19 (MPA-SQRT(M)),119.39 (KSI-SQRT(IN))
      TEARING MODULUS: 14.7
FILE NAME: 7HAH6
DISK DRIVE SPECIFIER: :,700,1
ANALYSIS SET SAVED

ANALYSIS FILE NAME: 7HAH6
```

ANALYZE
7HAH6

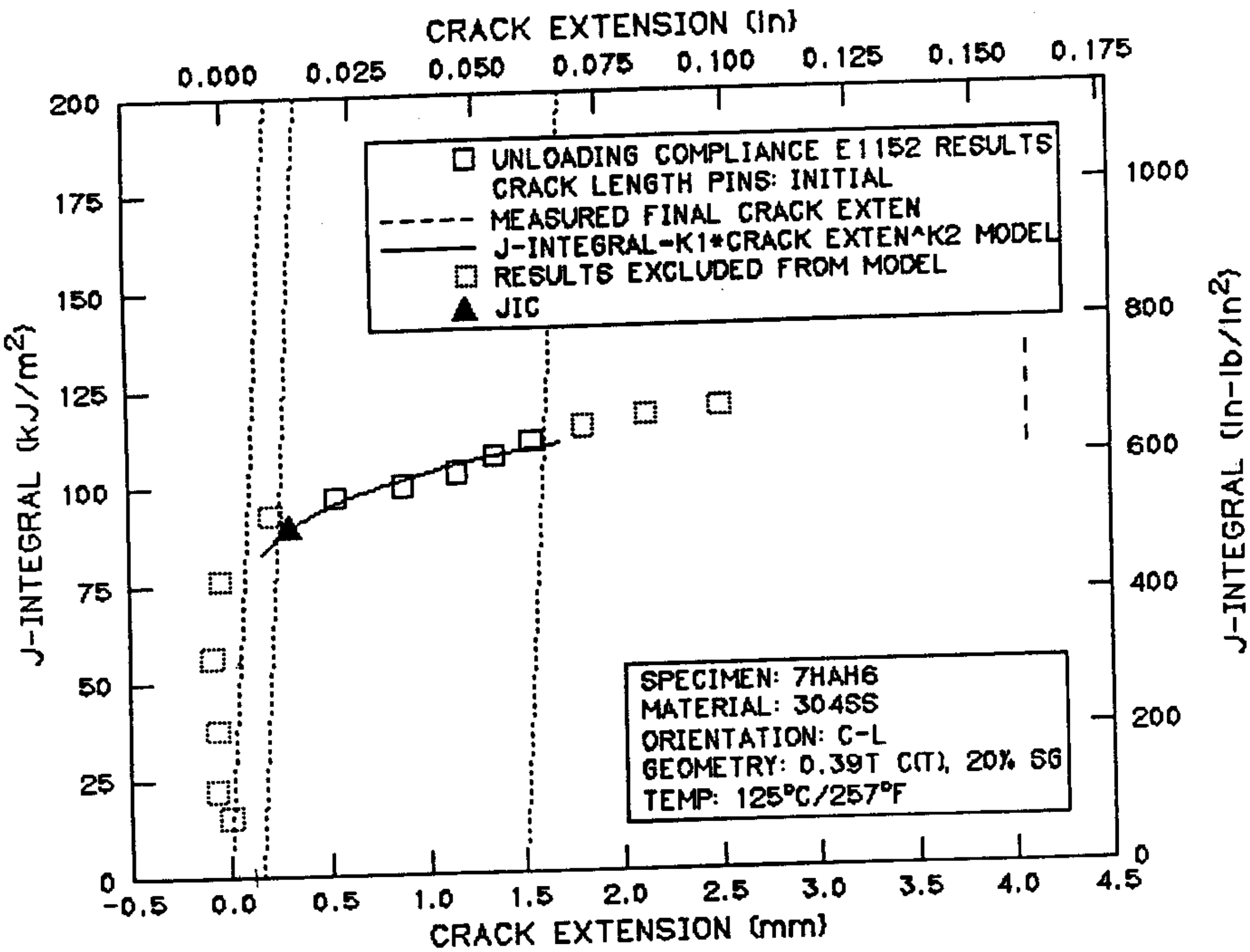
SPECIMEN
IDENTIFICATION: 7HAH6
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 10.72 (MM),0.422 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 125 (DEG C),257 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: E1152

CYCLE	LOAD (KN)	DISPL (MM)	ENERGY (J)	CRACK EXTN (MM)	J-INTEGRAL (KJ/M^2)	KJ (MPA-SQRT(M))
1	6.334	0.16	0.528	0.001	15.19	54.15
2	7.432	0.193	0.755	-0.064	21.94	65.08
3	9.239	0.257	1.294	-0.063	37.57	85.17
4	10.458	0.321	1.937	-0.085	56.33	104.28
5	10.896	0.385	2.637	-0.043	76.33	121.39
6	10.164	0.449	3.333	0.21	93.1	134.06
7	8.515	0.48	3.651	0.54	97.24	137.01
8	7.631	0.513	3.92	0.876	100.03	138.97
9	7.208	0.545	4.167	1.162	103.02	141.03
10	6.878	0.577	4.399	1.36	107.05	143.76
11	6.419	0.609	4.618	1.551	110.93	146.34
12	5.798	0.647	4.865	1.816	114.11	148.42
13	5.171	0.694	5.133	2.135	116.77	150.14
14	4.768	0.755	5.441	2.51	118.76	151.42

SPECIMEN
  IDENTIFICATION: 7HAH6
  MATERIAL CODE: 304SS
  ORIENTATION: C-L
  GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
  INITIAL CRACK LENGTH: 10.72 (MM),0.422 (IN)
TEST
  ATMOSPHERE: AIR
  TEMPERATURE: 125 (DEG C),257 (DEG F)
ANALYSIS
  CRACK LENGTH PINS: INITIAL
  CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
  J-INTEGRAL METHOD: E1152

CYCLE	LOAD (LB)	DISPL (IN)	ENERGY (IN-LB)	CRACK EXTN (IN)	J-INTEGRAL (IN-LB/IN^2)	KJ (KSI-SQRT(IN))
1	1424	0.0063	4.67	0	86.7	49.28
2	1671	0.0076	6.68	-0.0025	125.3	59.23
3	2077	0.0101	11.46	-0.0025	214.5	77.51
4	2351	0.0126	17.15	-0.0034	321.7	94.9
5	2449	0.0151	23.34	-0.0017	435.8	110.47
6	2285	0.0177	29.5	0.0083	531.6	122
7	1914	0.0189	32.31	0.0213	555.2	124.69
8	1715	0.0202	34.69	0.0345	571.2	126.47
9	1620	0.0215	36.88	0.0457	588.3	128.34
10	1546	0.0227	38.93	0.0535	611.3	130.82
11	1443	0.024	40.88	0.0611	633.4	133.18
12	1303	0.0255	43.06	0.0715	651.6	135.07
13	1163	0.0273	45.43	0.0841	666.8	136.64
14	1072	0.0297	48.16	0.0988	678.2	137.8

ANALYZE
7HAH6



DATA/RESULTS SOURCE: TEST FILE
TEST FILE NAME: 7WH4
DISK DRIVE SPECIFIER: :,700,1
J-INTEGRAL METHOD: E1152
ANALYSIS ANALYSIS TEMPLATE SOURCE: STANDARD
ANALYZE
7WH4

SPECIMEN
  IDENTIFICATION: 7WH4
  MATERIAL
    CODE: 304SS
    YOUNG'S MODULUS: 193.05 (GPA),28000 (KSI)
    POISSON'S RATIO: 0.3
    STRENGTHS
      YIELD: 393 (MPA),57 (KSI)
      ULTIMATE: 448.16 (MPA),65 (KSI)
  ORIENTATION: C-L
  GEOMETRY: C-L
  WIDTH: 19.964 (MM),0.786 (IN)
  THICKNESS: 10.008 (MM),0.394 (IN)
  SIDE GROOVE: 20 (PERCENT)
  LOAD PIN CENTER SPAN: 9.804 (MM),0.386 (IN)
  EXTENSOMETER LOCATION: 0 (MM),0 (IN)
  PRECRACK CONDITIONS
    MAXIMUM LOAD: 1.779 (KN),400 (LB)
    FREQUENCY: 30 (HZ)
  FRONT-SURFACE-TO-LOAD-LINE DISTANCE: 4.991 (MM),0.1965 (IN)

  USE GRAPHIC TABLET KEY 1 TO DELETE LAST DIGITIZED POINT
  REFERENCE VALUES
    LEFT DISTANCE: 0 (IN)
    RIGHT DISTANCE: 0.9825 (IN)
    BOTTOM THICKNESS: 0.394 (IN)
    TOP THICKNESS: 0 (IN)

POINT	DISTANCE (IN)	THICKNESS (IN)
1	0.63133	0.099268
2	0.63935	0.11443
3	0.64264	0.1266
4	0.64441	0.14183
5	0.64928	0.15551
6	0.65259	0.1692
7	0.65429	0.17986
8	0.65918	0.19506
9	0.65958	0.22557
10	0.66451	0.24383
11	0.66483	0.26824
12	0.662	0.29116
13	0.6638	0.30945
14	0.66719	0.32925
15	0.67054	0.34599
16	0.65658	0.35532

WAS THERE CRACK EXTENSION DURING TEST? YES

POINT	DISTANCE (IN)	THICKNESS (IN)
1	0.78142	0.091299

2	0.78473	0.10499
3	0.7896	0.11867
4	0.78982	0.13545
5	0.7916	0.15221
6	0.7981	0.17044
7	0.80303	0.18869
8	0.81436	0.21755
9	0.81307	0.23893
10	0.81809	0.26328
11	0.8152	0.28163
12	0.81546	0.30146
13	0.81567	0.31825
14	0.81435	0.33658
15	0.81607	0.34876
16	0.82255	0.36547

MEASURED CRACK LENGTHS
INITIAL: 11.679 (MM),0.4598 (IN)
FINAL: 15.497 (MM),0.6101 (IN)

TEST
ROUTINE REVISION: 1.02/07-JUL-88
TYPE: UCJR
ENGINEER: FMH
TECHNICIAN: RLS
TEST DATE: 05-MAR-93
ATMOSPHERE: AIR
TEMPERATURE: 125 (DEG C),257 (DEG F)
REMARK: NONE

DID SPECIMEN CLEAVE? NO
FILE NAME: 7WH4
DISK DRIVE SPECIFIER: :,700,1

OVERWRITE EXISTING 7WH4:,700,1 FILE? YES
EXISTING FILE PURGED
UCJR TEST FILE CREATED
TEST SET SAVED
ANALYSIS
ROUTINE REVISION: 1.10/06-MAR-90
CRACK LENGTH PINS
UC
INITIAL
DETERMINATION TEST CYCLE: 1
EFFECTIVE MODULUS: 234.96 (GPA),34078 (KSI)
YOUNG'S MODULUS-EFFECTIVE MODULUS:-21.7 (PERCENT)
FINAL
PIN NOT APPLIED
UC RESULTS
MEASURED FINAL CRACK EXTENSION: 3.818 (MM),0.1503 (IN)
FINAL CRACK EXTENSION: 2.481 (MM),0.0977 (IN)
FINAL CRACK EXTENSION ERROR:-35 (PERCENT)
PQ: 4.838 (KN),1088 (LB)
KQ: 45.93 (MPA-SQRT(M)),41803 (KSI-SQRT(IN))
KIC: NO VALID KIC FOR TEST
PMX: 11.882 (KN),2671 (LB)
KMX: 112.82 (MPA-SQRT(M)),102.68 (KSI-SQRT(IN))

```
    E1152 J-INTEGRAL
      PMX J-INTEGRAL: 168.08 (KJ/M^2),959.8 (IN-LB/IN^2)
      FINAL J-INTEGRAL: 665.11 (KJ/M^2),3797.9 (IN-LB/IN^2)
      FINAL KJ: 358.33 (MPA-SQRT(M)),326.1 (KSI-SQRT(IN))
      POWER-LAW MODEL [J-INTEGRAL=A0*CRACK EXTENSION^A1]
        A0: 470.41 (SI),15015 (ENGLISH)
        A1: 0.53201 (SI),0.53201 (ENGLISH)
        RESULTS EXCLUDED FROM MODEL: CYCLES 1,2,3,4,5,6,7,8,9,10,11,12 AND 23
      JIC: 371.49 (KJ/M^2),2121.3 (IN-LB/IN^2)
      KJIC: 267.8 (MPA-SQRT(M)),243.71 (KSI-SQRT(IN))
      TEARING MODULUS: 235
FILE NAME: 7WH4
DISK DRIVE SPECIFIER: :,700,1
ANALYSIS SET SAVED

ANALYSIS FILE NAME: 7WH4
```

ANALYZE
7WH4

SPECIMEN
IDENTIFICATION: 7WH4
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 11.679 (MM),0.4598 (IN)

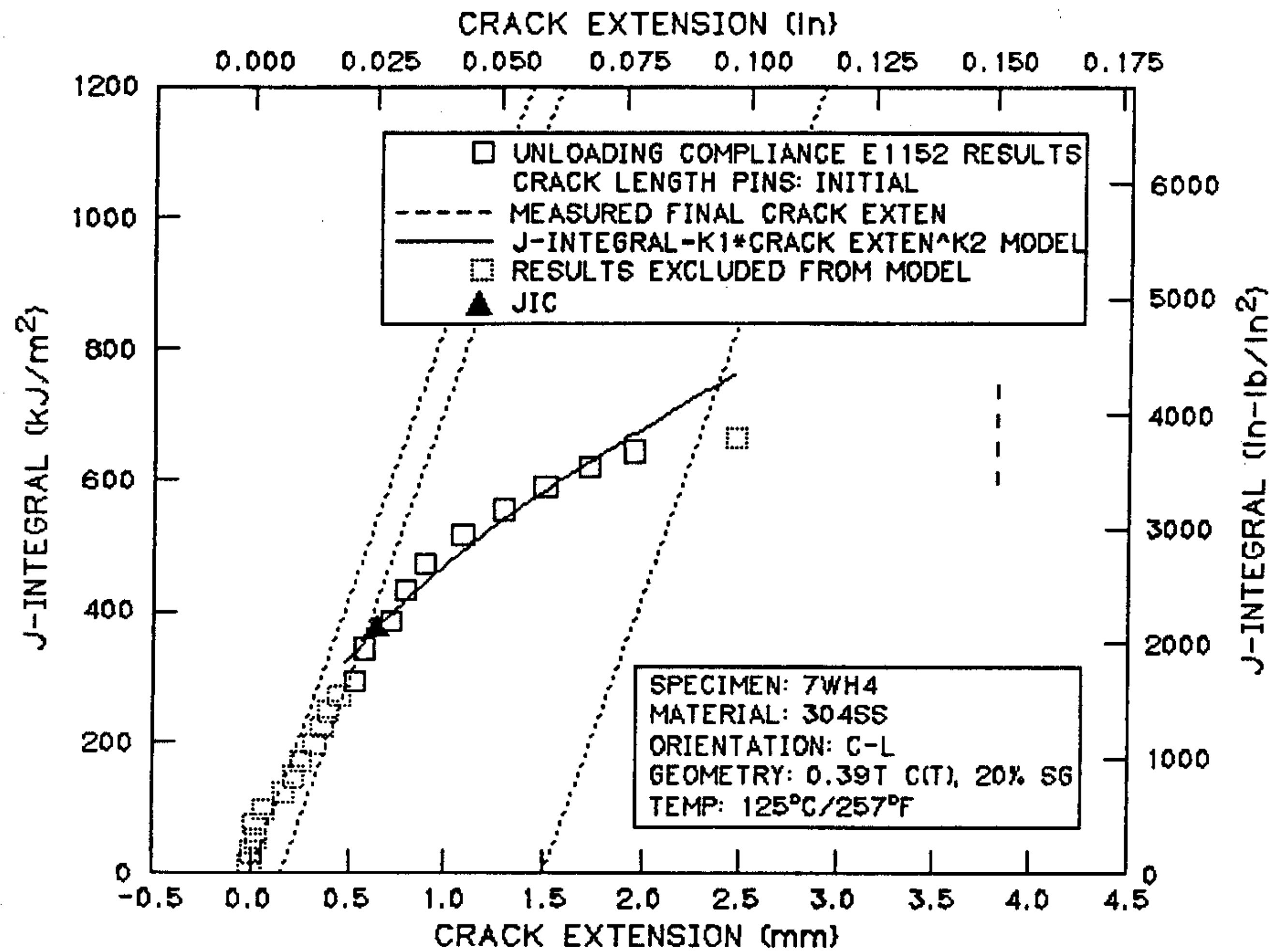
TEST
ATMOSPHERE: AIR
TEMPERATURE: 125 (DEG C),257 (DEG F)

ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: E1152

CYCLE	LOAD (KN)	DISPL (MM)	ENERGY (J)	CRACK EXTN (MM)	J-INTEGRAL (KJ/M^2)	KJ (MPA-SQRT(M))
1	6.293	0.165	0.542	-0.002	16.76	56.88
2	8.292	0.231	1.028	0.002	32.14	78.76
3	9.811	0.298	1.643	0.027	51.37	99.59
4	10.825	0.364	2.344	0.022	73.98	119.51
5	11.341	0.431	3.101	0.07	97.71	137.34
6	11.466	0.498	3.884	0.167	121.22	152.98
7	11.543	0.565	4.668	0.216	146.18	167.99
8	11.566	0.632	5.456	0.257	171.33	181.87
9	11.537	0.698	6.244	0.325	195.5	194.27
10	11.493	0.765	7.029	0.361	220.73	206.43
11	11.422	0.832	7.812	0.39	246.22	218.02
12	11.314	0.898	8.585	0.451	269.95	228.28
13	11.191	0.965	9.359	0.53	292.47	237.62
14	10.97	1.098	10.87	0.58	342.23	257.04
15	10.671	1.231	12.357	0.723	384.7	272.52
16	10.436	1.365	13.804	0.791	431.07	288.48
17	10.174	1.498	15.218	0.893	473.3	302.28
18	9.667	1.664	16.92	1.09	516.99	315.92
19	9.089	1.83	18.52	1.298	556.03	327.63
20	8.493	1.997	20.031	1.504	591.18	337.83
21	7.965	2.164	21.447	1.719	621.1	346.27
22	7.294	2.33	22.757	1.951	644.56	352.75
23	6.256	2.668	25.067	2.481	665.11	358.33

SPECIMEN
IDENTIFICATION: 7WH4
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 11.679 (MM),0.4598 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 125 (DEG C),257 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: E1152

CYCLE	LOAD (LB)	DISPL (IN)	ENERGY (IN-LB)	CRACK EXTN (IN)	J-INTEGRAL (IN-LB/IN^2)	KJ (KSI-SQRT(IN))
1	1415	0.0065	4.8	-0.0001	95.7	51.77
2	1864	0.0091	9.1	0.0001	183.5	71.68
3	2206	0.0117	14.55	0.0011	293.4	90.63
4	2434	0.0143	20.74	0.0009	422.4	108.76
5	2550	0.017	27.45	0.0027	557.9	124.99
6	2578	0.0196	34.38	0.0066	692.2	139.22
7	2595	0.0222	41.31	0.0085	834.7	152.88
8	2600	0.0249	48.29	0.0101	978.3	165.51
9	2594	0.0275	55.26	0.0128	1116.4	176.8
10	2584	0.0301	62.21	0.0142	1260.4	187.86
11	2568	0.0327	69.14	0.0153	1406	198.41
12	2544	0.0354	75.99	0.0177	1541.4	207.75
13	2516	0.038	82.83	0.0209	1670.1	216.24
14	2466	0.0432	96.21	0.0228	1954.2	233.92
15	2399	0.0485	109.37	0.0285	2196.7	248.01
16	2346	0.0537	122.17	0.0311	2461.5	262.53
17	2287	0.059	134.69	0.0352	2702.6	275.09
18	2173	0.0655	149.76	0.0429	2952.1	287.5
19	2043	0.0721	163.91	0.0511	3175	298.16
20	1909	0.0786	177.29	0.0592	3375.7	307.44
21	1791	0.0852	189.82	0.0677	3546.6	315.13
22	1640	0.0917	201.42	0.0768	3680.5	321.02
23	1406	0.105	221.86	0.0977	3797.9	326.1


CRACK EXTENSION (In)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
1200
1000
800
600
400
200
0
6000
5000
4000
3000
2000
1000
0
UNLOADING COMPLIANCE E1152 RESULTS
CRACK LENGTH PINS: INITIAL
MEASURED FINAL CRACK EXTEN
J-INTEGRAL-K1*CRACK EXTEN^K2 MODEL
RESULTS EXCLUDED FROM MODEL
JIC
J-INTEGRAL (kJ/m2)
J-INTEGRAL (In-lb/In2)
SPECIMEN: 7WH4
MATERIAL: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T), 20% SG
TEMP: 125°C/257°F
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
CRACK EXTENSION (mm)

DATA/RESULTS SOURCE: TEST FILE
TEST FILE NAME: 1BBH18
DISK DRIVE SPECIFIER: :,700,1
J-INTEGRAL METHOD: E1152
ANALYSIS ANALYSIS TEMPLATE SOURCE: STANDARD
ANALYZE
1BBH18

SPECIMEN
  IDENTIFICATION: 1BBH18
  MATERIAL
    CODE: 304SS
    YOUNG'S MODULUS: 193.05 (GPA),28000 (KSI)
    POISSON'S RATIO: 0.3
    STRENGTHS
      YIELD: 620.53 (MPA),90 (KSI)
      ULTIMATE: 717.05 (MPA),104 (KSI)
  ORIENTATION: C-L
  GEOMETRY: C-L
  WIDTH: 19.964 (MM),0.786 (IN)
  THICKNESS: 10.008 (MM),0.394 (IN)
  SIDE GROOVE: 20 (PERCENT)
  LOAD PIN CENTER SPAN: 9.804 (MM),0.386 (IN)
  EXTENSOMETER LOCATION: 0 (MM),0 (IN)
  PRECRACK CONDITIONS
    MAXIMUM LOAD: 1.779 (KN),400 (LB)
    FREQUENCY: 30 (HZ)
  FRONT-SURFACE-TO-LOAD-LINE DISTANCE: 4.991 (MM),0.1965 (IN)

  USE GRAPHIC TABLET KEY 1 TO DELETE LAST DIGITIZED POINT
  REFERENCE VALUES
    LEFT DISTANCE: 0 (IN)
    RIGHT DISTANCE: 0.9825 (IN)
    BOTTOM THICKNESS: 0.394 (IN)
    TOP THICKNESS: 0 (IN)

POINT	DISTANCE (IN)	THICKNESS (IN)
1	0.63361	0.047817
2	0.63711	0.067327
3	0.63929	0.085409
4	0.63858	0.10895
5	0.63804	0.12694
6	0.63874	0.14914
7	0.63375	0.17947
8	0.63169	0.20296
9	0.62966	0.22507
10	0.62624	0.24853
11	0.6215	0.27055
12	0.61672	0.29396
13	0.61741	0.31615
14	0.61551	0.33411
15	0.60674	0.35462

WAS THERE CRACK EXTENSION DURING TEST? YES

POINT	DISTANCE (IN)	THICKNESS (IN)
1	0.79041	0.03744
2	0.76787	0.06307

3	0.73305	0.089705
4	0.70137	0.10258
5	0.68748	0.11185
6	0.69312	0.15083
7	0.71994	0.16413
8	0.751	0.17202
9	0.7737	0.18658
10	0.80027	0.2082
11	0.81081	0.21961
12	0.81036	0.23484
13	0.78914	0.26189
14	0.8017	0.2512
15	0.7804	0.28102
16	0.77327	0.29189
17	0.75778	0.30942
18	0.74402	0.31454
19	0.72749	0.32096
20	0.71896	0.33316
21	0.71039	0.34675

```
  MEASURED CRACK LENGTHS
    INITIAL: 10.982 (MM),0.4324 (IN)
    FINAL: 14.132 (MM),0.5564 (IN)
TEST
  ROUTINE REVISION: 1.02/07-JUL-88
  TYPE: UCJR
  ENGINEER: FMH
  TECHNICIAN: RLS
  TEST DATE: 04-MAR-93
  ATMOSPHERE: AIR
  TEMPERATURE: 25 (DEG C),77 (DEG F)
  REMARK: NONE

  DID SPECIMEN CLEAVE? NO
FILE NAME: 1BBH18
DISK DRIVE SPECIFIER: :,700,1

OVERWRITE EXISTING 1BBH18:,700,1 FILE? YES
EXISTING FILE PURGED
UCJR TEST FILE CREATED
TEST SET SAVED
ANALYSIS
  ROUTINE REVISION: 1.10/06-MAR-90
  CRACK LENGTH PINS
    UC
      INITIAL
        DETERMINATION TEST CYCLE: 1
        EFFECTIVE MODULUS: 183.38 (GPA),26597 (KSI)
        YOUNG'S MODULUS-EFFECTIVE MODULUS: 5 (PERCENT)
      FINAL
        PIN NOT APPLIED
  UC RESULTS
    MEASURED FINAL CRACK EXTENSION: 3.151 (MM),0.124 (IN)
    FINAL CRACK EXTENSION: 2.449 (MM),0.0964 (IN)
    FINAL CRACK EXTENSION ERROR:-22.3 (PERCENT)
    PQ: 6.012 (KN),1352 (LB)
```

KQ: 50.34 (MPA-SQRT(M)),45812 (KSI-SQRT(IN))
KIC: NO VALID KIC FOR TEST
PMX: 11.361 (KN),2554 (LB)
KMX: 95.13 (MPA-SQRT(M)),86.57 (KSI-SQRT(IN))
E1152 J-INTEGRAL
PMX J-INTEGRAL: 113.07 (KJ/M^2),645.6 (IN-LB/IN^2)
FINAL J-INTEGRAL: 464.6 (KJ/M^2),2652.9 (IN-LB/IN^2)
FINAL KJ: 299.49 (MPA-SQRT(M)),272.55 (KSI-SQRT(IN))
POWER-LAW MODEL [J-INTEGRAL=A0*CRACK EXTENSION^A1]
A0: 315.27 (SI),9178 (ENGLISH)
A1: 0.50354 (SI),0.50354 (ENGLISH)
RESULTS EXCLUDED FROM MODEL: CYCLES 1,2,3,4,5,6,7,20 AND 21
JIC: 182.09 (KJ/M^2),1039.8 (IN-LB/IN^2)
KJIC: 187.49 (MPA-SQRT(M)),170.63 (KSI-SQRT(IN))
TEARING MODULUS: 71
FILE NAME: 1BBH18
DISK DRIVE SPECIFIER: :,700,1
ANALYSIS SET SAVED

ANALYSIS FILE NAME: 1BBH18

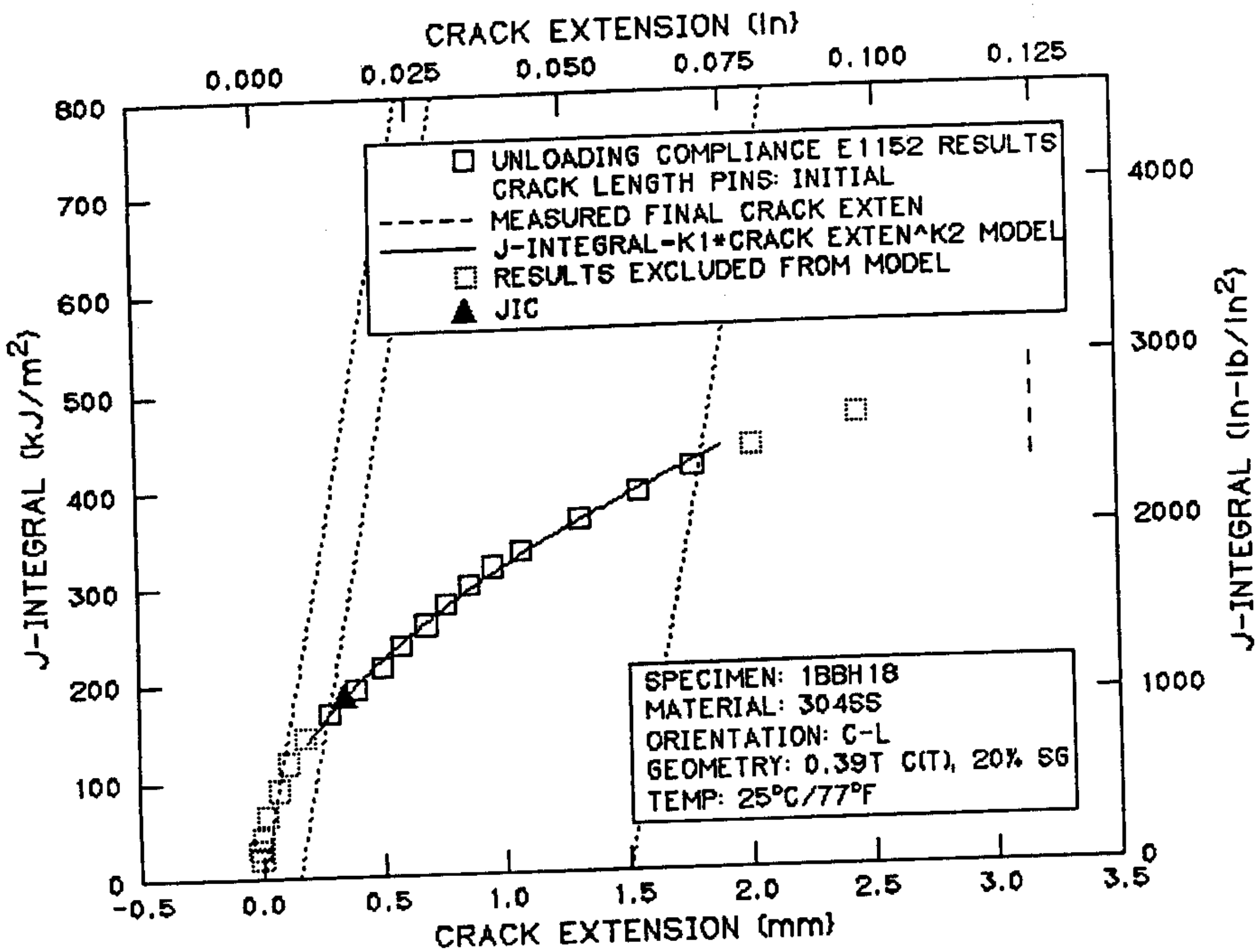
SPECIMEN
  IDENTIFICATION: 1BBH18
  MATERIAL CODE: 304SS
  ORIENTATION: C-L
  GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
  INITIAL CRACK LENGTH: 10.982 (MM),0.4324 (IN)
TEST
  ATMOSPHERE: AIR
  TEMPERATURE: 25 (DEG C),77 (DEG F)
ANALYSIS
  CRACK LENGTH PINS: INITIAL
  CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
  J-INTEGRAL METHOD: E1152

CYCLE	LOAD (KN)	DISPL (MM)	ENERGY (J)	CRACK EXTN (MM)	J-INTEGRAL (KJ/M^2)	KJ (MPA-SQRT(M))
1	7	0.201	0.73	0	21.32	64.15
2	8.114	0.243	1.045	-0.011	30.58	76.83
3	9.018	0.283	1.395	0.008	40.98	88.95
4	10.227	0.364	2.197	0.028	64.62	111.69
5	10.793	0.445	3.072	0.07	90.23	131.98
6	10.921	0.526	3.982	0.113	117.02	150.31
7	10.795	0.607	4.893	0.182	143.35	166.35
8	10.418	0.689	5.79	0.279	168.33	180.27
9	10.095	0.77	6.646	0.393	191.68	192.37
10	9.727	0.851	7.472	0.497	214.3	203.4
11	9.459	0.933	8.282	0.578	236.89	213.85
12	9.192	1.014	9.063	0.681	257.69	223.04
13	8.882	1.095	9.82	0.763	278.7	231.96
14	8.639	1.176	10.555	0.866	297.71	239.74
15	8.425	1.258	11.274	0.962	316.57	247.21
16	8.132	1.338	11.963	1.079	333.3	253.66
17	7.557	1.501	13.292	1.321	363.52	264.91
18	7.086	1.663	14.525	1.554	390.79	274.67
19	6.633	1.825	15.675	1.777	415.74	283.3
20	6.189	1.987	16.755	2.02	436.13	290.17
21	5.459	2.284	18.537	2.449	464.6	299.49

SPECIMEN
IDENTIFICATION: 1BBH18
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 10.982 (MM),0.4324 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 25 (DEG C),77 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: E1152

CYCLE	LOAD (LB)	DISPL (IN)	ENERGY (IN-LB)	CRACK EXTN (IN)	J-INTEGRAL (IN-LB/IN^2)	KJ (KSI-SQRT(IN))
1	1574	0.0079	6.46	0	121.7	58.38
2	1824	0.0096	9.25	-0.0004	174.6	69.92
3	2027	0.0111	12.35	0.0003	234	80.95
4	2299	0.0143	19.45	0.0011	369	101.64
5	2426	0.0175	27.19	0.0028	515.2	120.11
6	2455	0.0207	35.24	0.0044	668.2	136.79
7	2427	0.0239	43.31	0.0071	818.5	151.39
8	2342	0.0271	51.24	0.011	961.2	164.05
9	2269	0.0303	58.82	0.0155	1094.5	175.06
10	2187	0.0335	66.13	0.0196	1223.7	185.1
11	2127	0.0367	73.31	0.0228	1352.7	194.61
12	2066	0.0399	80.21	0.0268	1471.4	202.98
13	1997	0.0431	86.92	0.03	1591.4	211.09
14	1942	0.0463	93.42	0.0341	1700	218.17
15	1894	0.0495	99.79	0.0379	1807.7	224.98
16	1828	0.0527	105.88	0.0425	1903.2	230.85
17	1699	0.0591	117.64	0.052	2075.8	241.08
18	1593	0.0655	128.56	0.0612	2231.5	249.96
19	1491	0.0719	138.74	0.0699	2373.9	257.82
20	1391	0.0782	148.29	0.0795	2490.4	264.06
21	1227	0.0899	164.06	0.0964	2652.9	272.55

ANALYZE
1BBH18



DATA/RESULTS SOURCE: TEST FILE
TEST FILE NAME: 4BBH12
DISK DRIVE SPECIFIER: :,700,1
J-INTEGRAL METHOD: E1152
ANALYSIS ANALYSIS TEMPLATE SOURCE: STANDARD
ANALYZE
4BBH12

SPECIMEN
  IDENTIFICATION: 4BBH12
  MATERIAL
    CODE: 304SS
    YOUNG'S MODULUS: 193.05 (GPA),28000 (KSI)
    POISSON'S RATIO: 0.3
    STRENGTHS
      YIELD: 448.16 (MPA),65 (KSI)
      ULTIMATE: 517.11 (MPA),75 (KSI)
  ORIENTATION: C-L
  GEOMETRY: C-L
  WIDTH: 19.964 (MM),0.786 (IN)
  THICKNESS: 10.008 (MM),0.394 (IN)
  SIDE GROOVE: 20 (PERCENT)
  LOAD PIN CENTER SPAN: 9.804 (MM),0.386 (IN)
  EXTENSOMETER LOCATION: 0 (MM),0 (IN)
  PRECRACK CONDITIONS
    MAXIMUM LOAD: 1.779 (KN),400 (LB)
    FREQUENCY: 30 (HZ)
  FRONT-SURFACE-TO-LOAD-LINE DISTANCE: 4.991 (MM),0.1965 (IN)

USE GRAPHIC TABLET KEY 1 TO DELETE LAST DIGITIZED POINT
REFERENCE VALUES
  LEFT DISTANCE: 0 (IN)
  RIGHT DISTANCE: 0.9825 (IN)
  BOTTOM THICKNESS: 0.394 (IN)
  TOP THICKNESS: 0 (IN)

POINT	DISTANCE (IN)	THICKNESS (IN)
1	0.62459	0.053977
2	0.62191	0.070837
3	0.62906	0.089609
4	0.62799	0.1091
5	0.63127	0.13098
6	0.63109	0.14485
7	0.63038	0.16847
8	0.63056	0.18646
9	0.63134	0.21133
10	0.63223	0.23758
11	0.6289	0.26281
12	0.63057	0.28206
13	0.63046	0.31255
14	0.63248	0.33593
15	0.63886	0.3617

WAS THERE CRACK EXTENSION DURING TEST? YES

POINT	DISTANCE (IN)	THICKNESS (IN)
1	0.77405	0.058921
2	0.77125	0.074406

3	0.76834	0.088516
4	0.76816	0.10239
5	0.77156	0.12564
6	0.77757	0.14729
7	0.77627	0.16403
8	0.78193	0.18154
9	0.78449	0.19517
10	0.78342	0.21466
11	0.78211	0.2314
12	0.78217	0.24803
13	0.77848	0.26913
14	0.7692	0.28934
15	0.75854	0.30967
16	0.75175	0.32689
17	0.74532	0.34823
18	0.74354	0.35947

```
  MEASURED CRACK LENGTHS
    INITIAL: 11.032 (MM),0.4343 (IN)
    FINAL: 14.601 (MM),0.5748 (IN)
TEST
  ROUTINE REVISION: 1.02/07-JUL-88
  TYPE: UCJR
  ENGINEER: FMH
  TECHNICIAN: RLS
  TEST DATE: 05-MAR-93
  ATMOSPHERE: AIR
  TEMPERATURE: 125 (DEG C),257 (DEG F)
  REMARK: NONE

  DID SPECIMEN CLEAVE? NO
FILE NAME: 4BBH12
DISK DRIVE SPECIFIER: :,700,1

OVERWRITE EXISTING 4BBH12:,700,1 FILE? YES
EXISTING FILE PURGED
UCJR TEST FILE CREATED
TEST SET SAVED
ANALYSIS
  ROUTINE REVISION: 1.10/06-MAR-90
  CRACK LENGTH PINS
    UC
      INITIAL
        DETERMINATION TEST CYCLE: 1
        EFFECTIVE MODULUS: 195.4 (GPA),28341 (KSI)
        YOUNG'S MODULUS-EFFECTIVE MODULUS:-1.2 (PERCENT)
      FINAL
        PIN NOT APPLIED
  UC RESULTS
    MEASURED FINAL CRACK EXTENSION: 3.569 (MM),0.1405 (IN)
    FINAL CRACK EXTENSION: 2.723 (MM),0.1072 (IN)
    FINAL CRACK EXTENSION ERROR:-23.7 (PERCENT)
    PQ: 6.77 (KN),1522 (LB)
    KQ: 57.18 (MPA-SQRT(M)),52038 (KSI-SQRT(IN))
    KIC: NO VALID KIC FOR TEST
    PMX: 11.568 (KN),2601 (LB)
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    KMX: 97.71 (MPA-SQRT(M)),88.92 (KSI-SQRT(IN))
    E1152 J-INTEGRAL
      PMX J-INTEGRAL: 125.77 (KJ/M^2),718.2 (IN-LB/IN^2)
      FINAL J-INTEGRAL: 366.83 (KJ/M^2),2094.7 (IN-LB/IN^2)
      FINAL KJ: 266.12 (MPA-SQRT(M)),242.18 (KSI-SQRT(IN))
      POWER-LAW MODEL [J-INTEGRAL=A0*CRACK EXTENSION^A1]
        A0: 268.63 (SI),4830 (ENGLISH)
        A1: 0.35461 (SI),0.35461 (ENGLISH)
        RESULTS EXCLUDED FROM MODEL: CYCLES 1,2,3,4,5,12,13,14 AND 15
      JIC: 194.35 (KJ/M^2),1109.8 (IN-LB/IN^2)
      KJIC: 193.7 (MPA-SQRT(M)),176.28 (KSI-SQRT(IN))
      TEARING MODULUS: 80
FILE NAME: 4BBH12
DISK DRIVE SPECIFIER: :,700,1
ANALYSIS SET SAVED

