

RMIS View/Print Document Cover Sheet

This document was retrieved from the Boeing ISEARCH System.

Accession #: D196050134

Document #: SD-FF-TRP-019

Title/Desc:

EFFECT OF LONG TERM THERMAL AGING ON THE FRACTURE
TOUGHNESS OF AUSTENITIC STAINLESS STEEL BASE &
WELD METALS

Sept 23, 1995
Station 35

ENGINEERING DATA TRANSMITTAL

2. To: (Receiving Organization) Distribution	3. From: (Originating Organization) Mechanisms Engineering/57E00	4. Related EDT No.: NA
5. Proj./Prog./Dept./Div.: FFTF/B181G	6. Cog. Engr.: F. H. Huang	7. Purchase Order No.: NA
8. Originator Remarks: Supporting document for review/release.		9. Equip./Component No.: NA
		10. System/Bldg./Facility: NA
11. Receiver Remarks:		12. Major Assm. Dwg. No.: NA
		13. Permit/Permit Application No.: NA
		14. Required Response Date: NA

15. DATA TRANSMITTED					(F)	(G)	(H)	(I)
(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	Impact Level	Reason for Transmittal	Originator Disposition	Receiver Disposition
1.	WHC-SD-FF-TRP-019	NA	0	Effect of Long Term-Thermal Aging on the Fracture Toughness of Austenitic Stainless Steel Base and Weld Metals	NA	1,4	1	

16. KEY			
Impact Level (F)	Reason for Transmittal (G)		Disposition (H) & (I)
1, 2, 3, or 4 (see MRP 5.43)	1. Approval	4. Review	1. Approved
	2. Release	5. Post-Review	2. Approved w/comment
	3. Information	6. Dist. (Receipt Acknow. Required)	3. Disapproved w/comment
			4. Reviewed no/comment
			5. Reviewed w/comment
			6. Receipt acknowledged

17. SIGNATURE/DISTRIBUTION (See Impact Level for required signatures)										(G)	(H)
(G)	(H)	(J) Name	(K) Signature	(L) Date	(M) MSIN	(J) Name	(K) Signature	(L) Date	(M) MSIN	Reason	Disp.
1	1	Cog. Eng. F. H. Huang	<i>F. H. Huang</i>	9/17/95	H5-53						
1	1	Cog. Mgr. R. B. Pan	<i>R. B. Pan</i>	9/20/95	H5-53						
		Safety									
		Indep.									
1	1	W. F. Brehm	<i>W. F. Brehm</i>	9-26-95	Nz-56						

18. F. H. Huang <i>F. H. Huang</i> 9/17/95 Signature of EDT Originator Date	19. G. G. McCargar <i>G. G. McCargar</i> 9-26-95 Authorized Representative for Receiving Organization Date	20. R. B. Pan <i>R. B. Pan</i> 09/20/95 Cognizant/Project Engineer's Manager Date	21. DOE APPROVAL (if required) Ltr. No. <input type="checkbox"/> Approved <input type="checkbox"/> Approved w/comments <input type="checkbox"/> Disapproved w/comments
--	---	--	--

**THIS PAGE INTENTIONALLY
LEFT BLANK**

RELEASE AUTHORIZATION

Document Number: WHC-SD-FF-TRP-019, Rev. 0

Document Title: Effect of Long-Term Thermal Aging on the Fracture Toughness of Austenitic Stainless Steel Base and Weld Metals

Release Date: 9/27/95

This document was reviewed following the procedures described in WHC-CM-3-4 and is:

APPROVED FOR PUBLIC RELEASE

WHC Information Release Administration Specialist:



C. WILLINGHAM

9/27/95

TRADEMARK DISCLAIMER. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

This report has been reproduced from the best available copy. Available in paper copy. Printed in the United States of America. To obtain copies of this report, contact:

Westinghouse Hanford Company - Document Control Services
P.O. Box 1970, Mailstop H6-08, Richland, WA 99352
Telephone: (509) 372-2420; Fax: (509) 376-4989

MTS is a registered trademark of MTS Systems Corporation, Eden Prairie, MN

**THIS PAGE INTENTIONALLY
LEFT BLANK**

SUPPORTING DOCUMENT

1. Total Pages \ 25

2. Title Effect of Long-Term Thermal Aging on the Fracture Toughness of Austenitic Stainless Steel Base and Weld Metals	3. Number WMC-SD-FF-TRP-019	4. Rev No. 0
5. Key Words fracture toughness, aging effect, FFTF primary piping, reactor vessel, fractography, 304 SS, 316 SS, 16-8-2 SSW, 308 SSW.	6. Author Name: F. H. Huang <i>F. H. Huang</i> Signature Organization/Charge Code 57E00/B181G	
7. Abstract Compact tension specimens taken from FFTF primary piping materials (Type 316 stainless steel (SS) and 16-8-2 SS weld metal) and from reactor vessel materials (304 SS and 308 SS weld metal) were heated in laboratory furnaces for 100,000 hours. Fracture toughness testing was performed on these specimens, which are 7.62- and 25.4-mm thick, respectively, at the aging temperature (482 and 427 °C). Results were analyzed with the multiple-specimen method. Thermal aging continues to reduce the fracture toughness of FFTF component materials. Results show that thermal aging has a strong effect on the toughness degradation of weld metals, particularly for 16-8-2 SS weld whose aged/unaged J_c ratio is only 0.31 after 100,000-hour aging. The fracture toughness of the 308 and 16-8-2 SS weld metals fluctuated during 20,000 to 50,000-hour aging but deteriorated as the aging time increased to 100,000 hours; the toughness degradation is significant. Fracture control based on a fracture mechanics approach should be considered.		
8. PURPOSE AND USE OF DOCUMENT - This document was prepared for use within the U.S. Department of Energy and its contractors. It is to be used only to perform, direct, or integrate work under U.S. Department of Energy contracts. This document is not approved for public release until reviewed. PATENT STATUS - This document copy, since it is transmitted in advance of patent clearance, is made available in confidence solely for use in performance of work under contracts with the U.S. Department of Energy. This document is not to be published nor its contents otherwise disseminated or used for purposes other than those specified above before patent approval for such release or use has been secured, upon request, from the Patent Counsel, U.S. Department of Energy Field Office, Richland, WA. DISCLAIMER - This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.	10. RELEASE STAMP <div style="border: 1px solid black; padding: 5px;">OFFICIAL RELEASE BY WMC DATE <i>Sept. 27, 1995</i> <i>Station 35</i></div>	
9. Impact Level NA		

APPROVED FOR
PUBLIC RELEASE
Dec 9-27-95

22

THIS PAGE INTENTIONALLY
LEFT BLANK

EFFECT OF LONG-TERM THERMAL AGING ON THE FRACTURE TOUGHNESS
OF AUSTENITIC STAINLESS STEEL BASE AND WELD METALS

September 1995

Prepared by: *F. H. Huang* 9/16/95
F. H. Huang, Principal Scientist
Mechanisms Engineering Date

Review by: *E. S. Ruff* SEPT. 6, 1995
E. S. Ruff, Sr. Principal Engineer
Mechanisms Engineering Date

Approved by: *R. B. Pan* 09/20/95
R. B. Pan, Deputy Manager
Mechanisms Engineering Date

ICF Kaiser Hanford Company
Richland, Washington
Hanford Operations and Engineering Contractor
for the
U. S. Department of Energy

**THIS PAGE INTENTIONALLY
LEFT BLANK**

CONTENTS

1.0	INTRODUCTION	1
2.0	SUMMARY	1
3.0	EXPERIMENTAL PROCEDURE	2
3.1	SPECIMEN PREPARATION	2
3.2	TEST PROCEDURE	3
4.0	RESULTS AND DISCUSSION	4
4.1	MULTIPLE-SPECIMEN METHOD	4
4.2	FRACTOGRAPHY	5
4.3	FRACTURE TOUGHNESS OF AGED ALLOYS	5
5.0	CONCLUSION	7
6.0	REFERENCES	7
APPENDIX A	Load Versus Displacement Records for J_c Fracture Toughness Tests	A-1
APPENDIX B	Additional Test Records for 316 Stainless Steel and 16-8-2 Stainless Steel Weld	B-1
APPENDIX C	Additional Test Records for 304 Stainless Steel and 308 Stainless Steel Weld	C-1

**THIS PAGE INTENTIONALLY
LEFT BLANK**

EFFECT OF LONG-TERM THERMAL AGING ON THE FRACTURE TOUGHNESS OF AUSTENITIC STAINLESS STEEL BASE AND WELD METALS

1.0 INTRODUCTION

Type 304 and 316 stainless steel (SS) alloys are known to exhibit adequate strength, excellent resistance to sodium, and high fracture toughness. Because of these advantages, the steels are used in the components of the Fast Flux Test Facility (FFTF) which is a liquid metal reactor. The reactor is located at the U.S. Department of Energy's Hanford Site in Richland, Washington. During the period of operation, components are subjected to prolonged exposure to neutron irradiation, elevated temperatures, and to liquid sodium on the inside surfaces. Long-term thermal aging was postulated to degrade the fracture properties of the component materials; therefore, the FFTF Aging Surveillance Fracture Toughness Program was established to provide assurance that the structural integrity of the FFTF primary piping and the reactor vessel is maintained throughout the reactor lifetime.

Tensile and compact tension specimens taken from the actual heats of FFTF component materials were heated in laboratory furnaces for 10,000, 20,000, 50,000, and 100,000 hours. The aging temperatures were 427 °C for the vessel (304 SS and 308 SS weld metal), and 482 °C for the outlet piping (316 SS and 16-8-2 SS weld metal). Testing of specimens aged for 0, 10,000, 20,000, and 50,000 hours is completed and results have been reported [1-4]. Results for reactor materials aged at 566°C showed no degradation in fracture properties [1]; therefore, thermal aging studies at 566°C were stopped, only 427- and 482°C-aging have been continued. The 100,000-hour aging completed in September 1994 concluded the FFTF aging program. Specimens from this longest aging time have been tested, and the results analyzed by means of the multi-specimen method to evaluate the fracture toughness of the aged primary piping and reactor vessel materials. These experimental data now are used to assess the effect of thermal aging on the fracture toughness degradation potential. Such information is needed to verify that the fracture toughness is adequate for continued long-term safe operation of the FFTF or other similar reactors.

2.0 SUMMARY

One of the FFTF surveillance experiments is to investigate the effect of thermal aging on the fracture toughness degradation of the unirradiated, archival FFTF component materials. Tensile and compact tension specimens taken from FFTF primary piping materials (Type 316 stainless steel (SS) and 16-8-2 SS weld metal) and from reactor vessel materials (304 SS and 308 SS weld metal) were heated in laboratory furnaces for 100,000 hours. Fracture toughness testing was performed on these specimens, which are 7.62- and 25.4-mm thick, respectively, at the aging temperature (piping materials were aged at 482 °C and vessel materials at 427 °C). Results were analyzed with

the multiple-specimen method; the test procedures of the method are detailed in ASTM Standard E813.