ANALYSIS FILE NAME: 4BBH12
```

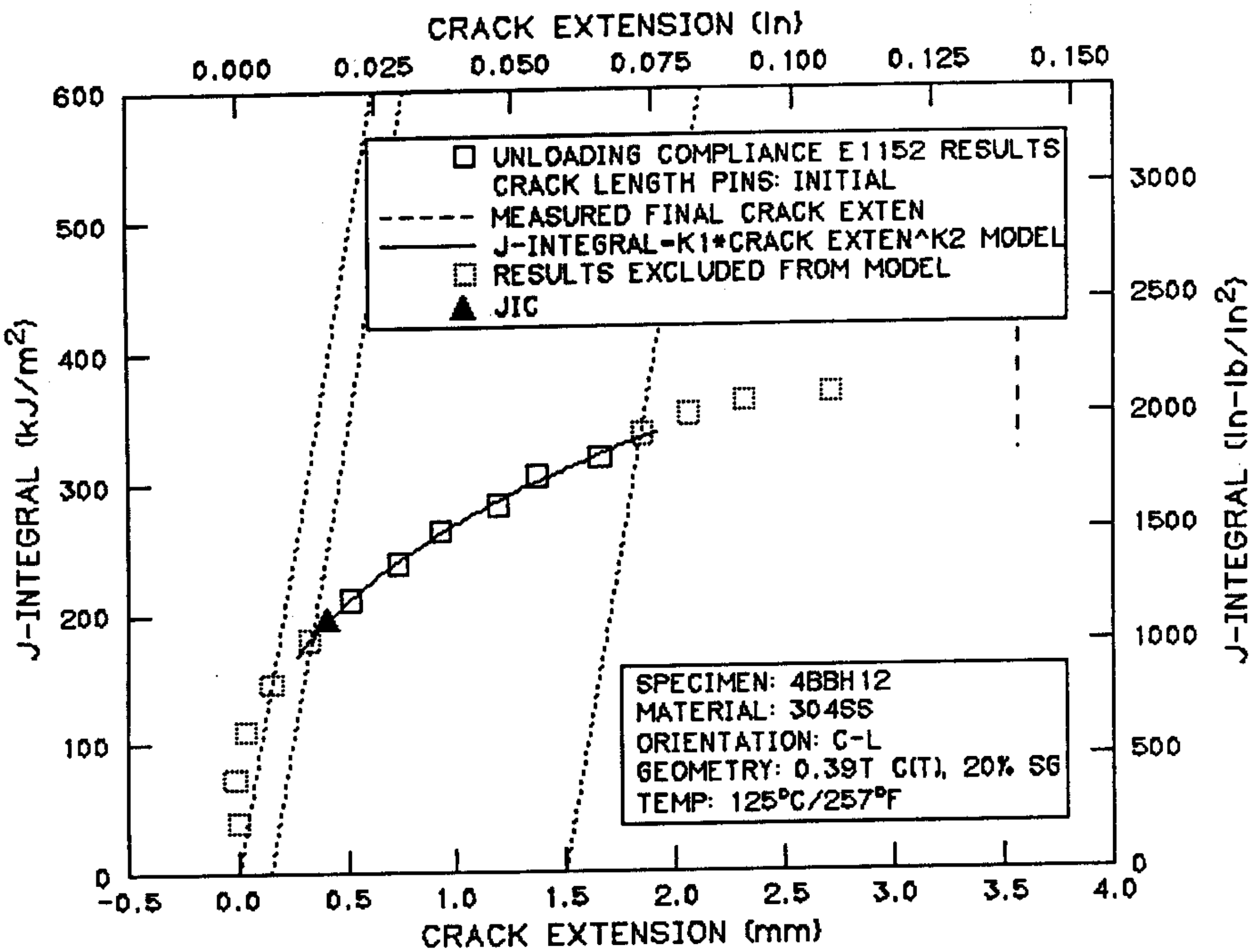
ANALYZE
4BBH12

SPECIMEN
IDENTIFICATION: 4BBH12
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 11.032 (MM),0.4343 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 125 (DEG C),257 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: E1152

CYCLE	LOAD (KN)	DISPL (MM)	ENERGY (J)	CRACK EXTN (MM)	J-INTEGRAL (KJ/M^2)	KJ (MPA-SQRT(M))
1	9.029	0.275	1.345	0	38.58	86.3
2	10.719	0.387	2.481	-0.017	72.38	118.21
3	11.287	0.498	3.729	0.037	109.38	145.31
4	11.17	0.609	5.013	0.15	146.12	167.95
5	10.649	0.72	6.248	0.323	179.94	186.38
6	10.214	0.831	7.437	0.51	211.5	202.06
7	9.207	0.942	8.562	0.733	239.06	214.83
8	8.542	1.053	9.568	0.931	264.09	225.79
9	8.117	1.164	10.513	1.196	283.44	233.92
10	7.645	1.276	11.416	1.379	305.42	242.82
11	7.179	1.387	12.259	1.66	319.35	248.3
12	6.858	1.498	13.054	1.855	337.02	255.07
13	6.408	1.608	13.81	2.067	351.74	260.59
14	5.912	1.719	14.513	2.322	361.41	264.14
15	5.134	1.88	15.421	2.723	366.83	266.12

SPECIMEN
IDENTIFICATION: 4BBH12
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 11.032 (MM),0.4343 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 125 (DEG C),257 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: E1152

CYCLE	LOAD (LB)	DISPL (IN)	ENERGY (IN-LB)	CRACK EXTN (IN)	J-INTEGRAL (IN-LB/IN^2)	KJ (KSI-SQRT(IN))
1	2030	0.0108	11.9	0	220.3	78.54
2	2410	0.0152	21.95	-0.0007	413.3	107.58
3	2537	0.0196	33	0.0014	624.6	132.24
4	2511	0.024	44.37	0.0059	834.4	152.85
5	2394	0.0283	55.3	0.0127	1027.5	169.61
6	2296	0.0327	65.83	0.0201	1207.7	183.89
7	2070	0.0371	75.78	0.0288	1365.1	195.51
8	1920	0.0415	84.68	0.0367	1508	205.48
9	1825	0.0458	93.05	0.0471	1618.5	212.88
10	1719	0.0502	101.04	0.0543	1744	220.98
11	1614	0.0546	108.5	0.0654	1823.5	225.96
12	1542	0.059	115.53	0.073	1924.4	232.13
13	1441	0.0633	122.23	0.0814	2008.5	237.14
14	1329	0.0677	128.45	0.0914	2063.7	240.38
15	1154	0.074	136.49	0.1072	2094.7	242.18


CRACK EXTENSION (in)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
600
500
400
300
200
100
0
J-INTEGRAL (kJ/m²)
3000
2500
2000
1500
1000
500
0
J-INTEGRAL (in-lb/in²)
UNLOADING COMPLIANCE E1152 RESULTS
CRACK LENGTH PINS: INITIAL
MEASURED FINAL CRACK EXTEN
J-INTEGRAL=K1*CRACK EXTEN^K2 MODEL
RESULTS EXCLUDED FROM MODEL
JIC
SPECIMEN: 4BBH12
MATERIAL: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T), 20% SG
TEMP: 125°C/257°F
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
CRACK EXTENSION (mm)

DATA/RESULTS SOURCE: TEST FILE
TEST FILE NAME: 7WH3
DISK DRIVE SPECIFIER: :,700,1
J-INTEGRAL METHOD: E1152
ANALYSIS ANALYSIS TEMPLATE SOURCE: STANDARD
ANALYZE
7WH3

SPECIMEN
IDENTIFICATION: 7WH3
MATERIAL
CODE: 304SS
YOUNG'S MODULUS: 193.05 (GPA),28000 (KSI)
POISSON'S RATIO: 0.3
STRENGTHS
YIELD: 586.05 (MPA),85 (KSI)
ULTIMATE: 717.05 (MPA),104 (KSI)
ORIENTATION: C-L
GEOMETRY: C-L
WIDTH: 19.964 (MM),0.786 (IN)
THICKNESS: 10.008 (MM),0.394 (IN)
SIDE GROOVE: 20 (PERCENT)
LOAD PIN CENTER SPAN: 9.804 (MM),0.386 (IN)
EXTENSOMETER LOCATION: 0 (MM),0 (IN)
PRECRACK CONDITIONS
MAXIMUM LOAD: 1.779 (KN),400 (LB)
FREQUENCY: 30 (HZ)
FRONT-SURFACE-TO-LOAD-LINE DISTANCE: 4.991 (MM),0.1965 (IN)

USE GRAPHIC TABLET KEY 1 TO DELETE LAST DIGITIZED POINT
REFERENCE VALUES
LEFT DISTANCE: 0 (IN)
RIGHT DISTANCE: 0.9825 (IN)
BOTTOM THICKNESS: 0.394 (IN)
TOP THICKNESS: 0 (IN)

POINT	DISTANCE (IN)	THICKNESS (IN)
1	0.57361	0.074511
2	0.57587	0.098846
3	0.57939	0.12026
4	0.57914	0.15044
5	0.58634	0.19756
6	0.58977	0.25346
7	0.59152	0.30081
8	0.58676	0.31968
9	0.5855	0.32261
10	0.57561	0.35031
11	0.50387	0.36618
12	0.5176	0.36849
13	0.5013	0.3706
14	0.50413	0.37336
15	0.49329	0.37524

WAS THERE CRACK EXTENSION DURING TEST? YES

POINT	DISTANCE (IN)	THICKNESS (IN)
1	0.72019	0.090062
2	0.70862	0.10922

3	0.7092	0.125
4	0.70423	0.13813
5	0.70874	0.14944
6	0.7121	0.16655
7	0.71268	0.18233
8	0.70907	0.19541
9	0.71348	0.20385
10	0.72517	0.22493
11	0.72062	0.24954
12	0.71476	0.27564
13	0.71593	0.30721
14	0.71573	0.33883
15	0.70851	0.36499
16	0.72313	0.35433
17	0.72334	0.36007
18	0.71679	0.36752

MEASURED CRACK LENGTHS
INITIAL: 9.694 (MM),0.3816 (IN)
FINAL: 13.174 (MM),0.5186 (IN)
TEST
ROUTINE REVISION: 1.02/07-JUL-88
TYPE: UCJR
ENGINEER: FMH
TECHNICIAN: RLS
TEST DATE: 04-MAR-93
ATMOSPHERE: AIR
TEMPERATURE: 25 (DEG C),77 (DEG F)
REMARK: NONE

DID SPECIMEN CLEAVE? NO
FILE NAME: 7WH3
DISK DRIVE SPECIFIER: :,700,1

OVERWRITE EXISTING 7WH3:,700,1 FILE? YES
EXISTING FILE PURGED
UCJR TEST FILE CREATED
TEST SET SAVED
ANALYSIS
ROUTINE REVISION: 1.10/06-MAR-90
CRACK LENGTH PINS
UC
INITIAL
DETERMINATION TEST CYCLE: 1
EFFECTIVE MODULUS: 130.05 (GPA),18862 (KSI)
YOUNG'S MODULUS-EFFECTIVE MODULUS: 32.6 (PERCENT)
FINAL
PIN NOT APPLIED
UC RESULTS
MEASURED FINAL CRACK EXTENSION: 3.48 (MM),0.137 (IN)
FINAL CRACK EXTENSION: 2.958 (MM),0.1164 (IN)
FINAL CRACK EXTENSION ERROR:-15 (PERCENT)
PQ: 4.64 (KN),1043 (LB)
KQ: 31.6 (MPA-SQRT(M)),28754 (KSI-SQRT(IN))
KIC: NO VALID KIC FOR TEST
PMX: 13.609 (KN),3059 (LB)

```
    KMX: 92.68 (MPA-SQRT(M)),84.35 (KSI-SQRT(IN))
      PMX J-INTEGRAL: 162.23 (KJ/M^2),926.3 (IN-LB/IN^2)
      FINAL J-INTEGRAL: 518.14 (KJ/M^2),2958.7 (IN-LB/IN^2)
      FINAL KJ: 316.27 (MPA-SQRT(M)),287.82 (KSI-SQRT(IN))
      POWER-LAW MODEL [J-INTEGRAL=A0*CRACK EXTENSION^A1]
        A0: 341.93 (SI),8426 (ENGLISH)
        A1: 0.45201 (SI),0.45201 (ENGLISH)
        RESULTS EXCLUDED FROM MODEL: CYCLES 1,2,3,4,5,6,7,8,9,20,21,22 AND 23
      JIC: 217.3 (KJ/M^2),1240.8 (IN-LB/IN^2)
      KJIC: 204.82 (MPA-SQRT(M)),186.39 (KSI-SQRT(IN))
      TEARING MODULUS: 71.9
FILE NAME: 7WH3
DISK DRIVE SPECIFIER: :,700,1
ANALYSIS SET SAVED

ANALYSIS FILE NAME: 7WH3
```

SPECIMEN
IDENTIFICATION: 7WH3
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 9.694 (MM),0.3816 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 25 (DEG C),77 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: E1152

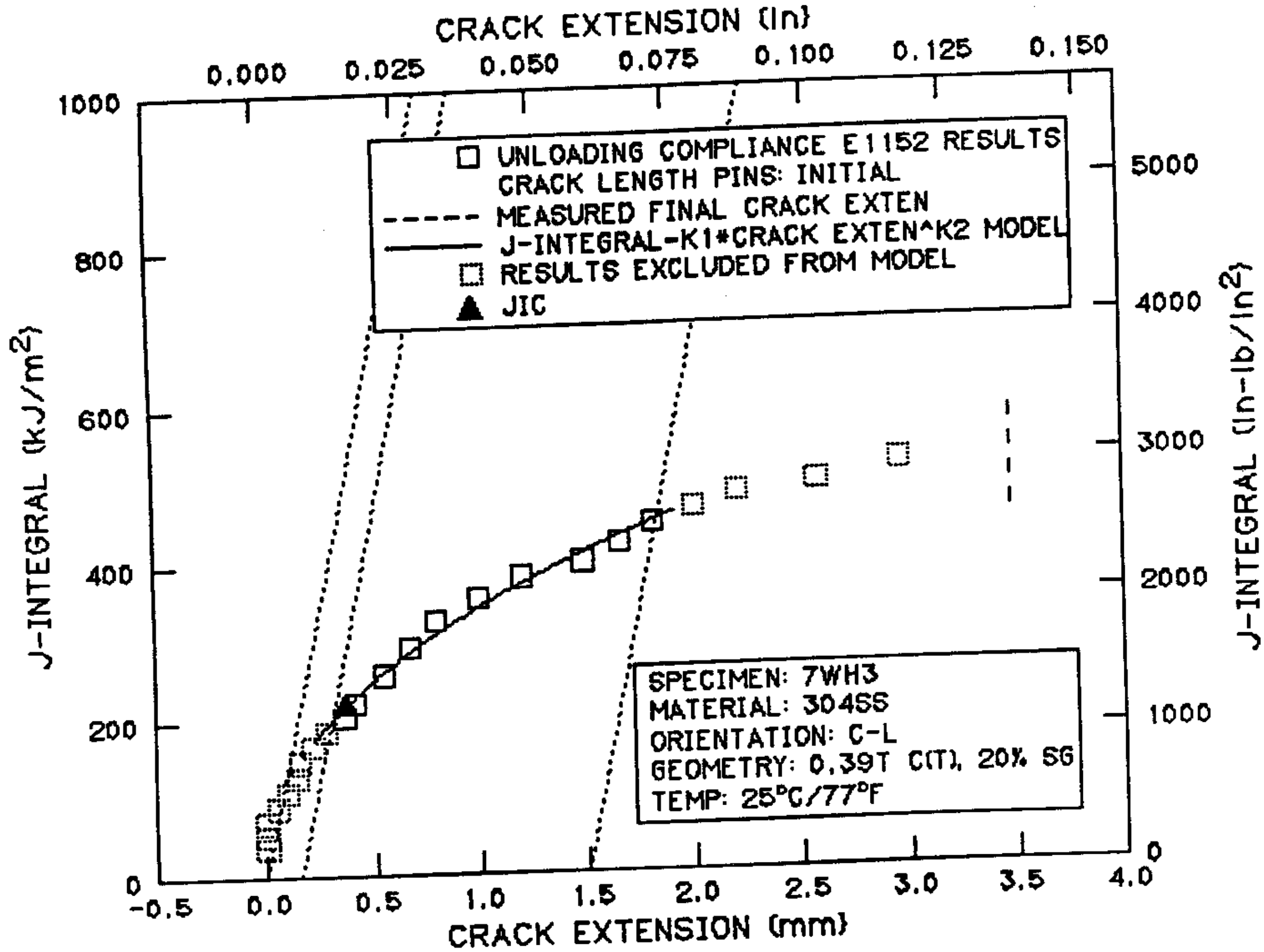
CYCLE	LOAD (KN)	DISPL (MM)	ENERGY (J)	CRACK EXTN (MM)	J-INTEGRAL (KJ/M^2)	KJ (MPA-SQRT(M))
1	9.51	0.275	1.399	0.003	36.87	84.37
2	10.793	0.331	1.973	0.003	52.42	100.6
3	11.773	0.388	2.626	0.002	69.94	116.2
4	12.428	0.445	3.329	0.051	88.1	130.41
5	12.817	0.501	4.056	0.097	107.06	143.77
6	13.07	0.557	4.797	0.144	126.26	156.13
7	13.192	0.614	5.556	0.155	146.67	168.27
8	13.183	0.67	6.313	0.219	165.69	178.85
9	13.086	0.726	7.074	0.278	184.89	188.93
10	12.852	0.782	7.82	0.364	202.84	197.89
11	12.709	0.839	8.564	0.414	221.8	206.93
12	12.458	0.951	10.02	0.553	257.15	222.81
13	12.213	1.063	11.45	0.677	292.13	237.48
14	11.9	1.176	12.852	0.797	326.15	250.93
15	11.418	1.288	14.202	0.999	354.34	261.55
16	10.826	1.4	15.49	1.202	380.47	271.02
17	10.059	1.513	16.714	1.49	398.92	277.51
18	9.693	1.626	17.867	1.665	422.7	285.66
19	9.393	1.737	18.967	1.821	446.25	293.51
20	8.942	1.85	20.028	2.015	465.54	299.79
21	8.503	1.962	21.044	2.217	482.57	305.22
22	7.642	2.119	22.355	2.583	494.98	309.12
23	6.897	2.345	24.04	2.958	518.14	316.27

ANALYZE
7WH3

SPECIMEN
IDENTIFICATION: 7WH3
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 9.694 (MM),0.3816 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 25 (DEG C),77 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: E1152

CYCLE	LOAD (LB)	DISPL (IN)	ENERGY (IN-LB)	CRACK EXTN (IN)	J-INTEGRAL (IN-LB/IN^2)	KJ (KSI-SQRT(IN))
1	2138	0.0108	12.38	0.0001	210.6	76.78
2	2426	0.013	17.47	0.0001	299.3	91.55
3	2647	0.0153	23.24	0.0001	399.4	105.75
4	2794	0.0175	29.46	0.002	503	118.68
5	2881	0.0197	35.9	0.0038	611.3	130.83
6	2938	0.0219	42.46	0.0057	721	142.08
7	2966	0.0242	49.18	0.0061	837.5	153.14
8	2964	0.0264	55.88	0.0086	946.1	162.76
9	2942	0.0286	62.61	0.011	1055.8	171.93
10	2889	0.0308	69.21	0.0143	1158.3	180.09
11	2857	0.033	75.8	0.0163	1266.5	188.31
12	2801	0.0374	88.68	0.0218	1468.3	202.77
13	2746	0.0419	101.34	0.0266	1668.1	216.12
14	2675	0.0463	113.75	0.0314	1862.4	228.36
15	2567	0.0507	125.7	0.0393	2023.3	238.02
16	2434	0.0551	137.1	0.0473	2172.5	246.64
17	2261	0.0596	147.94	0.0587	2277.9	252.55
18	2179	0.064	158.13	0.0655	2413.7	259.97
19	2112	0.0684	167.88	0.0717	2548.1	267.11
20	2010	0.0728	177.27	0.0793	2658.3	272.82
21	1911	0.0773	186.26	0.0873	2755.6	277.77
22	1718	0.0834	197.86	0.1017	2826.4	281.32
23	1550	0.0923	212.77	0.1165	2958.7	287.82

ANALYZE
7WH3



DATA/RESULTS SOURCE: TEST FILE
TEST FILE NAME: 7HAH8
DISK DRIVE SPECIFIER: :,700,1
J-INTEGRAL METHOD: E1152
ANALYSIS ANALYSIS TEMPLATE SOURCE: STANDARD
ANALYZE
7HAH8

SPECIMEN
IDENTIFICATION: 7HAH8
MATERIAL
CODE: 304SS
YOUNG'S MODULUS: 193.05 (GPA),28000 (KSI)
POISSON'S RATIO: 0.3
STRENGTHS
YIELD: 599.84 (MPA),87 (KSI)
ULTIMATE: 717.05 (MPA),104 (KSI)
ORIENTATION: C-L
GEOMETRY: C-L
WIDTH: 19.964 (MM),0.786 (IN)
THICKNESS: 10.008 (MM),0.394 (IN)
SIDE GROOVE: 20 (PERCENT)
LOAD PIN CENTER SPAN: 9.804 (MM),0.386 (IN)
EXTENSOMETER LOCATION: 0 (MM),0 (IN)
PRECRACK CONDITIONS
MAXIMUM LOAD: 1.779 (KN),400 (LB)
FREQUENCY: 30 (HZ)
FRONT-SURFACE-TO-LOAD-LINE DISTANCE: 4.991 (MM),0.1965 (IN)

USE GRAPHIC TABLET KEY 1 TO DELETE LAST DIGITIZED POINT
REFERENCE VALUES
LEFT DISTANCE: 0 (IN)
RIGHT DISTANCE: 0.9825 (IN)
BOTTOM THICKNESS: 0.394 (IN)
TOP THICKNESS: 0 (IN)

POINT	DISTANCE (IN)	THICKNESS (IN)
1	0.62687	0.072023
2	0.62986	0.086198
3	0.6312	0.097912
4	0.63043	0.11512
5	0.62665	0.13001
6	0.63279	0.1478
7	0.63141	0.17166
8	0.62885	0.18511
9	0.62837	0.20492
10	0.62685	0.22748
11	0.63148	0.24411
12	0.62846	0.26551
13	0.62739	0.28012
14	0.62421	0.30021
15	0.62435	0.31337
16	0.62343	0.32928
17	0.62221	0.34258
18	0.62235	0.35574
19	0.62054	0.36384

WAS THERE CRACK EXTENSION DURING TEST? YES

ANALYZE
7HAH8

POINT	DISTANCE (IN)	THICKNESS (IN)
1	0.77977	0.080857
2	0.78396	0.093587
3	0.78124	0.10573
4	0.78303	0.12135
5	0.78256	0.14116
6	0.78284	0.15562
7	0.78312	0.17008
8	0.781	0.18744
9	0.77647	0.20768
10	0.77585	0.22619
11	0.77117	0.24512
12	0.7677	0.26262
13	0.76258	0.27765
14	0.7621	0.29746
15	0.74931	0.31726
16	0.73337	0.33344
17	0.71414	0.3447
18	0.70331	0.3577

MEASURED CRACK LENGTHS
INITIAL: 10.955 (MM),0.4313 (IN)
FINAL: 14.501 (MM),0.5709 (IN)

TEST
ROUTINE REVISION: 1.02/07-JUL-88
TYPE: UCJR
ENGINEER: FMH
TECHNICIAN: RLS
TEST DATE: 04-MAR-93
ATMOSPHERE: AIR
TEMPERATURE: 25 (DEG C),77 (DEG F)
REMARK: NONE

DID SPECIMEN CLEAVE? NO

FILE NAME: 7HAH8
DISK DRIVE SPECIFIER: :,700,1

OVERWRITE EXISTING 7HAH8:,700,1 FILE? YES
EXISTING FILE PURGED
UCJR TEST FILE CREATED
TEST SET SAVED

ANALYSIS
ROUTINE REVISION: 1.10/06-MAR-90
CRACK LENGTH PINS
UC
INITIAL
DETERMINATION TEST CYCLE: 1
EFFECTIVE MODULUS: 173.28 (GPA),25132 (KSI)
YOUNG'S MODULUS-EFFECTIVE MODULUS: 10.2 (PERCENT)
FINAL
PIN NOT APPLIED
UC RESULTS
MEASURED FINAL CRACK EXTENSION: 3.546 (MM),0.1396 (IN)
FINAL CRACK EXTENSION: 2.949 (MM),0.1161 (IN)
FINAL CRACK EXTENSION ERROR:-16.8 (PERCENT)

```
    PQ: 5.154 (KN),1159 (LB)
    KQ: 42.96 (MPA-SQRT(M)),39097 (KSI-SQRT(IN))
    KIC: NO VALID KIC FOR TEST
    PMX: 10.118 (KN),2275 (LB)
    KMX: 84.34 (MPA-SQRT(M)),76.76 (KSI-SQRT(IN))
    E1152 J-INTEGRAL
      PMX J-INTEGRAL: 73.15 (KJ/M^2),417.7 (IN-LB/IN^2)
      FINAL J-INTEGRAL: 200.52 (KJ/M^2),1145 (IN-LB/IN^2)
      FINAL KJ: 196.75 (MPA-SQRT(M)),179.05 (KSI-SQRT(IN))
      POWER-LAW MODEL [J-INTEGRAL=A0*CRACK EXTENSION^A1]
        A0: 120.21 (SI),4026 (ENGLISH)
        A1: 0.54691 (SI),0.54691 (ENGLISH)
        RESULTS EXCLUDED FROM MODEL: CYCLES 1,2,10,11,12,13,14 AND 15
      JIC: 55.31 (KJ/M^2),315.9 (IN-LB/IN^2)
      KJIC: 103.34 (MPA-SQRT(M)),94.04 (KSI-SQRT(IN))
      TEARING MODULUS: 32.7
FILE NAME: 7HAH8
DISK DRIVE SPECIFIER: :,700,1
ANALYSIS SET SAVED

ANALYSIS FILE NAME: 7HAH8
```

ANALYZE
7HAH8

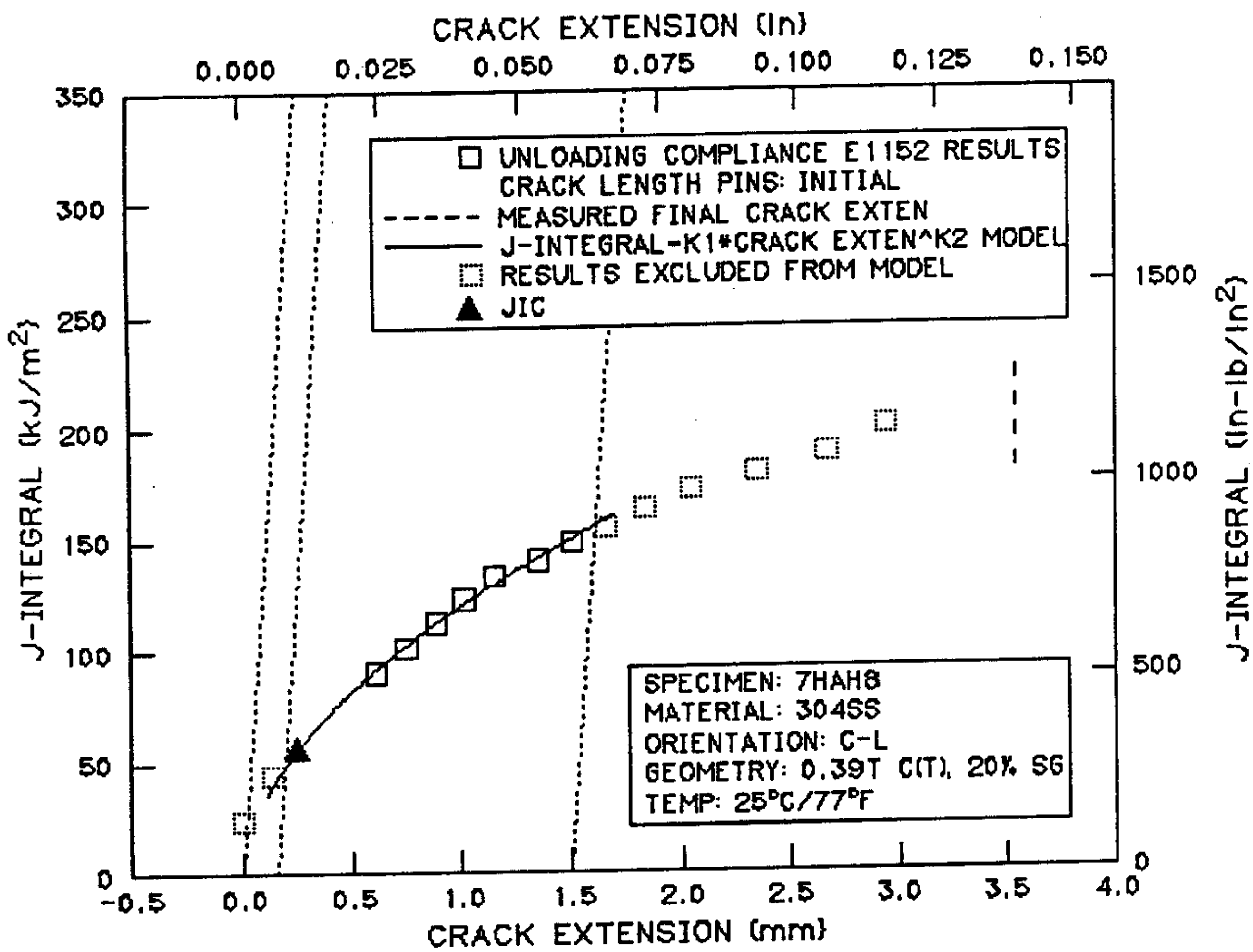
SPECIMEN
IDENTIFICATION: 7HAH8
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 10.955 (MM),0.4313 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 25 (DEG C),77 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: E1152

CYCLE	LOAD (KN)	DISPL (MM)	ENERGY (J)	CRACK EXTN (MM)	J-INTEGRAL (KJ/M^2)	KJ (MPA-SQRT(M))
1	7.256	0.216	0.829	0	23.97	68.02
2	9.02	0.304	1.562	0.135	44.59	92.78
3	9.673	0.479	3.285	0.607	89.97	131.79
4	9.454	0.522	3.713	0.747	101.37	139.89
5	9.119	0.567	4.134	0.887	112.49	147.36
6	8.809	0.61	4.536	1.013	123.24	154.25
7	8.223	0.654	4.923	1.148	133.19	160.35
8	7.629	0.698	5.281	1.35	140.66	164.79
9	7.259	0.741	5.613	1.506	148.28	169.19
10	6.982	0.785	5.934	1.66	155.43	173.23
11	6.674	0.837	6.304	1.84	163.43	177.63
12	6.274	0.9	6.726	2.05	172.46	182.47
13	5.706	0.975	7.196	2.352	179.88	186.35
14	5.25	1.067	7.711	2.675	188.2	190.61
15	4.888	1.18	8.301	2.95	200.52	196.75

ANALYZE
7HAH8

SPECIMEN
IDENTIFICATION: 7HAH8
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 10.955 (MM),0.4313 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 25 (DEG C),77 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: E1152

CYCLE	LOAD (LB)	DISPL (IN)	ENERGY (IN-LB)	CRACK EXTN (IN)	J-INTEGRAL (IN-LB/IN^2)	KJ (KSI-SQRT(IN))
1	1631	0.0085	7.34	0	136.9	61.9
2	2028	0.012	13.83	0.0053	254.6	84.43
3	2175	0.0188	29.08	0.0239	513.8	119.94
4	2125	0.0206	32.87	0.0294	578.9	127.31
5	2050	0.0223	36.59	0.0349	642.3	134.11
6	1980	0.024	40.15	0.0399	703.7	140.37
7	1849	0.0257	43.57	0.0452	760.5	145.93
8	1715	0.0275	46.74	0.0531	803.2	149.96
9	1632	0.0292	49.68	0.0593	846.7	153.97
10	1570	0.0309	52.52	0.0653	887.6	157.64
11	1500	0.033	55.8	0.0725	933.2	161.65
12	1411	0.0354	59.53	0.0807	984.8	166.05
13	1283	0.0384	63.69	0.0926	1027.1	169.59
14	1180	0.042	68.25	0.1053	1074.6	173.46
15	1099	0.0464	73.47	0.1161	1145	179.05


CRACK EXTENSION (in)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
350
300
250
200
150
100
50
0
J-INTEGRAL (kJ/m^2)
UNLOADING COMPLIANCE E1152 RESULTS
CRACK LENGTH PINS: INITIAL
MEASURED FINAL CRACK EXTEN
J-INTEGRAL-K1*CRACK EXTEN^K2 MODEL
RESULTS EXCLUDED FROM MODEL
JIC
1500
1000
500
0
J-INTEGRAL (in-lb/in^2)
SPECIMEN: 7HAH8
MATERIAL: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T), 20% SG
TEMP: 25°C/77°F
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
CRACK EXTENSION (mm)

Attachment 1, Appendix B -- Results of 0.4T (C(T) Fracture Toughness Specimens Irradiated in the HFIR Capsule 12M (Modified Ernst J-Integral)