Primary piping and reactor vessel materials exhibited high fracture resistance in the unaged condition. The fracture toughness of Type 316 SS and 304 SS decreased as the specimens were aged for 20,000 hours. Thermal aging continues to reduce the fracture toughness of FFTF component materials. Results show that thermal aging has a strong effect on the toughness degradation of weld metals, particularly for 16-8-2 SS weld metal whose aged/unaged J_c ratio is only 0.31 after 100,000-hour aging. The fracture toughness of the 308 SS and 16-8-2 SS weld metal fluctuated during 20,000 to 50,000-hour aging but decreased as the aging time increased to 100,000 hours. The fracture surfaces of base and weld metal specimens were examined by scanning electron microscope. Fractographs show that dimple rupture and deep microvoids dominate in the fracture surfaces of 316 base metal samples. Thermal aging increases the size of the dimples in both base and weld metals from the primary piping and the reactor vessel.

Longer exposures generate more transformation products and reduce fracture toughness. Present studies show that 100,000-hour aging degrades the fracture toughness of both piping and vessel weld metals to a low value of about 100 kJ/m², an indication that the materials may fail after extended service by non-ductile fracture. Therefore, fracture evaluations based on a fracture mechanics approach should be considered for the primary piping and reactor vessel of the FFTF or other reactors after 100,000-hour service.

3.0 EXPERIMENTAL PROCEDURE

3.1 SPECIMEN PREPARATION

Compact tension specimens with a width (W) of 29.3 mm (1.154 in.) and thickness (B) of 7.6 mm (0.3 in.) were prepared from primary piping (Type 316 SS and 16-8-2 SS weld metal); the compact tension specimens from the reactor vessel (304 SS and 308 SS weld metal) have a width of 50.8 mm (2 in.) and thickness (B) of 25.4 mm (1 in.) (Figure 1). The chemical compositions for these materials are given in Table 1. Notches in weld specimens were centered in the weld deposit and were oriented in a direction parallel to the welding direction (see Figure 1b in Ref. 4). The notches in base metal specimens of 316 SS piping were oriented in the circumferential direction. In addition, two tensile specimen were prepared for each set of compact tension specimens.

Preparation and testing of the thicker specimens from reactor vessel materials (304 SS and 308 SS weld metal) were contracted to Accurate Metallurgical Services (AMS), Inc, Santa Fe Springs, California; the thinner specimens of primary piping (316 SS and 16-8-2 SS weld metal) were prepared and tested by Metcut Research Associates (MRA), Inc, Cincinnati, Ohio. All specimens tested were fabricated from the specimen blanks aged for 100,000 hours.

3.2 TEST PROCEDURE

All specimens were fatigue precracked before testing by a servo-hydraulic test machine. Fracture toughness testing was conducted at the aging temperature, i.e., 427 °C for the thicker specimens of 304 SS and 308 SS weld metal, and 482 °C for the thinner specimens of 316 SS and 16-8-2 SS weld metal. Loadline displacements were measured by either a clip gage or from loading time by correcting for the load-train and machine compliance. In the present work, AMS did not use a clip gauge to measure loadline displacements at high temperatures, but MRA did. The single-specimen method that uses the electric-potential technique [2] to measure crack extension used previously could not be used in the present work because the tests were performed by off-site testers not equipped for the electric-potential technique.

During testing, the load, loadline displacement, and ram displacement were recorded continuously. The specimens were loaded to various displacements to produce different amounts of crack extension as recommended in American Society for Testing and Materials (ASTM) E813-91. After the test was completed, each cracked specimen was heat tinted to reveal the crack extension. Six specimens of each alloy were tested at the aging temperatures, 427 or 482 °C with one exception as noted in Section 4.1. Results were analyzed by means of the J-integral approach. The value of J was determined from the area under the load vs. the loadline displacement curve (Figure 2) by the following equation [5]:

$$J = \frac{2A}{Bb} \frac{(1+\alpha)}{(1+\alpha^2)}$$

where

- A = area under load versus load-line displacement curve
- B = specimen thickness
- b = unbroken ligament size
- $\alpha = [(2a/b)^2 + 2(2a/b) + 2]^{1/2} - (2a/b + 1)$
- a = crack length.

The values of J were plotted in terms of crack extension (Δa) to construct the J- Δa curve. The crack extensions were obtained from direct measures.

Fractographic examinations were performed on a scanning electron microscope (SEM), model ESEM-E3, operated at 20 kV.

All specimens tested exhibited stable crack tearing. The initiation fracture toughness, J_{Ic} , was generally determined to be the value of J, where a least-squares regression line through the Δa data points intersected the blunting line ($J = 2 \sigma_f \Delta a$, where σ_f is the average of the yield and ultimate strengths). For high-strain hardening materials [6] such as the materials tested in this work, the notch in the specimen blunted initially in a manner that $J = 4 \sigma_f \Delta a$. Fracture toughness data were obtained by this method for

comparisons with those generated previously from piping and vessel materials aged for 10,000 and 50,000 hours. Results also were analyzed by a power-law regression analysis according to ASTM E813-91. Fracture toughness values obtained in this work are termed J_c rather than J_{Ic} . Values of the tearing modulus (T) were computed from the following equation:

$$T = \left(\frac{E}{\sigma_f^2} \right) \frac{dJ}{da}$$

where dJ/da is the slope of J - Δa curve, E is Young's modulus.

4.0 RESULTS AND DISCUSSION

Load-vs.-displacement curves for each specimen tested are attached in Appendix A. Typical load and loadline displacement curves are shown in Figure 2. The area under the load vs. loadline displacement was measured to determine the value of J for each specimen.

4.1 MULTIPLE-SPECIMEN METHOD

The values of J are plotted as a function of crack extension measured from heat tinting of tested specimens. Since the value of critical fracture toughness is determined from the J - Δa curve drawn through the J -vs.-crack extension data points, additional data points are desirable. A set of six specimens is commonly used to evaluate the value of J_c . All materials tested in this work involved six specimens for the determination of fracture toughness except the J_c value of 304 SS samples aged for 100,000 hours was determined from three specimens.

The J - Δa curves of specimens cut from primary piping and reactor vessel materials and aged for 100,000 hours are shown in Figures 3 and 4, respectively. The results of J_c and T determined by means of the multiple-specimen method are given in Table 2. Previous data obtained from reactor vessel and primary piping specimens aged for shorter times are listed in Table 3 for comparisons. The dependence of fracture toughness and tearing modulus on aging time for base metals and weld metals tested at the aging temperature is shown in Figures 5 through 10. Both J_c and the aged/unaged ratio of J_c are plotted as a function of aging time. The values of the tearing modulus are plotted in terms of aging time for primary piping and reactor vessel materials as shown in Figures 9 and 10.

The values of J_c can be determined from the J - Δa curves with either a linear regression analysis or a power-law regression analysis. Previous results from aged samples were analyzed with a linear regression method. The J_c value was evaluated at the intersection of the portion of the J - Δa curve with the 0.15-mm offset and the blunting line. For comparison, all fracture

toughness results from compact tension specimens fabricated from reactor vessel and primary piping materials aged for times up to 100,000 hours were obtained from the J- Δa linear regression analysis (Figures 5 through 8). The fracture toughness results were also obtained from the power-law analysis. Table 2 also lists the values of critical fracture toughness determined by a power-law regression analysis according to ASTM E813-91. The values of J_c evaluated by this new method are much higher than those listed in Table 2 for 316 SS and 16-8-2 SS weld metal.

4.2 FRACTOGRAPHY

Fractographic examination of the fracture surfaces characterizes fracture surface morphologies. Specimens of 316 SS with cracks propagating in the axial direction exhibited lower J_c values as compared to those with cracks propagating in the circumferential orientation. As shown in the SEM fractographs in Reference 4, the lower fracture toughness values in the axial direction were attributed to the alignment of stringers in the axial direction. In the circumferential orientation, stringers are normal to the crack propagation direction; they nucleated deep microvoids that blunt the crack tip as shown in Figure 11a. As a result, the fracture toughness of specimens with cracks advancing in the circumferential direction is higher than for those in the axial direction. The deep microvoids are shown in Figure 11b where gross plastic deformation surrounding the microvoids is visible.

The unaged 304 SS base metal exhibits a very high toughness and fails by dimple rupture in a transgranular mode. For stainless steels subject to thermal aging at temperatures below 900 °C, carbide network ($M_{23}C_6$) forms first; longer exposures produce intermetallic phases such as the sigma phase [7]. Under triaxial stress conditions ahead of the crack tip, microvoids are initiated at the interface between the matrix and a particle in the specimens which fail in a ductile fracture mode. Cavities or dimples are formed by the coalescence of microvoids. Dimple rupture is evidenced in Figure 12 for the 304 SS reactor vessel specimen. As shown in Figure 12a, the fracture features are rough compared to the fatigue surfaces, which are flat.

Microvoid coalescence is the primary fracture mechanism for both unaged and aged 16-8-2 SS and 308 SS weld metals (Figures 13 and 14). Dimples are initiated by delta ferrite in these weld metals. Thermal aging transforms delta ferrite into carbide or sigma phases if the aging temperature is high. These transformation products provide microvoid nucleation sites (see Figure 14b). Generally, the dimple size increases with increasing aging time.

4.3 FRACTURE TOUGHNESS OF AGED ALLOYS

Previous results show that thermal aging to aging time of about 20,000 hours reduces the fracture toughness of 16-8-2 SS weld metal; the toughness then increases for 50,000-hour aging, but it decreases again after longer exposures. For 316 SS, the fracture toughness in the circumferential direction decreases with increasing aging time. The effect of thermal aging

on the fracture properties of reactor vessel material (304 SS and 308 SS weld metal) is similar. Figures 5 through 10 show the effect of thermal aging on fracture toughness and tearing modulus. Both fracture toughness and the aged/unaged J_c ratio are plotted as a function of aging time. As shown in the figures, long-term aging resulted in a significant reduction in fracture toughness for primary piping as well as for reactor vessel materials.

The fracture toughness of 304 SS and 308 SS weld metal decreases with aging time, a phenomenon that is consistent with the previous studies [1]. Thermal aging appears to increase the tearing resistance of 316 SS and 16-8-2 SS weld metal while reducing the tearing resistance of 304 SS and 308 SS weld metal slightly. The fracture toughness of 16-8-2 SS weld metal is about one-half that of 316 SS. Thermal aging has a stronger effect on the fracture toughness of 16-8-2 weld metal than on 316 base metal, as illustrated in Figure 6 where the aged/unaged J_c ratio is 72% for 316 SS and 31% for 16-8-2 SS weld metal after 100,000 hours of aging. Although the initiation fracture toughness of 316 SS decreases, the tearing modulus increases (Figure 9) with aging time.

The effect of aging on the fracture properties of the reactor vessel base metal and weld after thermal aging at 427 °C are shown in Figures 7 and 8. As seen in the figures, 50,000-hour aging caused a 30% reduction in J_c and a 20% decrease in tearing modulus. Longer exposures resulted in further degradation in both fracture toughness and tearing modulus; there was no evidence of a saturation in fracture toughness degradation at this temperature. The J_c ratio shown in Figure 8 indicates that the fracture toughness degradation rates for both 304 SS and 308 SS weld metal are comparable. The tearing modulus of the materials continues to decrease with aging time; this trend differs from what is observed for 316 SS primary piping materials in which the tearing resistance increases slightly with thermal aging.

SEM fractography is used to correlate the microstructural change and toughness degradation. As evidenced by fractography, thermal aging induced carbide precipitation and sigma phase formation in piping and vessel welds. High concentrations of stress were created around these particles causing the nucleation of microvoids and the reduction of fracture toughness. Microvoid coalescence and dimple size changes resulting from aging are closely related to the fracture mechanism for 16-8-2 SS and 308 SS weld metals.

Fracture toughness values larger than 140 kJ/m² or lower than 25 kJ/m² are classified as "high toughness" or "low toughness," respectively. Similarly, tearing modulus values larger than 100 or lower than 10 are "high tearing resistance" or "low tearing resistance." Because aging for 50,000 hours did not degrade fracture toughness values for all FFTF component materials except 308 SS weld metal to below 140 kJ/m² (Figures 5 and 7), fracture control was not an important engineering issue. Also, because the tearing moduli remained above 100 (Figures 9 and 10), potential tearing instabilities and non-ductile failures are not expected to occur in stainless steel components aged for less than 100,000 hours. However, the present studies indicate that the fracture toughness of the materials continues to decline with increasing aging time; the fracture toughness values of the weld

metals are degraded to below 140 kJ/m^2 , therefore, fracture evaluation needs attention after 100,000 hours of aging, although the tearing resistance is not affected significantly. Any possibility that such long-term aged materials with J_c values below 140 kJ/m^2 fail by non-ductile fracture should not be ruled out; engineering fracture evaluation for the components made of these materials should be considered in design and safety analyses.

5.0 CONCLUSION

The values of fracture toughness for FFTF primary piping and reactor vessel materials aged for 100,000 hours are determined by using the multi-specimen method. Results clearly show that the fracture resistance of both stainless steel base and weld metals decreases with increasing aging time. The trend for aging time shorter than 50,000 hours is erratic, but the fracture toughness is substantially reduced for longer exposures. Test results on 16-8-2 SS weld metal show that fracture resistance deteriorates rapidly with aging time longer than 50,000 hours. The fracture toughness of 308 SS weld metal also decreases with aging time at a degradation rate comparable to that of 304 SS base metal with aging time longer than 50,000 hours (Figure 8).

Fractographic examination of base metal specimens revealed that the stringer-created microvoids resulted from the perpendicular alignment of stringer to the crack propagation direction and that the fracture surfaces of weld-metal specimens were characterized by the appearances of dimple rupture. Thermal aging produces carbides and causes delta ferrite transformation to second phases. As a result, more microvoid nucleation sites are provided and fracture resistance is reduced. Increases in aging time do not alter the features of the fracture surfaces appreciably but change the size of tear ridges in base metals and dimples in weld metals.

Previous work showed that fracture evaluation was not an important engineering issue for FFTF piping and vessel materials aged less than 50,000 hours. However, as the present study shows, longer-term thermal aging generates significantly more transformation products and reduces fracture toughness. Specifically, the fracture toughness of both piping and vessel weld metals degrades to a lower value of about 100 kJ/m^2 after 100,000-hour aging, an indication that the materials may fail by non-ductile fracture. Therefore, fracture evaluation analyses based on a fracture mechanics approach should be considered for the FFTF primary piping and reactor vessel.

6.0 REFERENCES

1. W. J. Mills, "Fracture toughness of aged stainless steel primary piping and reactor vessel materials," *Journal of Pressure Vessel Technology* 109, pp. 440-448, 1987.

2. "Fracture toughness of FFTF primary piping aged at 427 and 428 °C," WHC-SD-FF-TRP-009, Westinghouse Hanford Company, Richland, Washington, 1990.
3. F. H. Huang, "Fracture toughness of aged stainless primary piping welds evaluated by multiple- and single-specimen methods," *Journal of Pressure Vessel Technology* 115, pp. 201-206, 1993.
4. "Fracture toughness of FFTF primary piping aged for 20,000 hours," WHC-SD-FF-TRP-014, Westinghouse Hanford Company, Richland, Washington, 1992.
5. G. A. Clark and J. D. Landes, "Evaluation of the J-Integral for the Compact Tension," *Journal of Testing and Evaluation* 7, pp. 264, 1979.
6. W. J. Mills, "On the Relationship Between Strength Zone Formation and the J-Integral for high Strain-Hardening Materials," *Journal of Testing and Evaluation* 9, pp. 56-62, 1981.
7. B. Weiss and R. Stickler, "Phase Instabilities During High Temperature Exposure of 316 Austenitic Stainless Steel," *Metallurgical Transactions* 3, pp. 851-866, 1972.

Table 1 Chemical Composition (wt. %)

Component	Outlet Piping	Outlet Piping	Reactor Vessel	Reactor Vessel
Material	316 SS	16-8-2 SSW	304 SS	308 SSW
Heat No.	55319	Y2367R16/8/2	300380	D/H
C	0.061	0.045	0.060	0.07
Mn	1.91	1.25	1.60	1.92
Si	0.34	0.29	0.57	0.62
S	0.021	0.013	0.012	0.010
P	0.021	0.024	0.018	0.010
Cr	16.34	16.36	18.61	20.26
Ni	12.14	8.62	8.64	9.58
Mo	2.30	1.67	0	0.16

* SS = Stainless steel
SSW = Stainless steel weld metal

TABLE 2. Fracture Toughness of Aged Primary Piping and Reactor Vessel Evaluated With Linear and Power Law Regression Analysis

Material	Heat Number	Aging Temp. (°C)	Aging Time (h)	Test Temp. (°C)	Linear Regression		Power Law
					J_f (kJ/m ²)	T	
304 SS	300380	427	100,000	427	438	470	543
308 SSW	D/H	427	100,000	427	103	158	106
316 SS(L-C)	55319	482	100,000	482	395	683	747
16-8-2 SSW	Y2367R16 /8/2	482	100,000	482	114	445	197

L-C: Circumferential orientation

Table 3 Fracture Toughness of Aged Reactor Vessel and Primary Piping
(Test temp. = Aging temp.)

Material	Component	Aging temp (°C)	Aging time (h)	J _c (kJ/m ²)	T	J _c Ratio (aged/unaged)	REFERENCE
304 SS	Reactor Vessel	427	0	751	611	1	2
			50,000	533	503	0.71	2
			100,000	438	473	0.58	p.w.
308 SSW	Reactor Vessel	427	0	155	254	1	2
			20,000	166	184	1.07	2
			50,000	117	184	0.75	2
			100,000	103	158	0.66	p.w.
316 SS (L-C)	Primary Piping	482	0	549	596	1	1
			100,000	395	683	0.72	p.w.
16-8-2 SSW	Primary Piping	482	0	373	248	1	1
			20,000	223	414	0.6	4
			51,539	283	441	0.76	3
			100,000	114	445	0.31	p.w.

* p.w. : present work

Figure 2. Load and Loadline Displacement Records for
304 SS and 316 SS Aged for 100,000 Hours

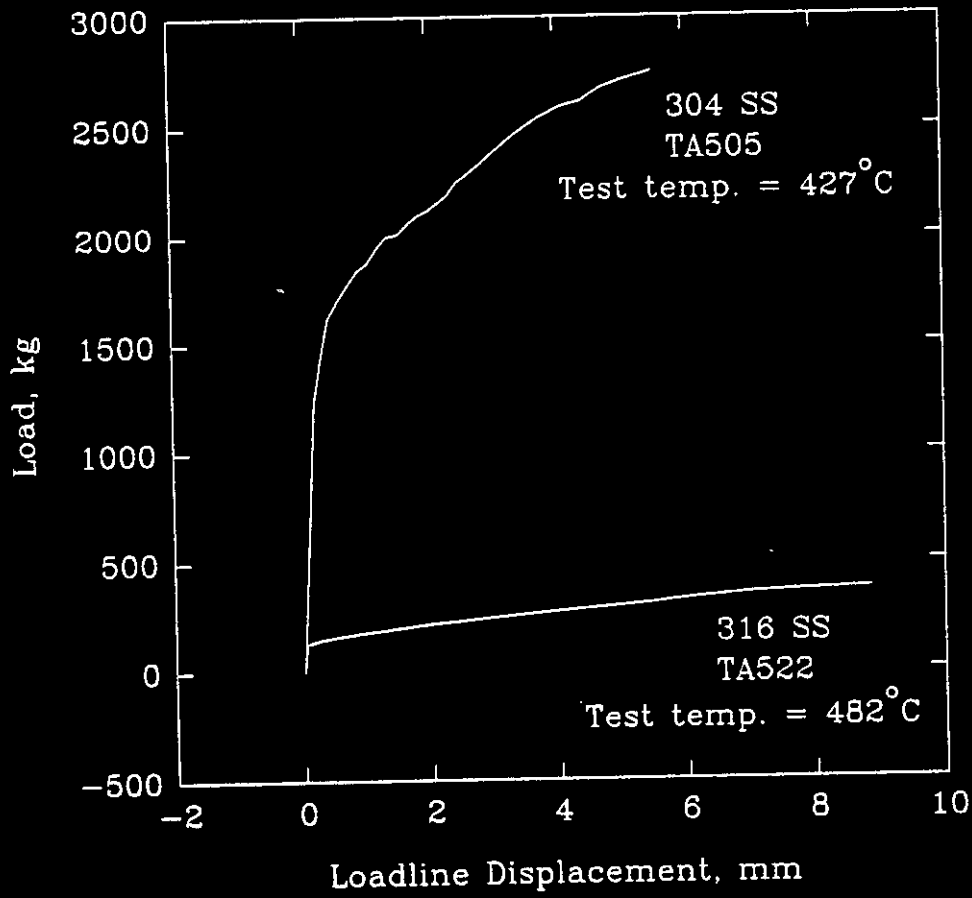


Figure 3. J- Δa Curves for 316 SS and 16-8-2 SS Weld Metal (SSW)
Aged for 100,000 Hours and Tested at Aging Temperature