```
COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 4BBH11

SPECIMEN
  IDENTIFICATION: 4BBH11
  MATERIAL
    CODE: 304SS
    YOUNG'S MODULUS: 193.05 (GPA),28000 (KSI)
    POISSON'S RATIO: 0.3
    STRENGTHS
      YIELD: 448.16 (MPA),65 (KSI)
      ULTIMATE: 517.11 (MPA),75 (KSI)
  ORIENTATION: C-L
  GEOMETRY: C(T)
  WIDTH: 19.964 (MM),0.786 (IN)
  THICKNESS: 10.008 (MM),0.394 (IN)
  SIDE GROOVE: 20 (PERCENT)
  LOAD PIN CENTER SPAN: 9.804 (MM),0.386 (IN)
  EXTENSOMETER LOCATION: 0 (MM),0 (IN)
  PRECRACK CONDITIONS
    MAXIMUM LOAD: 1.779 (KN),400 (LB)
    FREQUENCY: 30 (HZ)
  FRONT-SURFACE-TO-LOAD-LINE DISTANCE: 4.991 (MM),0.1965 (IN)
  FRONT-SURFACE-TO-INITIAL-CRACK-FRONT DISTANCES
    DISTANCE 1: 15.948 (MM),0.6279 (IN)
    DISTANCE 2: 16.064 (MM),0.6325 (IN)
    DISTANCE 3: 16.023 (MM),0.6308 (IN)
    DISTANCE 4: 16.107 (MM),0.6341 (IN)
    DISTANCE 5: 16.186 (MM),0.6373 (IN)
    DISTANCE 6: 16.11 (MM),0.6343 (IN)
    DISTANCE 7: 16.19 (MM),0.6374 (IN)
    DISTANCE 8: 16.029 (MM),0.6311 (IN)
    DISTANCE 9: 15.969 (MM),0.6287 (IN)
  FRONT-SURFACE-TO-FINAL-CRACK-FRONT DISTANCES
    DISTANCE 1: 20.296 (MM),0.7991 (IN)
    DISTANCE 2: 19.966 (MM),0.7861 (IN)
    DISTANCE 3: 20.009 (MM),0.7877 (IN)
    DISTANCE 4: 19.85 (MM),0.7815 (IN)
    DISTANCE 5: 19.88 (MM),0.7827 (IN)
    DISTANCE 6: 20.033 (MM),0.7887 (IN)
    DISTANCE 7: 20.234 (MM),0.7966 (IN)
    DISTANCE 8: 20.196 (MM),0.7951 (IN)
    DISTANCE 9: 19.894 (MM),0.7833 (IN)
  MEASURED CRACK LENGTHS
    INITIAL: 11.093 (MM),0.4367 (IN)
    FINAL: 15.042 (MM),0.5922 (IN)
TEST
  ROUTINE REVISION: 1.02/07-JUL-88
  TYPE: UCJR
  ENGINEER: FMH
  TECHNICIAN: RLS
  TEST DATE: 04-MAR-93
  ATMOSPHERE: AIR
  TEMPERATURE: 125 (DEG C),257 (DEG F)
  REMARK: NONE
  DID SPECIMEN CLEAVE? NO
ANALYSIS
  ROUTINE REVISION: 1.10/06-MAR-90
  CRACK LENGTH PINS
```

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 4BBH11

UC
  INITIAL
    DETERMINATION TEST CYCLE: 4
    EFFECTIVE MODULUS: 192.42 (GPA),27908 (KSI)
    YOUNG'S MODULUS-EFFECTIVE MODULUS: 0.3 (PERCENT)
  FINAL
    PIN NOT APPLIED
UC RESULTS
  MEASURED FINAL CRACK EXTENSION: 3.949 (MM),0.1555 (IN)
  FINAL CRACK EXTENSION: 3.123 (MM),0.123 (IN)
  FINAL CRACK EXTENSION ERROR:-20.9 (PERCENT)
  PQ: 3.505 (KN),788 (LB)
  KQ: 29.92 (MPA-SQRT(M)),27227 (KSI-SQRT(IN))
  KIC: NO VALID KIC FOR TEST
  PMX: 9.997 (KN),2247 (LB)
  KMX: 85.34 (MPA-SQRT(M)),77.66 (KSI-SQRT(IN))
  MODIFIED ERNST J-INTEGRAL
    PMX J-INTEGRAL: 111.72 (KJ/M^2),637.9 (IN-LB/IN^2)
    FINAL J-INTEGRAL: 663.69 (KJ/M^2),3789.8 (IN-LB/IN^2)
    FINAL KJ: 357.95 (MPA-SQRT(M)),325.75 (KSI-SQRT(IN))
    POWER-LAW MODEL [J-INTEGRAL=A0*CRACK EXTENSION^A1]
      A0: 364.76 (SI),16645 (ENGLISH)
      A1: 0.6425 (SI),0.6425 (ENGLISH)
      RESULTS EXCLUDED FROM MODEL: CYCLES 1,2,3,4,5,6,7,8,9,10,11,12,13,14,
      15,29 AND 30
    JIC: 207.21 (KJ/M^2),1183.2 (IN-LB/IN^2)
    KJIC: 200.01 (MPA-SQRT(M)),182.02 (KSI-SQRT(IN))
    TEARING MODULUS: 187

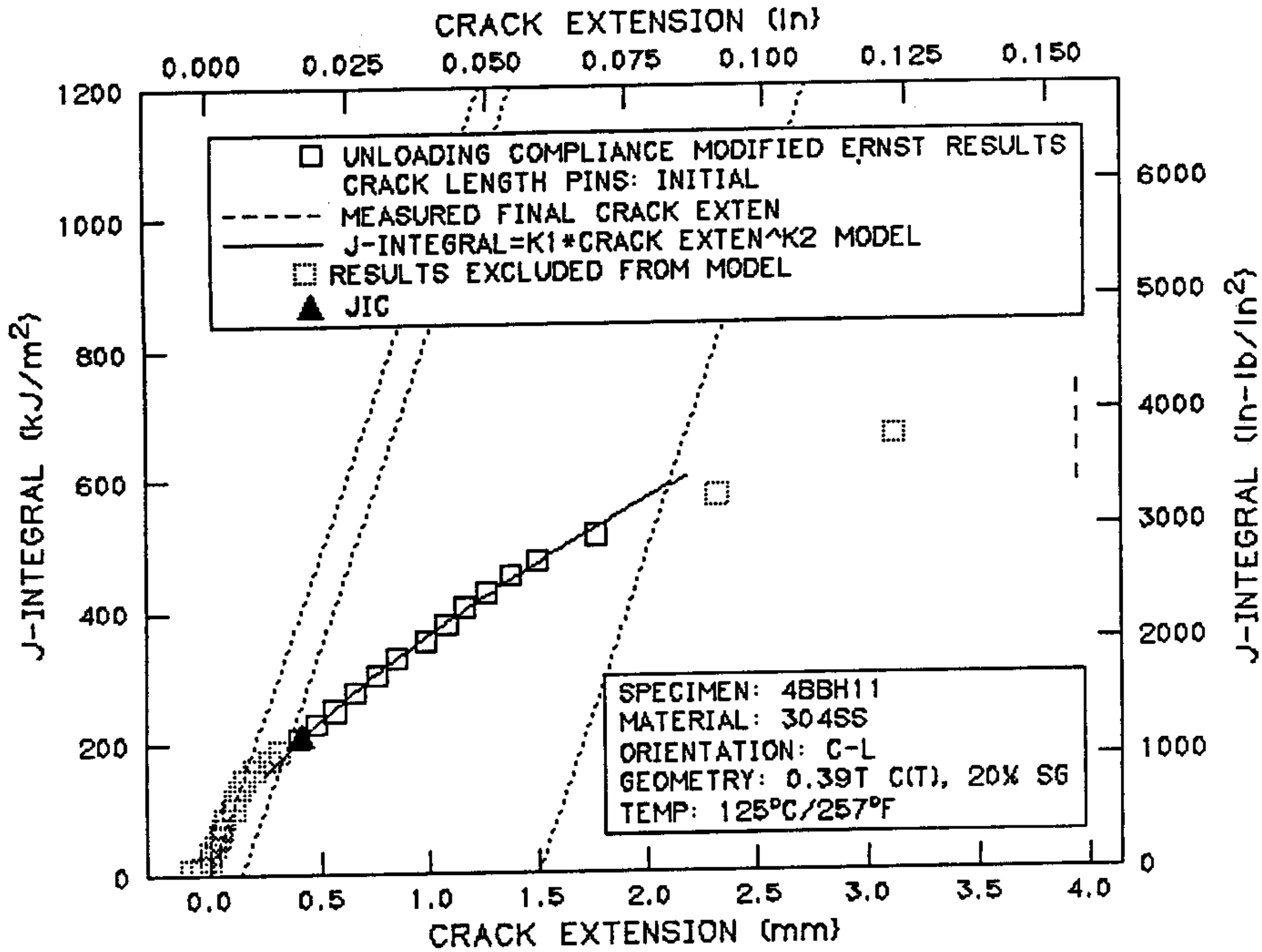
COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 4BBH11

SPECIMEN
IDENTIFICATION: 4BBH11
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 11.093 (MM),0.4367 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 125 (DEG C),257 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: MODIFIED ERNST

CYCLE	LOAD (KN)	DISPL (MM)	ENERGY (J)	CRACK EXTN (MM)	J-INTEGRAL (KJ/M^2)	KJ (MPA-SQRT(M))
1	4.646	0.115	0.285	-0.086	9.19	42.11
2	5.432	0.14	0.409	-0.037	12.88	49.87
3	6.755	0.186	0.693	0.006	21.61	64.59
4	7.852	0.233	1.039	0	32.6	79.34
5	8.627	0.28	1.434	0.026	44.79	92.99
6	9.136	0.326	1.856	0.046	57.94	105.76
7	9.471	0.374	2.305	0.059	71.99	117.89
8	9.645	0.421	2.762	0.072	86.31	129.08
9	9.725	0.468	3.227	0.109	100.73	139.45
10	9.747	0.514	3.692	0.116	115.49	149.31
11	9.728	0.561	4.159	0.134	130.12	158.5
12	9.69	0.608	4.624	0.159	144.76	167.17
13	9.614	0.655	5.089	0.202	159.2	175.31
14	9.475	0.702	5.547	0.27	173.32	182.92
15	9.309	0.749	5.994	0.315	187.41	190.21
16	9.121	0.819	6.656	0.405	208.14	200.46
17	8.994	0.89	7.313	0.483	228.81	210.17
18	8.845	0.96	7.954	0.566	249.22	219.35
19	8.67	1.054	8.797	0.659	276.26	230.94
20	8.503	1.147	9.619	0.76	302.92	241.83
21	8.282	1.241	10.427	0.848	329.47	252.2
22	7.977	1.335	11.214	0.981	355.1	261.83
23	7.715	1.429	11.97	1.08	380.42	271
24	7.521	1.522	12.7	1.162	405.39	279.75
25	7.284	1.615	13.411	1.263	429.76	288.04
26	7.059	1.709	14.108	1.376	453.73	295.96
27	6.755	1.803	14.775	1.493	476.86	303.41
28	6.24	1.972	15.905	1.761	515.37	315.43
29	5.327	2.276	17.699	2.328	574.2	332.94
30	4.319	2.826	20.386	3.123	663.69	357.95

SPECIMEN
IDENTIFICATION: 4BBH11
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 11.093 (MM),0.4367 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 125 (DEG C),257 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: MODIFIED ERNST

CYCLE	LOAD (LB)	DISPL (IN)	ENERGY (IN-LB)	CRACK EXTN (IN)	J-INTEGRAL (IN-LB/IN^2)	KJ (KSI-SQRT(IN))
1	1045	0.0045	2.52	-0.0034	52.5	38.32
2	1221	0.0055	3.62	-0.0015	73.6	45.38
3	1519	0.0073	6.13	0.0002	123.4	58.78
4	1765	0.0092	9.2	0	186.2	72.2
5	1939	0.011	12.69	0.001	255.8	84.63
6	2054	0.0129	16.42	0.0018	330.8	96.25
7	2129	0.0147	20.4	0.0023	411.1	107.28
8	2168	0.0166	24.44	0.0028	492.8	117.47
9	2186	0.0184	28.56	0.0043	575.2	126.9
10	2191	0.0203	32.68	0.0046	659.4	135.88
11	2187	0.0221	36.81	0.0053	743	144.24
12	2178	0.0239	40.92	0.0063	826.6	152.14
13	2161	0.0258	45.04	0.0079	909	159.54
14	2130	0.0276	49.1	0.0106	989.7	166.47
15	2093	0.0295	53.05	0.0124	1070.1	173.1
16	2050	0.0322	58.91	0.0159	1188.5	182.42
17	2022	0.035	64.72	0.019	1306.5	191.27
18	1988	0.0378	70.4	0.0223	1423.1	199.62
19	1949	0.0415	77.86	0.0259	1577.5	210.16
20	1912	0.0452	85.14	0.0299	1729.7	220.07
21	1862	0.0488	92.29	0.0334	1881.3	229.52
22	1793	0.0526	99.26	0.0386	2027.7	238.27
23	1734	0.0562	105.94	0.0425	2172.2	246.62
24	1691	0.0599	112.4	0.0458	2314.8	254.59
25	1638	0.0636	118.7	0.0497	2454	262.13
26	1587	0.0673	124.86	0.0542	2590.8	269.34
27	1519	0.071	130.77	0.0588	2723	276.12
28	1403	0.0776	140.77	0.0693	2942.8	287.05
29	1198	0.0896	156.65	0.0916	3278.7	302.99
30	971	0.1113	180.43	0.123	3789.8	325.75


CRACK EXTENSION (in)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
UNLOADING COMPLIANCE MODIFIED ERNST RESULTS
CRACK LENGTH PINS: INITIAL
MEASURED FINAL CRACK EXTEN
J-INTEGRAL=K1*CRACK EXTEN^K2 MODEL
RESULTS EXCLUDED FROM MODEL
JIC
J-INTEGRAL (kJ/m2)
0
200
400
600
800
1000
1200
J-INTEGRAL (in-lb/in2)
0
1000
2000
3000
4000
5000
6000
SPECIMEN: 4BBH11
MATERIAL: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T), 20% SG
TEMP: 125°C/257°F
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
CRACK EXTENSION (mm)

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 1BBH11

SPECIMEN
  IDENTIFICATION: 1BBH11
  MATERIAL
    CODE: 304SS
    YOUNG'S MODULUS: 193.05 (GPA),28000 (KSI)
    POISSON'S RATIO: 0.3
    STRENGTHS
      YIELD: 448.16 (MPA),65 (KSI)
      ULTIMATE: 517.11 (MPA),75 (KSI)
  ORIENTATION: L-C
  GEOMETRY: C(T)
  WIDTH: 19.964 (MM),0.786 (IN)
  THICKNESS: 10.008 (MM),0.394 (IN)
  SIDE GROOVE: 20 (PERCENT)
  LOAD PIN CENTER SPAN: 9.804 (MM),0.386 (IN)
  EXTENSOMETER LOCATION: 0 (MM),0 (IN)
  PRECRACK CONDITIONS
    MAXIMUM LOAD: 1.779 (KN),400 (LB)
    FREQUENCY: 30 (HZ)
  FRONT-SURFACE-TO-LOAD-LINE DISTANCE: 4.991 (MM),0.1965 (IN)
  FRONT-SURFACE-TO-INITIAL-CRACK-FRONT DISTANCES
    DISTANCE 1: 16.473 (MM),0.6485 (IN)
    DISTANCE 2: 16.455 (MM),0.6478 (IN)
    DISTANCE 3: 16.307 (MM),0.642 (IN)
    DISTANCE 4: 16.134 (MM),0.6352 (IN)
    DISTANCE 5: 16.21 (MM),0.6382 (IN)
    DISTANCE 6: 16.133 (MM),0.6351 (IN)
    DISTANCE 7: 16.163 (MM),0.6363 (IN)
    DISTANCE 8: 16.103 (MM),0.634 (IN)
    DISTANCE 9: 15.948 (MM),0.6279 (IN)
  FRONT-SURFACE-TO-FINAL-CRACK-FRONT DISTANCES
    DISTANCE 1: 19.548 (MM),0.7696 (IN)
    DISTANCE 2: 19.094 (MM),0.7517 (IN)
    DISTANCE 3: 19.045 (MM),0.7498 (IN)
    DISTANCE 4: 19.089 (MM),0.7516 (IN)
    DISTANCE 5: 19.039 (MM),0.7496 (IN)
    DISTANCE 6: 18.892 (MM),0.7438 (IN)
    DISTANCE 7: 18.706 (MM),0.7365 (IN)
    DISTANCE 8: 18.324 (MM),0.7214 (IN)
    DISTANCE 9: 17.916 (MM),0.7053 (IN)
  MEASURED CRACK LENGTHS
    INITIAL: 11.223 (MM),0.4419 (IN)
    FINAL: 13.874 (MM),0.5462 (IN)
TEST
  ROUTINE REVISION: 1.02/07-JUL-88
  TYPE: UCJR
  ENGINEER: FMH
  TECHNICIAN: RLS
  TEST DATE: 05-MAR-93
  ATMOSPHERE: AIR
  TEMPERATURE: 125 (DEG C),257 (DEG F)
  REMARK: NONE
  DID SPECIMEN CLEAVE? NO
ANALYSIS
  ROUTINE REVISION: 1.10/06-MAR-90
  CRACK LENGTH PINS

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 1BBH11

UC
  INITIAL
    DETERMINATION TEST CYCLE: 1
    EFFECTIVE MODULUS: 207.72 (GPA),30128 (KSI)
    YOUNG'S MODULUS-EFFECTIVE MODULUS:-7.6 (PERCENT)
  FINAL
    PIN NOT APPLIED
UC RESULTS
  MEASURED FINAL CRACK EXTENSION: 2.651 (MM),0.1044 (IN)
  FINAL CRACK EXTENSION: 2.361 (MM),0.093 (IN)
  FINAL CRACK EXTENSION ERROR:-10.9 (PERCENT)
  PQ: 5.592 (KN),1257 (LB)
  KQ: 48.84 (MPA-SQRT(M)),44452 (KSI-SQRT(IN))
  KIC: NO VALID KIC FOR TEST
  PMX: 9.826 (KN),2209 (LB)
  KMX: 85.83 (MPA-SQRT(M)),78.11 (KSI-SQRT(IN))
  MODIFIED ERNST J-INTEGRAL
    PMX J-INTEGRAL: 158.38 (KJ/M^2),904.4 (IN-LB/IN^2)
    FINAL J-INTEGRAL: 994.52 (KJ/M^2),5678.8 (IN-LB/IN^2)
    FINAL KJ: 438.17 (MPA-SQRT(M)),398.76 (KSI-SQRT(IN))
    POWER-LAW MODEL [J-INTEGRAL=A0*CRACK EXTENSION^A1]
      A0: 594.19 (SI),23642 (ENGLISH)
      A1: 0.60014 (SI),0.60014 (ENGLISH)
      RESULTS EXCLUDED FROM MODEL: CYCLES 1,2,3,4,5,6,7,8,9,10,11,12,13,14,
      15,16,17,18 AND 19
    JIC: 477.51 (KJ/M^2),2726.6 (IN-LB/IN^2)
    KJIC: 303.62 (MPA-SQRT(M)),276.31 (KSI-SQRT(IN))
    TEARING MODULUS: 251

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 1BBH11

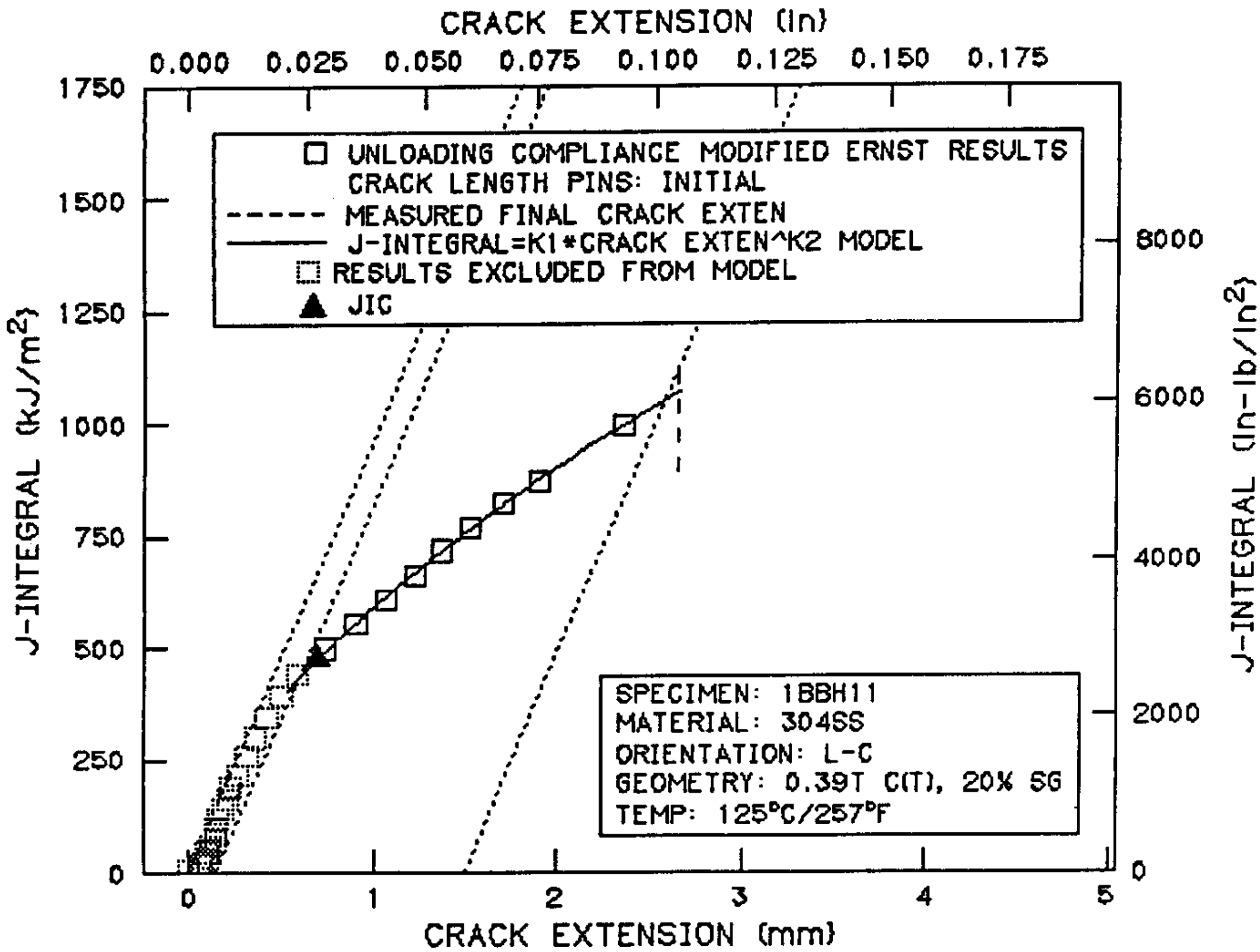
SPECIMEN
IDENTIFICATION: 1BBH11
MATERIAL CODE: 304SS
ORIENTATION: L-C
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 11.223 (MM),0.4419 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 125 (DEG C),257 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: MODIFIED ERNST

CYCLE	LOAD (KN)	DISPL (MM)	ENERGY (J)	CRACK EXTN (MM)	J-INTEGRAL (KJ/M^2)	KJ (MPA-SQRT(M))
1	4.329	0.115	0.26	-0.001	8.32	40.08
2	5.747	0.159	0.484	0.062	15.25	54.26
3	6.974	0.203	0.768	0.082	24.2	68.35
4	7.919	0.247	1.103	0.102	34.86	82.03
5	8.592	0.292	1.474	0.098	46.74	94.99
6	8.996	0.335	1.863	0.124	59.17	106.88
7	9.241	0.379	2.271	0.148	72.23	118.09
8	9.406	0.423	2.696	0.149	85.81	128.71
9	9.466	0.467	3.118	0.143	99.5	138.59
10	9.53	0.533	3.759	0.162	120.04	152.23
11	9.539	0.599	4.4	0.181	140.68	164.8
12	9.537	0.664	5.043	0.207	161.39	176.51
13	9.528	0.753	5.907	0.228	189.17	191.1
14	9.491	0.841	6.767	0.27	216.77	204.57
15	9.428	0.972	8.039	0.313	257.9	223.13
16	9.355	1.104	9.311	0.36	299.16	240.32
17	9.241	1.257	10.775	0.419	346.96	258.81
18	9.11	1.411	12.228	0.497	394.04	275.81
19	8.861	1.564	13.65	0.585	440.53	291.63
20	8.594	1.763	15.428	0.733	498.29	310.16
21	8.282	1.96	17.139	0.895	554.8	327.27
22	7.972	2.157	18.787	1.06	610.04	343.18
23	7.739	2.355	20.386	1.225	664.56	358.18
24	7.511	2.552	21.935	1.364	718.89	372.54
25	7.197	2.75	23.439	1.529	771.8	386
26	6.852	2.948	24.865	1.708	823.03	398.61
27	6.455	3.145	26.216	1.907	872.28	410.36
28	5.753	3.703	29.677	2.361	994.52	438.17

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 1BBH11

SPECIMEN
IDENTIFICATION: 1BBH11
MATERIAL CODE: 304SS
ORIENTATION: L-C
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 11.223 (MM),0.4419 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 125 (DEG C),257 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: MODIFIED ERNST

CYCLE	LOAD (LB)	DISPL (IN)	ENERGY (IN-LB)	CRACK EXTN (IN)	J-INTEGRAL (IN-LB/IN^2)	KJ (KSI-SQRT(IN))
1	973	0.0045	2.3	0	47.5	36.47
2	1292	0.0063	4.29	0.0025	87.1	49.38
3	1568	0.008	6.8	0.0032	138.2	62.21
4	1780	0.0097	9.76	0.004	199	74.65
5	1932	0.0115	13.05	0.0039	266.9	86.45
6	2022	0.0132	16.49	0.0049	337.9	97.27
7	2077	0.0149	20.1	0.0058	412.5	107.47
8	2114	0.0167	23.86	0.0059	490	117.13
9	2128	0.0184	27.59	0.0056	568.2	126.13
10	2142	0.021	33.27	0.0064	685.4	138.54
11	2144	0.0236	38.94	0.0071	803.3	149.98
12	2144	0.0262	44.63	0.0082	921.5	160.63
13	2142	0.0296	52.28	0.009	1080.2	173.91
14	2134	0.0331	59.89	0.0106	1237.8	186.17
15	2120	0.0383	71.15	0.0123	1472.6	203.06
16	2103	0.0435	82.41	0.0142	1708.2	218.7
17	2077	0.0495	95.36	0.0165	1981.2	235.53
18	2048	0.0555	108.23	0.0196	2250	251
19	1992	0.0616	120.81	0.023	2515.5	265.39
20	1932	0.0694	136.55	0.0289	2845.3	282.26
21	1862	0.0772	151.69	0.0352	3168	297.83
22	1792	0.0849	166.28	0.0417	3483.4	312.31
23	1740	0.0927	180.43	0.0482	3794.7	325.96
24	1688	0.1005	194.14	0.0537	4105	339.03
25	1618	0.1083	207.45	0.0602	4407.1	351.28
26	1540	0.1161	220.07	0.0672	4699.6	362.75
27	1451	0.1238	232.04	0.0751	4980.8	373.45
28	1293	0.1458	262.66	0.093	5678.8	398.76


CRACK EXTENSION (in)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
1750
1500
1250
1000
750
500
250
0
J-INTEGRAL (kJ/m2)
UNLOADING COMPLIANCE MODIFIED ERNST RESULTS
CRACK LENGTH PINS: INITIAL
MEASURED FINAL CRACK EXTEN
J-INTEGRAL=K1*CRACK EXTEN^K2 MODEL
RESULTS EXCLUDED FROM MODEL
JIC
8000
6000
4000
2000
0
J-INTEGRAL (in-lb/in2)
SPECIMEN: 1BBH11
MATERIAL: 304SS
ORIENTATION: L-C
GEOMETRY: 0.39T C(T), 20% SG
TEMP: 125°C/257°F
0
1
2
3
4
5
CRACK EXTENSION (mm)

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 7HAH6

SPECIMEN
  IDENTIFICATION: 7HAH6
  MATERIAL
    CODE: 304SS
    YOUNG'S MODULUS: 193.05 (GPA),28000 (KSI)
    POISSON'S RATIO: 0.3
    STRENGTHS
      YIELD: 413.69 (MPA),60 (KSI)
      ULTIMATE: 482.63 (MPA),70 (KSI)
  ORIENTATION: C-L
  GEOMETRY: C(T)
  WIDTH: 19.964 (MM),0.786 (IN)
  THICKNESS: 10.008 (MM),0.394 (IN)
  SIDE GROOVE: 20 (PERCENT)
  LOAD PIN CENTER SPAN: 9.804 (MM),0.386 (IN)
  EXTENSOMETER LOCATION: 0 (MM),0 (IN)
  PRECRACK CONDITIONS
    MAXIMUM LOAD: 1.779 (KN),400 (LB)
    FREQUENCY: 30 (HZ)
  FRONT-SURFACE-TO-LOAD-LINE DISTANCE: 4.991 (MM),0.1965 (IN)
  FRONT-SURFACE-TO-INITIAL-CRACK-FRONT DISTANCES
    DISTANCE 1: 15.839 (MM),0.6236 (IN)
    DISTANCE 2: 15.809 (MM),0.6224 (IN)
    DISTANCE 3: 15.819 (MM),0.6228 (IN)
    DISTANCE 4: 15.764 (MM),0.6206 (IN)
    DISTANCE 5: 15.636 (MM),0.6156 (IN)
    DISTANCE 6: 15.617 (MM),0.6148 (IN)
    DISTANCE 7: 15.591 (MM),0.6138 (IN)
    DISTANCE 8: 15.663 (MM),0.6167 (IN)
    DISTANCE 9: 15.737 (MM),0.6196 (IN)
  FRONT-SURFACE-TO-FINAL-CRACK-FRONT DISTANCES
    DISTANCE 1: 19.228 (MM),0.757 (IN)
    DISTANCE 2: 20.029 (MM),0.7885 (IN)
    DISTANCE 3: 20 (MM),0.7874 (IN)
    DISTANCE 4: 20.233 (MM),0.7966 (IN)
    DISTANCE 5: 20.261 (MM),0.7977 (IN)
    DISTANCE 6: 20.093 (MM),0.7911 (IN)
    DISTANCE 7: 19.658 (MM),0.7739 (IN)
    DISTANCE 8: 19.213 (MM),0.7564 (IN)
    DISTANCE 9: 18.526 (MM),0.7294 (IN)
  MEASURED CRACK LENGTHS
    INITIAL: 10.72 (MM),0.422 (IN)
    FINAL: 14.805 (MM),0.5828 (IN)
TEST
  ROUTINE REVISION: 1.02/07-JUL-88
  TYPE: UCJR
  ENGINEER: FMH
  TECHNICIAN: RLS
  TEST DATE: 05-MAR-93
  ATMOSPHERE: AIR
  TEMPERATURE: 125 (DEG C),257 (DEG F)
  REMARK: NONE
  DID SPECIMEN CLEAVE? NO
ANALYSIS
  ROUTINE REVISION: 1.10/06-MAR-90
  CRACK LENGTH PINS

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 7HAH6

SPECIMEN
IDENTIFICATION: 7HAH6
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 10.72 (MM),0.422 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 125 (DEG C),257 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: MODIFIED ERNST

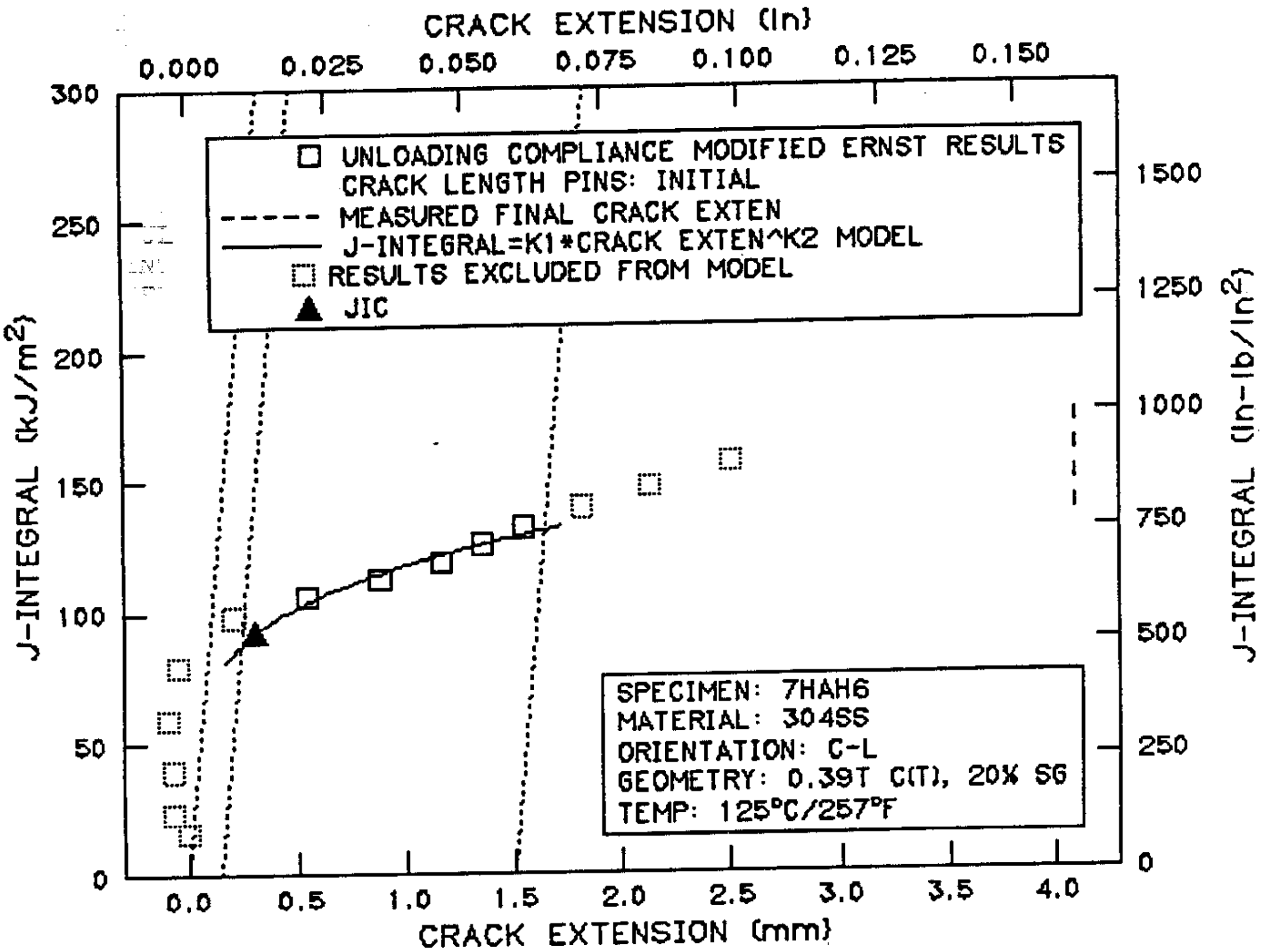
CYCLE	LOAD (KN)	DISPL (MM)	ENERGY (J)	CRACK EXTN (MM)	J-INTEGRAL (KJ/M^2)	KJ (MPA-SQRT(M))
1	6.334	0.16	0.528	0.001	16.04	55.64
2	7.432	0.193	0.755	-0.064	23.08	66.75
3	9.239	0.257	1.294	-0.063	39.38	87.19
4	10.458	0.321	1.937	-0.085	58.85	106.59
5	10.896	0.385	2.637	-0.043	79.63	123.99
6	10.164	0.449	3.333	0.21	98.35	137.79
7	8.515	0.48	3.651	0.54	106.02	143.06
8	7.631	0.513	3.92	0.876	112.64	147.46
9	7.208	0.545	4.167	1.162	119.24	151.72
10	6.878	0.577	4.399	1.36	125.96	155.94
11	6.419	0.609	4.618	1.551	132.6	159.99
12	5.798	0.647	4.865	1.816	139.86	164.32
13	5.171	0.694	5.133	2.135	147.85	168.95
14	4.768	0.755	5.441	2.51	156.58	173.86

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 7HAH6

SPECIMEN
IDENTIFICATION: 7HAH6
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 10.72 (MM),0.422 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 125 (DEG C),257 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: MODIFIED ERNST

CYCLE	LOAD (LB)	DISPL (IN)	ENERGY (IN-LB)	CRACK EXTN (IN)	J-INTEGRAL (IN-LB/IN^2)	KJ (KSI-SQRT(IN))
1	1424	0.0063	4.67	0	91.6	50.64
2	1671	0.0076	6.68	-0.0025	131.8	60.75
3	2077	0.0101	11.46	-0.0025	224.9	79.35
4	2351	0.0126	17.15	-0.0034	336	97
5	2449	0.0151	23.34	-0.0017	454.7	112.84
6	2285	0.0177	29.5	0.0083	561.6	125.4
7	1914	0.0189	32.31	0.0213	605.4	130.2
8	1715	0.0202	34.69	0.0345	643.2	134.2
9	1620	0.0215	36.88	0.0457	680.9	138.07
10	1546	0.0227	38.93	0.0535	719.2	141.91
11	1443	0.024	40.88	0.0611	757.1	145.6
12	1303	0.0255	43.06	0.0715	798.6	149.54
13	1163	0.0273	45.43	0.0841	844.2	153.75
14	1072	0.0297	48.16	0.0988	894.1	158.22

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 7HAH6



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SPECIMEN
  IDENTIFICATION: 7WH4
  MATERIAL
    CODE: 304SS
    YOUNG'S MODULUS: 193.05 (GPA),28000 (KSI)
    POISSON'S RATIO: 0.3
    STRENGTHS
      YIELD: 393 (MPA),57 (KSI)
      ULTIMATE: 448.16 (MPA),65 (KSI)
  ORIENTATION: C-L
  GEOMETRY: C(T)
  WIDTH: 19.964 (MM),0.786 (IN)
  THICKNESS: 10.008 (MM),0.394 (IN)
  SIDE GROOVE: 20 (PERCENT)
  LOAD PIN CENTER SPAN: 9.804 (MM),0.386 (IN)
  EXTENSOMETER LOCATION: 0 (MM),0 (IN)
  PRECRACK CONDITIONS
    MAXIMUM LOAD: 1.779 (KN),400 (LB)
    FREQUENCY: 30 (HZ)
  FRONT-SURFACE-TO-LOAD-LINE DISTANCE: 4.991 (MM),0.1965 (IN)
  FRONT-SURFACE-TO-INITIAL-CRACK-FRONT DISTANCES
    DISTANCE 1: 16.036 (MM),0.6313 (IN)
    DISTANCE 2: 16.337 (MM),0.6432 (IN)
    DISTANCE 3: 16.539 (MM),0.6512 (IN)
    DISTANCE 4: 16.743 (MM),0.6592 (IN)
    DISTANCE 5: 16.765 (MM),0.66 (IN)
    DISTANCE 6: 16.884 (MM),0.6647 (IN)
    DISTANCE 7: 16.815 (MM),0.662 (IN)
    DISTANCE 8: 16.921 (MM),0.6662 (IN)
    DISTANCE 9: 16.677 (MM),0.6566 (IN)
  FRONT-SURFACE-TO-FINAL-CRACK-FRONT DISTANCES
    DISTANCE 1: 19.848 (MM),0.7814 (IN)
    DISTANCE 2: 20.058 (MM),0.7897 (IN)
    DISTANCE 3: 20.176 (MM),0.7943 (IN)
    DISTANCE 4: 20.451 (MM),0.8052 (IN)
    DISTANCE 5: 20.668 (MM),0.8137 (IN)
    DISTANCE 6: 20.776 (MM),0.818 (IN)
    DISTANCE 7: 20.711 (MM),0.8154 (IN)
    DISTANCE 8: 20.694 (MM),0.8147 (IN)
    DISTANCE 9: 20.893 (MM),0.8226 (IN)
  MEASURED CRACK LENGTHS
    INITIAL: 11.679 (MM),0.4598 (IN)
    FINAL: 15.497 (MM),0.6101 (IN)
TEST
  ROUTINE REVISION: 1.02/07-JUL-88
  TYPE: UCJR
  ENGINEER: FMH
  TECHNICIAN: RLS
  TEST DATE: 05-MAR-93
  ATMOSPHERE: AIR
  TEMPERATURE: 125 (DEG C),257 (DEG F)
  REMARK: NONE
  DID SPECIMEN CLEAVE? NO
ANALYSIS
  ROUTINE REVISION: 1.10/06-MAR-90
  CRACK LENGTH PINS
```

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 7WH4

UC
INITIAL
DETERMINATION TEST CYCLE: 1
EFFECTIVE MODULUS: 234.96 (GPA),34078 (KSI)
YOUNG'S MODULUS-EFFECTIVE MODULUS:-21.7 (PERCENT)
FINAL
PIN NOT APPLIED
UC RESULTS
MEASURED FINAL CRACK EXTENSION: 3.818 (MM),0.1503 (IN)
FINAL CRACK EXTENSION: 2.481 (MM),0.0977 (IN)
FINAL CRACK EXTENSION ERROR:-35 (PERCENT)
PQ: 4.838 (KN),1088 (LB)
KQ: 45.93 (MPA-SQRT(M)),41803 (KSI-SQRT(IN))
KIC: NO VALID KIC FOR TEST
PMX: 11.882 (KN),2671 (LB)
KMX: 112.82 (MPA-SQRT(M)),102.68 (KSI-SQRT(IN))
MODIFIED ERNST J-INTEGRAL
PMX J-INTEGRAL: 175.75 (KJ/M^2),1003.6 (IN-LB/IN^2)
FINAL J-INTEGRAL: 869.2 (KJ/M^2),4963.3 (IN-LB/IN^2)
FINAL KJ: 409.64 (MPA-SQRT(M)),372.79 (KSI-SQRT(IN))
POWER-LAW MODEL [J-INTEGRAL=A0*CRACK EXTENSION^A1]
A0: 527.13 (SI),20360 (ENGLISH)
A1: 0.59095 (SI),0.59095 (ENGLISH)
RESULTS EXCLUDED FROM MODEL: CYCLES 1,2,3,4,5,6,7,8,9,10,11,12 AND 14
JIC: 431.72 (KJ/M^2),2465.2 (IN-LB/IN^2)
KJIC: 288.7 (MPA-SQRT(M)),262.73 (KSI-SQRT(IN))
TEARING MODULUS: 286

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 7WH4

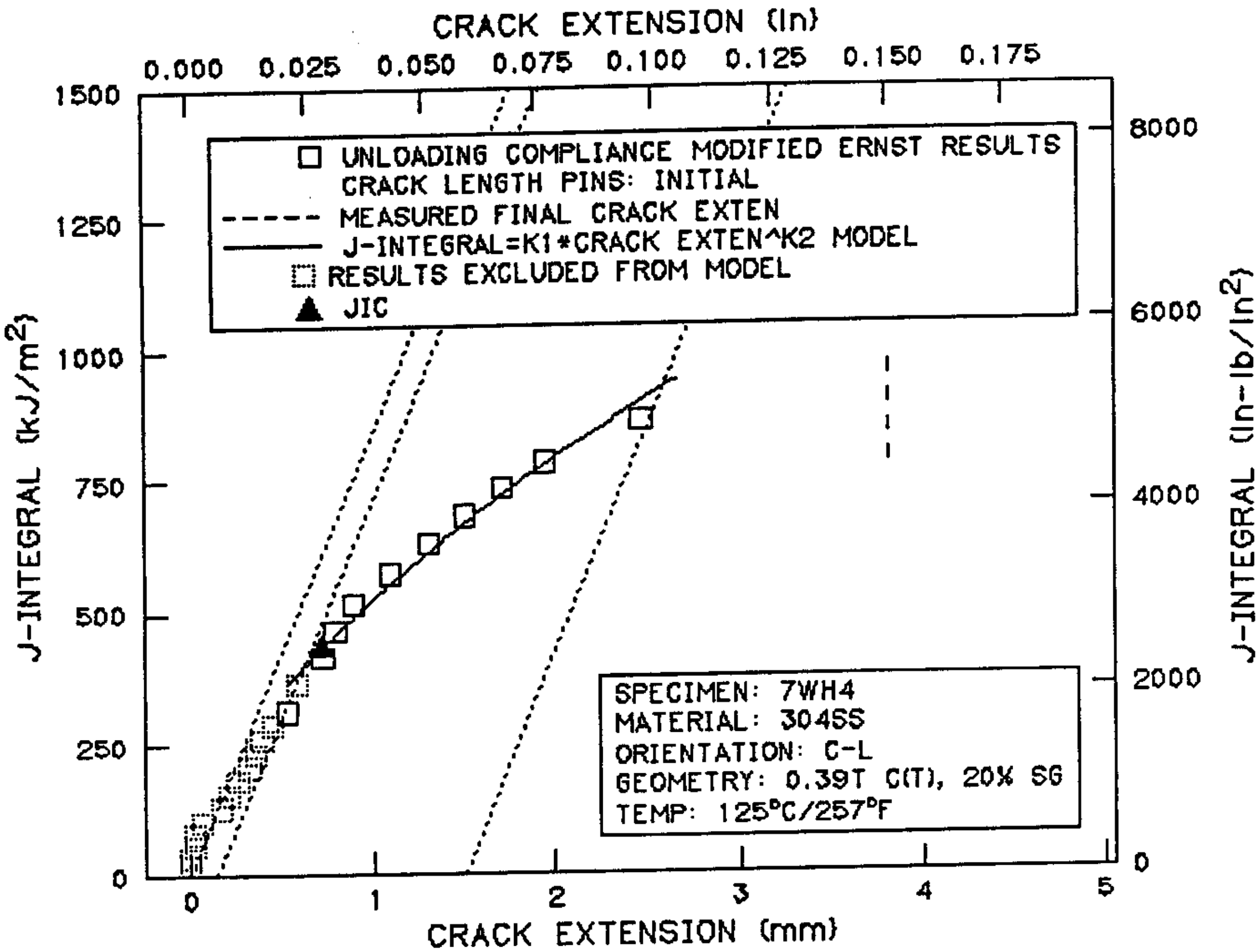
SPECIMEN
IDENTIFICATION: 7WH4
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 11.679 (MM),0.4598 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 125 (DEG C),257 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: MODIFIED ERNST

CYCLE	LOAD (KN)	DISPL (MM)	ENERGY (J)	CRACK EXTN (MM)	J-INTEGRAL (KJ/M^2)	KJ (MPA-SQRT(M))
1	6.293	0.165	0.542	-0.002	18.13	59.16
2	8.292	0.231	1.028	0.002	34.46	81.57
3	9.811	0.298	1.643	0.027	54.7	102.77
4	10.825	0.364	2.344	0.022	78.29	122.94
5	11.341	0.431	3.101	0.07	103.04	141.04
6	11.466	0.498	3.884	0.167	127.89	157.13
7	11.543	0.565	4.668	0.216	153.97	172.41
8	11.566	0.632	5.456	0.257	180.35	186.59
9	11.537	0.698	6.244	0.325	206.36	199.59
10	11.493	0.765	7.029	0.361	232.97	212.08
11	11.422	0.832	7.812	0.39	259.82	223.96
12	11.314	0.898	8.585	0.451	286.03	234.99
13	11.191	0.965	9.359	0.53	311.86	245.37
14	10.97	1.098	10.87	0.58	364.67	265.33
15	10.671	1.231	12.357	0.723	414.71	282.95
16	10.436	1.365	13.804	0.791	465.86	299.89
17	10.174	1.498	15.218	0.893	515.64	315.51
18	9.667	1.664	16.92	1.09	574.4	333
19	9.089	1.83	18.52	1.298	630.8	348.97
20	8.493	1.997	20.031	1.504	685.42	363.76
21	7.965	2.164	21.447	1.719	737.58	377.35
22	7.294	2.33	22.757	1.951	786.99	389.78
23	6.256	2.668	25.067	2.481	869.2	409.64