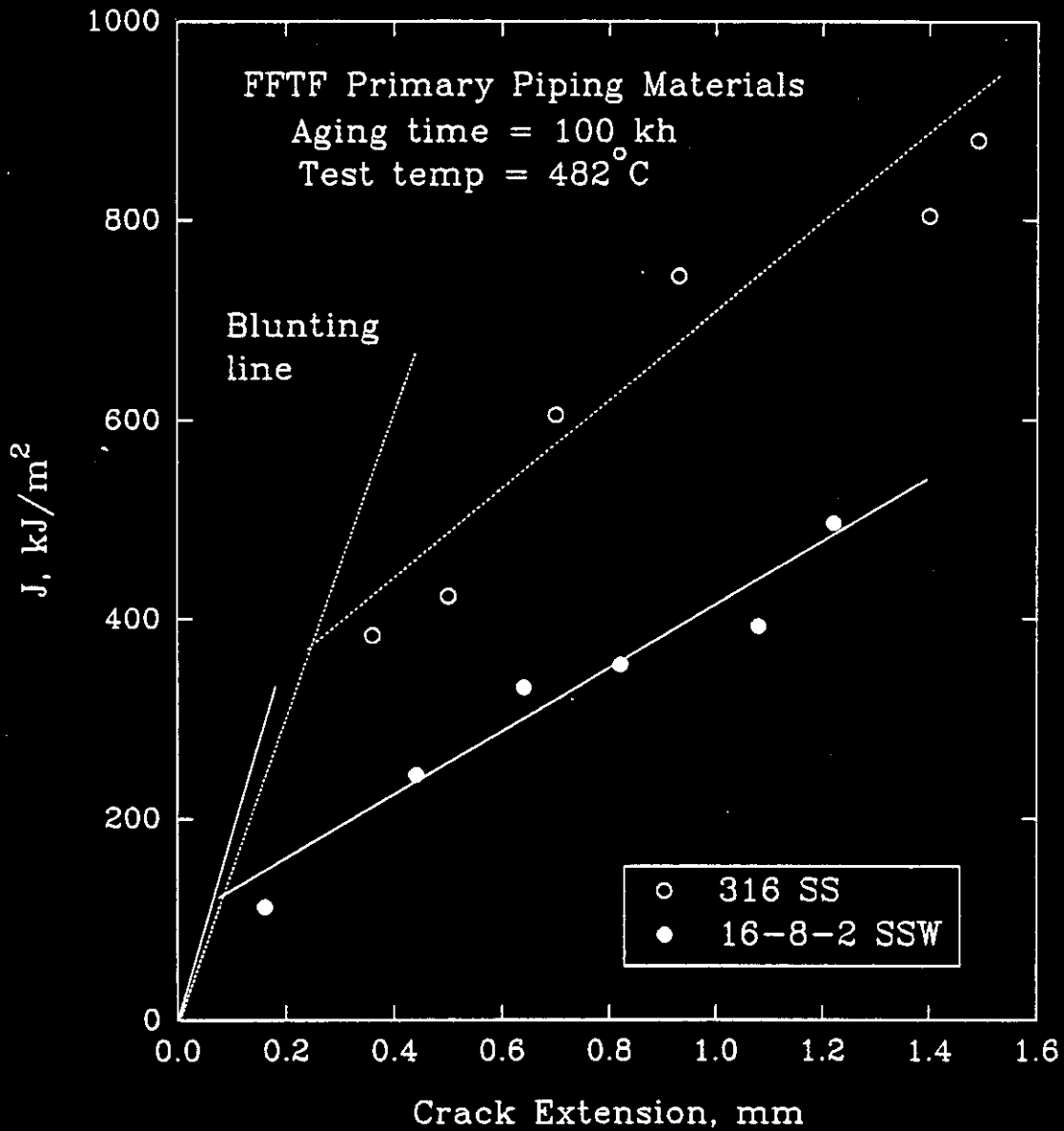


Figure 4. J- Δa Curves for 304 SS and 308 SS Weld Metal Aged for 100,000 Hours and Tested at Aging Temperature

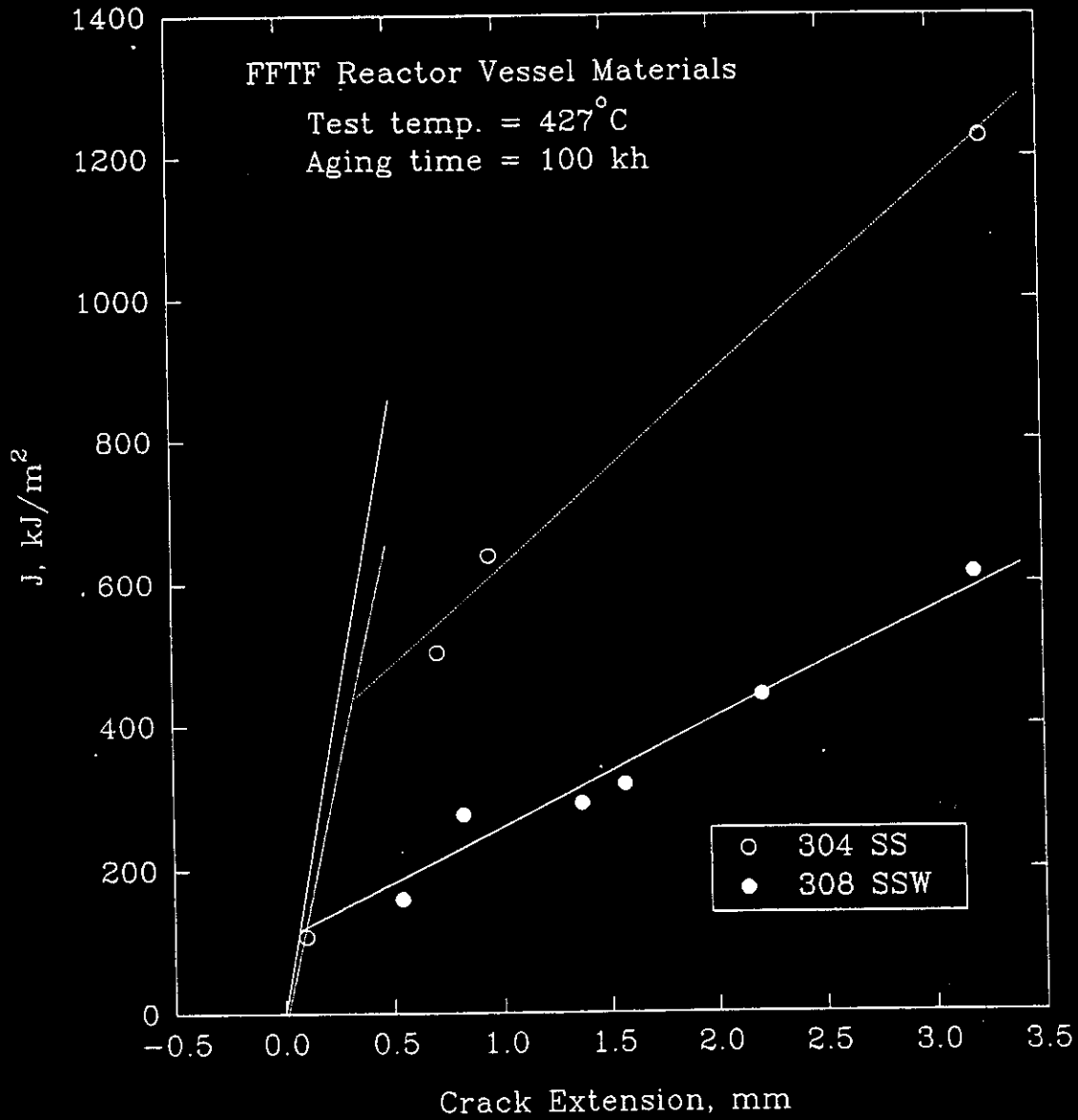


Figure 5. Aging Time Dependence of J_c Value for FFTF Piping Materials

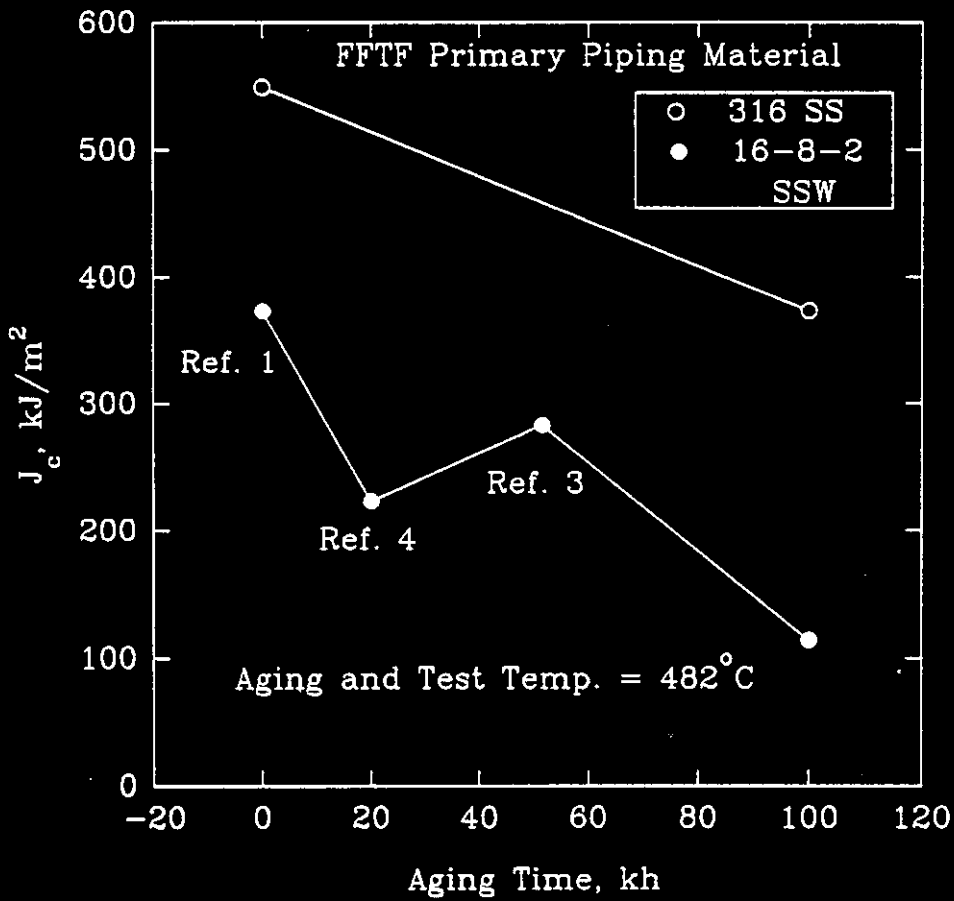


Figure 6. Aging Time Dependence of Aged/Unaged J_c Ratio for FFTF Piping Materials