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 7WH4

SPECIMEN
  IDENTIFICATION: 7WH4
  MATERIAL CODE: 304SS
  ORIENTATION: C-L
  GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
  INITIAL CRACK LENGTH: 11.679 (MM),0.4598 (IN)
TEST
  ATMOSPHERE: AIR
  TEMPERATURE: 125 (DEG C),257 (DEG F)
ANALYSIS
  CRACK LENGTH PINS: INITIAL
  CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
  J-INTEGRAL METHOD: MODIFIED ERNST

CYCLE	LOAD (LB)	DISPL (IN)	ENERGY (IN-LB)	CRACK EXTN (IN)	J-INTEGRAL (IN-LB/IN^2)	KJ (KSI-SQRT(IN),
1	1415	0.0065	4.8	-0.0001	103.5	53.84
2	1864	0.0091	9.1	0.0001	196.8	74.23
3	2206	0.0117	14.55	0.0011	312.4	93.52
4	2434	0.0143	20.74	0.0009	447.1	111.88
5	2550	0.017	27.45	0.0027	588.4	128.35
6	2578	0.0196	34.38	0.0066	730.3	142.99
7	2595	0.0222	41.31	0.0085	879.2	156.9
8	2600	0.0249	48.29	0.0101	1029.8	169.81
9	2594	0.0275	55.26	0.0128	1178.3	181.64
10	2584	0.0301	62.21	0.0142	1330.3	193
11	2568	0.0327	69.14	0.0153	1483.6	203.82
12	2544	0.0354	75.99	0.0177	1633.3	213.85
13	2516	0.038	82.83	0.0209	1780.8	223.3
14	2466	0.0432	96.21	0.0228	2082.3	241.46
15	2399	0.0485	109.37	0.0285	2368	257.5
16	2346	0.0537	122.17	0.0311	2660.1	272.92
17	2287	0.059	134.69	0.0352	2944.4	287.13
18	2173	0.0655	149.76	0.0429	3279.9	303.05
19	2043	0.0721	163.91	0.0511	3602	317.58
20	1909	0.0786	177.29	0.0592	3913.8	331.04
21	1791	0.0852	189.82	0.0677	4211.7	343.41
22	1640	0.0917	201.42	0.0768	4493.8	354.72
23	1406	0.105	221.86	0.0977	4963.3	372.79


CRACK EXTENSION (In)
0.000 0.025 0.050 0.075 0.100 0.125 0.150 0.175
1500
1250
1000
750
500
250
0
8000
6000
4000
2000
0
UNLOADING COMPLIANCE MODIFIED ERNST RESULTS
CRACK LENGTH PINS: INITIAL
MEASURED FINAL CRACK EXTEN
J-INTEGRAL=K1*CRACK EXTEN^K2 MODEL
RESULTS EXCLUDED FROM MODEL
JIC
J-INTEGRAL (kJ/m2)
J-INTEGRAL (In-lb/In2)
SPECIMEN: 7WH4
MATERIAL: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T), 20% SG
TEMP: 125°C/257°F
0 1 2 3 4 5
CRACK EXTENSION (mm)

SPECIMEN
  IDENTIFICATION: 1BBH18
  MATERIAL
    CODE: 304SS
    YOUNG'S MODULUS: 193.05 (GPA),28000 (KSI)
    POISSON'S RATIO: 0.3
    STRENGTHS
      YIELD: 620.53 (MPA),90 (KSI)
      ULTIMATE: 717.05 (MPA),104 (KSI)
  ORIENTATION: C-L
  GEOMETRY: C(T)
  WIDTH: 19.964 (MM),0.786 (IN)
  THICKNESS: 10.008 (MM),0.394 (IN)
  SIDE GROOVE: 20 (PERCENT)
  LOAD PIN CENTER SPAN: 9.804 (MM),0.386 (IN)
  EXTENSOMETER LOCATION: 0 (MM),0 (IN)
  PRECRACK CONDITIONS
    MAXIMUM LOAD: 1.779 (KN),400 (LB)
    FREQUENCY: 30 (HZ)
  FRONT-SURFACE-TO-LOAD-LINE DISTANCE: 4.991 (MM),0.1965 (IN)
  FRONT-SURFACE-TO-INITIAL-CRACK-FRONT DISTANCES
    DISTANCE 1: 16.094 (MM),0.6336 (IN)
    DISTANCE 2: 16.237 (MM),0.6393 (IN)
    DISTANCE 3: 16.208 (MM),0.6381 (IN)
    DISTANCE 4: 16.167 (MM),0.6365 (IN)
    DISTANCE 5: 16.049 (MM),0.6318 (IN)
    DISTANCE 6: 15.94 (MM),0.6276 (IN)
    DISTANCE 7: 15.748 (MM),0.62 (IN)
    DISTANCE 8: 15.682 (MM),0.6174 (IN)
    DISTANCE 9: 15.411 (MM),0.6067 (IN)
  FRONT-SURFACE-TO-FINAL-CRACK-FRONT DISTANCES
    DISTANCE 1: 20.076 (MM),0.7904 (IN)
    DISTANCE 2: 19.071 (MM),0.7508 (IN)
    DISTANCE 3: 17.473 (MM),0.6879 (IN)
    DISTANCE 4: 17.739 (MM),0.6984 (IN)
    DISTANCE 5: 19.824 (MM),0.7805 (IN)
    DISTANCE 6: 20.586 (MM),0.8105 (IN)
    DISTANCE 7: 19.957 (MM),0.7857 (IN)
    DISTANCE 8: 19.277 (MM),0.759 (IN)
    DISTANCE 9: 18.044 (MM),0.7104 (IN)
  MEASURED CRACK LENGTHS
    INITIAL: 10.982 (MM),0.4324 (IN)
    FINAL: 14.132 (MM),0.5564 (IN)
TEST
  ROUTINE REVISION: 1.02/07-JUL-88
  TYPE: UCJR
  ENGINEER: FMH
  TECHNICIAN: RLS
  TEST DATE: 04-MAR-93
  ATMOSPHERE: AIR
  TEMPERATURE: 25 (DEG C),77 (DEG F)
  REMARK: NONE
  DID SPECIMEN CLEAVE? NO
ANALYSIS
  ROUTINE REVISION: 1.10/06-MAR-90
  CRACK LENGTH PINS

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 1BBH18

UC
  INITIAL
    DETERMINATION TEST CYCLE: 1
    EFFECTIVE MODULUS: 183.38 (GPA),26597 (KSI)
    YOUNG'S MODULUS-EFFECTIVE MODULUS: 5 (PERCENT)
  FINAL
    PIN NOT APPLIED
UC RESULTS
  MEASURED FINAL CRACK EXTENSION: 3.151 (MM),0.124 (IN)
  FINAL CRACK EXTENSION: 2.449 (MM),0.0964 (IN)
  FINAL CRACK EXTENSION ERROR:-22.3 (PERCENT)
  PQ: 6.012 (KN),1352 (LB)
  KQ: 50.34 (MPA-SQRT(M)),45812 (KSI-SQRT(IN))
  KIC: NO VALID KIC FOR TEST
  PMX: 11.361 (KN),2554 (LB)
  KMX: 95.13 (MPA-SQRT(M)),86.57 (KSI-SQRT(IN))
  MODIFIED ERNST J-INTEGRAL
    PMX J-INTEGRAL: 117.52 (KJ/M^2),671 (IN-LB/IN^2)
    FINAL J-INTEGRAL: 595.05 (KJ/M^2),3397.8 (IN-LB/IN^2)
    FINAL KJ: 338.93 (MPA-SQRT(M)),308.45 (KSI-SQRT(IN))
    POWER-LAW MODEL [J-INTEGRAL=A0*CRACK EXTENSION^A1]
      A0: 354.09 (SI),13722 (ENGLISH)
      A1: 0.59198 (SI),0.59198 (ENGLISH)
      RESULTS EXCLUDED FROM MODEL: CYCLES 1,2,3,4,5,6,7,8,20 AND 21
    JIC: 186.89 (KJ/M^2),1067.2 (IN-LB/IN^2)
    KJIC: 189.95 (MPA-SQRT(M)),172.86 (KSI-SQRT(IN))
    TEARING MODULUS: 91.7

SPECIMEN
IDENTIFICATION: 1BBH18
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 10.982 (MM),0.4324 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 25 (DEG C),77 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: MODIFIED ERNST

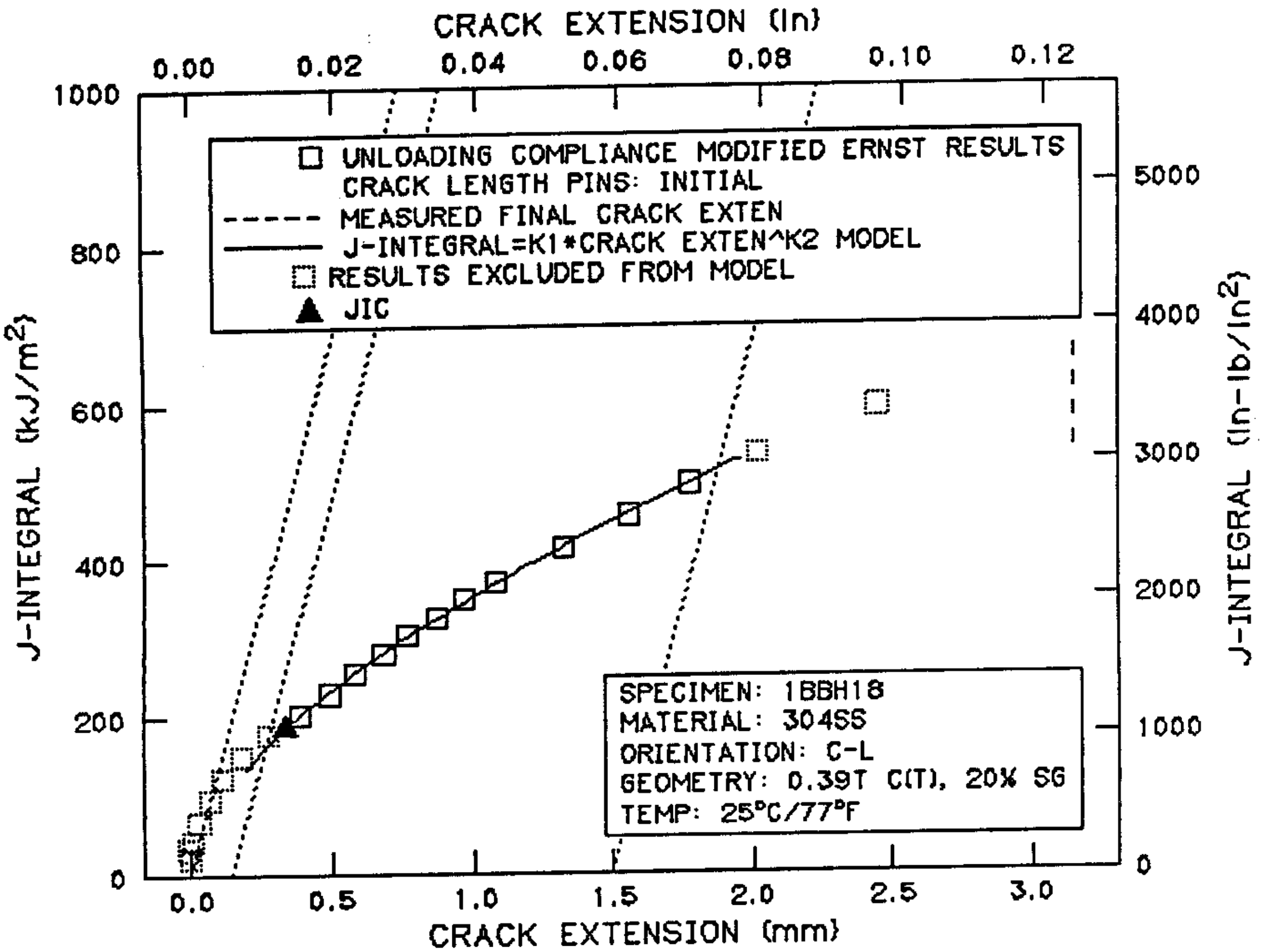
CYCLE	LOAD (KN)	DISPL (MM)	ENERGY (J)	CRACK EXTN (MM)	J-INTEGRAL (KJ/M^2)	KJ (MPA-SQRT(M))
1	7	0.201	0.73	0	22.79	66.33
2	8.114	0.243	1.045	-0.011	32.49	79.2
3	9.018	0.283	1.395	0.008	43.37	91.51
4	10.227	0.364	2.197	0.028	68.07	114.63
5	10.793	0.445	3.072	0.07	94.78	135.27
6	10.921	0.526	3.982	0.113	122.79	153.97
7	10.795	0.607	4.893	0.182	150.64	170.53
8	10.418	0.689	5.79	0.279	177.74	185.24
9	10.095	0.77	6.646	0.393	203.84	198.37
10	9.727	0.851	7.472	0.497	229.46	210.47
11	9.459	0.933	8.282	0.578	254.86	221.82
12	9.192	1.014	9.063	0.681	279.42	232.25
13	8.882	1.095	9.82	0.763	303.86	242.2
14	8.639	1.176	10.555	0.866	327.42	251.42
15	8.425	1.258	11.274	0.962	350.91	260.28
16	8.132	1.338	11.963	1.079	373.48	268.52
17	7.557	1.501	13.292	1.321	416.34	283.51
18	7.086	1.663	14.525	1.554	457.2	297.09
19	6.633	1.825	15.675	1.777	496.61	309.63
20	6.189	1.987	16.755	2.02	534.28	321.16
21	5.459	2.284	18.537	2.449	595.05	338.93

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 1BBH18

SPECIMEN
IDENTIFICATION: 1BBH18
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 10.982 (MM),0.4324 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 25 (DEG C),77 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: MODIFIED ERNST

CYCLE	LOAD (LB)	DISPL (IN)	ENERGY (IN-LB)	CRACK EXTN (IN)	J-INTEGRAL (IN-LB/IN^2)	KJ (KSI-SQRT(IN))
1	1574	0.0079	6.46	0	130.1	60.36
2	1824	0.0096	9.25	-0.0004	185.6	72.08
3	2027	0.0111	12.35	0.0003	247.7	83.28
4	2299	0.0143	19.45	0.0011	388.7	104.32
5	2426	0.0175	27.19	0.0028	541.2	123.1
6	2455	0.0207	35.24	0.0044	701.2	140.12
7	2427	0.0239	43.31	0.0071	860.2	155.19
8	2342	0.0271	51.24	0.011	1014.9	168.58
9	2269	0.0303	58.82	0.0155	1163.9	180.53
10	2187	0.0335	66.13	0.0196	1310.2	191.54
11	2127	0.0367	73.31	0.0228	1455.3	201.86
12	2066	0.0399	80.21	0.0268	1595.5	211.36
13	1997	0.0431	86.92	0.03	1735.1	220.42
14	1942	0.0463	93.42	0.0341	1869.6	228.8
15	1894	0.0495	99.79	0.0379	2003.7	236.86
16	1828	0.0527	105.88	0.0425	2132.6	244.36
17	1699	0.0591	117.64	0.052	2377.4	258.01
18	1593	0.0655	128.56	0.0612	2610.7	270.37
19	1491	0.0719	138.74	0.0699	2835.7	281.78
20	1391	0.0782	148.29	0.0795	3050.8	292.27
21	1227	0.0899	164.06	0.0964	3397.8	308.45

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 1BBH18



COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 4BBH12

SPECIMEN
  IDENTIFICATION: 4BBH12
  MATERIAL
    CODE: 304SS
    YOUNG'S MODULUS: 193.05 (GPA),28000 (KSI)
    POISSON'S RATIO: 0.3
    STRENGTHS
      YIELD: 448.16 (MPA),65 (KSI)
      ULTIMATE: 517.11 (MPA),75 (KSI)
  ORIENTATION: C-L
  GEOMETRY: C(T)
  WIDTH: 19.964 (MM),0.786 (IN)
  THICKNESS: 10.008 (MM),0.394 (IN)
  SIDE GROOVE: 20 (PERCENT)
  LOAD PIN CENTER SPAN: 9.804 (MM),0.386 (IN)
  EXTENSOMETER LOCATION: 0 (MM),0 (IN)
  PRECRACK CONDITIONS
    MAXIMUM LOAD: 1.779 (KN),400 (LB)
    FREQUENCY: 30 (HZ)
  FRONT-SURFACE-TO-LOAD-LINE DISTANCE: 4.991 (MM),0.1965 (IN)
  FRONT-SURFACE-TO-INITIAL-CRACK-FRONT DISTANCES
    DISTANCE 1: 15.865 (MM),0.6246 (IN)
    DISTANCE 2: 15.974 (MM),0.6289 (IN)
    DISTANCE 3: 16.034 (MM),0.6313 (IN)
    DISTANCE 4: 16.012 (MM),0.6304 (IN)
    DISTANCE 5: 16.033 (MM),0.6312 (IN)
    DISTANCE 6: 16.03 (MM),0.6311 (IN)
    DISTANCE 7: 16.016 (MM),0.6306 (IN)
    DISTANCE 8: 16.037 (MM),0.6314 (IN)
    DISTANCE 9: 16.227 (MM),0.6389 (IN)
  FRONT-SURFACE-TO-FINAL-CRACK-FRONT DISTANCES
    DISTANCE 1: 19.661 (MM),0.7741 (IN)
    DISTANCE 2: 19.513 (MM),0.7682 (IN)
    DISTANCE 3: 19.657 (MM),0.7739 (IN)
    DISTANCE 4: 19.78 (MM),0.7787 (IN)
    DISTANCE 5: 19.906 (MM),0.7837 (IN)
    DISTANCE 6: 19.867 (MM),0.7822 (IN)
    DISTANCE 7: 19.596 (MM),0.7715 (IN)
    DISTANCE 8: 19.144 (MM),0.7537 (IN)
    DISTANCE 9: 18.886 (MM),0.7435 (IN)
  MEASURED CRACK LENGTHS
    INITIAL: 11.032 (MM),0.4343 (IN)
    FINAL: 14.601 (MM),0.5748 (IN)
TEST
  ROUTINE REVISION: 1.02/07-JUL-88
  TYPE: UCJR
  ENGINEER: FMH
  TECHNICIAN: RLS
  TEST DATE: 05-MAR-93
  ATMOSPHERE: AIR
  TEMPERATURE: 125 (DEG C),257 (DEG F)
  REMARK: NONE
  DID SPECIMEN CLEAVE? NO
ANALYSIS
  ROUTINE REVISION: 1.10/06-MAR-90
  CRACK LENGTH PINS

```
    UC
      INITIAL
        DETERMINATION TEST CYCLE: 1
        EFFECTIVE MODULUS: 195.4 (GPA),28341 (KSI)
        YOUNG'S MODULUS-EFFECTIVE MODULUS:-1.2 (PERCENT)
      FINAL
        PIN NOT APPLIED
  UC RESULTS
    MEASURED FINAL CRACK EXTENSION: 3.569 (MM),0.1405 (IN)
    FINAL CRACK EXTENSION: 2.723 (MM),0.1072 (IN)
    FINAL CRACK EXTENSION ERROR:-23.7 (PERCENT)
    PQ: 6.77 (KN),1522 (LB)
    KQ: 57.18 (MPA-SQRT(M)),52038 (KSI-SQRT(IN))
    KIC: NO VALID KIC FOR TEST
    PMX: 11.568 (KN),2601 (LB)
    KMX: 97.71 (MPA-SQRT(M)),88.92 (KSI-SQRT(IN))
    MODIFIED ERNST J-INTEGRAL
      PMX J-INTEGRAL: 132.18 (KJ/M^2),754.8 (IN-LB/IN^2)
      FINAL J-INTEGRAL: 489.38 (KJ/M^2),2794.4 (IN-LB/IN^2)
      FINAL KJ: 307.37 (MPA-SQRT(M)),279.72 (KSI-SQRT(IN))
      POWER-LAW MODEL [J-INTEGRAL=A0*CRACK EXTENSION^A1]
        A0: 302.93 (SI),7587 (ENGLISH)
        A1: 0.45703 (SI),0.45703 (ENGLISH)
        RESULTS EXCLUDED FROM MODEL: CYCLES 1,2,3,4,5,13,14 AND 15
      JIC: 201.18 (KJ/M^2),1148.8 (IN-LB/IN^2)
      KJIC: 197.07 (MPA-SQRT(M)),179.35 (KSI-SQRT(IN))
      TEARING MODULUS: 113
```

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 4BBH12

SPECIMEN
IDENTIFICATION: 4BBH12
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 11.032 (MM),0.4343 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 125 (DEG C),257 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: MODIFIED ERNST

CYCLE	LOAD (KN)	DISPL (MM)	ENERGY (J)	CRACK EXTN (MM)	J-INTEGRAL (KJ/M^2)	KJ (MPA-SQRT(M))
1	9.029	0.275	1.345	0	42.13	90.18
2	10.719	0.387	2.481	-0.017	77.57	122.37
3	11.287	0.498	3.729	0.037	115.91	149.59
4	11.17	0.609	5.013	0.15	154.48	172.69
5	10.649	0.72	6.248	0.323	191.42	192.24
6	10.214	0.831	7.437	0.51	227.26	209.46
7	9.207	0.942	8.562	0.733	261.37	224.63
8	8.542	1.053	9.568	0.931	292.84	237.77
9	8.117	1.164	10.513	1.196	322.29	249.44
10	7.645	1.276	11.416	1.379	352.19	260.75
11	7.179	1.387	12.259	1.66	379.32	270.61
12	6.858	1.498	13.054	1.855	406.98	280.3
13	6.408	1.608	13.81	2.067	433.57	289.31
14	5.912	1.719	14.513	2.322	458.43	297.49
15	5.134	1.88	15.421	2.723	489.38	307.37

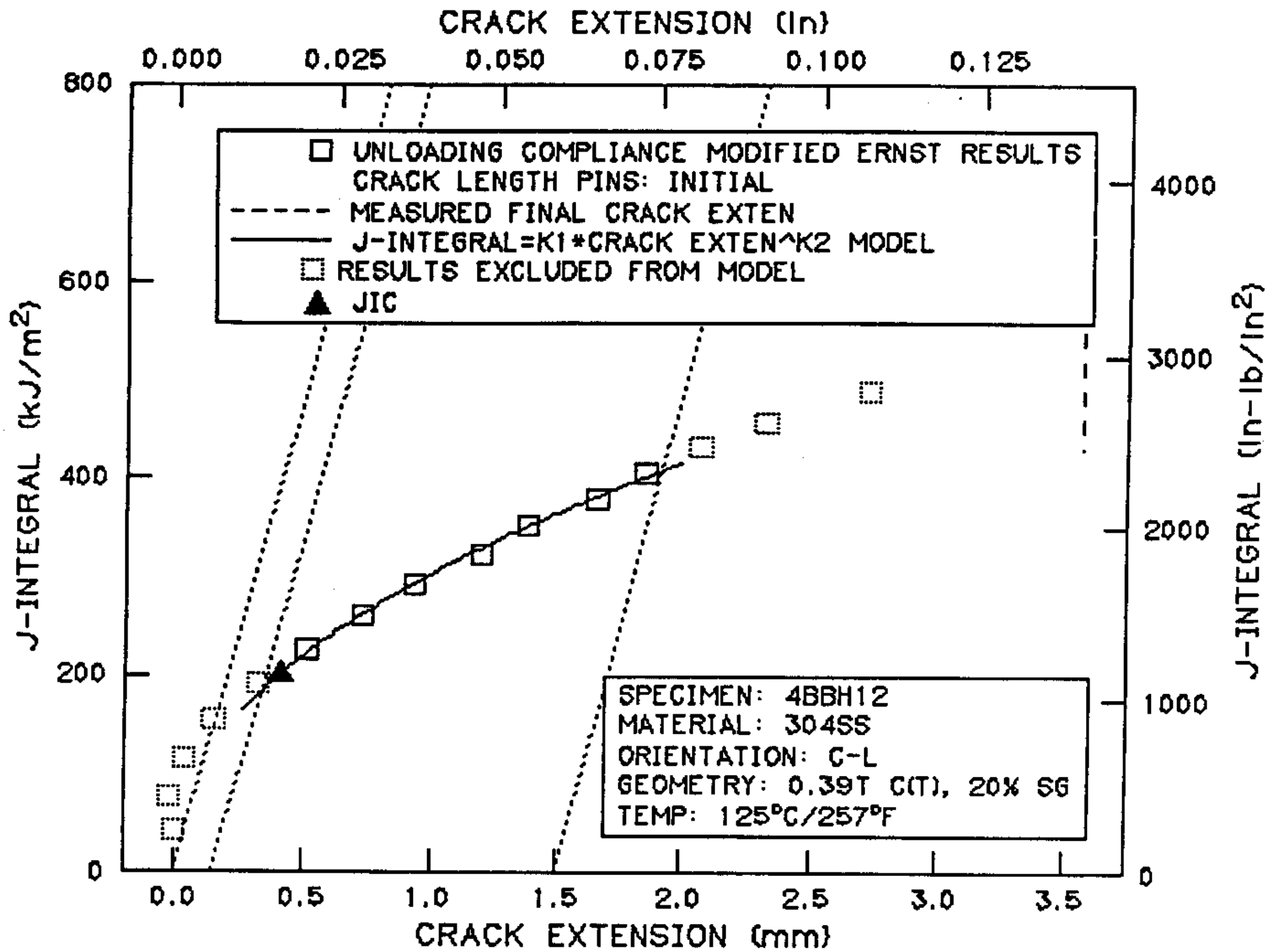
COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 4BBH12

SPECIMEN
IDENTIFICATION: 4BBH12
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 11.032 (MM),0.4343 (IN)

TEST
ATMOSPHERE: AIR
TEMPERATURE: 125 (DEG C),257 (DEG F)

ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: MODIFIED ERNST

CYCLE	LOAD (LB)	DISPL (IN)	ENERGY (IN-LB)	CRACK EXTN (IN)	J-INTEGRAL (IN-LB/IN^2)	KJ (KSI-SQRT(IN
1	2030	0.0108	11.9	0	240.5	82.07
2	2410	0.0152	21.95	-0.0007	442.9	111.36
3	2537	0.0196	33	0.0014	661.9	136.13
4	2511	0.024	44.37	0.0059	882.1	157.16
5	2394	0.0283	55.3	0.0127	1093	174.94
6	2296	0.0327	65.83	0.0201	1297.7	190.62
7	2070	0.0371	75.78	0.0288	1492.4	204.42
8	1920	0.0415	84.68	0.0367	1672.2	216.38
9	1825	0.0458	93.05	0.0471	1840.3	227
10	1719	0.0502	101.04	0.0543	2011	237.3
11	1614	0.0546	108.5	0.0654	2166	246.27
12	1542	0.059	115.53	0.073	2323.9	255.09
13	1441	0.0633	122.23	0.0814	2475.7	263.29
14	1329	0.0677	128.45	0.0914	2617.7	270.73
15	1154	0.074	136.49	0.1072	2794.4	279.72


CRACK EXTENSION (in)
0.000
0.025
0.050
0.075
0.100
0.125
UNLOADING COMPLIANCE MODIFIED ERNST RESULTS
CRACK LENGTH PINS: INITIAL
MEASURED FINAL CRACK EXTEN
J-INTEGRAL=K1*CRACK EXTEN^K2 MODEL
RESULTS EXCLUDED FROM MODEL
JIC
SPECIMEN: 4BBH12
MATERIAL: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T), 20% SG
TEMP: 125°C/257°F
J-INTEGRAL (kJ/m²)
0
200
400
600
800
J-INTEGRAL (in-lb/in²)
0
1000
2000
3000
4000
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
CRACK EXTENSION (mm)

```
COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 7WH3

SPECIMEN
  IDENTIFICATION: 7WH3
  MATERIAL
    CODE: 304SS
    YOUNG'S MODULUS: 193.05 (GPA),28000 (KSI)
    POISSON'S RATIO: 0.3
    STRENGTHS
      YIELD: 586.05 (MPA),85 (KSI)
      ULTIMATE: 717.05 (MPA),104 (KSI)
  ORIENTATION: C-L
  GEOMETRY: C(T)
  WIDTH: 19.964 (MM),0.786 (IN)
  THICKNESS: 10.008 (MM),0.394 (IN)
  SIDE GROOVE: 20 (PERCENT)
  LOAD PIN CENTER SPAN: 9.804 (MM),0.386 (IN)
  EXTENSOMETER LOCATION: 0 (MM),0 (IN)
  PRECRACK CONDITIONS
    MAXIMUM LOAD: 1.779 (KN),400 (LB)
    FREQUENCY: 30 (HZ)
  FRONT-SURFACE-TO-LOAD-LINE DISTANCE: 4.991 (MM),0.1965 (IN)
  FRONT-SURFACE-TO-INITIAL-CRACK-FRONT DISTANCES
    DISTANCE 1: 14.57 (MM),0.5736 (IN)
    DISTANCE 2: 14.682 (MM),0.5781 (IN)
    DISTANCE 3: 14.71 (MM),0.5792 (IN)
    DISTANCE 4: 14.853 (MM),0.5848 (IN)
    DISTANCE 5: 14.936 (MM),0.588 (IN)
    DISTANCE 6: 14.989 (MM),0.5901 (IN)
    DISTANCE 7: 15.024 (MM),0.5915 (IN)
    DISTANCE 8: 14.735 (MM),0.5801 (IN)
    DISTANCE 9: 12.529 (MM),0.4933 (IN)
  FRONT-SURFACE-TO-FINAL-CRACK-FRONT DISTANCES
    DISTANCE 1: 18.293 (MM),0.7202 (IN)
    DISTANCE 2: 18.013 (MM),0.7092 (IN)
    DISTANCE 3: 18.052 (MM),0.7107 (IN)
    DISTANCE 4: 18.02 (MM),0.7094 (IN)
    DISTANCE 5: 18.401 (MM),0.7245 (IN)
    DISTANCE 6: 18.224 (MM),0.7175 (IN)
    DISTANCE 7: 18.176 (MM),0.7156 (IN)
    DISTANCE 8: 18.181 (MM),0.7158 (IN)
    DISTANCE 9: 18.207 (MM),0.7168 (IN)
  MEASURED CRACK LENGTHS
    INITIAL: 9.694 (MM),0.3816 (IN)
    FINAL: 13.174 (MM),0.5186 (IN)
TEST
  ROUTINE REVISION: 1.02/07-JUL-88
  TYPE: UCJR
  ENGINEER: FMH
  TECHNICIAN: RLS
  TEST DATE: 04-MAR-93
  ATMOSPHERE: AIR
  TEMPERATURE: 25 (DEG C),77 (DEG F)
  REMARK: NONE
  DID SPECIMEN CLEAVE? NO
ANALYSIS
  ROUTINE REVISION: 1.10/06-MAR-90
  CRACK LENGTH PINS
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    UC
      INITIAL
        DETERMINATION TEST CYCLE: 1
        EFFECTIVE MODULUS: 130.05 (GPA),18862 (KSI)
        YOUNG'S MODULUS-EFFECTIVE MODULUS: 32.6 (PERCENT)
      FINAL
        PIN NOT APPLIED
  UC RESULTS
    MEASURED FINAL CRACK EXTENSION: 3.48 (MM),0.137 (IN)
    FINAL CRACK EXTENSION: 2.958 (MM),0.1164 (IN)
    FINAL CRACK EXTENSION ERROR:-15 (PERCENT)
    PQ: 4.64 (KN),1043 (LB)
    KQ: 31.6 (MPA-SQRT(M)),28754 (KSI-SQRT(IN))
    KIC: NO VALID KIC FOR TEST
    PMX: 13.609 (KN),3059 (LB)
    KMX: 92.68 (MPA-SQRT(M)),84.35 (KSI-SQRT(IN))
    MODIFIED ERNST J-INTEGRAL
      PMX J-INTEGRAL: 167.51 (KJ/M^2),956.5 (IN-LB/IN^2)
      FINAL J-INTEGRAL: 678.64 (KJ/M^2),3875.2 (IN-LB/IN^2)
      FINAL KJ: 361.96 (MPA-SQRT(M)),329.4 (KSI-SQRT(IN))
      POWER-LAW MODEL [J-INTEGRAL=A0*CRACK EXTENSION^A1]
        A0: 380.08 (SI),12018 (ENGLISH)
        A1: 0.52909 (SI),0.52909 (ENGLISH)
        RESULTS EXCLUDED FROM MODEL: CYCLES 1,2,3,4,5,6,7,8,9,20,21,22 AND 23
      JIC: 225.63 (KJ/M^2),1288.4 (IN-LB/IN^2)
      KJIC: 208.71 (MPA-SQRT(M)),189.93 (KSI-SQRT(IN))
      TEARING MODULUS: 91.6
```

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 7WH3

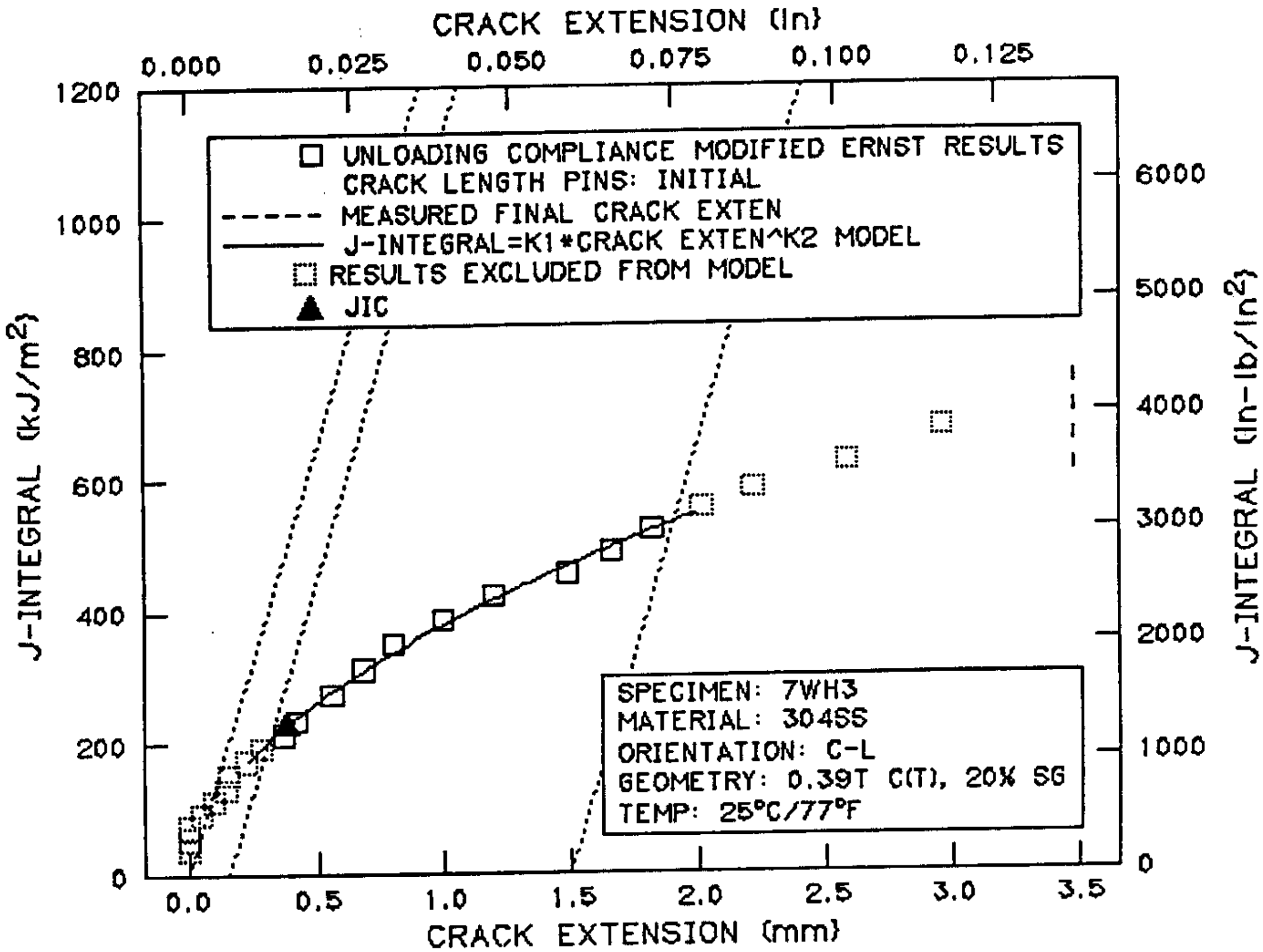
SPECIMEN
IDENTIFICATION: 7WH3
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 9.694 (MM),0.3816 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 25 (DEG C),77 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: MODIFIED ERNST

CYCLE	LOAD (KN)	DISPL (MM)	ENERGY (J)	CRACK EXTN (MM)	J-INTEGRAL (KJ/M^2)	KJ (MPA-SQRT(M))
1	9.51	0.275	1.399	0.003	38.7	86.44
2	10.793	0.331	1.973	0.003	54.61	102.68
3	11.773	0.388	2.626	0.002	72.54	118.34
4	12.428	0.445	3.329	0.051	91.31	132.77
5	12.817	0.501	4.056	0.097	110.98	146.37
6	13.07	0.557	4.797	0.144	131.03	159.05
7	13.192	0.614	5.556	0.155	152.05	171.33
8	13.183	0.67	6.313	0.219	172.4	182.44
9	13.086	0.726	7.074	0.278	193.05	193.05
10	12.852	0.782	7.82	0.364	213.09	202.82
11	12.709	0.839	8.564	0.414	233.59	212.36
12	12.458	0.951	10.02	0.553	273.13	229.63
13	12.213	1.063	11.45	0.677	312.6	245.66
14	11.9	1.176	12.852	0.797	351.67	260.56
15	11.418	1.288	14.202	0.999	388.56	273.89
16	10.826	1.4	15.49	1.202	424.46	286.26
17	10.059	1.513	16.714	1.49	457.81	297.29
18	9.693	1.626	17.867	1.665	491.57	308.06
19	9.393	1.737	18.967	1.821	524.86	318.32
20	8.942	1.85	20.028	2.015	556.77	327.85
21	8.503	1.962	21.044	2.217	587.74	336.85
22	7.642	2.119	22.355	2.583	626.69	347.83
23	6.897	2.345	24.04	2.958	678.64	361.96

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 7WH3

SPECIMEN
  IDENTIFICATION: 7WH3
  MATERIAL CODE: 304SS
  ORIENTATION: C-L
  GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
  INITIAL CRACK LENGTH: 9.694 (MM),0.3816 (IN)
TEST
  ATMOSPHERE: AIR
  TEMPERATURE: 25 (DEG C),77 (DEG F)
ANALYSIS
  CRACK LENGTH PINS: INITIAL
  CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
  J-INTEGRAL METHOD: MODIFIED ERNST

CYCLE	LOAD (LB)	DISPL (IN)	ENERGY (IN-LB)	CRACK EXTN (IN)	J-INTEGRAL (IN-LB/IN^2)	KJ (KSI-SQRT(IN))
1	2138	0.0108	12.38	0.0001	221	78.66
2	2426	0.013	17.47	0.0001	311.9	93.45
3	2647	0.0153	23.24	0.0001	414.2	107.7
4	2794	0.0175	29.46	0.002	521.4	120.83
5	2881	0.0197	35.9	0.0038	633.7	133.21
6	2938	0.0219	42.46	0.0057	748.2	144.74
7	2966	0.0242	49.18	0.0061	868.3	155.92
8	2964	0.0264	55.88	0.0086	984.4	166.03
9	2942	0.0286	62.61	0.011	1102.3	175.69
10	2889	0.0308	69.21	0.0143	1216.8	184.58
11	2857	0.033	75.8	0.0163	1333.8	193.25
12	2801	0.0374	88.68	0.0218	1559.6	208.97
13	2746	0.0419	101.34	0.0266	1785	223.56
14	2675	0.0463	113.75	0.0314	2008.1	237.12
15	2567	0.0507	125.7	0.0393	2218.8	249.25
16	2434	0.0551	137.1	0.0473	2423.7	260.51
17	2261	0.0596	147.94	0.0587	2614.1	270.55
18	2179	0.064	158.13	0.0655	2806.9	280.35
19	2112	0.0684	167.88	0.0717	2997.1	289.69
20	2010	0.0728	177.27	0.0793	3179.2	298.36
21	1911	0.0773	186.26	0.0873	3356.1	306.55
22	1718	0.0834	197.86	0.1017	3578.5	316.54
23	1550	0.0923	212.77	0.1165	3875.2	329.4