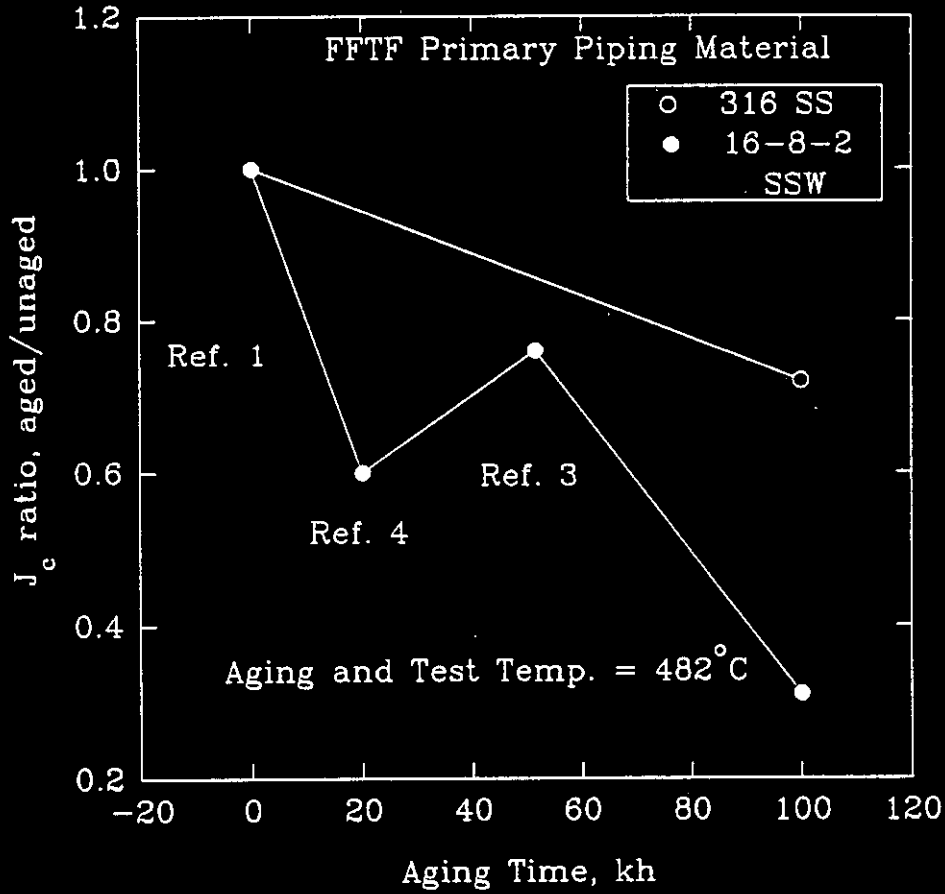


Figure 7. Aging Time Dependence of J_c Value for FFTF Reactor Vessel Materials

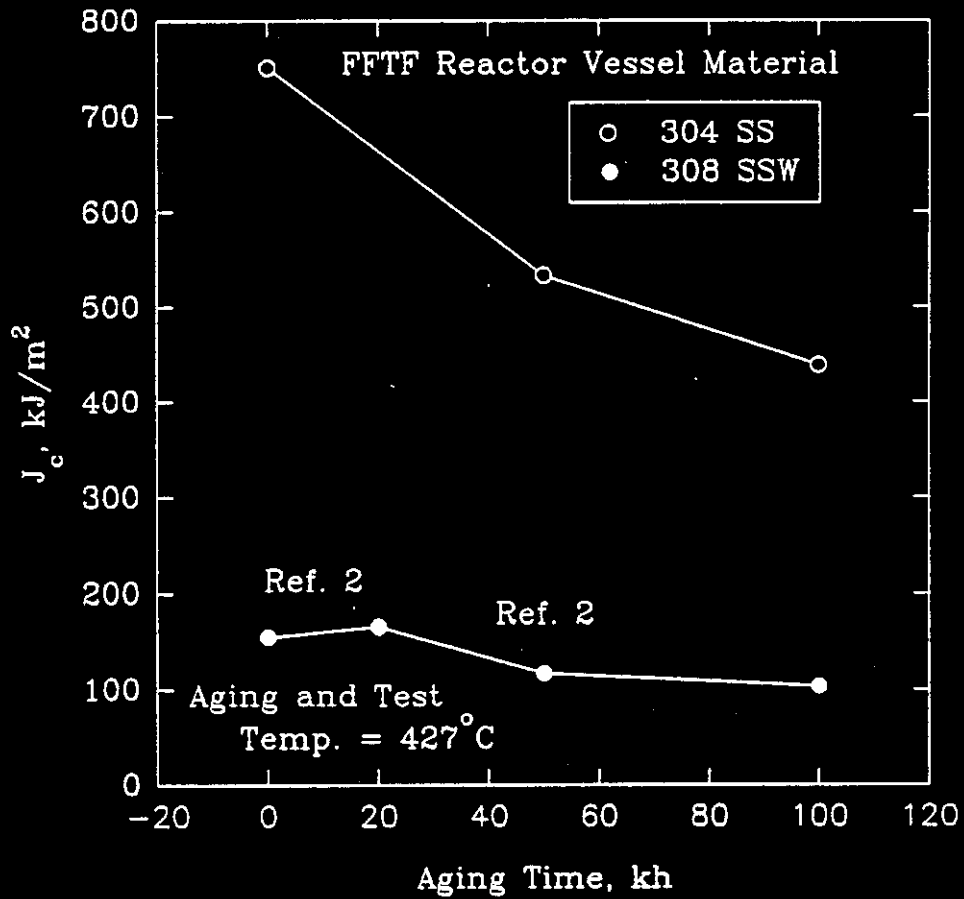


Figure 8. Aging Time Dependence of Aged/Unaged J_c Ratio for FFTF Reactor Vessel Materials

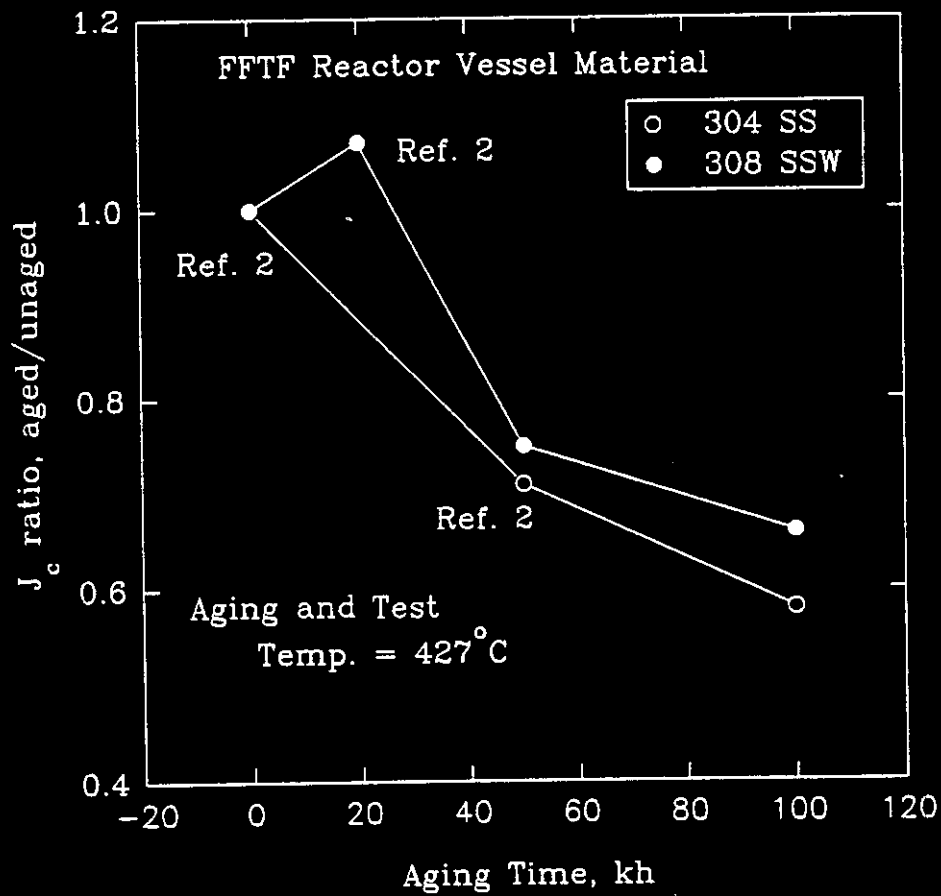


Figure 9. Aging Time Dependence of Tearing Modulus for FFTF Piping Materials

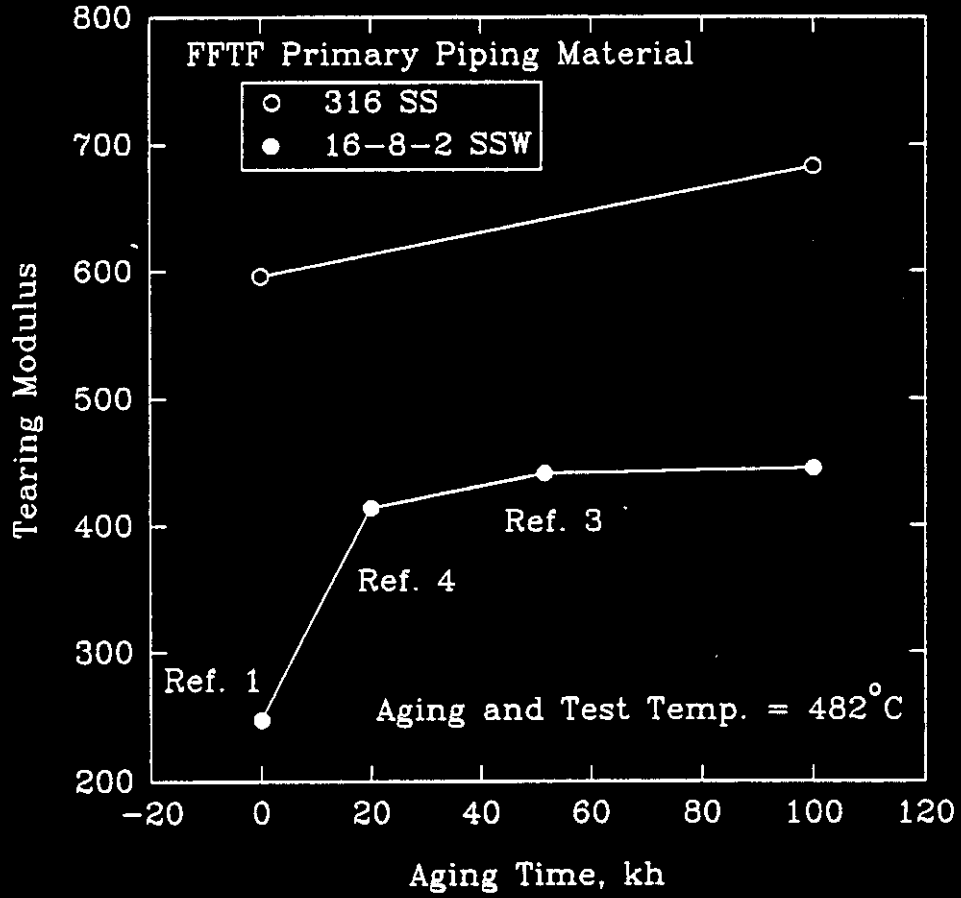


Figure 10. Aging Time Dependence of Tearing Modulus for FFTF Reactor Vessel Materials