CRACK EXTENSION (in)
0.000
0.025
0.050
0.075
0.100
0.125
UNLOADING COMPLIANCE MODIFIED ERNST RESULTS
CRACK LENGTH PINS: INITIAL
MEASURED FINAL CRACK EXTEN
J-INTEGRAL=K1*CRACK EXTEN^K2 MODEL
RESULTS EXCLUDED FROM MODEL
JIC
J-INTEGRAL (kJ/m2)
1200
1000
800
600
400
200
0
J-INTEGRAL (in-lb/in2)
6000
5000
4000
3000
2000
1000
0
SPECIMEN: 7WH3
MATERIAL: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T), 20% SG
TEMP: 25°C/77°F
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
CRACK EXTENSION (mm)

```
COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 7HAH8

SPECIMEN
  IDENTIFICATION: 7HAH8
  MATERIAL
    CODE: 304SS
    YOUNG'S MODULUS: 193.05 (GPA),28000 (KSI)
    POISSON'S RATIO: 0.3
    STRENGTHS
      YIELD: 599.84 (MPA),87 (KSI)
      ULTIMATE: 717.05 (MPA),104 (KSI)
  ORIENTATION: C-L
  GEOMETRY: C(T)
  WIDTH: 19.964 (MM),0.786 (IN)
  THICKNESS: 10.008 (MM),0.394 (IN)
  SIDE GROOVE: 20 (PERCENT)
  LOAD PIN CENTER SPAN: 9.804 (MM),0.386 (IN)
  EXTENSOMETER LOCATION: 0 (MM),0 (IN)
  PRECRACK CONDITIONS
    MAXIMUM LOAD: 1.779 (KN),400 (LB)
    FREQUENCY: 30 (HZ)
  FRONT-SURFACE-TO-LOAD-LINE DISTANCE: 4.991 (MM),0.1965 (IN)
  FRONT-SURFACE-TO-INITIAL-CRACK-FRONT DISTANCES
    DISTANCE 1: 15.922 (MM),0.6269 (IN)
    DISTANCE 2: 16.02 (MM),0.6307 (IN)
    DISTANCE 3: 16.048 (MM),0.6318 (IN)
    DISTANCE 4: 15.99 (MM),0.6295 (IN)
    DISTANCE 5: 15.938 (MM),0.6275 (IN)
    DISTANCE 6: 16.003 (MM),0.63 (IN)
    DISTANCE 7: 15.892 (MM),0.6257 (IN)
    DISTANCE 8: 15.838 (MM),0.6235 (IN)
    DISTANCE 9: 15.762 (MM),0.6205 (IN)
  FRONT-SURFACE-TO-FINAL-CRACK-FRONT DISTANCES
    DISTANCE 1: 19.806 (MM),0.7798 (IN)
    DISTANCE 2: 19.872 (MM),0.7824 (IN)
    DISTANCE 3: 19.881 (MM),0.7827 (IN)
    DISTANCE 4: 19.846 (MM),0.7813 (IN)
    DISTANCE 5: 19.713 (MM),0.7761 (IN)
    DISTANCE 6: 19.544 (MM),0.7694 (IN)
    DISTANCE 7: 19.363 (MM),0.7623 (IN)
    DISTANCE 8: 18.887 (MM),0.7436 (IN)
    DISTANCE 9: 17.864 (MM),0.7033 (IN)
  MEASURED CRACK LENGTHS
    INITIAL: 10.955 (MM),0.4313 (IN)
    FINAL: 14.501 (MM),0.5709 (IN)
TEST
  ROUTINE REVISION: 1.02/07-JUL-88
  TYPE: UCJR
  ENGINEER: FMH
  TECHNICIAN: RLS
  TEST DATE: 04-MAR-93
  ATMOSPHERE: AIR
  TEMPERATURE: 25 (DEG C),77 (DEG F)
  REMARK: NONE
  DID SPECIMEN CLEAVE? NO
ANALYSIS
  ROUTINE REVISION: 1.10/06-MAR-90
  CRACK LENGTH PINS
```

```
    UC
      INITIAL
        DETERMINATION TEST CYCLE: 1
        EFFECTIVE MODULUS: 173.28 (GPA),25132 (KSI)
        YOUNG'S MODULUS-EFFECTIVE MODULUS: 10.2 (PERCENT)
      FINAL
        PIN NOT APPLIED
  UC RESULTS
    MEASURED FINAL CRACK EXTENSION: 3.546 (MM),0.1396 (IN)
    FINAL CRACK EXTENSION: 2.949 (MM),0.1161 (IN)
    FINAL CRACK EXTENSION ERROR:-16.8 (PERCENT)
    PQ: 5.154 (KN),1159 (LB)
    KQ: 42.96 (MPA-SQRT(M)),39097 (KSI-SQRT(IN))
    KIC: NO VALID KIC FOR TEST
    PMX: 10.118 (KN),2275 (LB)
    KMX: 84.34 (MPA-SQRT(M)),76.76 (KSI-SQRT(IN))
    MODIFIED ERNST J-INTEGRAL
      PMX J-INTEGRAL: 74.85 (KJ/M^2),427.4 (IN-LB/IN^2)
      FINAL J-INTEGRAL: 255.06 (KJ/M^2),1456.4 (IN-LB/IN^2)
      FINAL KJ: 221.9 (MPA-SQRT(M)),201.94 (KSI-SQRT(IN))
      POWER-LAW MODEL [J-INTEGRAL=A0*CRACK EXTENSION^A1]
        A0: 129.01 (SI),5468 (ENGLISH)
        A1: 0.61966 (SI),0.61966 (ENGLISH)
        RESULTS EXCLUDED FROM MODEL: CYCLES 1,2,10,11,12,13,14 AND 15
      JIC: 53.34 (KJ/M^2),304.6 (IN-LB/IN^2)
      KJIC: 101.47 (MPA-SQRT(M)),92.34 (KSI-SQRT(IN))
      TEARING MODULUS: 38.9
```

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 7HAH8

SPECIMEN
IDENTIFICATION: 7HAH8
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 10.955 (MM),0.4313 (IN)
TEST
ATMOSPHERE: AIR
TEMPERATURE: 25 (DEG C),77 (DEG F)
ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: MODIFIED ERNST

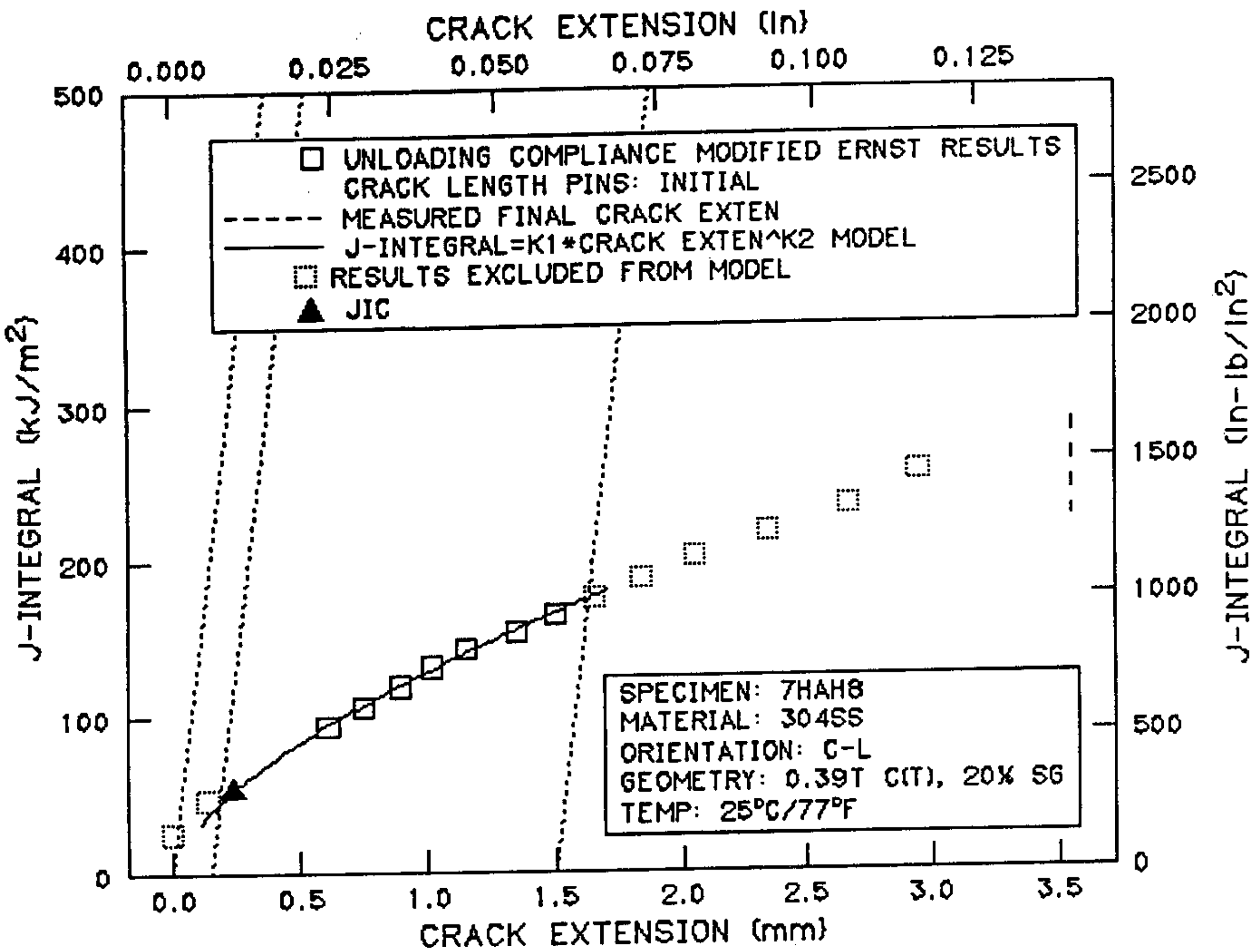
CYCLE	LOAD (KN)	DISPL (MM)	ENERGY (J)	CRACK EXTN (MM)	J-INTEGRAL (KJ/M^2)	KJ (MPA-SQRT(M))
1	7.256	0.216	0.829	0	25.78	70.55
2	9.02	0.304	1.562	0.135	47.15	95.41
3	9.673	0.479	3.285	0.607	93.9	134.64
4	9.454	0.522	3.713	0.747	106.62	143.47
5	9.119	0.567	4.134	0.887	119.27	151.74
6	8.809	0.61	4.536	1.013	131.66	159.43
7	8.223	0.654	4.923	1.148	143.63	166.52
8	7.629	0.698	5.281	1.35	154.36	172.63
9	7.259	0.741	5.613	1.506	164.9	178.42
10	6.982	0.785	5.934	1.66	175.22	183.92
11	6.674	0.837	6.304	1.84	187.26	190.14
12	6.274	0.9	6.726	2.05	201.36	197.16
13	5.706	0.975	7.196	2.352	216.64	204.51
14	5.25	1.067	7.711	2.675	234.07	212.58
15	4.888	1.18	8.301	2.95	255.06	221.9

SPECIMEN
IDENTIFICATION: 7HAH8
MATERIAL CODE: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T) 20 PERCENT SIDE GROOVE
INITIAL CRACK LENGTH: 10.955 (MM),0.4313 (IN)

TEST
ATMOSPHERE: AIR
TEMPERATURE: 25 (DEG C),77 (DEG F)

ANALYSIS
CRACK LENGTH PINS: INITIAL
CRACK EXTENSION METHOD: UNLOADING COMPLIANCE
J-INTEGRAL METHOD: MODIFIED ERNST

CYCLE	LOAD (LB)	DISPL (IN)	ENERGY (IN-LB)	CRACK EXTN (IN)	J-INTEGRAL (IN-LB/IN^2)	KJ (KSI-SQRT(IN))
1	1631	0.0085	7.34	0	147.2	64.2
2	2028	0.012	13.83	0.0053	269.2	86.83
3	2175	0.0188	29.08	0.0239	536.2	122.53
4	2125	0.0206	32.87	0.0294	608.8	130.57
5	2050	0.0223	36.59	0.0349	681.1	138.09
6	1980	0.024	40.15	0.0399	751.8	145.09
7	1849	0.0257	43.57	0.0452	820.1	151.54
8	1715	0.0275	46.74	0.0531	881.4	157.1
9	1632	0.0292	49.68	0.0593	941.6	162.37
10	1570	0.0309	52.52	0.0653	1000.6	167.38
11	1500	0.033	55.8	0.0725	1069.3	173.03
12	1411	0.0354	59.53	0.0807	1149.8	179.43
13	1283	0.0384	63.69	0.0926	1237	186.11
14	1180	0.042	68.25	0.1053	1336.6	193.45
15	1099	0.0464	73.47	0.1161	1456.4	201.94


CRACK EXTENSION (In)
0.000
0.025
0.050
0.075
0.100
0.125
500
400
300
200
100
0
2500
2000
1500
1000
500
0
J-INTEGRAL (kJ/m²)
J-INTEGRAL (In-lb/In²)
UNLOADING COMPLIANCE MODIFIED ERNST RESULTS
CRACK LENGTH PINS: INITIAL
MEASURED FINAL CRACK EXTEN
J-INTEGRAL=K1*CRACK EXTEN^K2 MODEL
RESULTS EXCLUDED FROM MODEL
JIC
SPECIMEN: 7HAH8
MATERIAL: 304SS
ORIENTATION: C-L
GEOMETRY: 0.39T C(T), 20% SG
TEMP: 25°C/77°F
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
CRACK EXTENSION (mm)

Attachment 1, Appendix C -- Photographs of the Fracture Surface of the 0.4T C(T) Specimens {Photographs are retained in the SRTC-RMP Task 89-023-1 Files}

Attachment 1, Appendix D -- Results of CVN Specimens Irradiated in the HFIR Capsule 12M

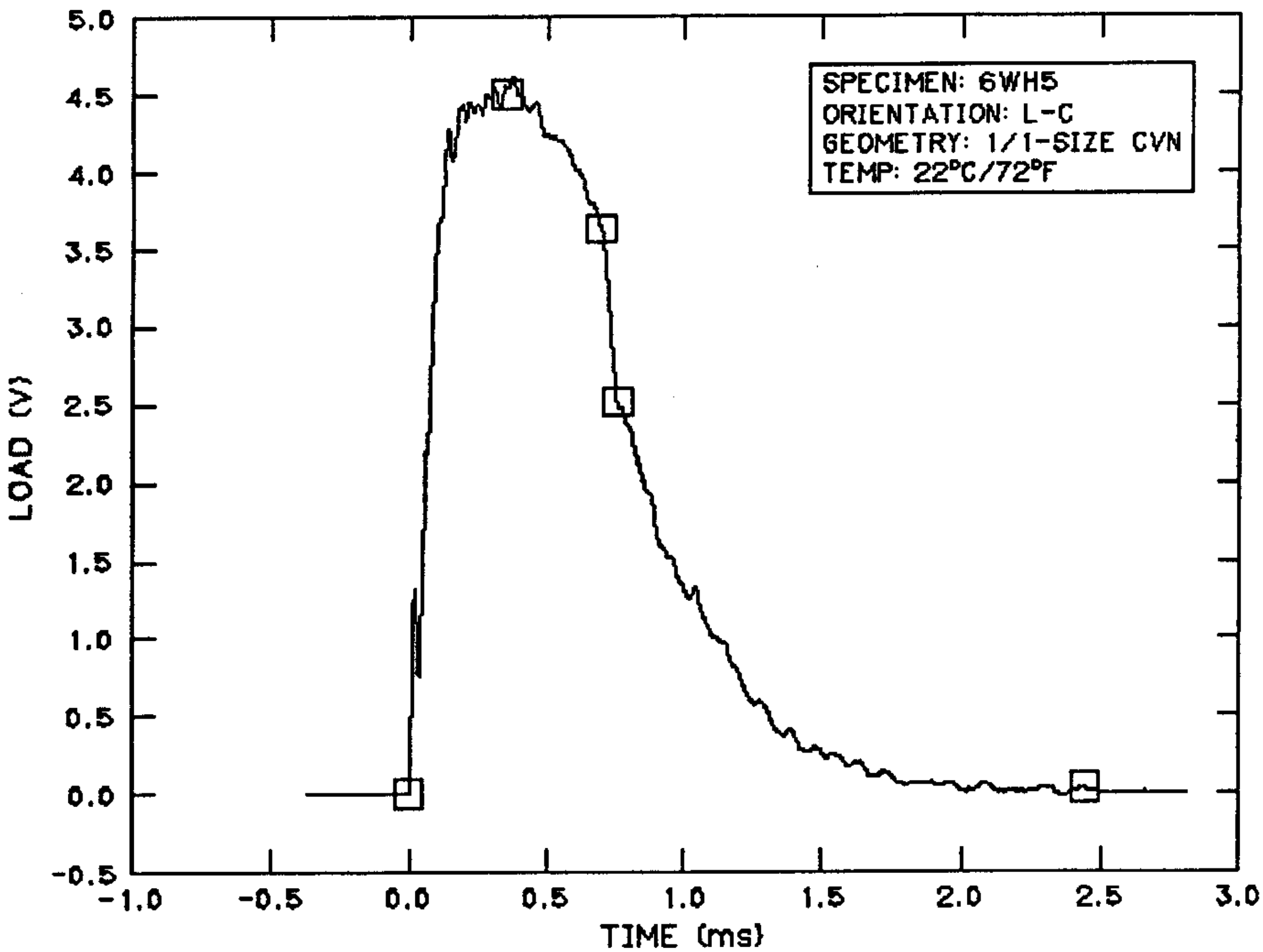
INSTRUMENTED CHARPY IMPACT TEST SCHEDULE

PROJECT: SAVANNAH RIVER LAB. - 12M CAPSULE ENGINEER: HAGGAG TECHNICIAN: MANNESCHMIDT

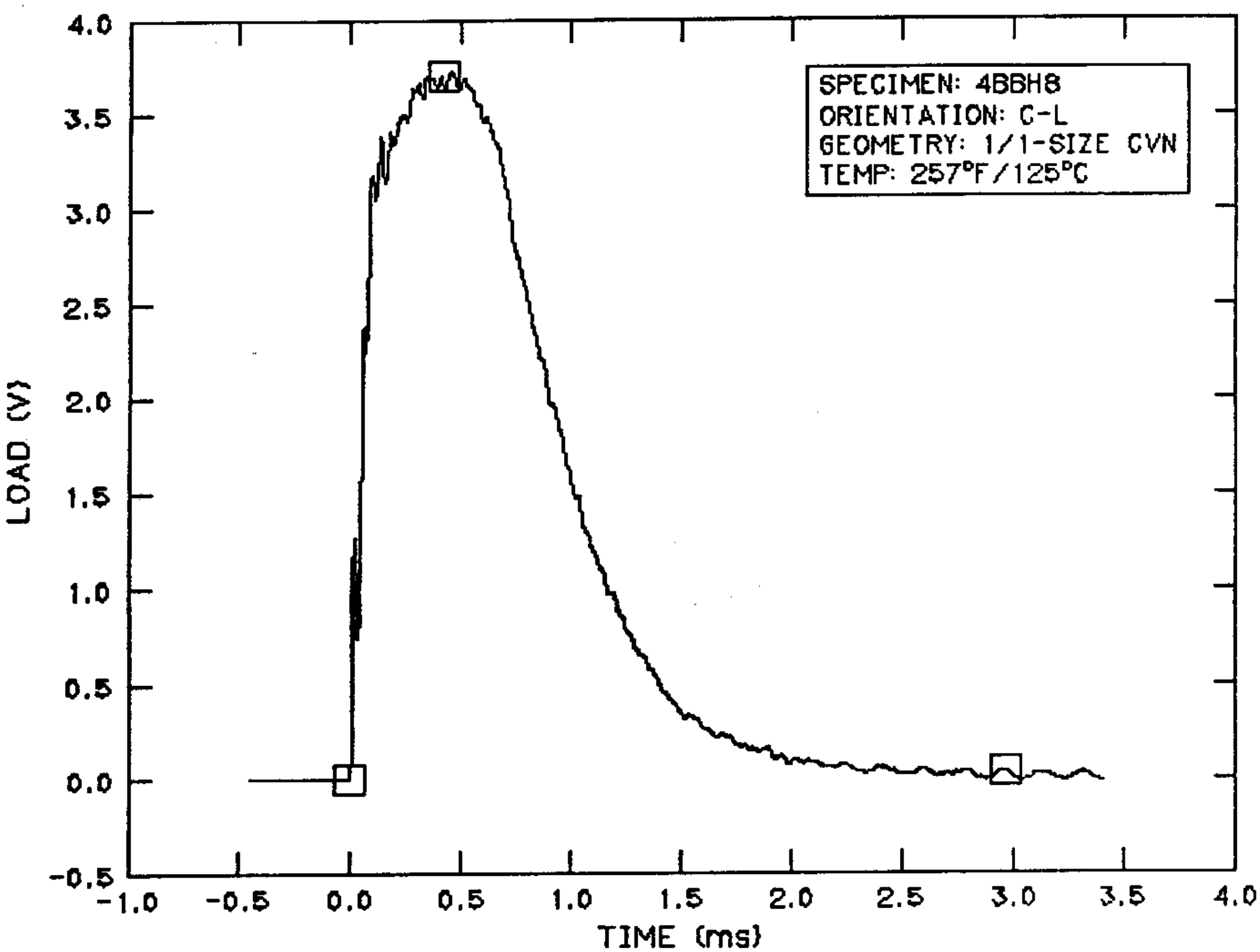
MATERIAL: 304 S.S. FROM PIPES SITE: Hot Cells TUP# T03 DATE: 3-2-93 DISK # CVN146

SPECIMEN IDENTIFICATION	FURNACE TEMP. °C	TEST TEMP. °F	DIAL ENERGY ft-lb	LATERAL EXPAN (mils)	FRACT. APP. % SHEAR	REMARKS
6WH5	22°C	72°F	69.6	44		L-C orientation
4BBH8	125°C	257°F	66.8	41		C-L "
6WH2	"	"	76.3	35		L-C " Has large stripe of pores
1HAH6	"	"	81.1	51		L-C

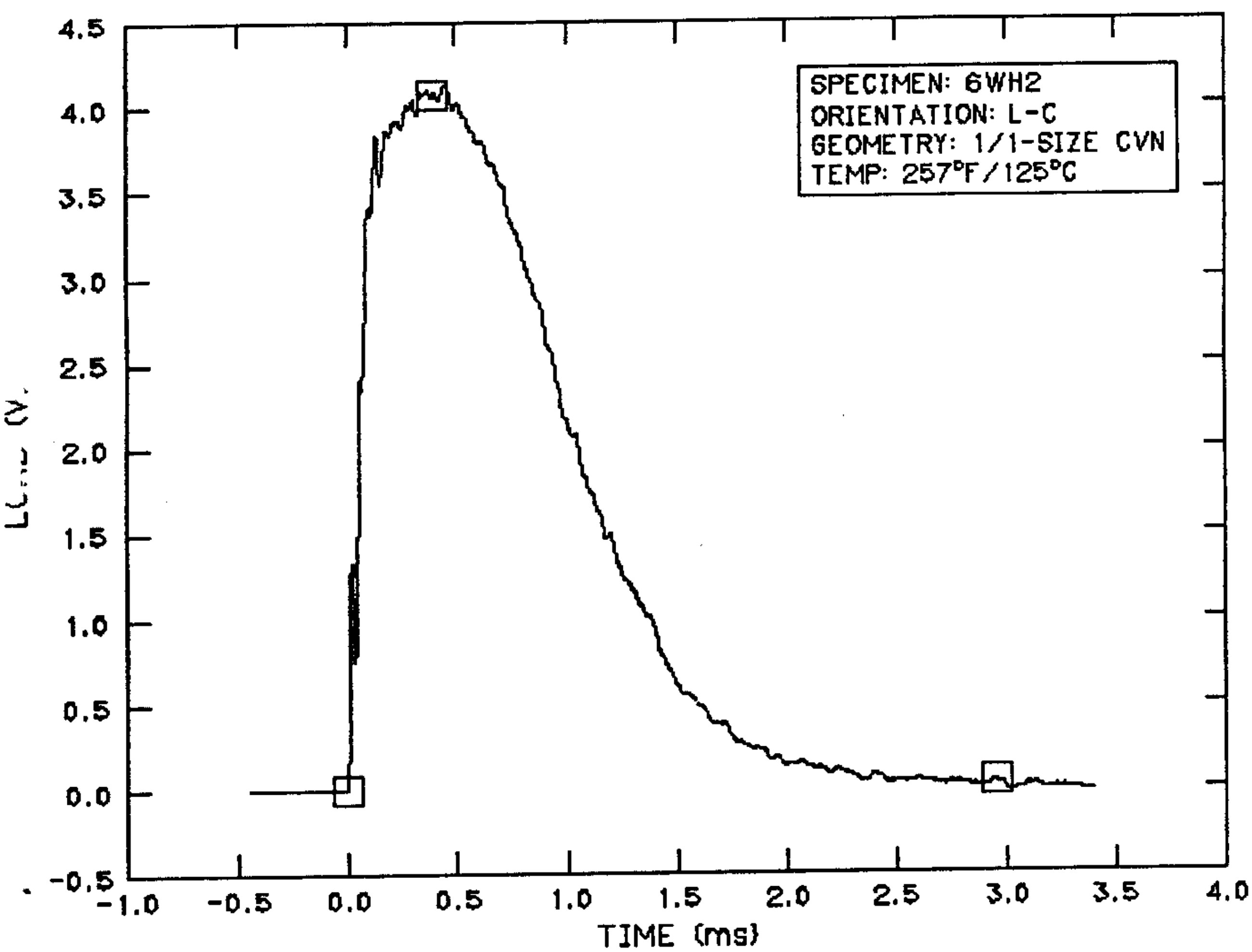
SPECIMEN
  IDENTIFICATION: 6WH5
  MATERIAL CODE: SRL - CAPSULE 12M
  GEOMETRY: CVN
  ORIENTATION: L-C
  THICKNESS: 10.01 (MM),0.394 (IN)
  WIDTH: 10.01 (MM),0.394 (IN)
REMARK: NONE
ENGINEER: F.M. HAGGAG
TECHNICIAN: E.T. MANNESCHMIDT
TEST
  TEMPERATURE: 22.2 (DEG C),72 (DEG F)
  HAMMER POTENTIAL ENERGY: 359.7 (J),265.3 (FT-LB)
  IMPACT ENERGY: 94.365 (J),69.6 (FT-LB)
ANALYSIS
  ROUTINE REVISION: 1.00/17-APR-89
  CHARPY AREA TO MAX LOAD: 0.00128 (VOLT-SEC)
  CHARPY AREA TO IMPACT END: 0.00387 (VOLT-SEC)
  TIME TO MAX LOAD: 348 (MICROSEC)
  MAX LOAD: 4.504 (VOLT)
  CHARPY AREA TO RAPID FRACTURE START: 0.002784 (VOLT-SEC)
  RAPID FRACTURE START LOAD: 3.633 (VOLT)
  RAPID FRACTURE ARREST LOAD: 2.518 (VOLT)
  RAPID FRACTURE DELTA LOAD: 1.115 (VOLT)
  RAPID FRACTURE DELTA LOAD/MAX LOAD RATIO: 0.24758



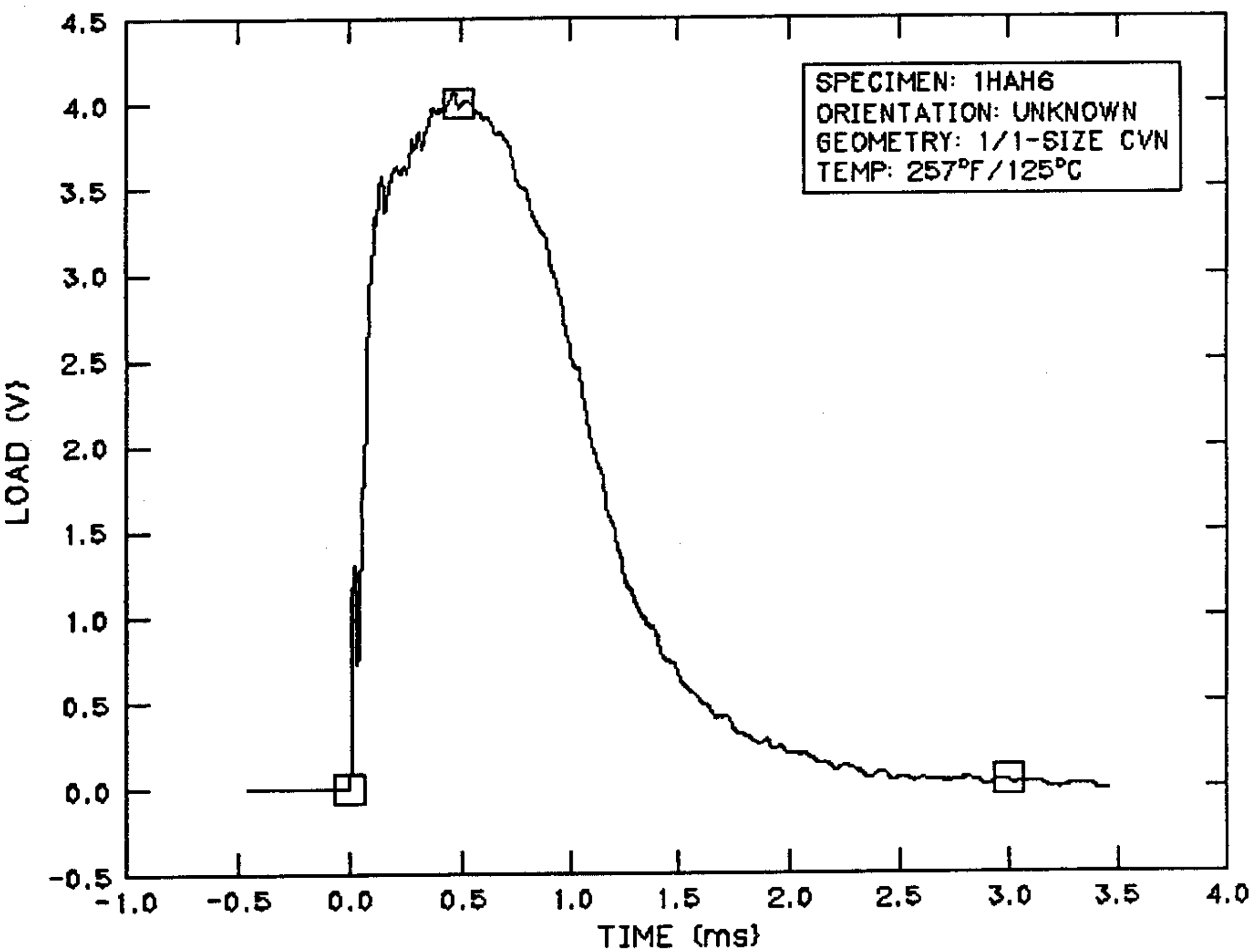
SPECIMEN
  IDENTIFICATION: 4BBH8
  MATERIAL CODE: SRL - CAPSULE 12M
  GEOMETRY: CVN
  ORIENTATION: C-L
  THICKNESS: 0.394 (IN),10.01 (MM)
  WIDTH: 0.394 (IN),10.01 (MM)
REMARK: NONE
ENGINEER: F.M. HAGGAG
TECHNICIAN: E.T. MANNESCHMIDT
TEST
  TEMPERATURE: 257 (DEG F),125 (DEG C)
  HAMMER POTENTIAL ENERGY: 265.3 (FT-LB),359.7 (J)
  IMPACT ENERGY: 66.8 (FT-LB),90.569 (J)
ANALYSIS
  ROUTINE REVISION: 1.00/17-APR-89
  CHARPY AREA TO MAX LOAD: 0.00132 (VOLT-SEC)
  CHARPY AREA TO IMPACT END: 0.00363 (VOLT-SEC)
  TIME TO MAX LOAD: 420 (MICROSEC)
  MAX LOAD: 3.706 (VOLT)



SPECIMEN
  IDENTIFICATION: 6WH2
  MATERIAL CODE: SRL - CAPSULE 12M
  GEOMETRY: CVN
  ORIENTATION: L-C
  THICKNESS: 0.394 (IN),10.01 (MM)
  WIDTH: 0.394 (IN),10.01 (MM)
REMARK: NONE
ENGINEER: F.M. HAGGAG
TECHNICIAN: E.T. MANNESCHMIDT
TEST
  TEMPERATURE: 257 (DEG F),125 (DEG C)
  HAMMER POTENTIAL ENERGY: 265.3 (FT-LB),359.7 (J)
  IMPACT ENERGY: 76.3 (FT-LB),103.45 (J)
ANALYSIS
  ROUTINE REVISION: 1.00/17-APR-89
  CHARPY AREA TO MAX LOAD: 0.00139 (VOLT-SEC)
  CHARPY AREA TO IMPACT END: 0.00437 (VOLT-SEC)
  TIME TO MAX LOAD: 402 (MICROSEC)
  MAX LOAD: 4.074 (VOLT)



SPECIMEN
  IDENTIFICATION: 1HAH6
  MATERIAL CODE: SRL - CAPSULE 12M
  GEOMETRY: CVN
  ORIENTATION: UNKNOWN
  THICKNESS: 0.394 (IN),10.01 (MM)
  WIDTH: 0.394 (IN),10.01 (MM)
REMARK: NONE
ENGINEER: F.M. HAGGAG
TECHNICIAN: E.T. MANNESCHMIDT
TEST
  TEMPERATURE: 257 (DEG F),125 (DEG C)
  HAMMER POTENTIAL ENERGY: 265.3 (FT-LB),359.7 (J)
  IMPACT ENERGY: 81.1 (FT-LB),109.96 (J)
ANALYSIS
  ROUTINE REVISION: 1.00/17-APR-89
  CHARPY AREA TO MAX LOAD: 0.00164 (VOLT-SEC)
  CHARPY AREA TO IMPACT END: 0.00449 (VOLT-SEC)
  TIME TO MAX LOAD: 486 (MICROSEC)
  MAX LOAD: 4.002 (VOLT)



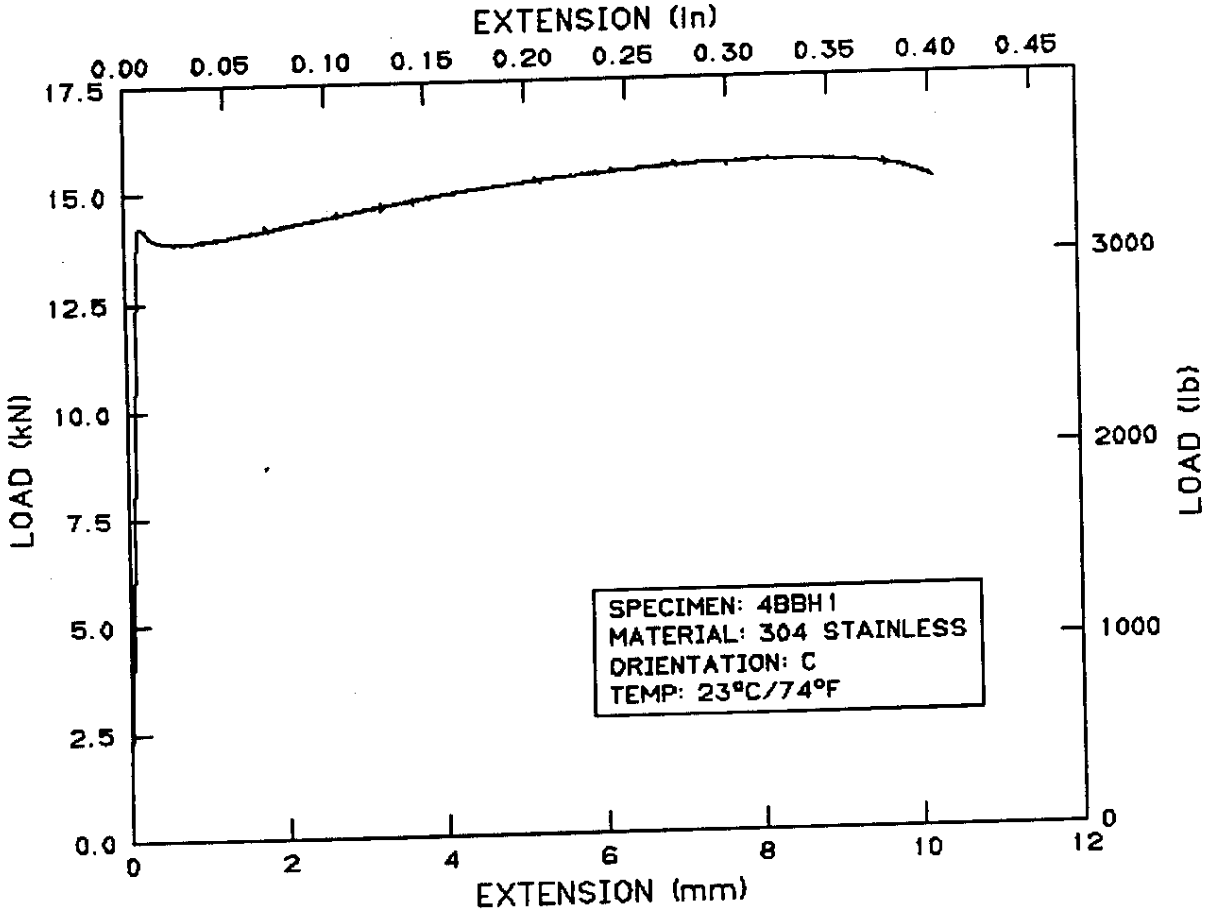
Attachment 1. Appendix E -- Photographs of the Fracture Surface of the CVN Specimens {Photographs are retained in the SRTC-RMP Task 89-023-1 Files}

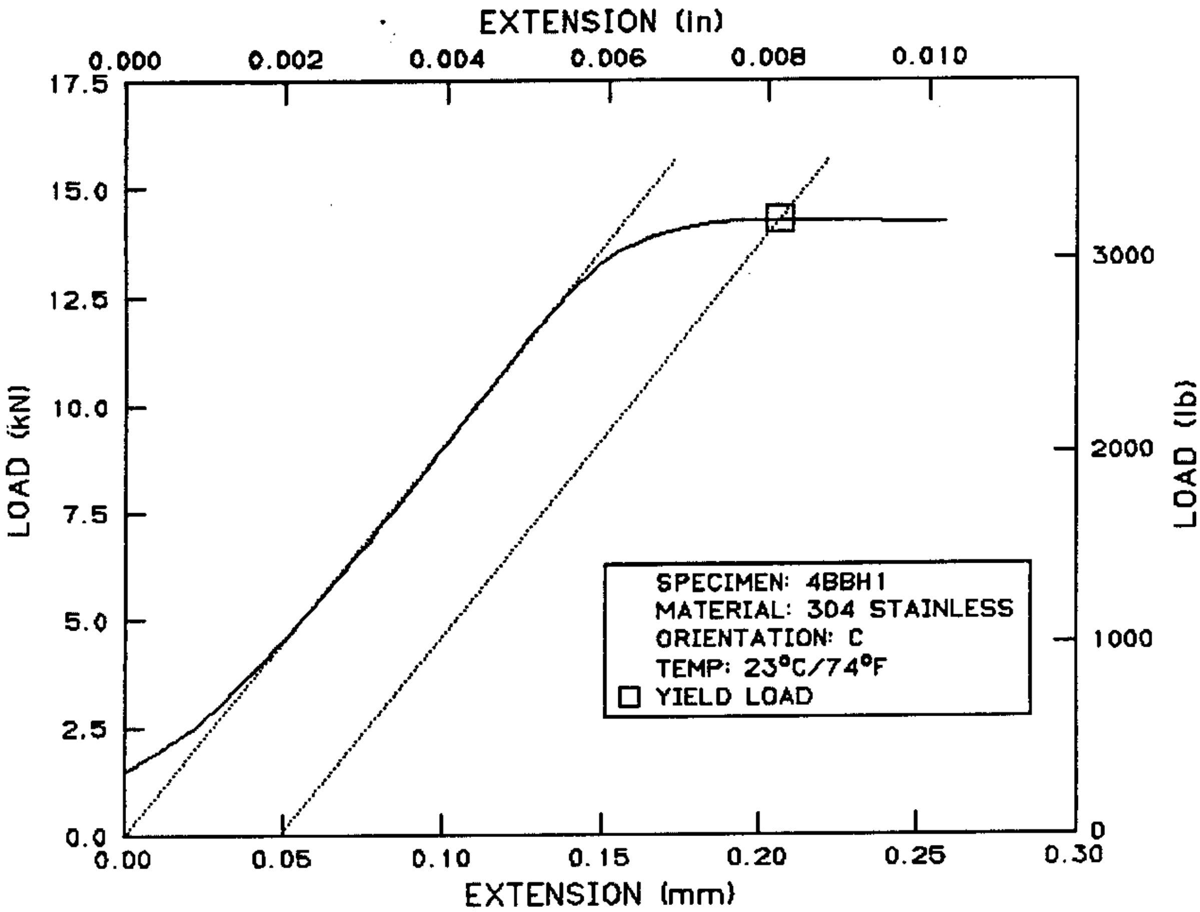
Attachment 1, Appendix F -- Results of Tensile Specimens Irradiated in the HFIR Capsule 12M

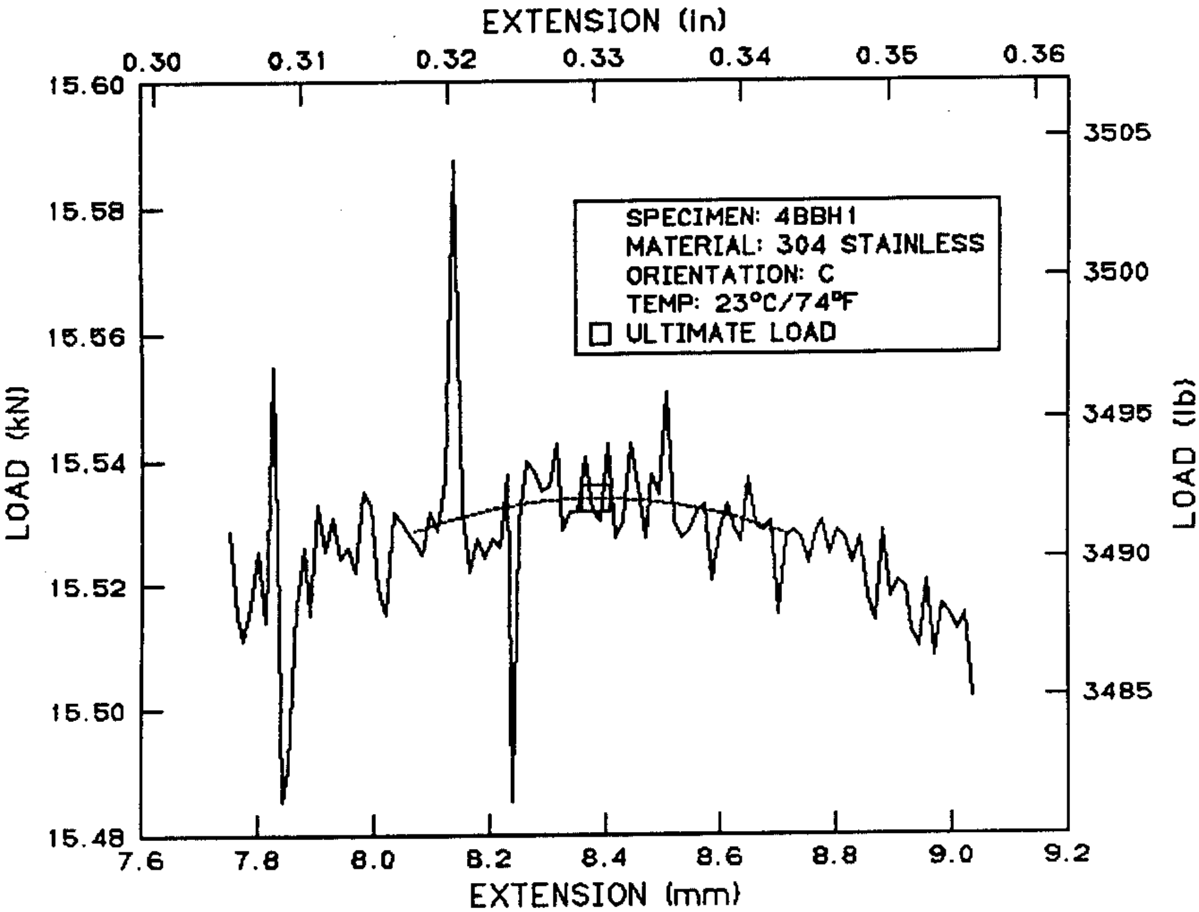
COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 4BBH1

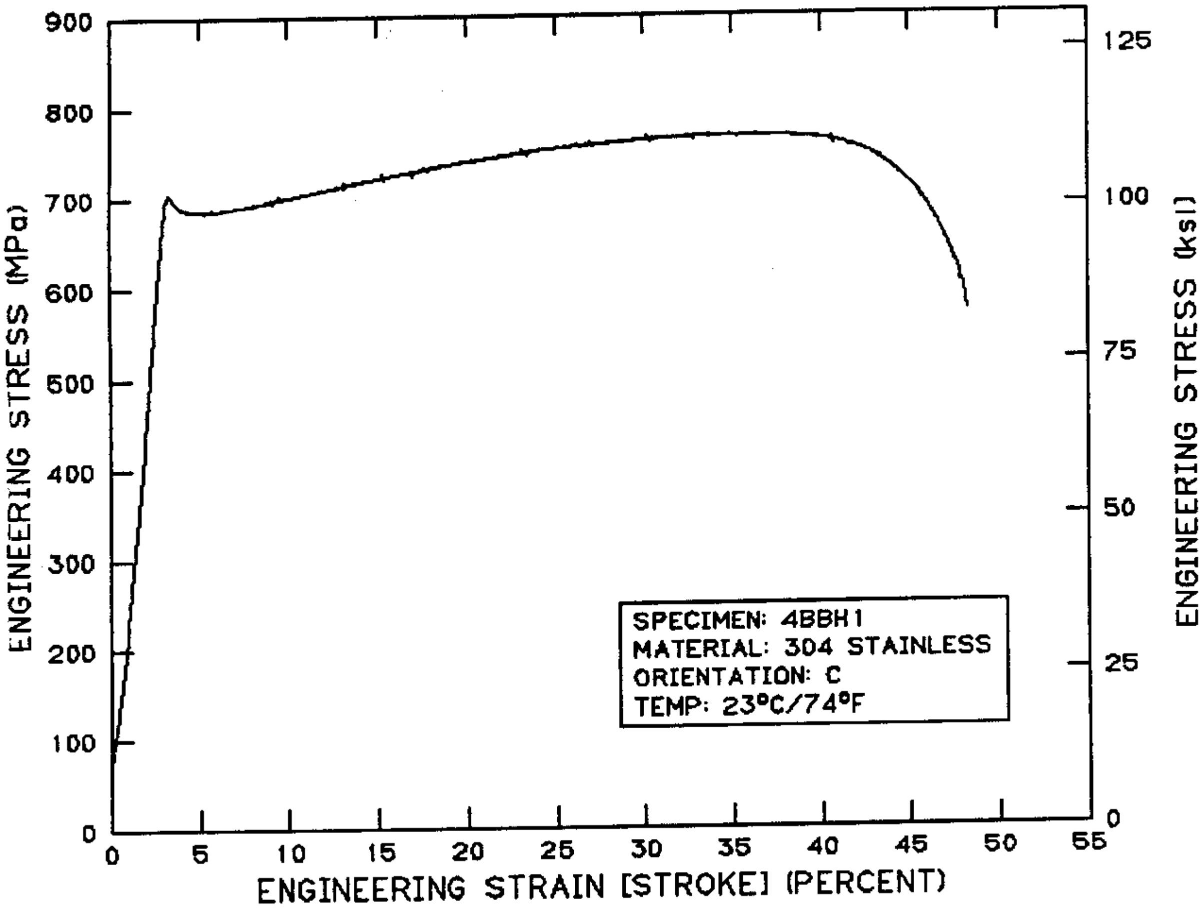
SPECIMEN
  IDENTIFICATION: 4BBH1
  MATERIAL CODE: 304 STAINLESS
  ORIENTATION: C
  CROSS-SECTION FORM: CIRCULAR
  INITIAL OVERALL LENGTH: 54.991 (MM),2.165 (IN)
  REDUCED SECTION LENGTH: 24.384 (MM),0.96 (IN)
  GAUGE LENGTH: 24.384 (MM),0.96 (IN)
  GAUGE DIAMETER: 5.08 (MM),0.2 (IN)
  FINAL OVERALL LENGTH: UNKNOWN
  NECK DIAMETER: UNKNOWN
TEST
  CROSSHEAD SPEED: 0.008 (MM/SEC),0.02 (IN/MIN)
  ATMOSPHERE: AIR
  TEMPERATURE: 23.3 (DEG C),74 (DEG F)
  DATE: 17-MAR-93
  ENGINEER: F.M. HAGGAG
  TECHNICIAN: R.L. SWAIN
  REMARK: NONE
ANALYSIS
  ROUTINE REVISION: 1.00/07-APR-93
  LOADS
    YIELD [0.2 PERCENT OFFSET, EXTENSION]: 14.263 (KN),3206.4 (LB)
    ULTIMATE [EXTENSION]: 15.534 (KN),3492.2 (LB)
    FRACTURE: 15.067 (KN),3387.1 (LB)
  ELONGATION
    UNIFORM [EXTENSION]: 31.13 (PERCENT)
    TOTAL [EXTENSION]: 31.85 (PERCENT)
  STRENGTHS
    YIELD [0.2 PERCENT OFFSET, EXTENSION]: 704 (MPA),102.1 (KSI)
    ULTIMATE [EXTENSION]: 766 (MPA),111.2 (KSI)
  TENSILE STRAIN-HARDENING
    EXPONENT: 0.114
    STRENGTH COEFFICIENT: 1032 (MPA),149.6 (KSI)
    STRAIN DATA RANGE [TRUE PLASTIC, EXTENSION]: 3.04 TO 13.04 (PERCENT)

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 4BBH1

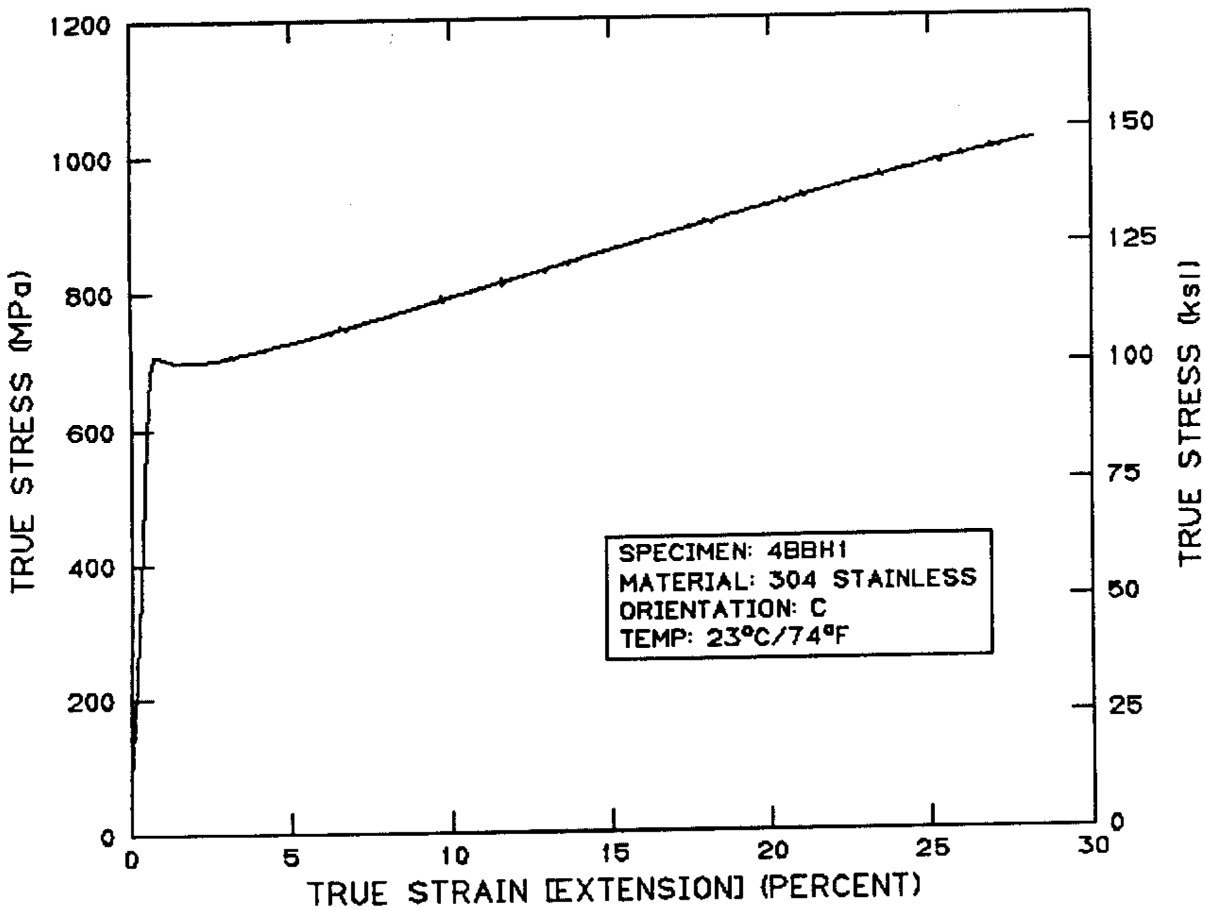


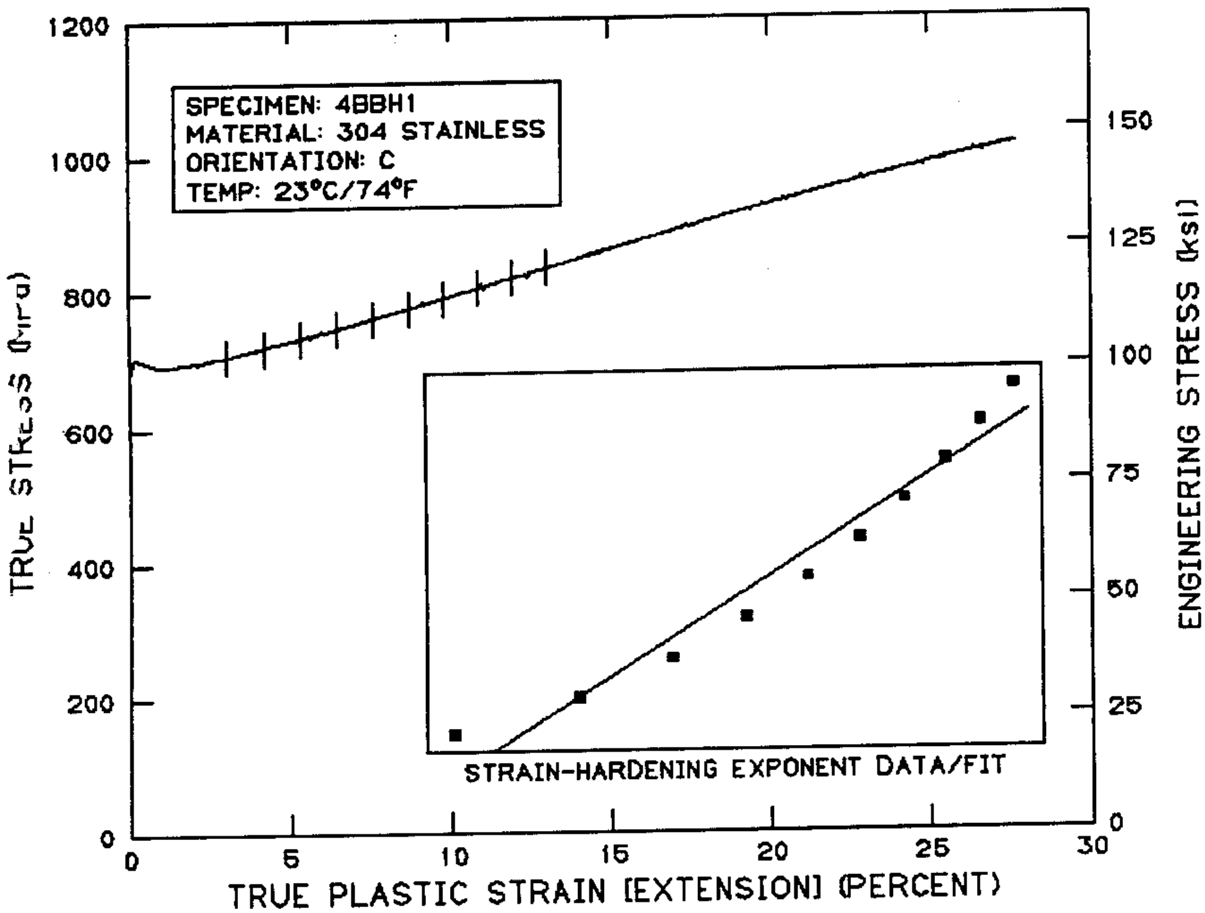

EXTENSION (in)
0.000
0.002
0.004
0.006
0.008
0.010
LOAD (kN)
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
LOAD (lb)
3000
2000
1000
0
SPECIMEN: 4BBH1
MATERIAL: 304 STAINLESS
ORIENTATION: C
TEMP: 23°C/74°F
YIELD LOAD
0.00
0.05
0.10
0.15
0.20
0.25
0.30
EXTENSION (mm)


EXTENSION (in)
0.30
0.31
0.32
0.33
0.34
0.35
0.36
15.60
15.58
15.56
15.54
15.52
15.50
15.48
LOAD (kN)
3505
3500
3495
3490
3485
LOAD (lb)
SPECIMEN: 4BBH1
MATERIAL: 304 STAINLESS
ORIENTATION: C
TEMP: 23°C/74°F
ULTIMATE LOAD
7.6
7.8
8.0
8.2
8.4
8.6
8.8
9.0
9.2
EXTENSION (mm)


900
800
700
600
500
400
300
200
100
0
ENGINEERING STRESS (MPa)
125
100
75
50
25
0
ENGINEERING STRESS (ksi)
0
5
10
15
20
25
30
35
40
45
50
55
ENGINEERING STRAIN [STROKE] (PERCENT)
SPECIMEN: 4BBH1
MATERIAL: 304 STAINLESS
ORIENTATION: C
TEMP: 23°C/74°F

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 4BBH1



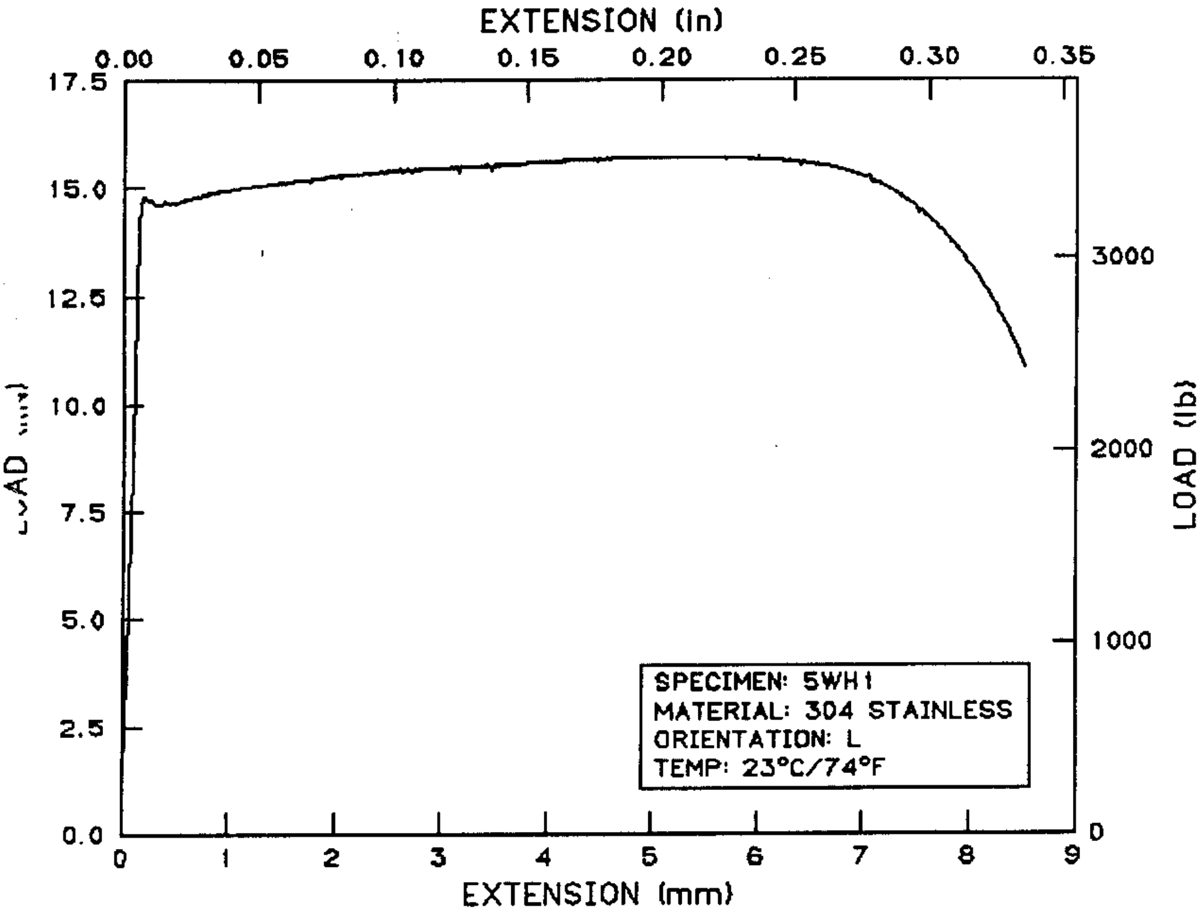

SPECIMEN: 4BBH1
MATERIAL: 304 STAINLESS
ORIENTATION: C
TEMP: 23°C/74°F
TRUE STRESS (MPa)
ENGINEERING STRESS (ksi)
STRAIN-HARDENING EXPONENT DATA/FIT
TRUE PLASTIC STRAIN [EXTENSION] (PERCENT)
0
200
400
600
800
1000
1200
0
25
50
75
100
125
150
0
5
10
15
20
25
30

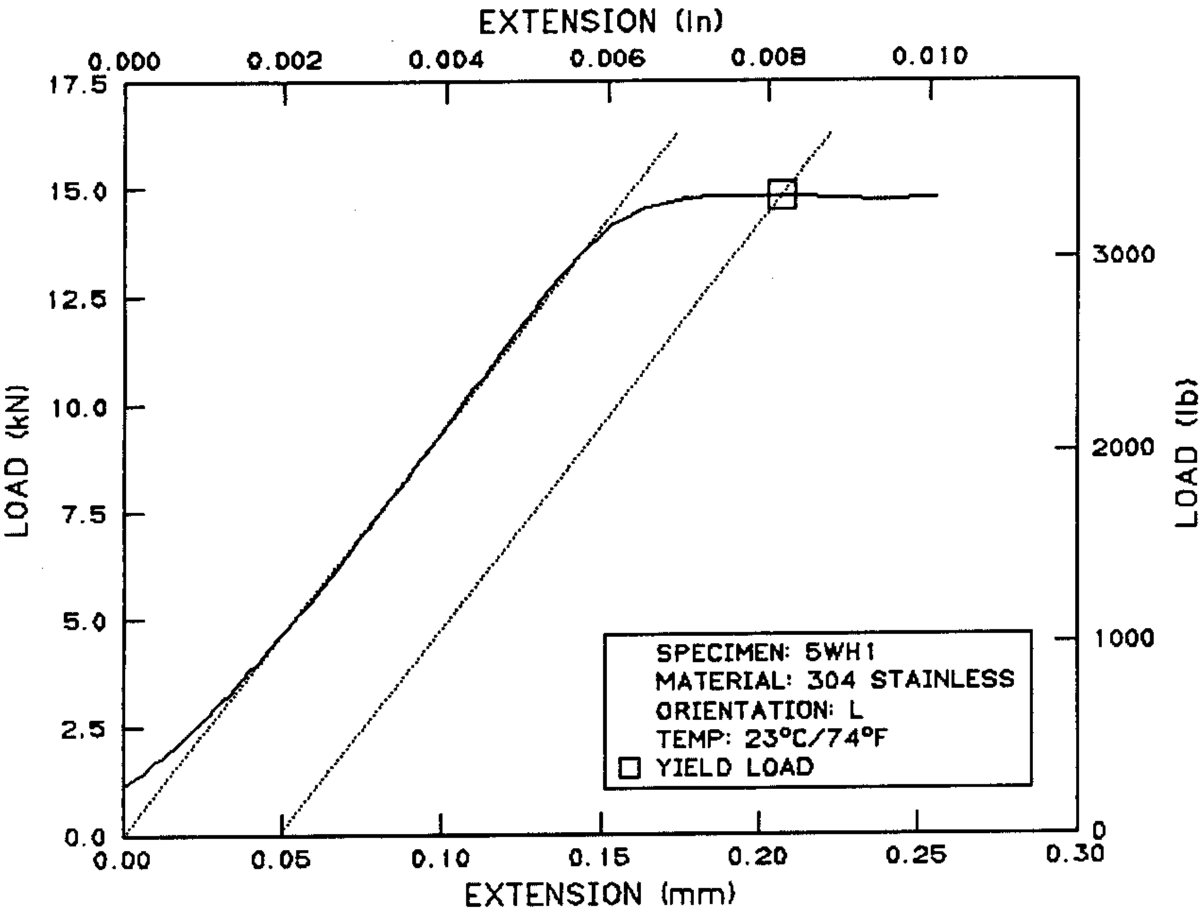
COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 5WH1

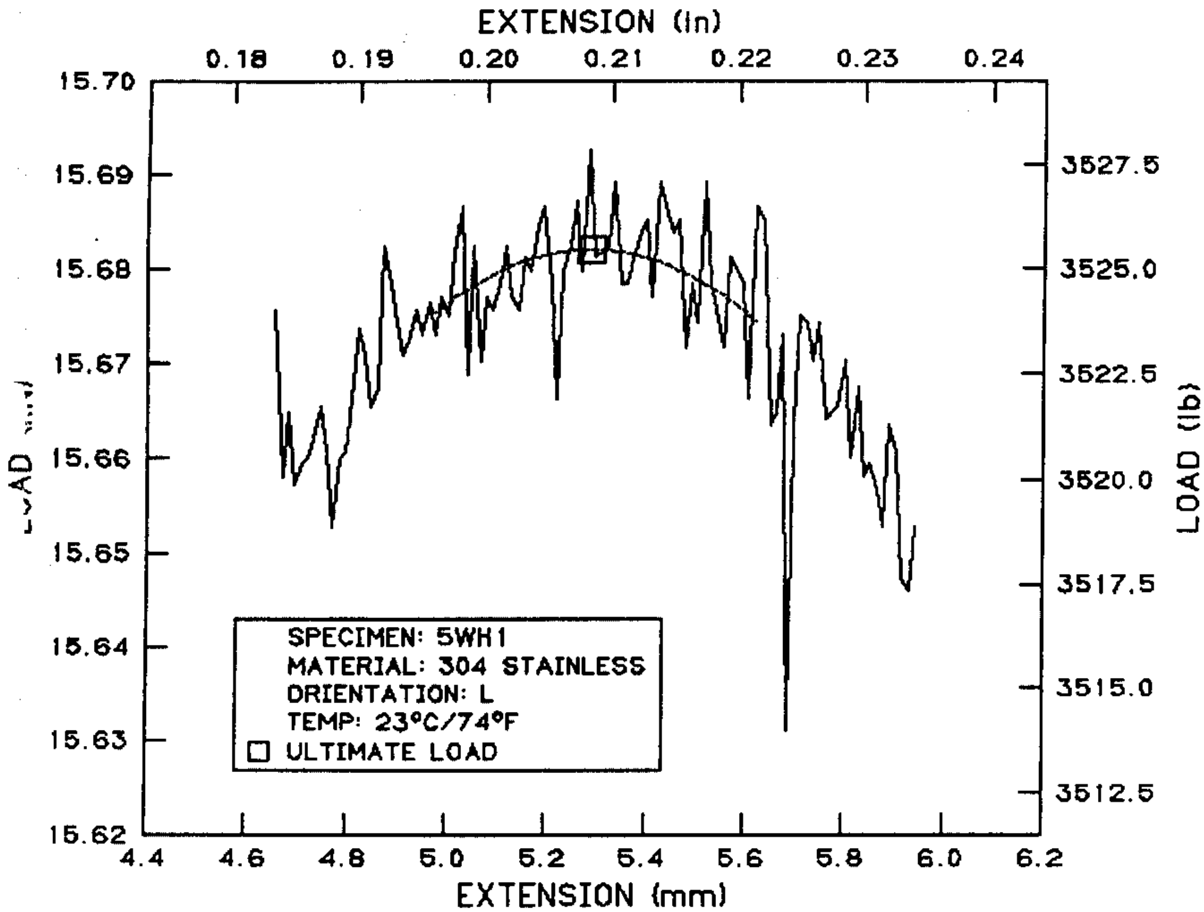
SPECIMEN
  IDENTIFICATION: 5WH1
  MATERIAL CODE: 304 STAINLESS
  ORIENTATION: L
  CROSS-SECTION FORM: CIRCULAR
  INITIAL OVERALL LENGTH: 54.991 (MM),2.165 (IN)
  REDUCED SECTION LENGTH: 24.384 (MM),0.96 (IN)
  GAUGE LENGTH: 24.384 (MM),0.96 (IN)
  GAUGE DIAMETERS
    DIAMETER 1: 5.08 (MM),0.2 (IN)
    DIAMETER 2: 5.08 (MM),0.2 (IN)
    DIAMETER 3: 5.08 (MM),0.2 (IN)
  FINAL OVERALL LENGTH: UNKNOWN
  NECK DIAMETER: UNKNOWN
TEST
  CROSSHEAD SPEED: 0.008 (MM/SEC),0.02 (IN/MIN)
  ATMOSPHERE: AIR
  TEMPERATURE: 23.3 (DEG C),74 (DEG F)
  DATE: 12-MAR-93
  ENGINEER: F.M. HAGGAG
  TECHNICIAN: R.L. SWAIN
  REMARK: NONE
ANALYSIS
  ROUTINE REVISION: 1.00/07-APR-93
  LOADS
    YIELD [0.2 PERCENT OFFSET, EXTENSION]: 14.82 (KN),3331.8 (LB)
    ULTIMATE [EXTENSION]: 15.682 (KN),3525.5 (LB)
    FRACTURE: 10.825 (KN),2433.6 (LB)
  ELONGATION
    UNIFORM [EXTENSION]: 19.42 (PERCENT)
    TOTAL [EXTENSION]: 31.85 (PERCENT)
  STRENGTHS
    YIELD [0.2 PERCENT OFFSET, EXTENSION]: 731 (MPA),106.1 (KSI)
    ULTIMATE [EXTENSION]: 774 (MPA),112.2 (KSI)
  TENSILE STRAIN-HARDENING
    EXPONENT: 0.085
    STRENGTH COEFFICIENT: 1023 (MPA),148.4 (KSI)
    STRAIN DATA RANGE [TRUE PLASTIC, EXTENSION]: 2.04 TO 12.05 (PERCENT)

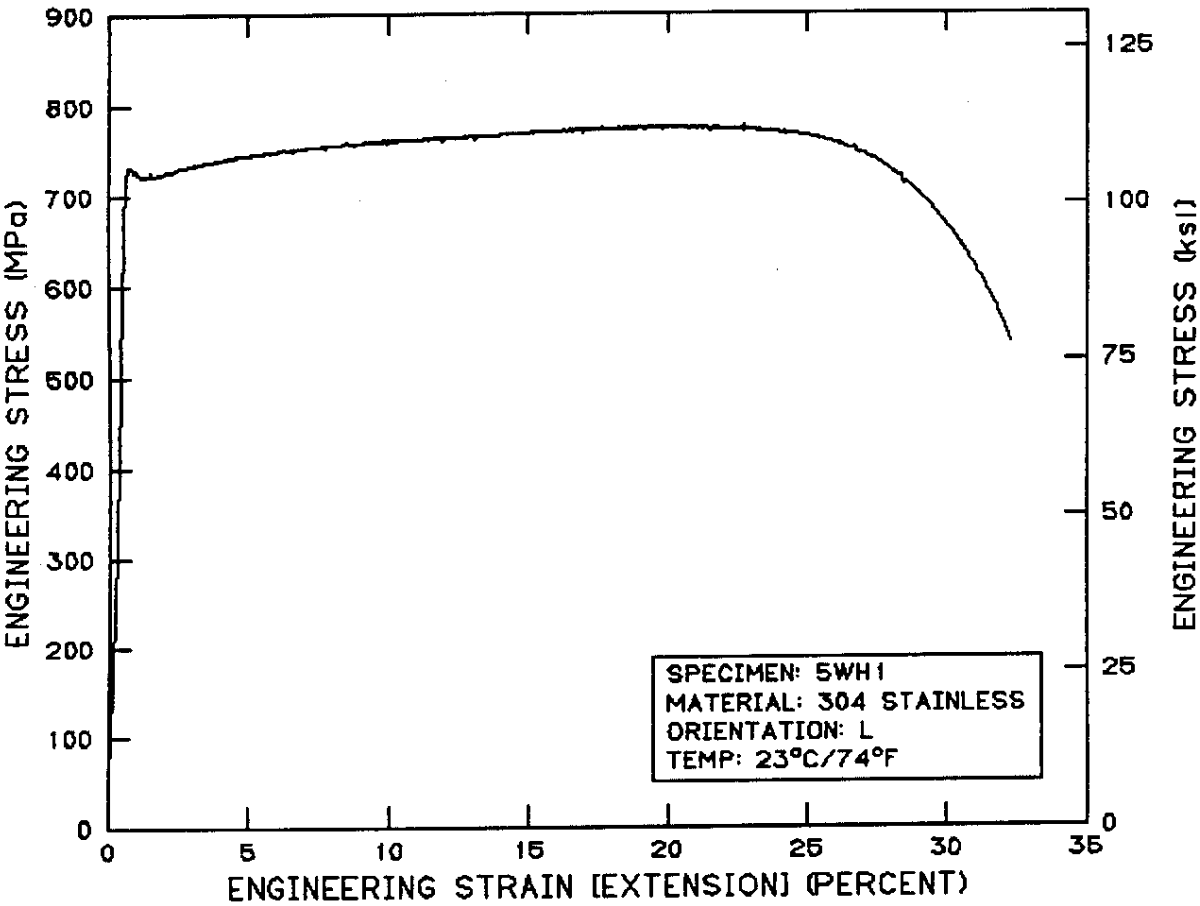
COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 5WH1

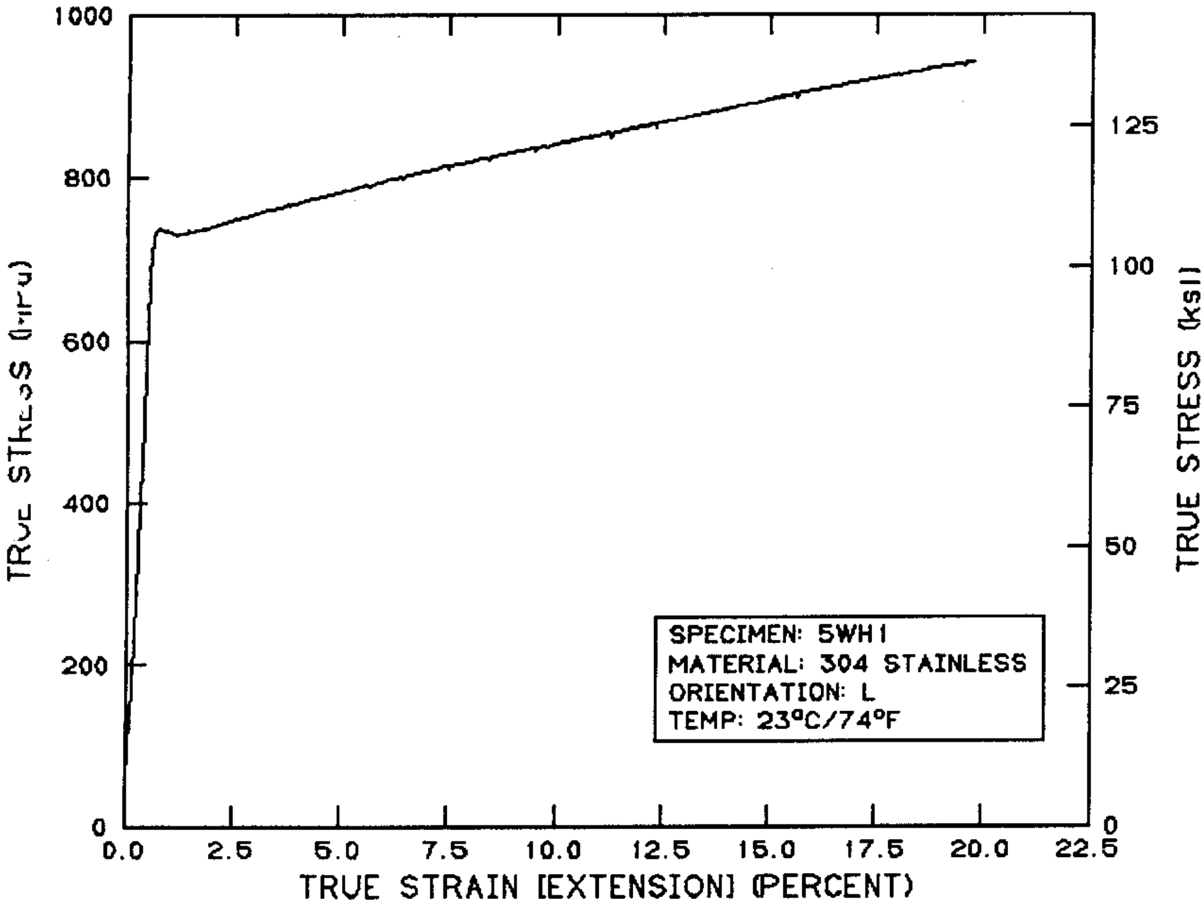
07-MAY-93

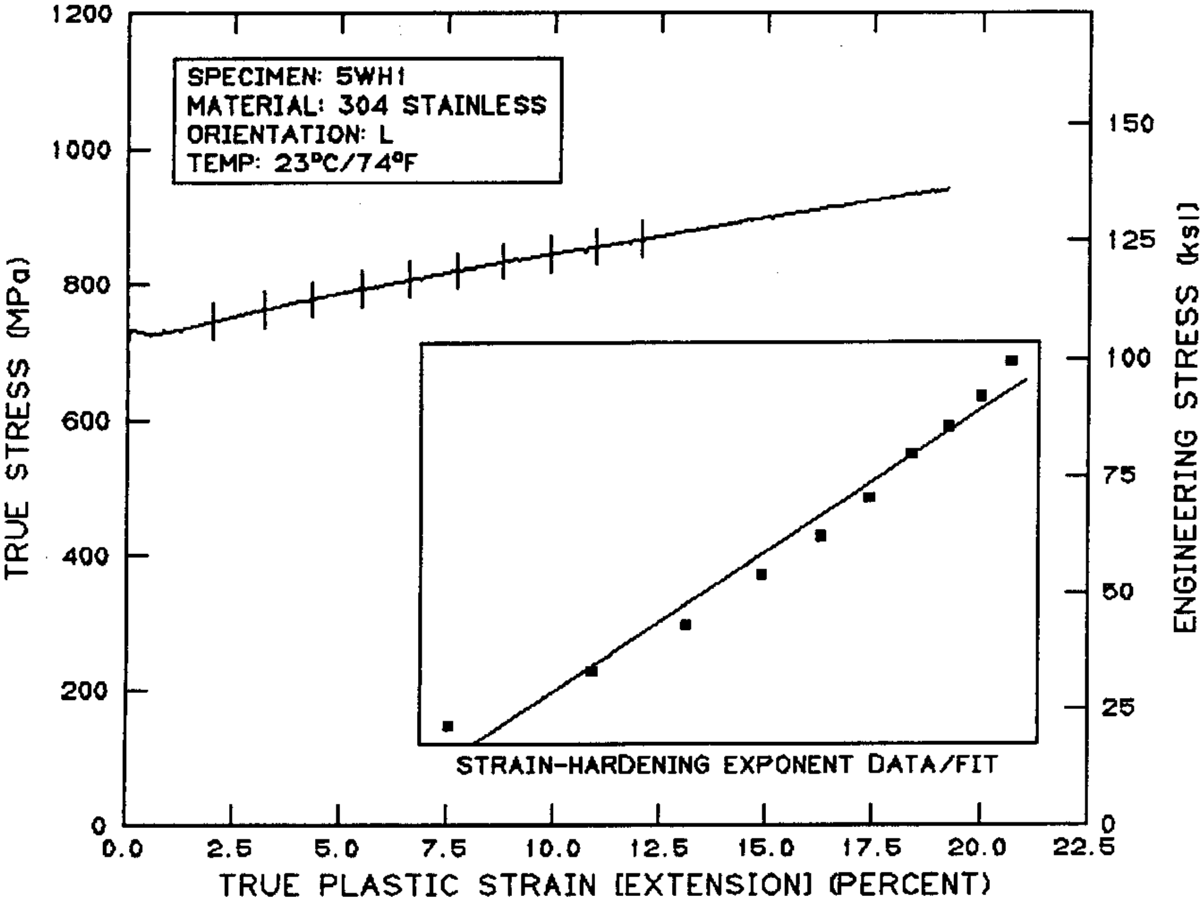



EXTENSION (in)
0.000
0.002
0.004
0.006
0.008
0.010
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
LOAD (kN)
3000
2000
1000
0
LOAD (lb)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
EXTENSION (mm)
SPECIMEN: 5WH1
MATERIAL: 304 STAINLESS
ORIENTATION: L
TEMP: 23°C/74°F
YIELD LOAD