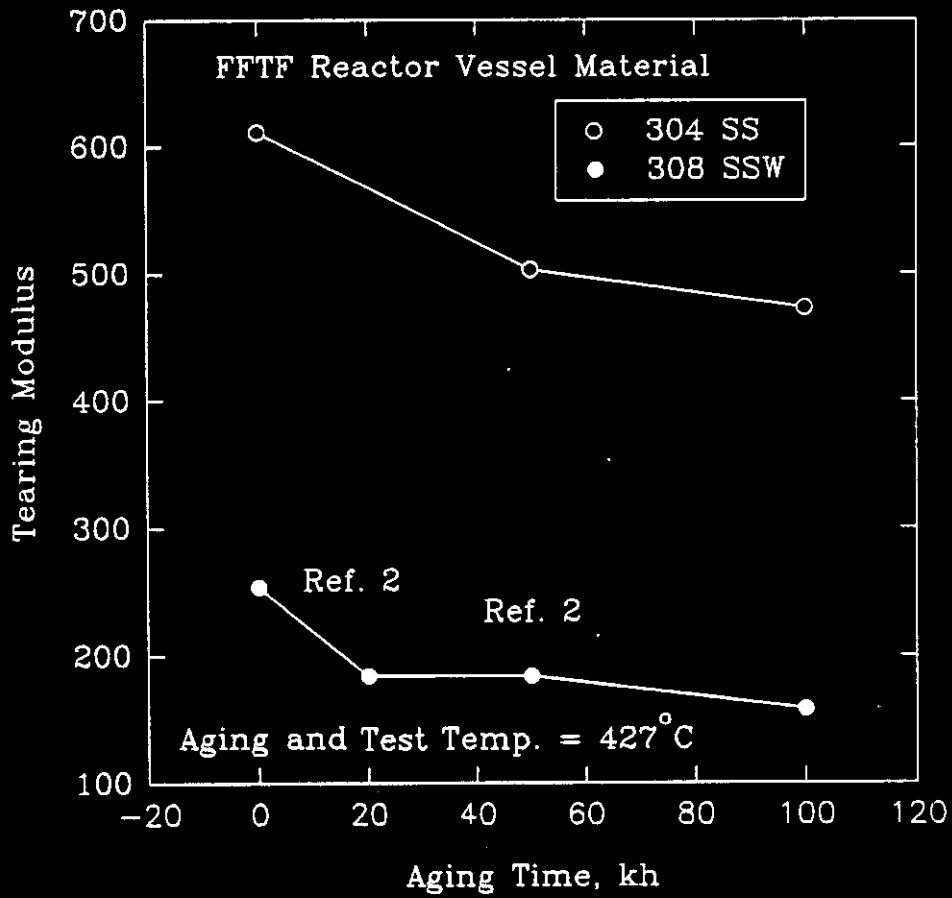
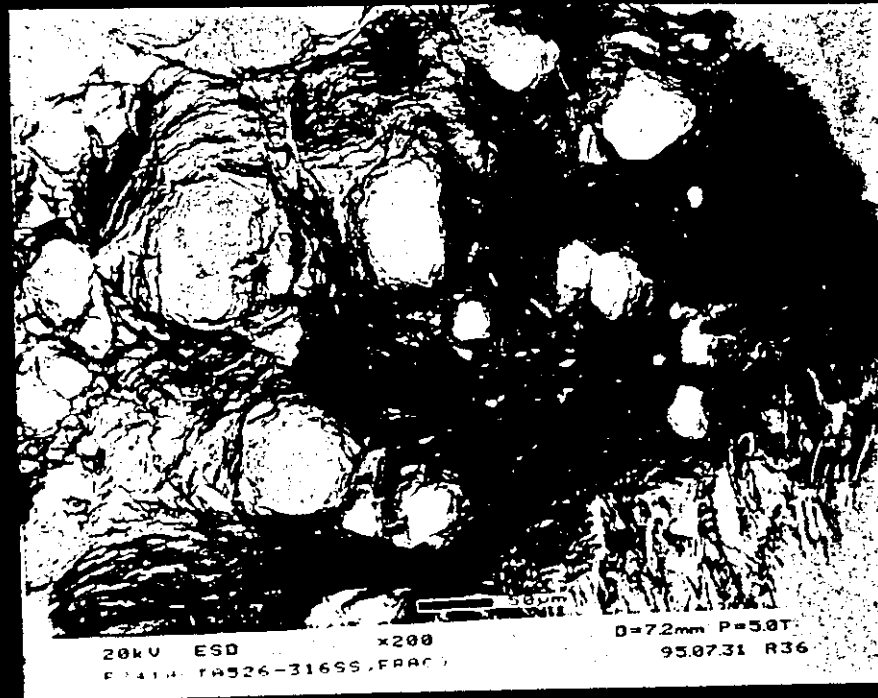
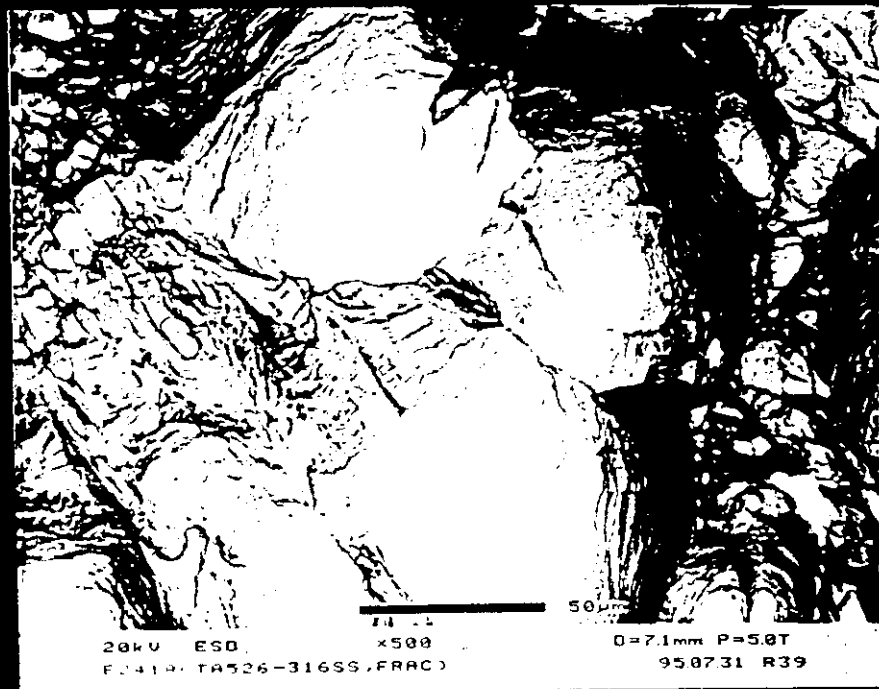


Figure 11. SEM Fractographs of 316 SS Aged for 100,000 Hours Showing
(a) Crack Fronts (200x), (b) Deep Dimples (1000x)



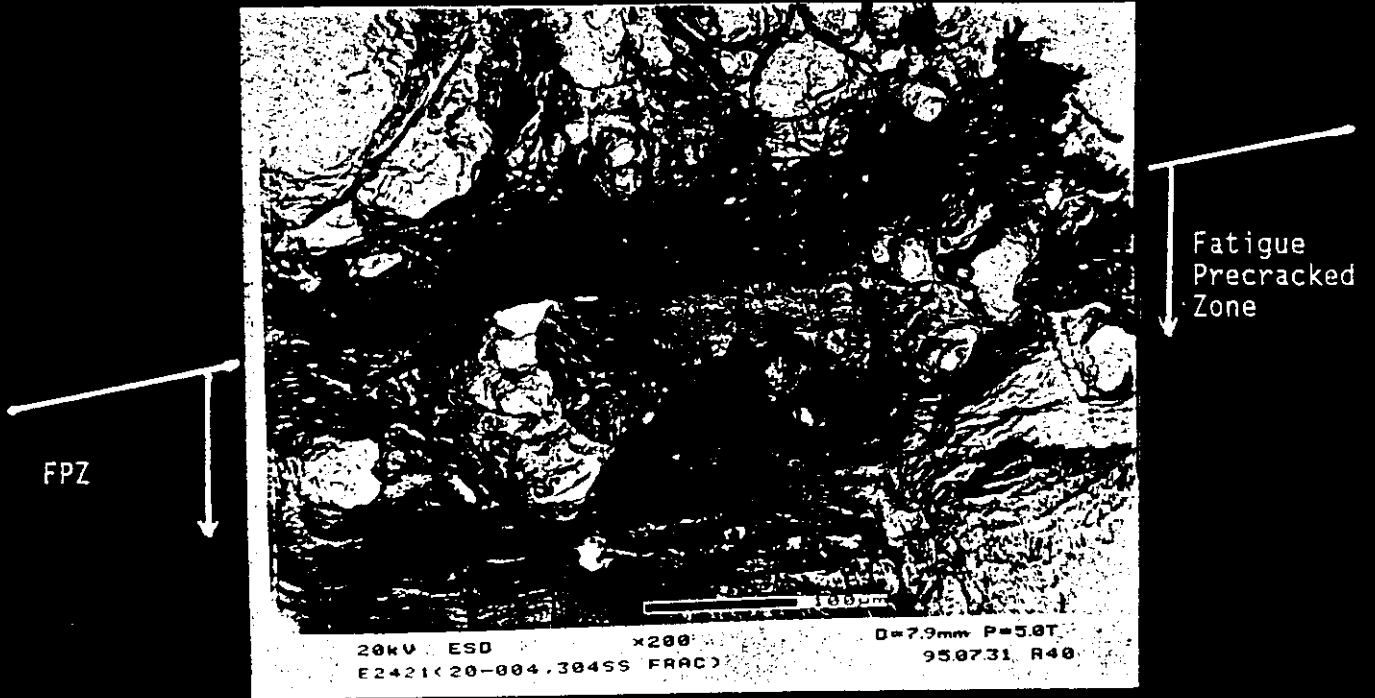
Fatigue
Pre-cracked
Zone

(a) → FPZ



(b)

Figure 12. SEM Fractographs of 304 SS Aged for 100,000 Hours Showing
(a) Crack Front (200x), (b) Microvoid Coalescence (1000x)