EXTENSION (in)
0.18
0.19
0.20
0.21
0.22
0.23
0.24
15.70
15.69
15.68
15.67
15.66
15.65
15.64
15.63
15.62
3527.5
3525.0
3522.5
3520.0
3517.5
3515.0
3512.5
LOAD (lb)
SPECIMEN: 5WH1
MATERIAL: 304 STAINLESS
ORIENTATION: L
TEMP: 23°C/74°F
ULTIMATE LOAD
4.4
4.6
4.8
5.0
5.2
5.4
5.6
5.8
6.0
6.2
EXTENSION (mm)


ENGINEERING STRESS (MPa)
900
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
35
ENGINEERING STRAIN [EXTENSION] (PERCENT)
125
100
75
50
25
0
ENGINEERING STRESS (ksi)
SPECIMEN: 5WH1
MATERIAL: 304 STAINLESS
ORIENTATION: L
TEMP: 23°C/74°F

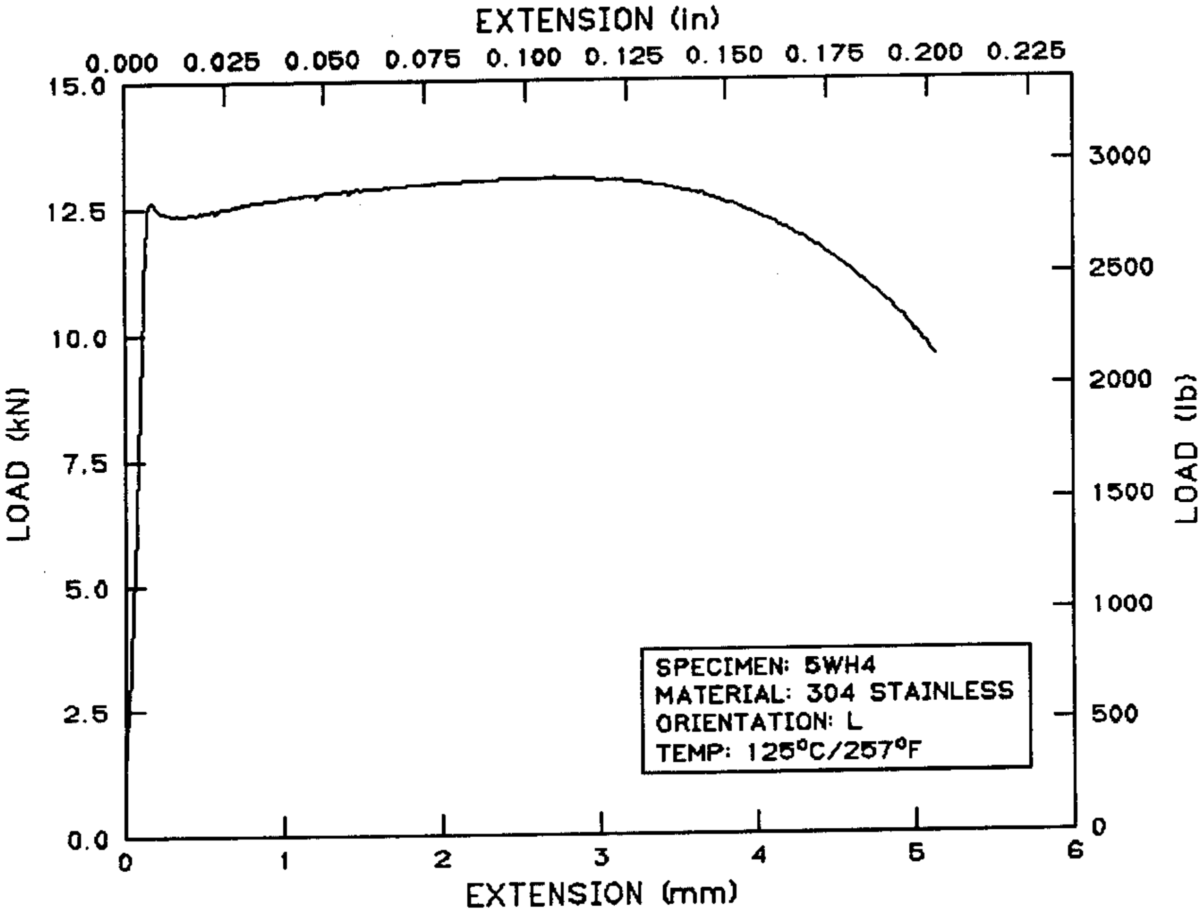

1000
800
600
400
200
0
TRUE STRESS (MPa)
125
100
75
50
25
0
TRUE STRESS (ksi)
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
TRUE STRAIN [EXTENSION] (PERCENT)
SPECIMEN: 5WH1
MATERIAL: 304 STAINLESS
ORIENTATION: L
TEMP: 23°C/74°F

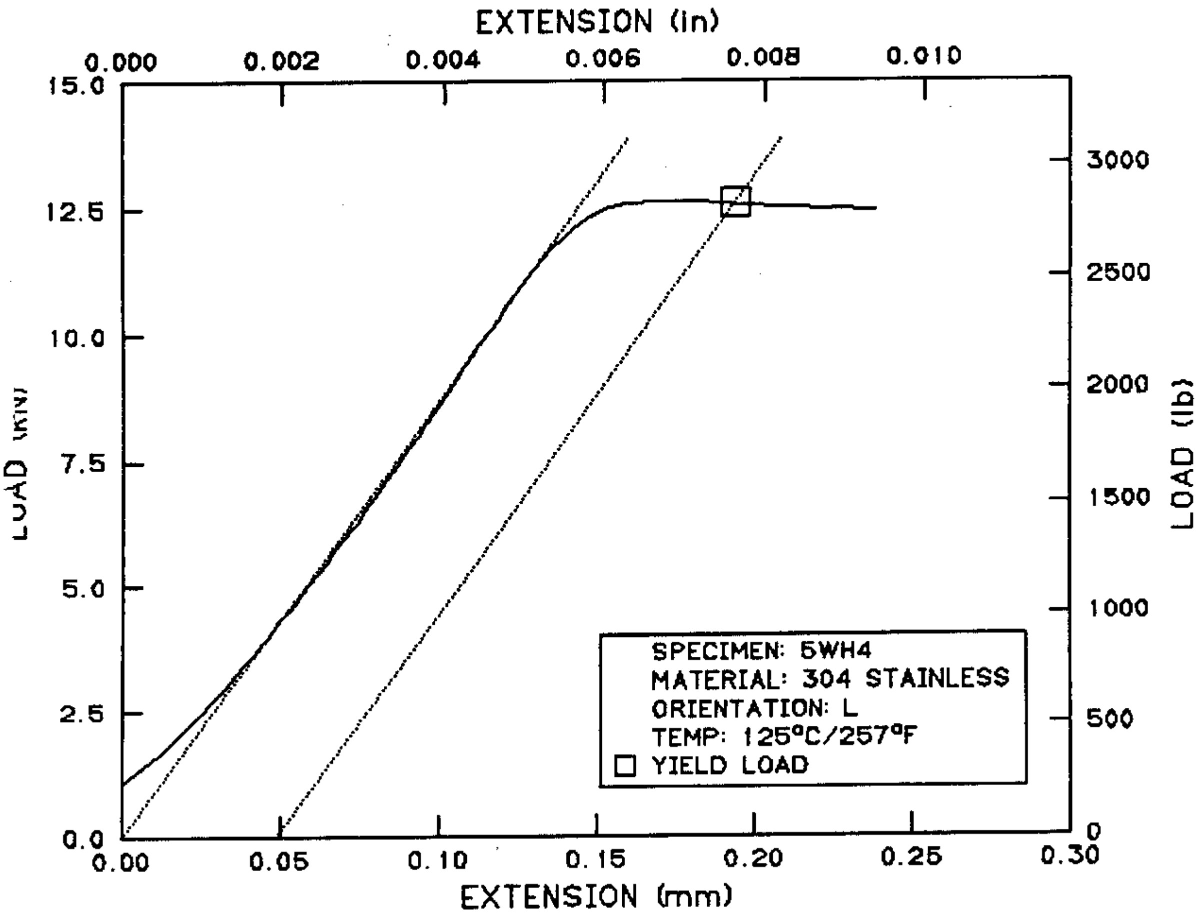

SPECIMEN: 5WH1
MATERIAL: 304 STAINLESS
ORIENTATION: L
TEMP: 23°C/74°F
STRAIN-HARDENING EXPONENT DATA/FIT
TRUE STRESS (MPa)
ENGINEERING STRESS (ksi)
TRUE PLASTIC STRAIN [EXTENSION] (PERCENT)
0
200
400
600
800
1000
1200
25
50
75
100
125
150
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 5WH4

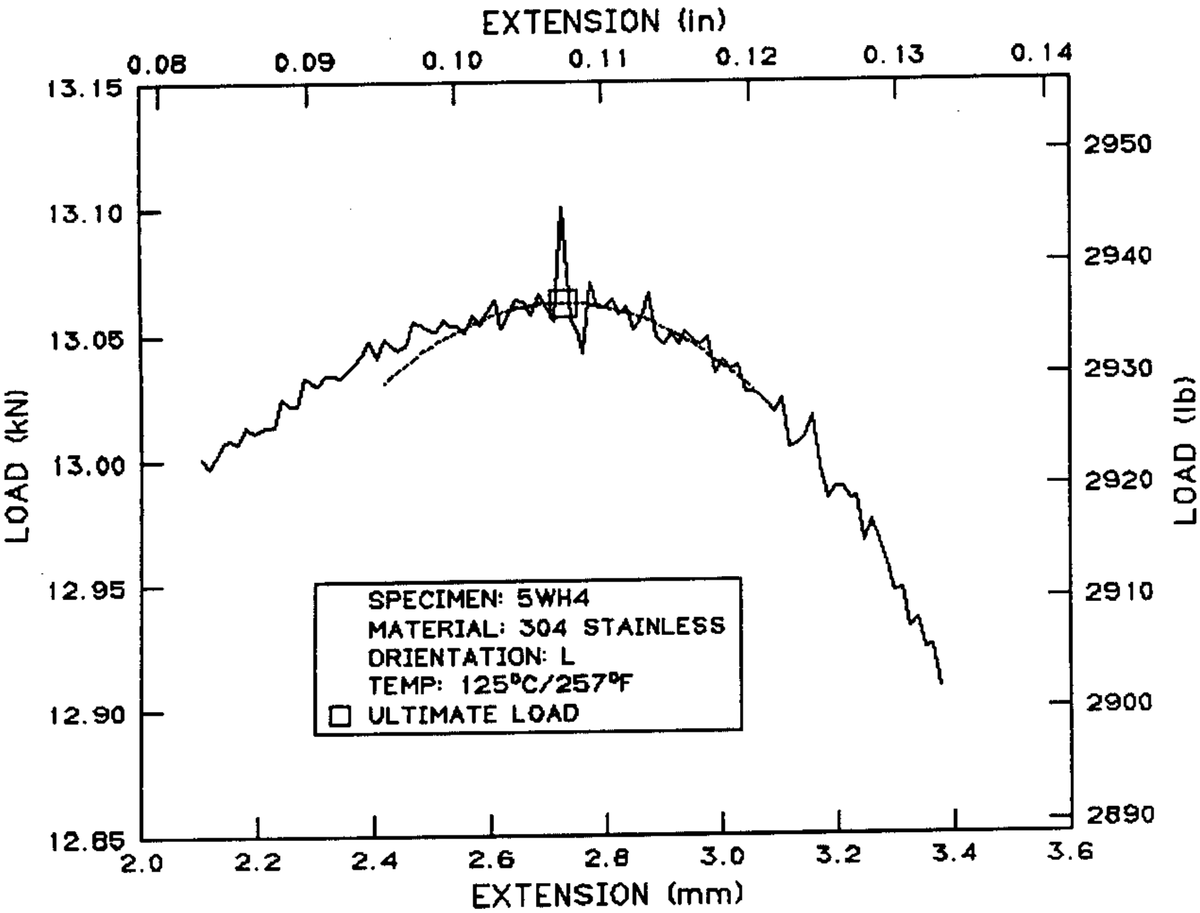
SPECIMEN
  IDENTIFICATION: 5WH4
  MATERIAL CODE: 304 STAINLESS
  ORIENTATION: L
  CROSS-SECTION FORM: CIRCULAR
  INITIAL OVERALL LENGTH: 54.991 (MM),2.165 (IN)
  REDUCED SECTION LENGTH: 24.384 (MM),0.96 (IN)
  GAUGE LENGTH: 24.384 (MM),0.96 (IN)
  GAUGE DIAMETERS
    DIAMETER 1: 5.08 (MM),0.2 (IN)
    DIAMETER 2: 5.08 (MM),0.2 (IN)
    DIAMETER 3: 5.08 (MM),0.2 (IN)
  FINAL OVERALL LENGTH: UNKNOWN
  NECK DIAMETER: UNKNOWN
TEST
  CROSSHEAD SPEED: 0.008 (MM/SEC),0.02 (IN/MIN)
  ATMOSPHERE: AIR
  TEMPERATURE: 125 (DEG C),257 (DEG F)
  DATE: 17-MAR-93
  ENGINEER: F.M. HAGGAG
  TECHNICIAN: R.L. SWAIN
  REMARK: NONE
ANALYSIS
  ROUTINE REVISION: 1.00/07-APR-93
  LOADS
    YIELD [0.2 PERCENT OFFSET, EXTENSION]: 12.593 (KN),2830.9 (LB)
    ULTIMATE [EXTENSION]: 13.062 (KN),2936.5 (LB)
    FRACTURE: 9.4945 (KN),2134.4 (LB)
  ELONGATION
    UNIFORM [EXTENSION]: 9.77 (PERCENT)
    TOTAL [EXTENSION]: 19.01 (PERCENT)
  STRENGTHS
    YIELD [0.2 PERCENT OFFSET, EXTENSION]: 621 (MPA),90.1 (KSI)
    ULTIMATE [EXTENSION]: 644 (MPA),93.5 (KSI)
  TENSILE STRAIN-HARDENING
    EXPONENT: 0.0669
    STRENGTH COEFFICIENT: 817 (MPA),118.6 (KSI)
    STRAIN DATA RANGE [TRUE PLASTIC, EXTENSION]: 1.53 TO 7.54 (PERCENT)

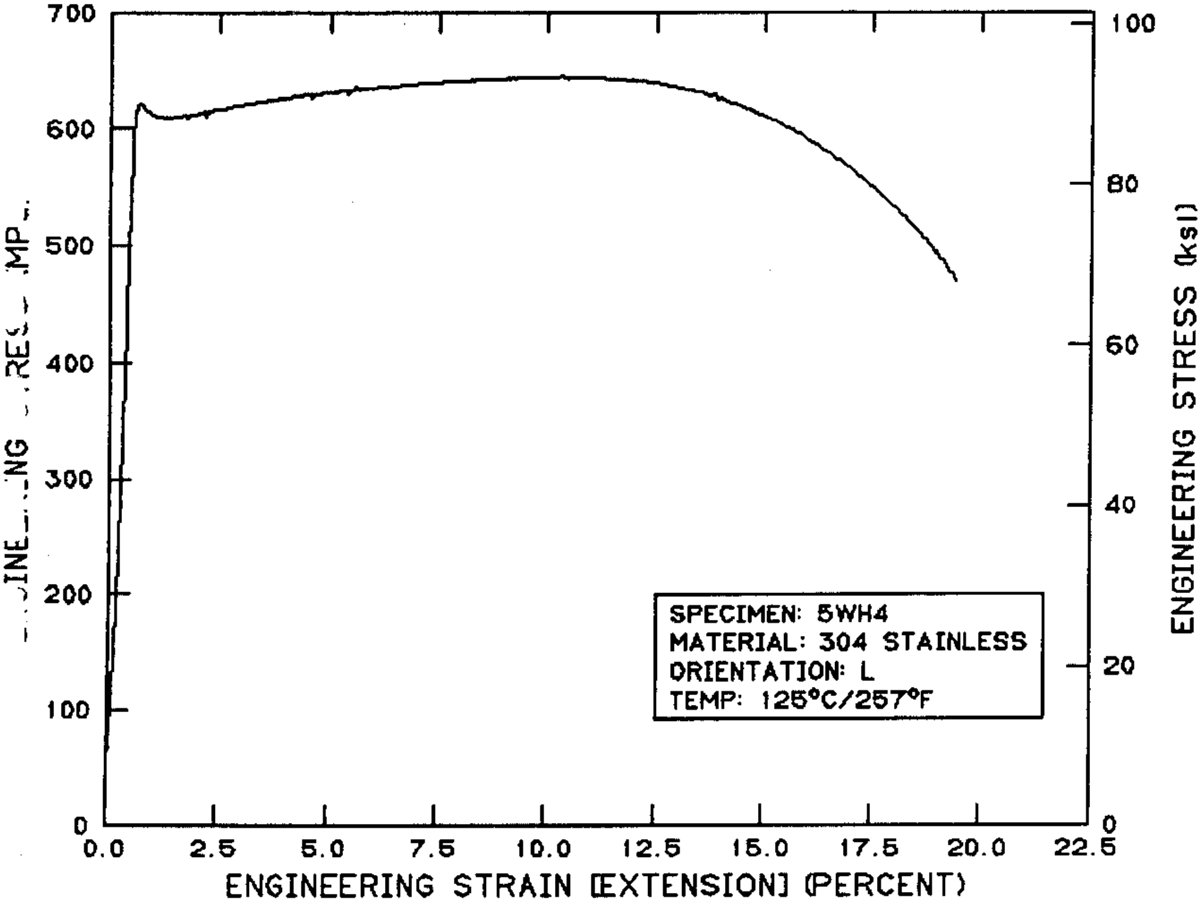
COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 5WH4



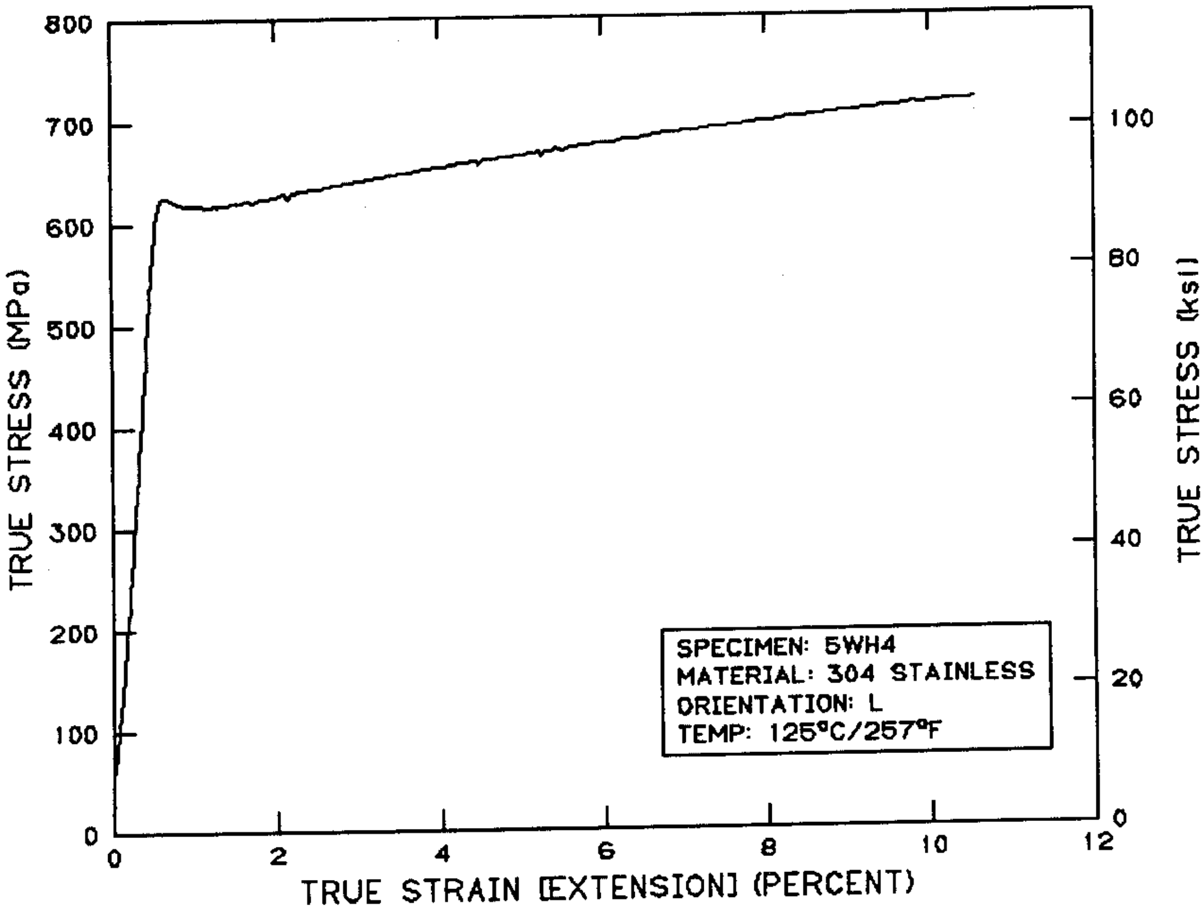

EXTENSION (in)
0.000
0.002
0.004
0.006
0.008
0.010
15.0
12.5
10.0
7.5
5.0
2.5
0.0
LOAD (kN)
3000
2500
2000
1500
1000
500
0
LOAD (lb)
SPECIMEN: 5WH4
MATERIAL: 304 STAINLESS
ORIENTATION: L
TEMP: 125°C/257°F
YIELD LOAD
0.00
0.05
0.10
0.15
0.20
0.25
0.30
EXTENSION (mm)

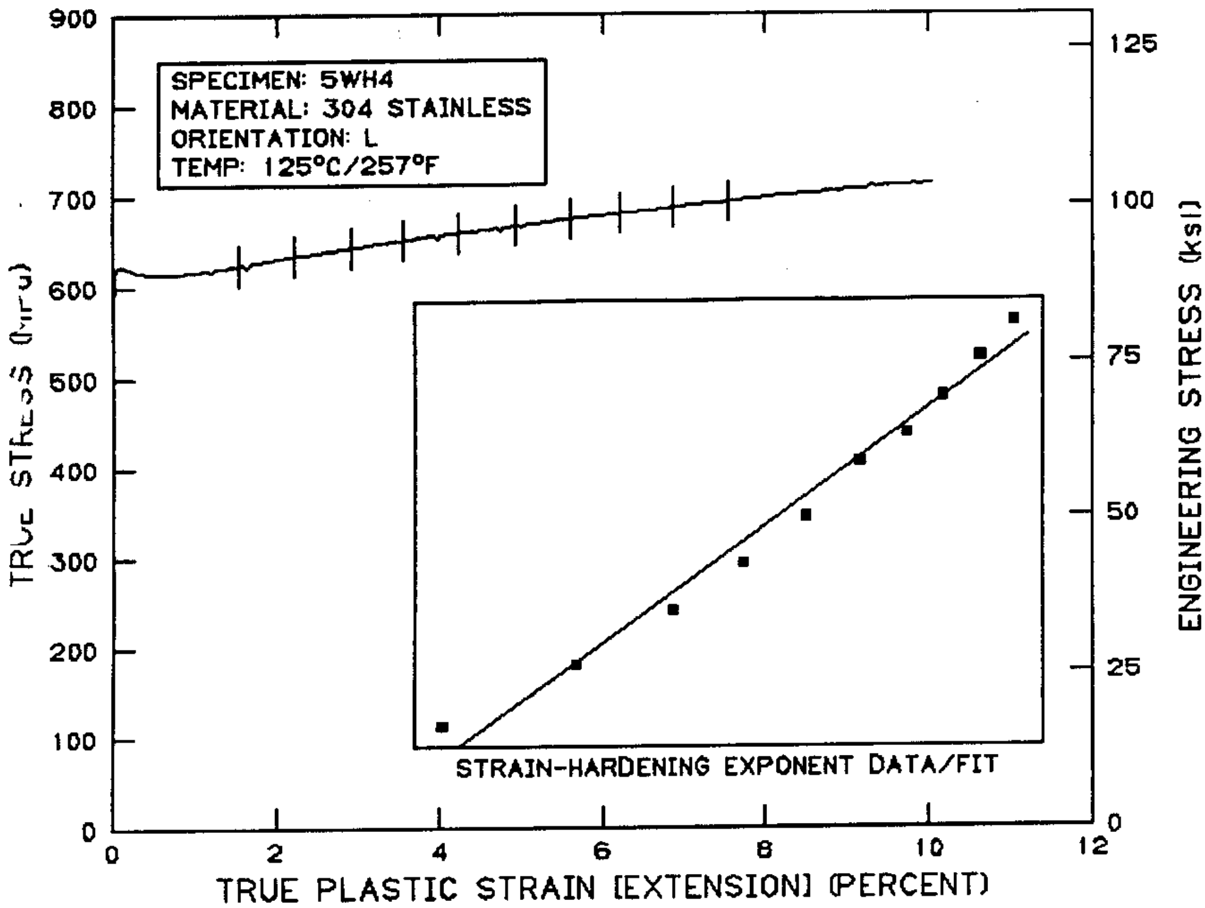
COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 5WH4




SPECIMEN: 5WH4
MATERIAL: 304 STAINLESS
ORIENTATION: L
TEMP: 125°C/257°F
ENGINEERING STRAIN [EXTENSION] (PERCENT)
ENGINEERING STRESS (ksi)
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
0
100
200
300
400
500
600
700
0
20
40
60
80
100

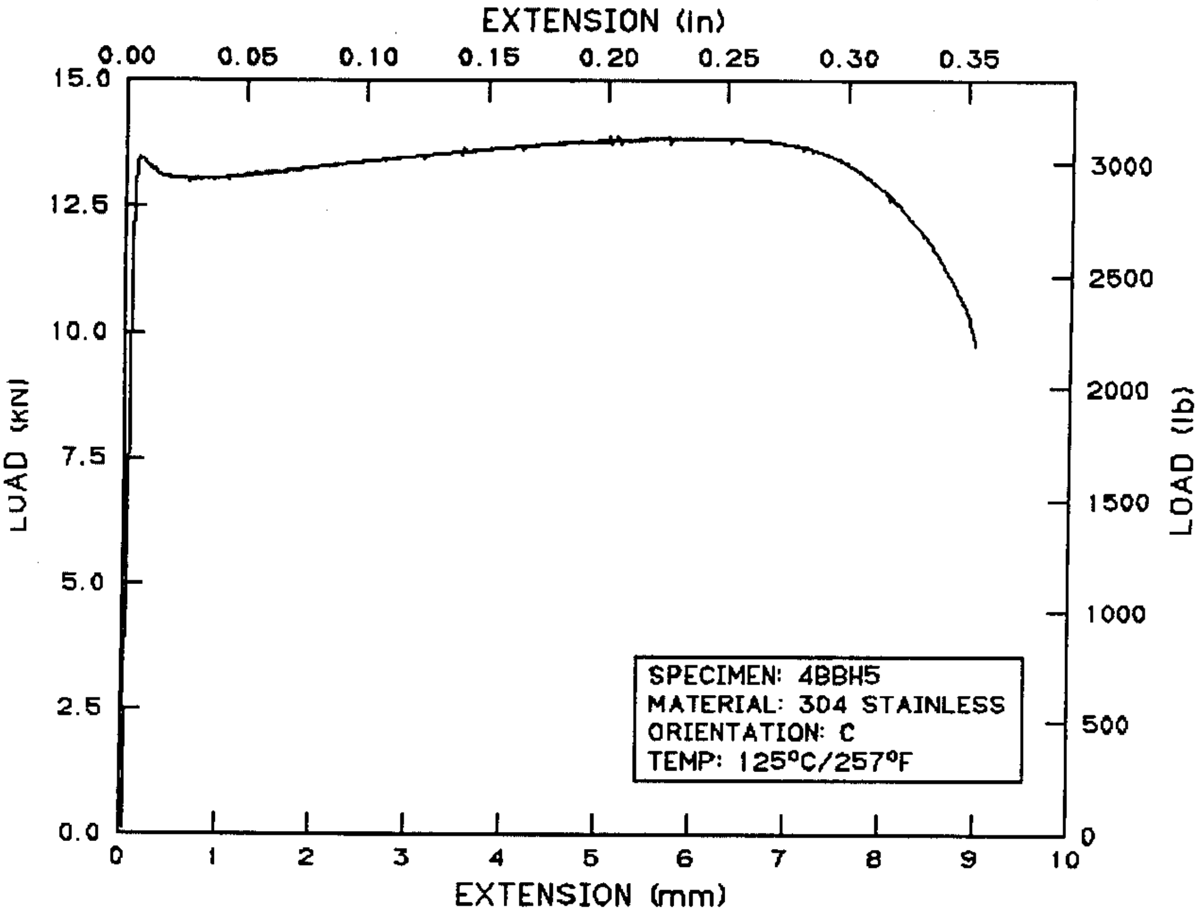
COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 5WH4



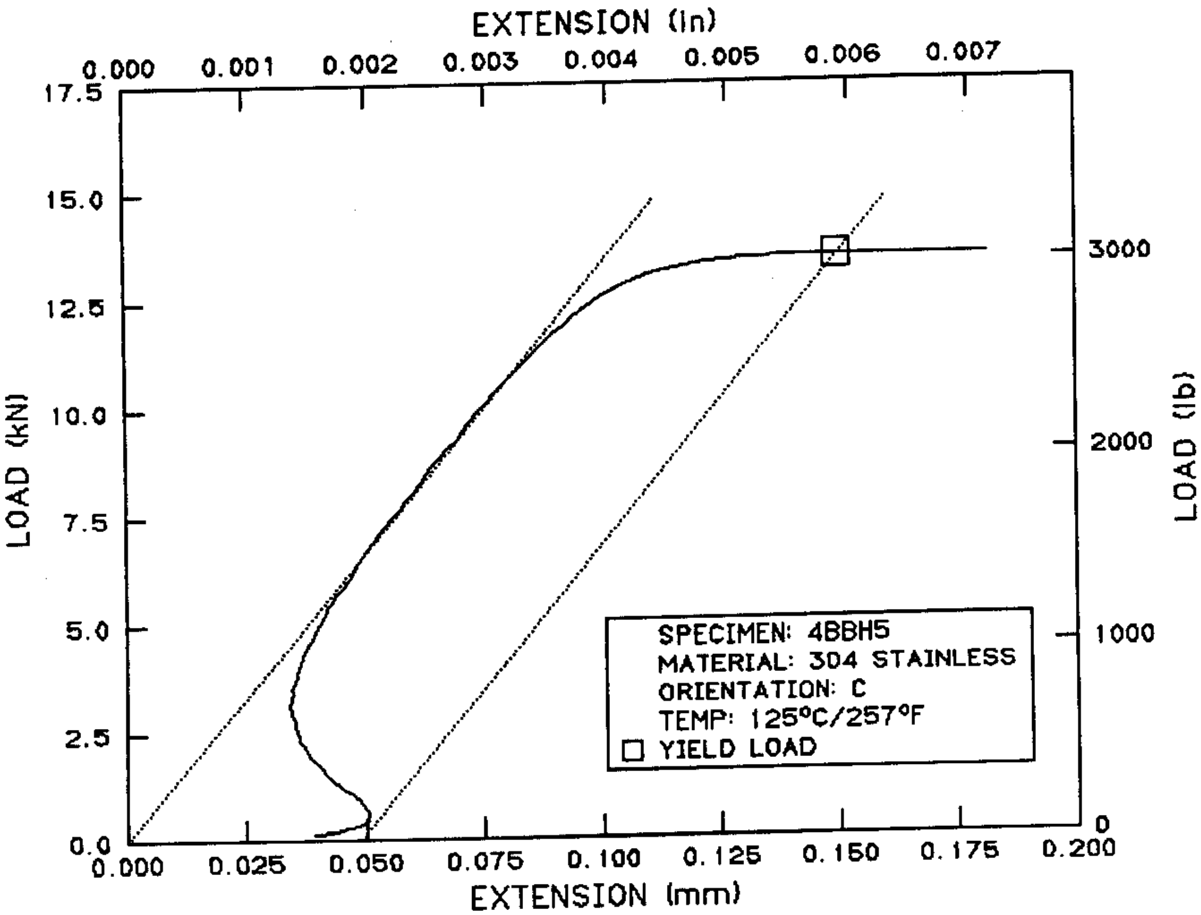

SPECIMEN: 5WH4
MATERIAL: 304 STAINLESS
ORIENTATION: L
TEMP: 125°C/257°F
STRAIN-HARDENING EXPONENT DATA/FIT
TRUE STRESS (MPa)
ENGINEERING STRESS (ksi)
TRUE PLASTIC STRAIN [EXTENSION] (PERCENT)
0
100
200
300
400
500
600
700
800
900
25
50
75
100
125
2
4
6
8
10
12

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 4BBH5

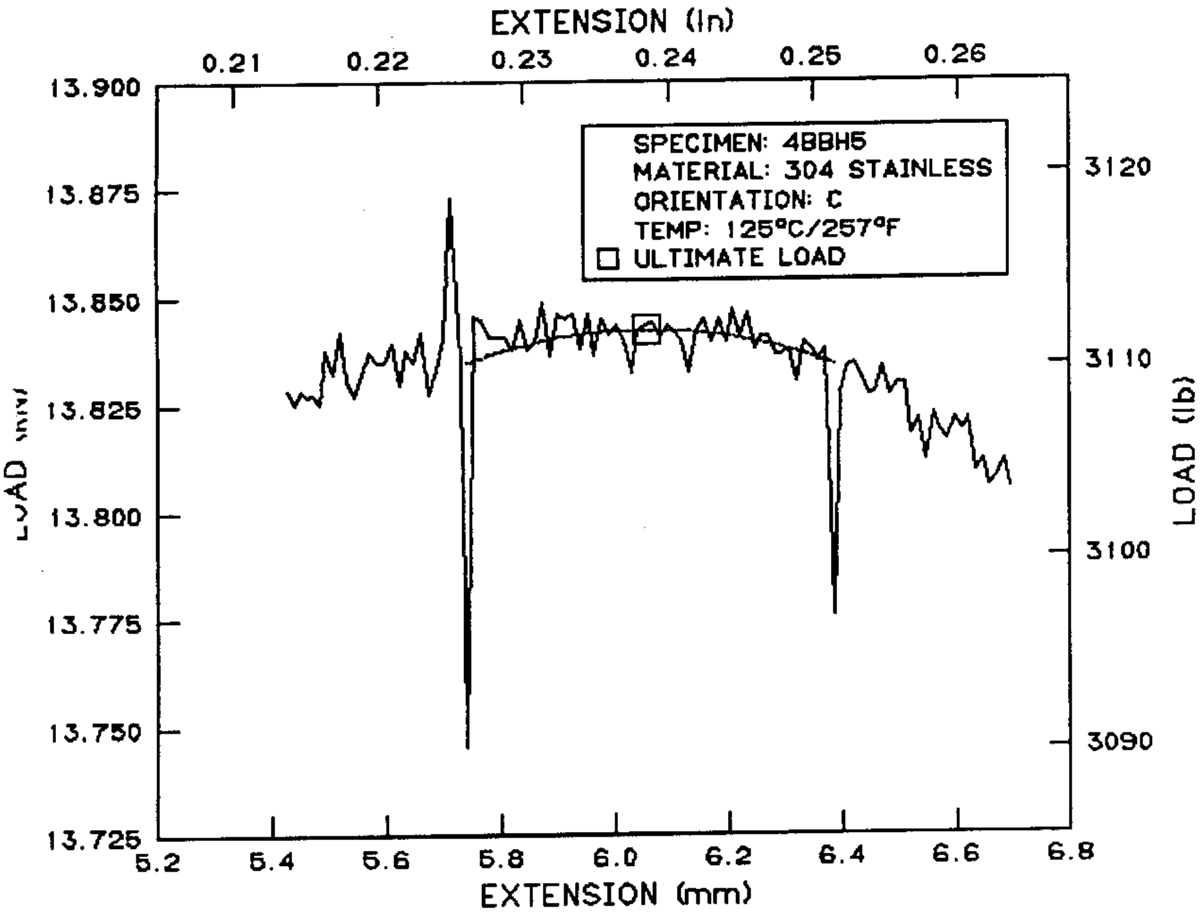
SPECIMEN
  IDENTIFICATION: 4BBH5
  MATERIAL CODE: 304 STAINLESS
  ORIENTATION: C
  CROSS-SECTION FORM: CIRCULAR
  INITIAL OVERALL LENGTH: 54.991 (MM),2.165 (IN)
  REDUCED SECTION LENGTH: 24.384 (MM),0.96 (IN)
  GAUGE LENGTH: 24.384 (MM),0.96 (IN)
  GAUGE DIAMETERS
    DIAMETER 1: 5.08 (MM),0.2 (IN)
    DIAMETER 2: 5.08 (MM),0.2 (IN)
    DIAMETER 3: 5.08 (MM),0.2 (IN)
  FINAL OVERALL LENGTH: UNKNOWN
  NECK DIAMETER: UNKNOWN
TEST
  CROSSHEAD SPEED: 0.008 (MM/SEC),0.02 (IN/MIN)
  ATMOSPHERE: AIR
  TEMPERATURE: 125 (DEG C),257 (DEG F)
  DATE: 19-MAR-93
  ENGINEER: F.M. HAGGAG
  TECHNICIAN: R.L. SWAIN
  REMARK: NONE
ANALYSIS
  ROUTINE REVISION: 1.00/07-APR-93
  LOADS
    YIELD [0.2 PERCENT OFFSET, EXTENSION]: 13.46 (KN),3025.9 (LB)
    ULTIMATE [EXTENSION]: 13.842 (KN),3111.8 (LB)
    FRACTURE: 9.7106 (KN),2183 (LB)
  ELONGATION
    UNIFORM [EXTENSION]: 22.57 (PERCENT)
    TOTAL [EXTENSION]: 33.78 (PERCENT)
  STRENGTHS
    YIELD [0.2 PERCENT OFFSET, EXTENSION]: 664 (MPA),96.3 (KSI)
    ULTIMATE [EXTENSION]: 683 (MPA),99.1 (KSI)
  TENSILE STRAIN-HARDENING
    EXPONENT: 0.0891
    STRENGTH COEFFICIENT: 905 (MPA),131.2 (KSI)
    STRAIN DATA RANGE [TRUE PLASTIC, EXTENSION]: 2.07 TO 14.07 (PERCENT)

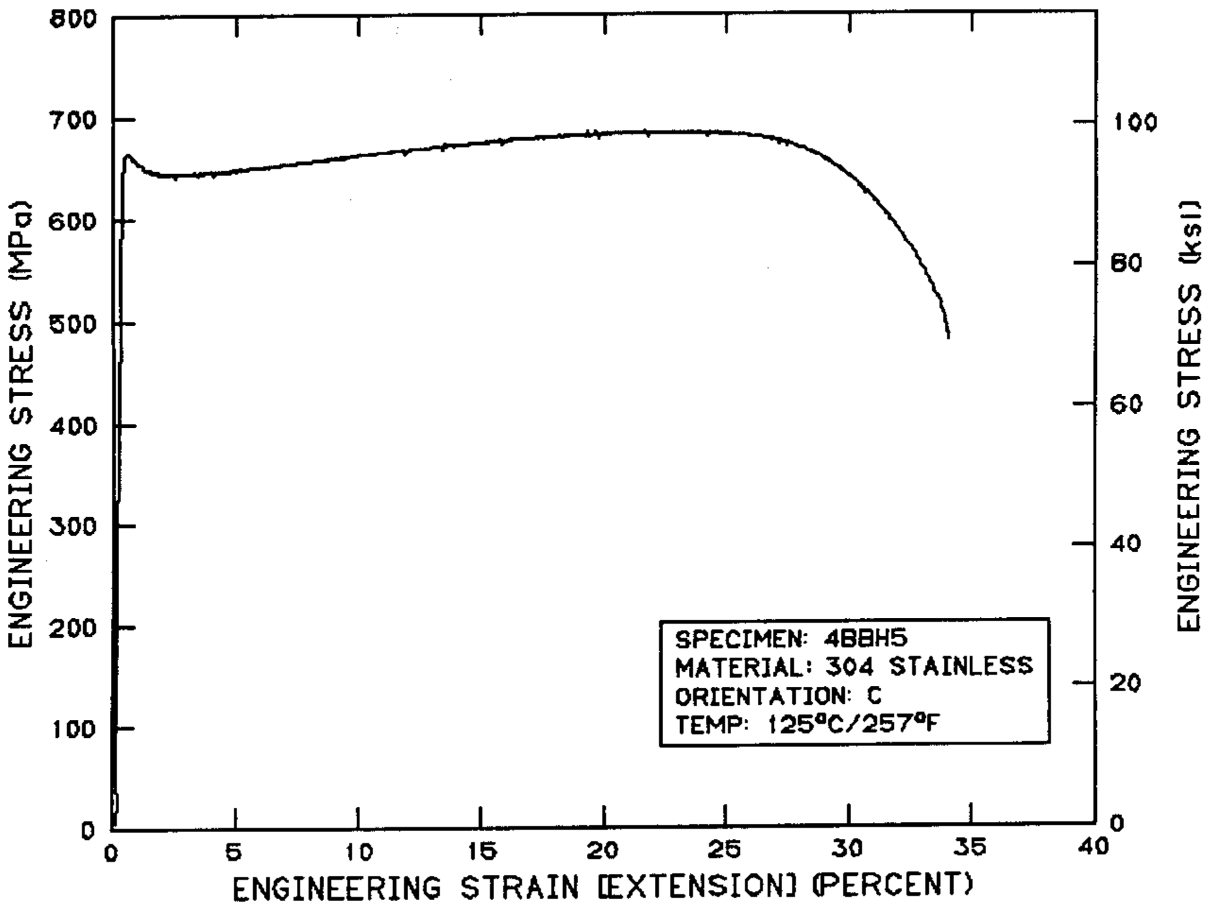

EXTENSION (in)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
15.0
12.5
10.0
7.5
5.0
2.5
0.0
LOAD (kN)
3000
2500
2000
1500
1000
500
0
LOAD (lb)
SPECIMEN: 4BBH5
MATERIAL: 304 STAINLESS
ORIENTATION: C
TEMP: 125°C/257°F
0
1
2
3
4
5
6
7
8
9
10
EXTENSION (mm)

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 4BBH5

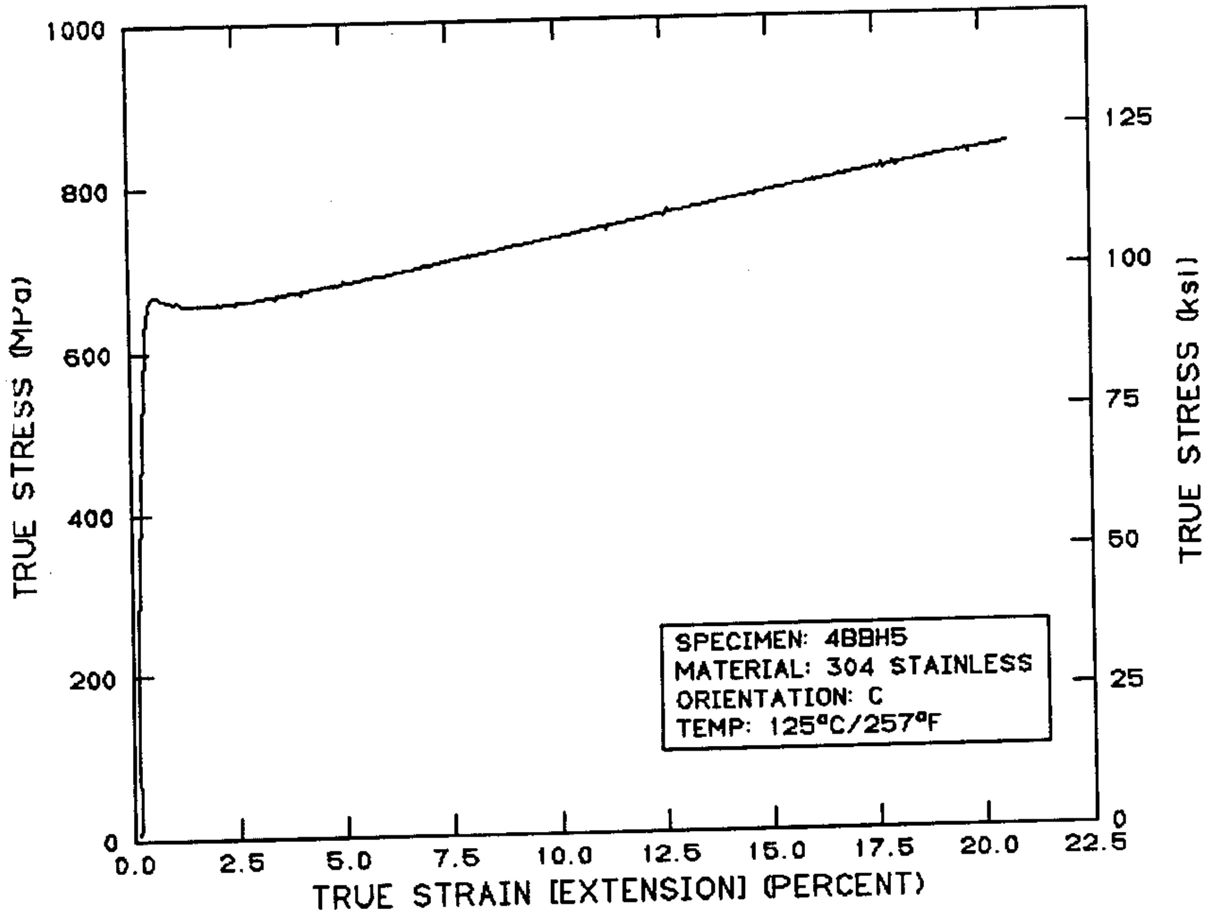


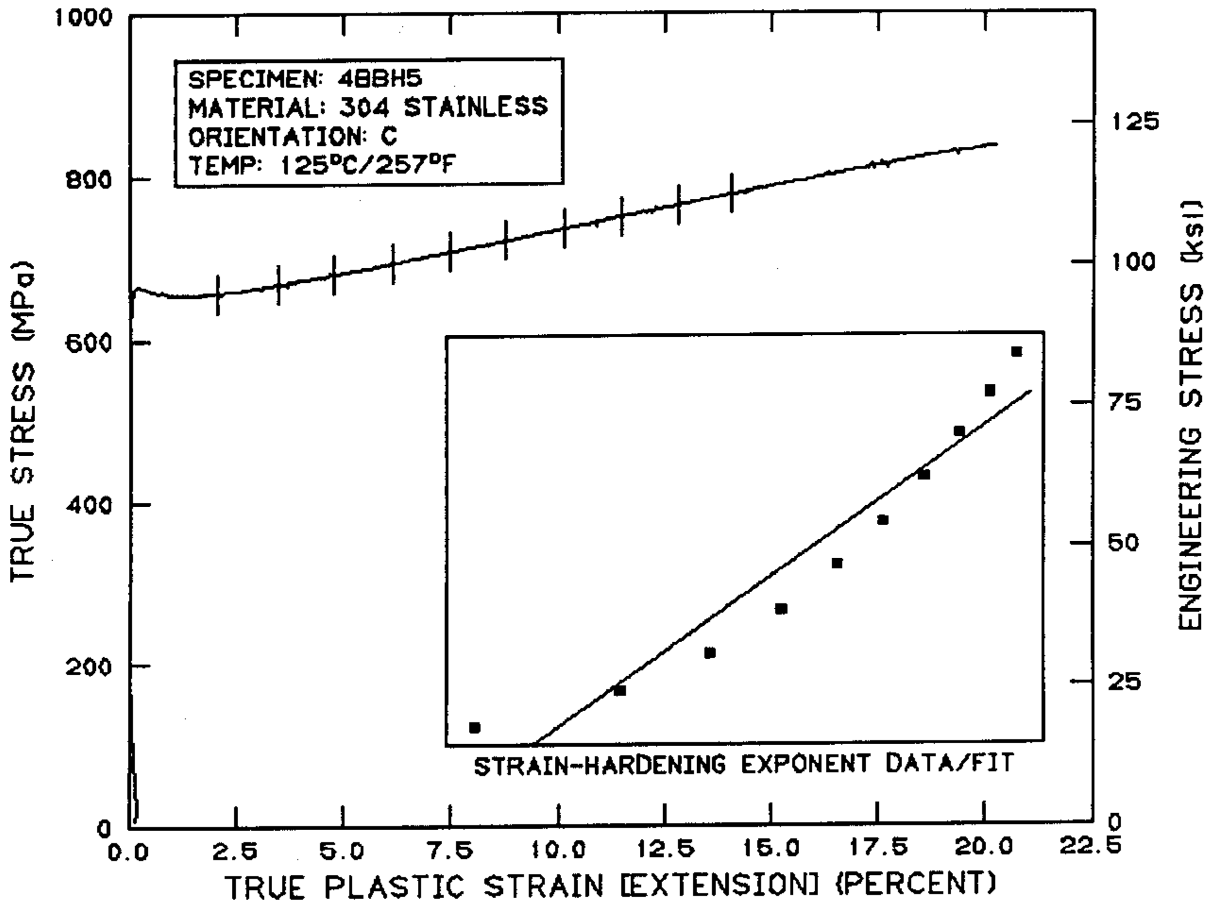
COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 4BBH5




800
700
600
500
400
300
200
100
0
ENGINEERING STRESS (MPa)
100
80
60
40
20
0
ENGINEERING STRESS (ksi)
0
5
10
15
20
25
30
35
40
ENGINEERING STRAIN [EXTENSION] (PERCENT)
SPECIMEN: 4BBH5
MATERIAL: 304 STAINLESS
ORIENTATION: C
TEMP: 125°C/257°F

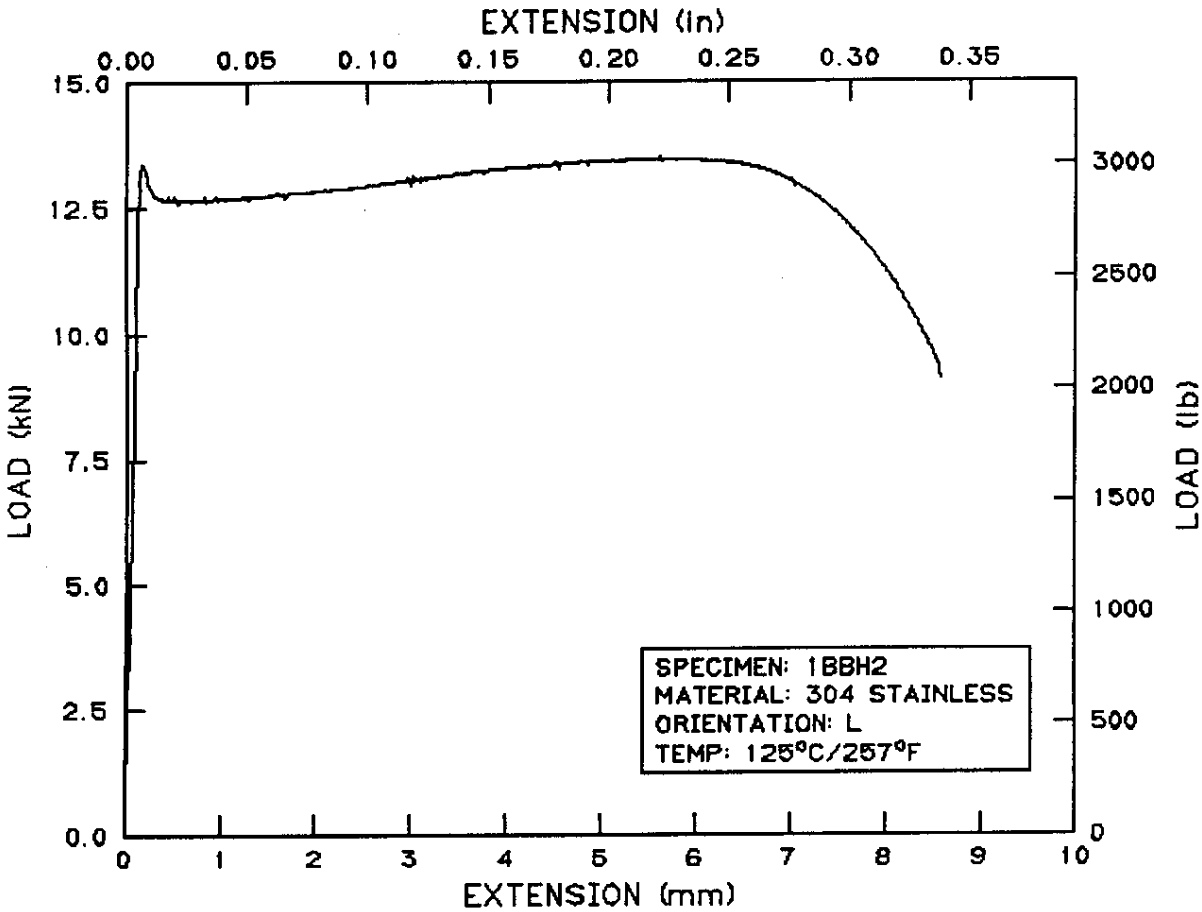
COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 4BBH5

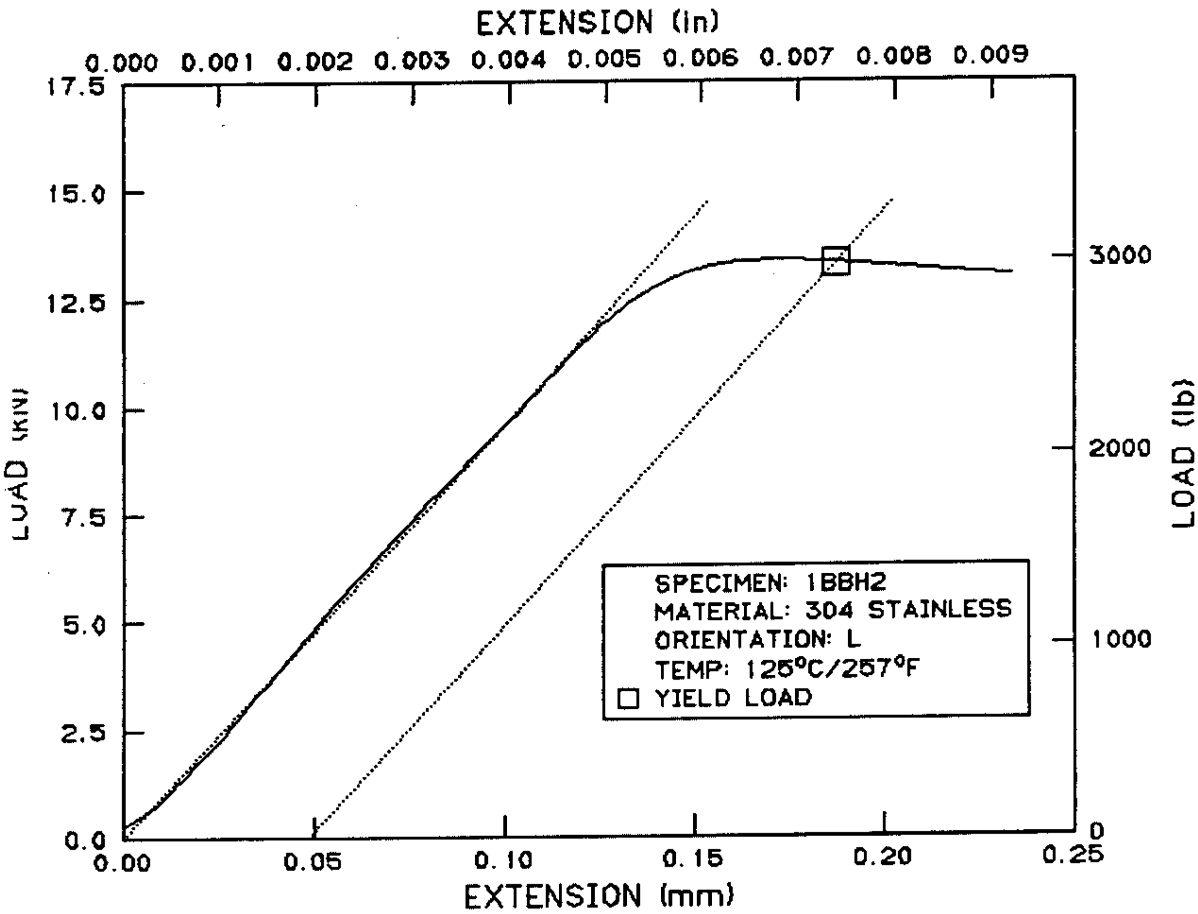


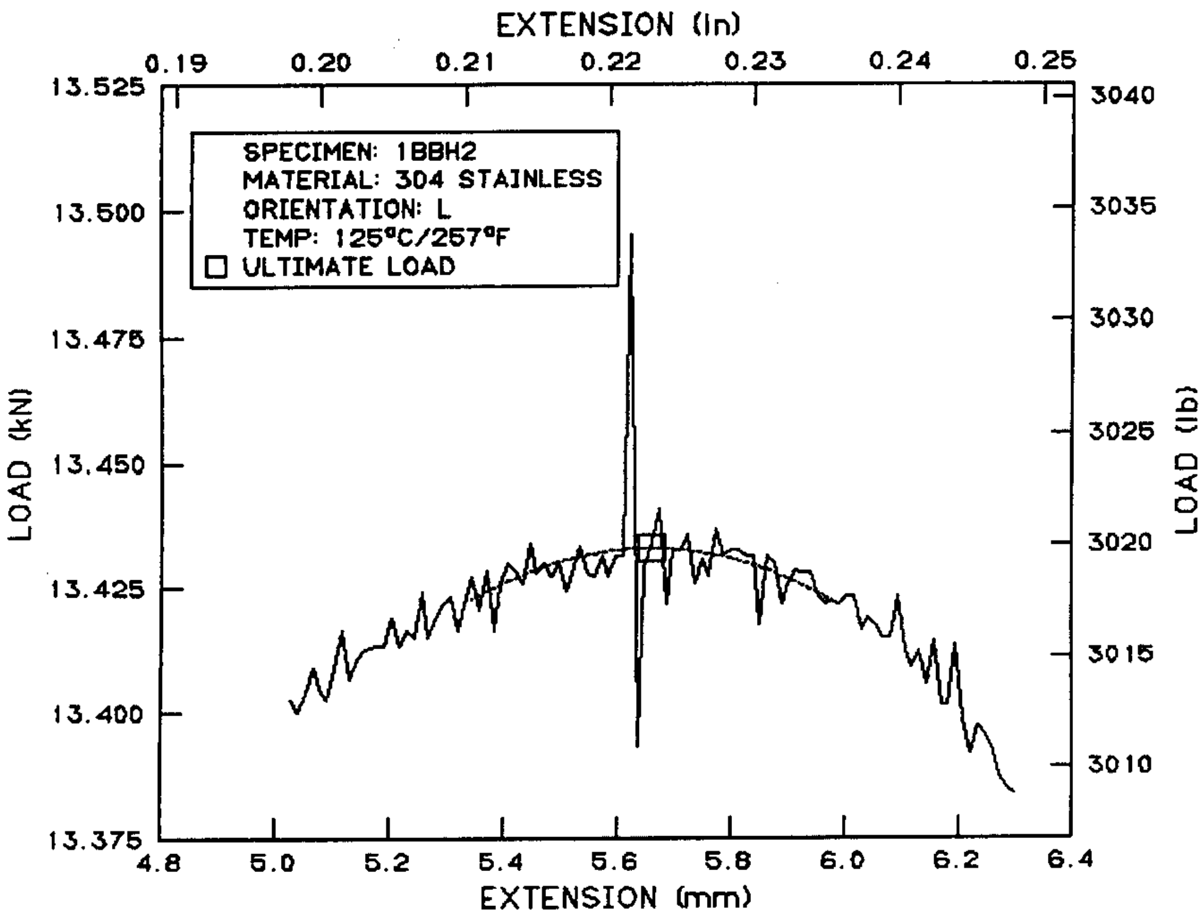

SPECIMEN: 4BBH5
MATERIAL: 304 STAINLESS
ORIENTATION: C
TEMP: 125°C/257°F
STRAIN-HARDENING EXPONENT DATA/FIT
TRUE STRESS (MPa)
ENGINEERING STRESS (ksi)
TRUE PLASTIC STRAIN [EXTENSION] (PERCENT)
0
200
400
600
800
1000
25
50
75
100
125
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 1BBH2

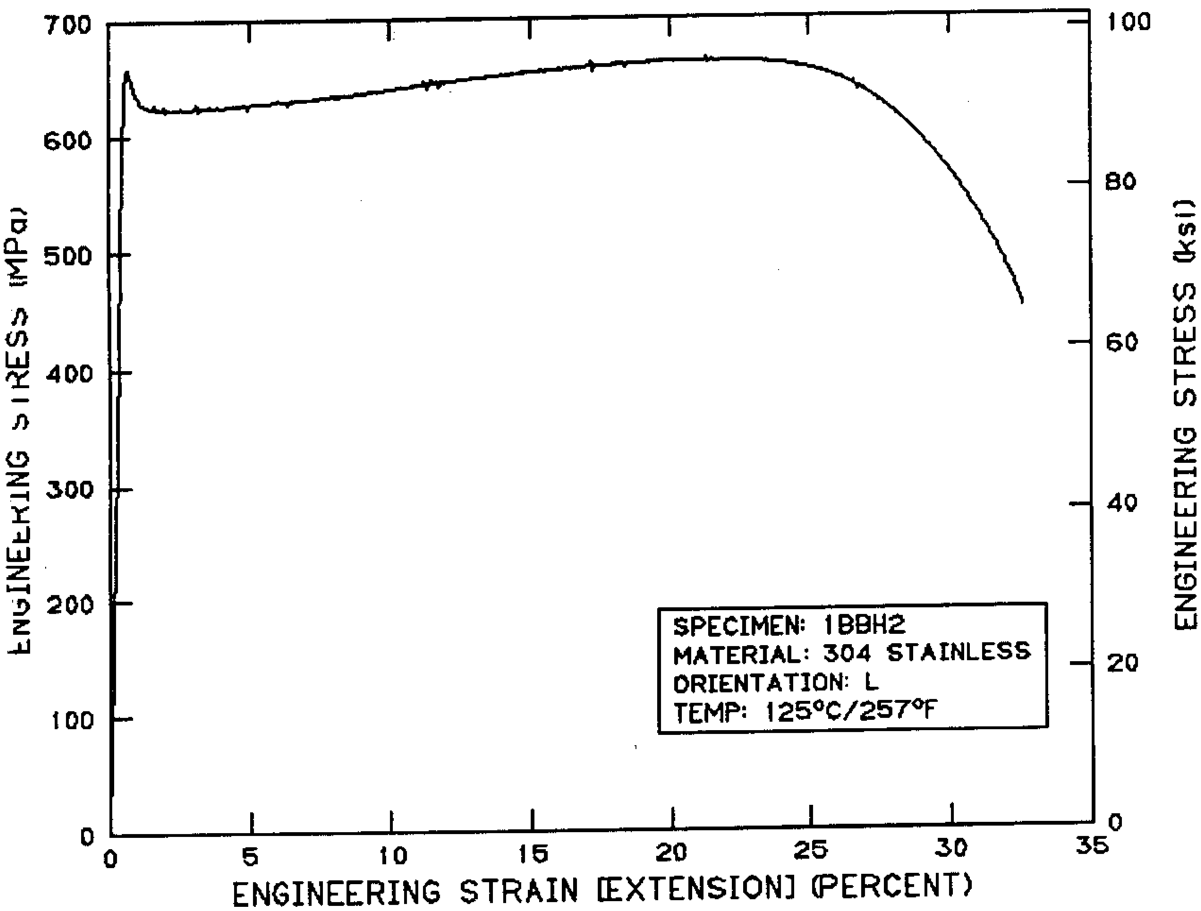
SPECIMEN
  IDENTIFICATION: 1BBH2
  MATERIAL CODE: 304 STAINLESS
  ORIENTATION: L
  CROSS-SECTION FORM: CIRCULAR
  INITIAL OVERALL LENGTH: 54.991 (MM),2.165 (IN)
  REDUCED SECTION LENGTH: 24.384 (MM),0.96 (IN)
  GAUGE LENGTH: 24.384 (MM),0.96 (IN)
  GAUGE DIAMETER: 5.08 (MM),0.2 (IN)
  FINAL OVERALL LENGTH: UNKNOWN
  NECK DIAMETER: UNKNOWN
TEST
  CROSSHEAD SPEED: 0.008 (MM/SEC),0.02 (IN/MIN)
  ATMOSPHERE: AIR
  TEMPERATURE: 125 (DEG C),257 (DEG F)
  DATE: 17-MAR-93
  ENGINEER: F.M. HAGGAG
  TECHNICIAN: R.L. SWAIN
  REMARK: NONE
ANALYSIS
  ROUTINE REVISION: 1.00/07-APR-93
  LOADS
    YIELD [0.2 PERCENT OFFSET, EXTENSION]: 13.271 (KN),2983.5 (LB)
    ULTIMATE [EXTENSION]: 13.433 (KN),3019.8 (LB)
    FRACTURE: 9.0853 (KN),2042.4 (LB)
  ELONGATION
    UNIFORM [EXTENSION]: 20.92 (PERCENT)
    TOTAL [EXTENSION]: 32.21 (PERCENT)
  STRENGTHS
    YIELD [0.2 PERCENT OFFSET, EXTENSION]: 655 (MPA),95 (KSI)
    ULTIMATE [EXTENSION]: 663 (MPA),96.1 (KSI)
  TENSILE STRAIN-HARDENING
    EXPONENT: 0.0704
    STRENGTH COEFFICIENT: 828 (MPA),120.2 (KSI)
    STRAIN DATA RANGE [TRUE PLASTIC, EXTENSION]: 1.53 TO 11.52 (PERCENT)

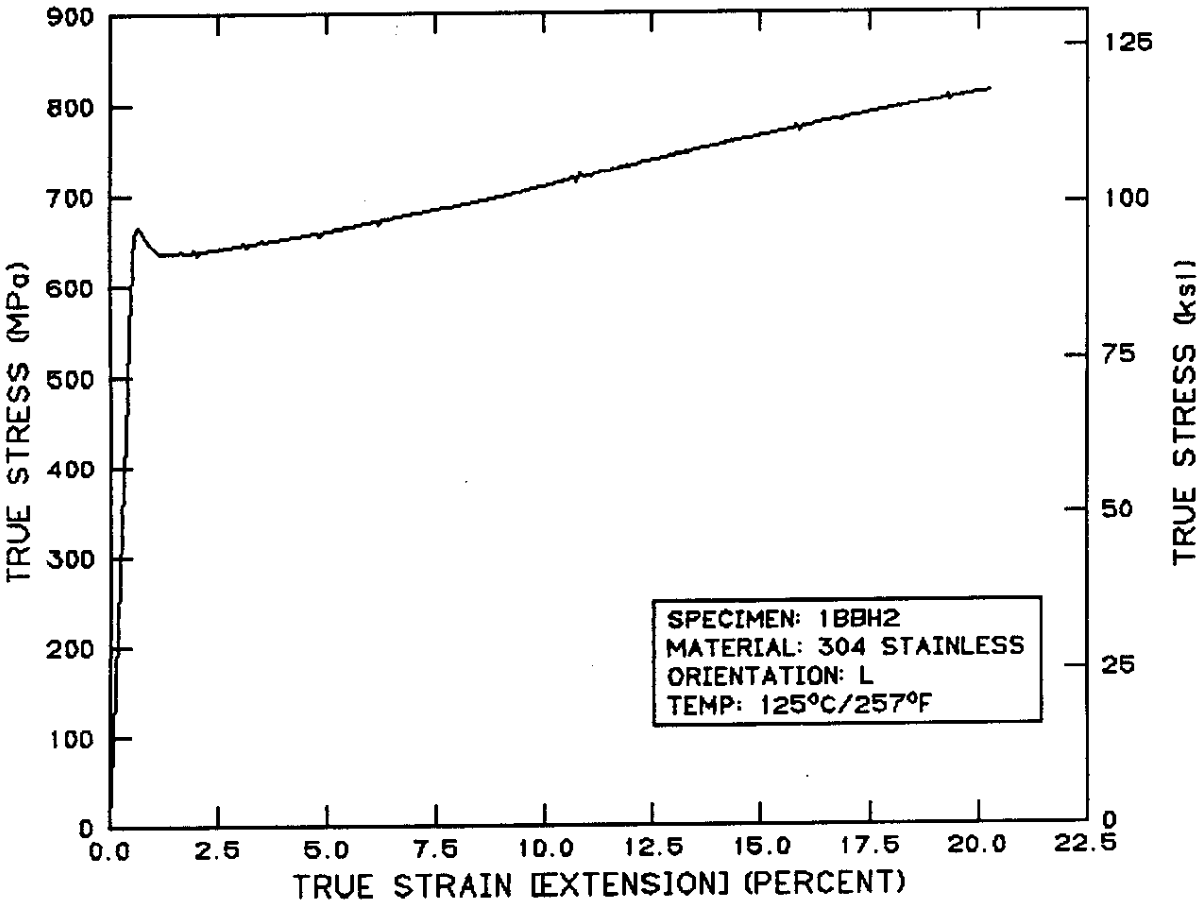

EXTENSION (in)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
LOAD (kN)
15.0
12.5
10.0
7.5
5.0
2.5
0.0
LOAD (lb)
3000
2500
2000
1500
1000
500
0
SPECIMEN: 1BBH2
MATERIAL: 304 STAINLESS
ORIENTATION: L
TEMP: 125°C/257°F
0
1
2
3
4
5
6
7
8
9
10
EXTENSION (mm)

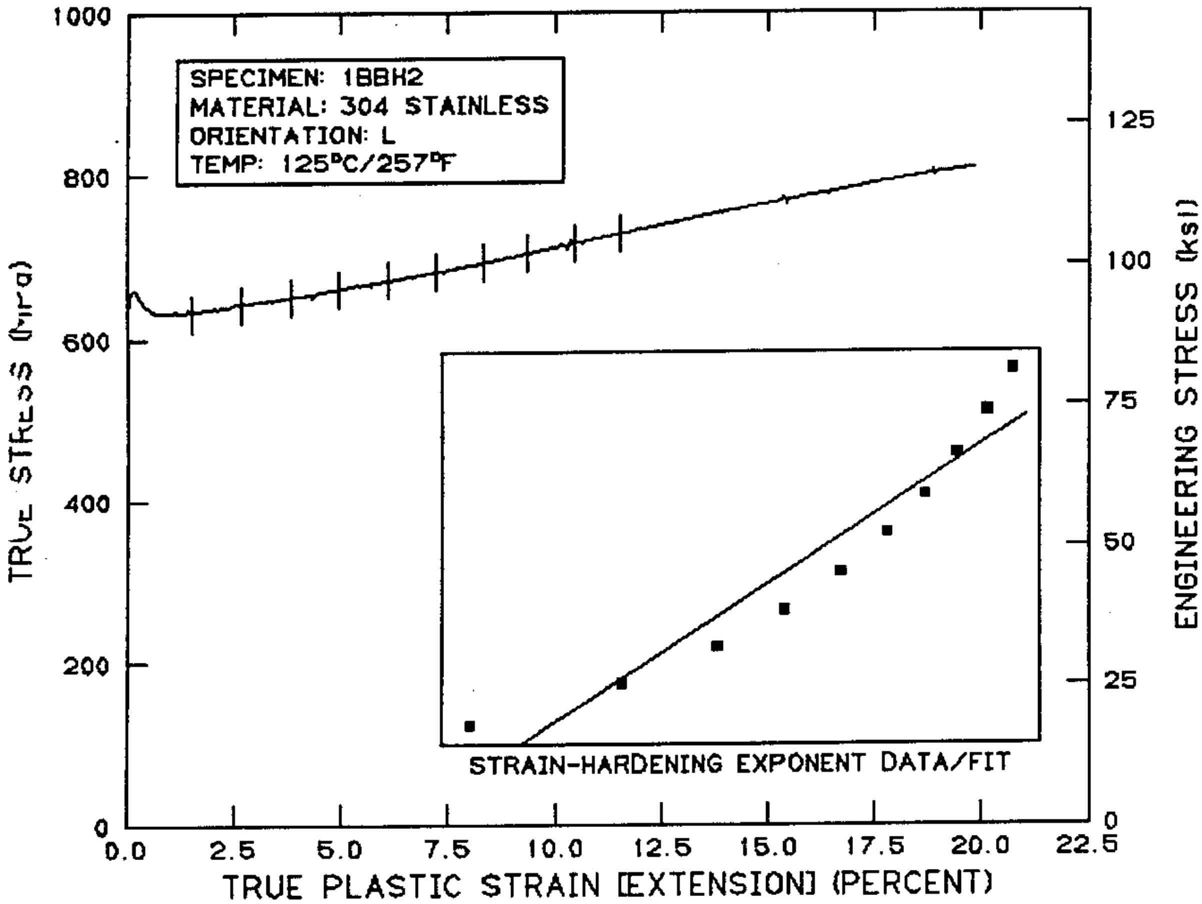

EXTENSION (in)
0.000
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
LOAD (kN)
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
LOAD (lb)
3000
2000
1000
0
SPECIMEN: 1BBH2
MATERIAL: 304 STAINLESS
ORIENTATION: L
TEMP: 125°C/257°F
YIELD LOAD
0.00
0.05
0.10
0.15
0.20
0.25
EXTENSION (mm)


EXTENSION (in)
0.19
0.20
0.21
0.22
0.23
0.24
0.25
SPECIMEN: 1BBH2
MATERIAL: 304 STAINLESS
ORIENTATION: L
TEMP: 125°C/257°F
ULTIMATE LOAD
LOAD (kN)
13.525
13.500
13.475
13.450
13.425
13.400
13.375
LOAD (lb)
3040
3035
3030
3025
3020
3015
3010
4.8
5.0
5.2
5.4
5.6
5.8
6.0
6.2
6.4
EXTENSION (mm)

COMMAND: ANALYZE
SPECIMEN IDENTIFICATION: 1BBH2




900
800
700
600
500
400
300
200
100
0
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
TRUE STRESS (MPa)
TRUE STRAIN [EXTENSION] (PERCENT)
125
100
75
50
25
0
TRUE STRESS (ksi)
SPECIMEN: 1BBH2
MATERIAL: 304 STAINLESS
ORIENTATION: L
TEMP: 125°C/257°F


SPECIMEN: 1BBH2
MATERIAL: 304 STAINLESS
ORIENTATION: L
TEMP: 125°C/257°F
STRAIN-HARDENING EXPONENT DATA/FIT
TRUE STRESS (MPa)
ENGINEERING STRESS (ksi)
TRUE PLASTIC STRAIN [EXTENSION] (PERCENT)
0
200
400
600
800
1000
25
50
75
100
125
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5

ATTACHMENT 2 TO WSRC-TR-93-196

OAK RIDGE NATIONAL LABORATORY
OPERATED BY MARTIN MARIETTA ENERGY SYSTEMS, INC.

POST OFFICE BOX 2008
OAK RIDGE, TENNESSEE 37831

Dr. R.L. Sindelar
Westinghouse Savannah River Company
Bldg. 773-41A
P.O. Box 616
Aiken, SC 29802

April 19, 1993

Dear Bob:

I have enclosed 3 defect cluster size distribution drawings and 2 transmission electron microscopy (TEM) figures that summarize the microstructural information obtained on the Savannah River steel specimens irradiated in the University of Buffalo Reactor (UBR) and the High Flux Isotope Reactor (HFIR) 1Q capsules. Copies of the log book notes and prints of the electron micrographs associated with these figures were sent to you previously in April 1991. The 3 specimen identification codes associated with these figures were:

1. 1HA21-1 and 1HA21-2 (304 stainless steel base metal and heat affected zone irradiated in UBR as a CV specimen).
2. 7W7 (weld metal irradiated in UBR as a CV specimen)
3. F50-X1 (304 stainless steel irradiated in HFIR 1Q capsule as a CV specimen).

The defect cluster histograms were prepared by counting between 150 and 250 defect clusters for each irradiation condition with a 0.2 mm graduated reticle eyepiece on prints with a total magnification of about 4×10^5.

The most significant aspects of the microstructural analysis performed on the irradiated specimens are as follows: There was no evidence for clearly resolvable (diam > 2 nm) He bubbles in any of the irradiated metals. This is in contrast to the small bubbles observed in the R-tank material. It seems likely that the bubbles are still too small to be resolvable in the 3 specimens listed above, perhaps because the irradiation time (~ 1 month) was much shorter than the R tank irradiation (8.5 years) and storage (22 years) time. The defect clusters in both the R tank and reactor-irradiated specimens were of roughly comparable size and density, and as shown in Fig. 1 did not exhibit well defined shapes (in contrast to irradiated pure metals such as Cu or Ni). The observable defect clusters in the δ-ferrite regions of the weld metal irradiated in UBR were larger and of much lower density compared with the austenite phase (compare Figs. 3 and 5). There was some evidence of defect cluster coarsening (larger size and lower density) with increasing irradiation dose (see Figs. 2-4). Confirmation of this coarsening effect must await microstructural analysis of the HFIR 4M and 12M specimens.

The TEM results may be correlated with your tensile results scheduled to be published in ASTM STP 1175 by using the dispersed barrier hardening equation,

$$\Delta\sigma_y = M \alpha \mu b (N d)^{1/2}$$

where $\Delta\sigma_y$ is the polycrystalline yield strength, M is the Taylor factor (3.06 for fcc metals), α is the defect cluster barrier strength, μ is the shear modulus (58 GPa for stainless steel), b is the Burgers vector for the slip system dislocations ($a_o/\sqrt{2}$ = 2.544 Å), N is the defect cluster density, and d is the mean defect cluster diameter. The value of α derived from this analysis is approximately 0.15 for both the UBR and HFIR 1Q specimens. The precise value derived for the HFIR 1 Q specimen was 0.146. The precise value for the UBR specimen is somewhat dependent on the density of the very small (~ 1 nm) defect clusters, which are near the visibility limit for the electron microscope. If only the clearly resolvable clusters are included in the analysis ($N=6x10^{23}/m^3$), the value of α is 0.18. If all of the dubious small clusters are included ($N=1.2x10^{24}/m^3$), the value of α is 0.124. Other TEM studies have found typical values for α of about 0.2 for slightly larger mean defect clusters sizes (d~ 2.5 to 3 nm). Hence a value of α = 0.15 is quite reasonable for the defect cluster sizes observed in the irradiated stainless steel specimens.

If you need any further information, please contact me.

Sincerely,

Steve

Steven J. Zinkle

Attachment 2 -- Original copies of the enclosures are retained in the SRTC-RMP Task 89-023-1 Files. Report WSRC-TR-93-196 contains the enclosures as the figures

WESTINGHOUSE SAVANNAH RIVER CO. REPORT WSRC-TR-93-196

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