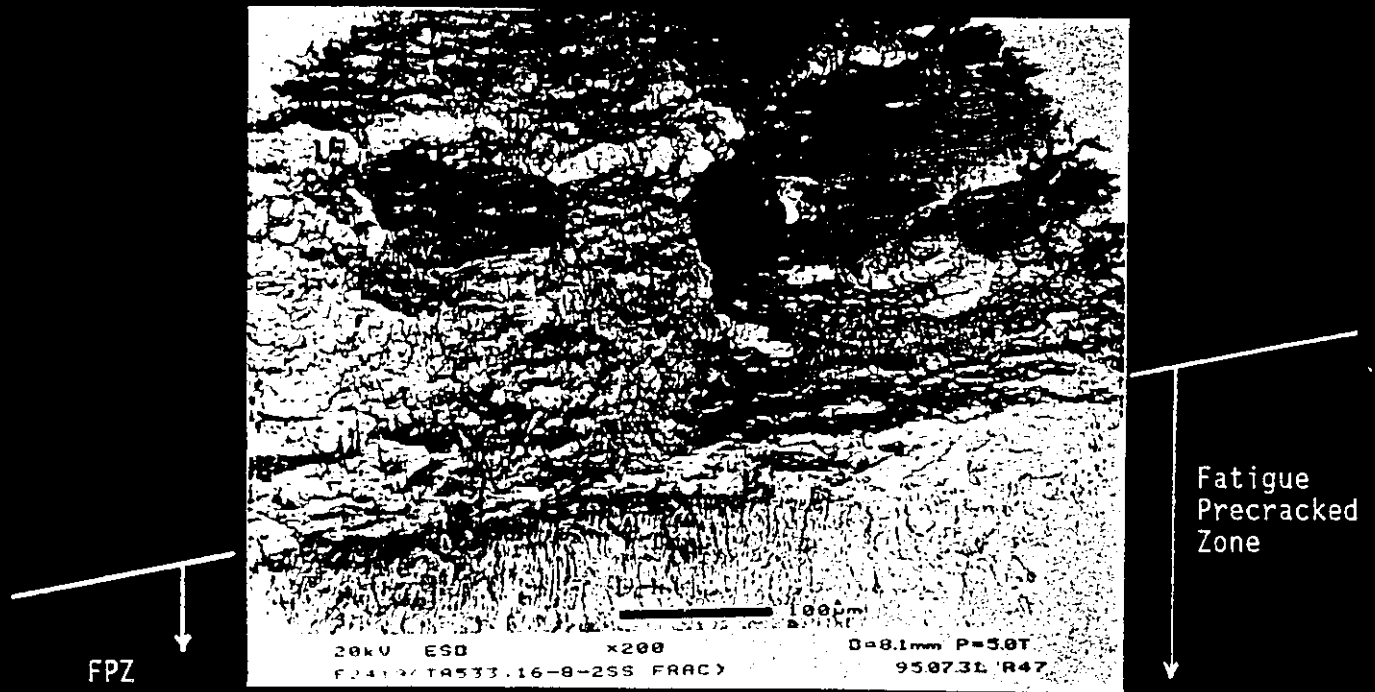


(a)

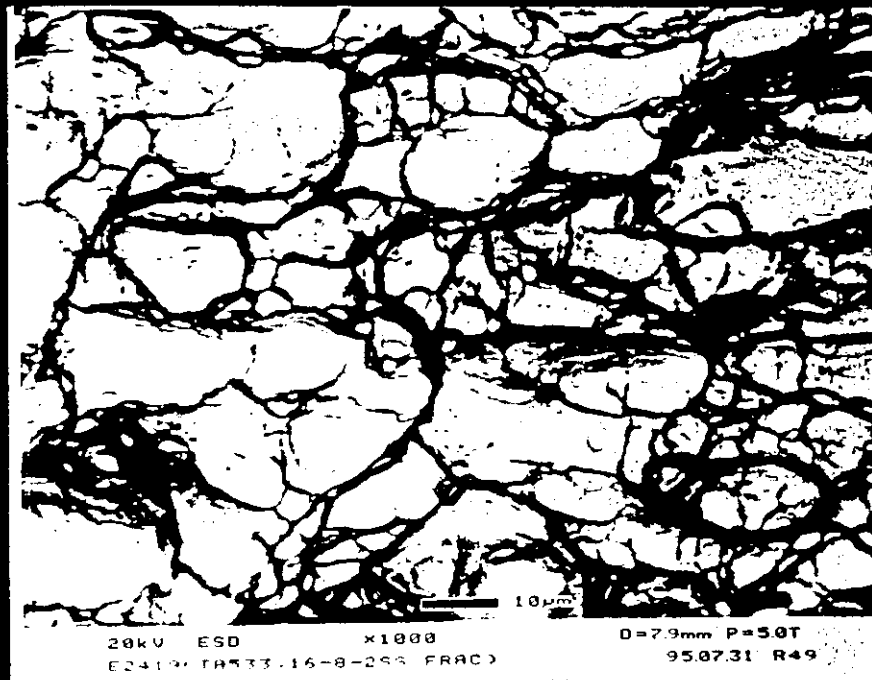


(b)

Figure 13. SEM Fractographs of 16-8-2 SS Weld Metal Aged for 100,000 Hours Showing (a) Crack Fronts (200x), (b) Dimple Size (1000x)



(a)



(b)

Figure 14. SEM Fractographs of 308 SS Weld Metal Aged for 100,000 Hours Showing (a) Crack Front (200x), (b) Dimples and Transformation Products (1000x)



(a)



(b)

**THIS PAGE INTENTIONALLY
LEFT BLANK**

APPENDIX A

Load Versus Displacement Records for J_c Fracture Toughness Tests

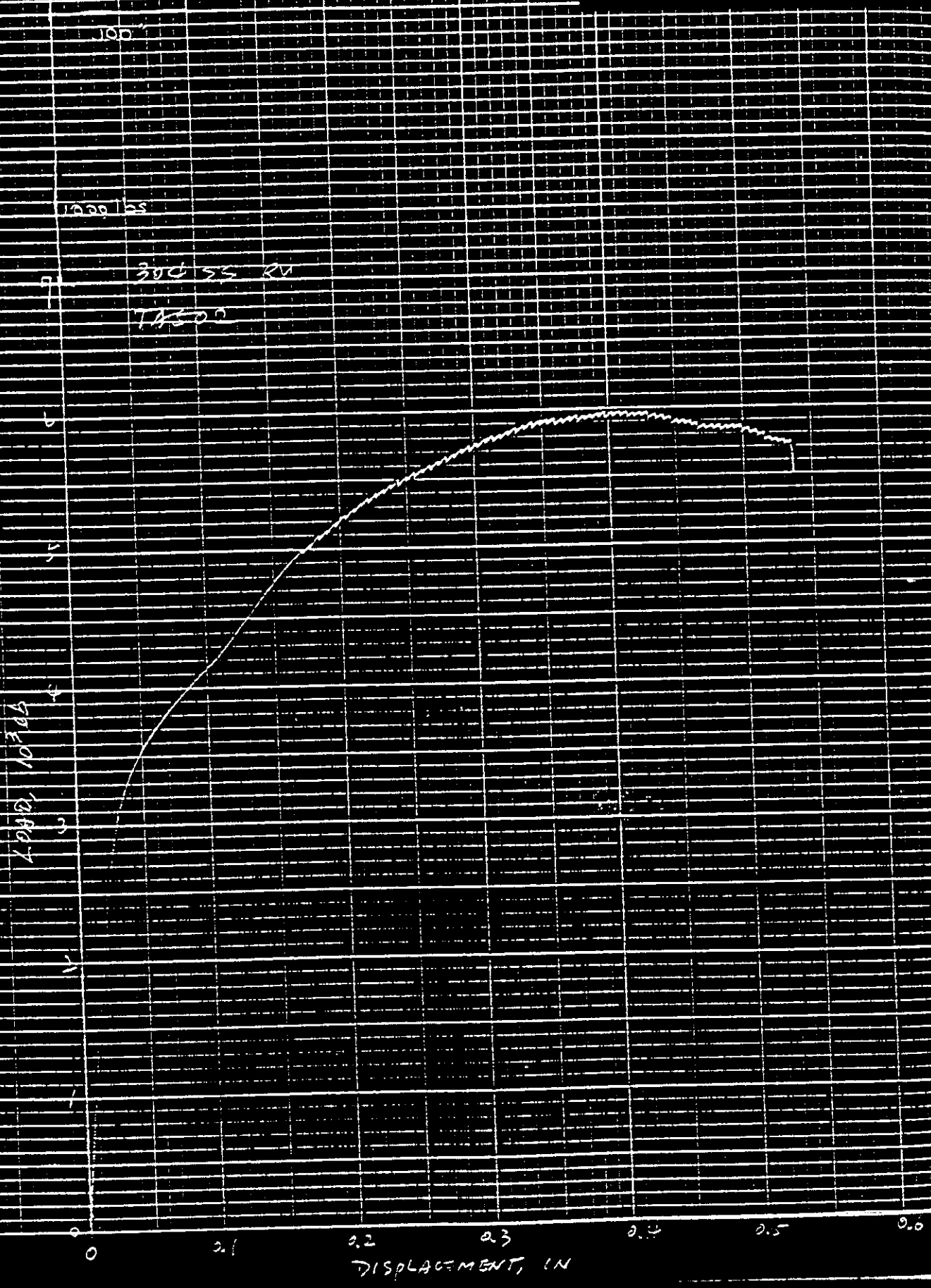
**THIS PAGE INTENTIONALLY
LEFT BLANK**

TAS02

BEST AVAILABLE COPY

WHC-SD-AF-TRP-019
Rev. 0

PAGE A-3 OF A-25



TA503

WHC-SD-FF-TRP-019
Rev. 0

PAGE A-4 OF A-25

BEST AVAILABLE COPY

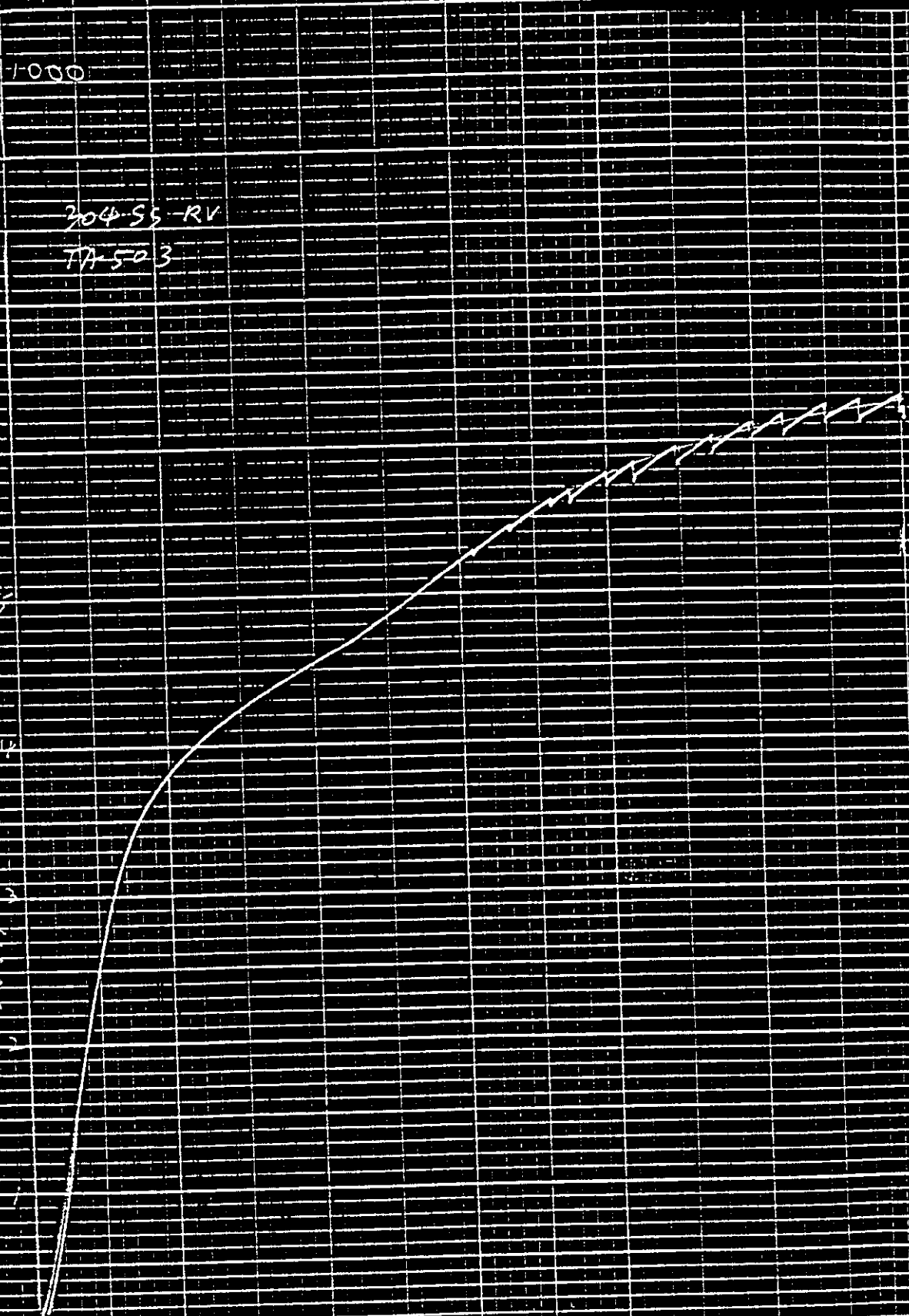
LOAD, LBS

704-55-RV
TA-503

1000

0.05

0.05 0.10 0.15 0.20 0.25 0.30
DISPLACEMENT, IN



WHC-SD-FF-TRP-019
Rev. 0

PAGE A-5 OF A-25

BEST AVAILABLE COPY

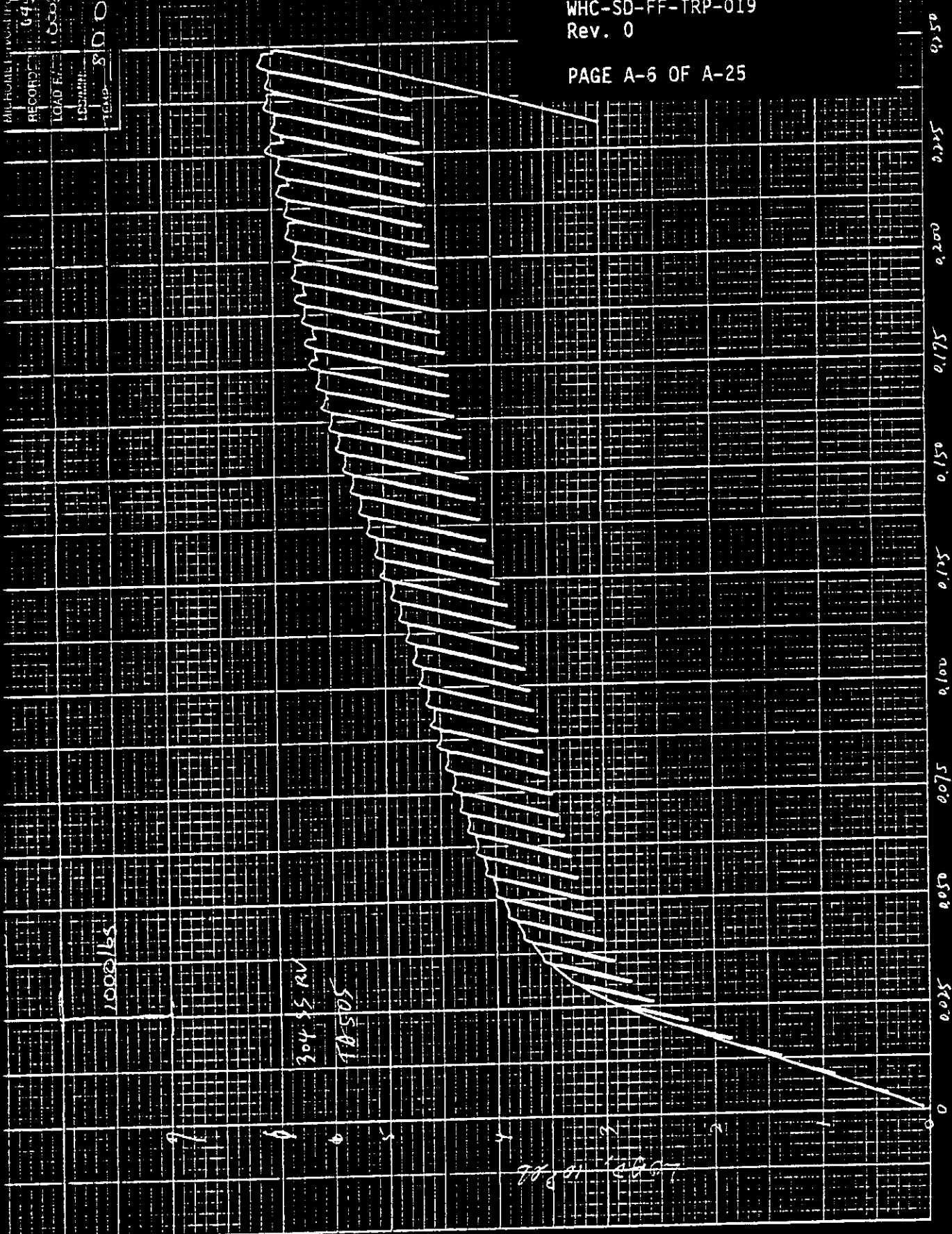
20455 RV
TASDA

10-10-79
100
9/1

0
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.200
0.150
0.100
0.050
0

DISPLACEMENT IN

RECORD 64
LOAD F. 10000
TEMP 80.0



0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
9500
10000

BEST AVAILABLE COPY

BEST AVAILABLE COPY

LOSS: 1000 lbs

1000 lbs

204 SS RV
TA 506

1-080, 100 lbs

0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09

DISCONTINUOUS



308 SS RV
TA511

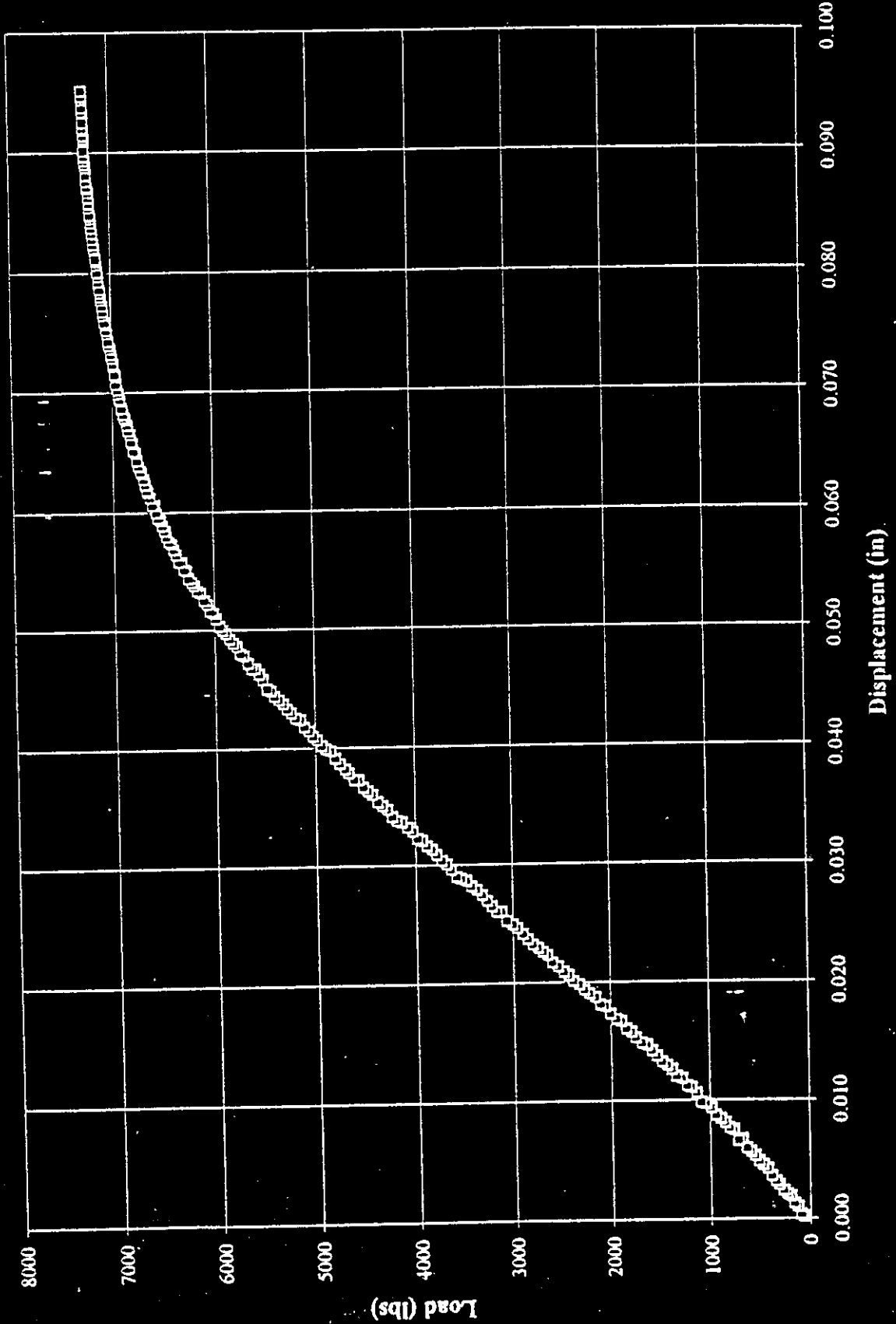


WHC-SD-FF-TRP-019
Rev. 0

PAGE A-8 OF A-25

TA511

207910-1-LS



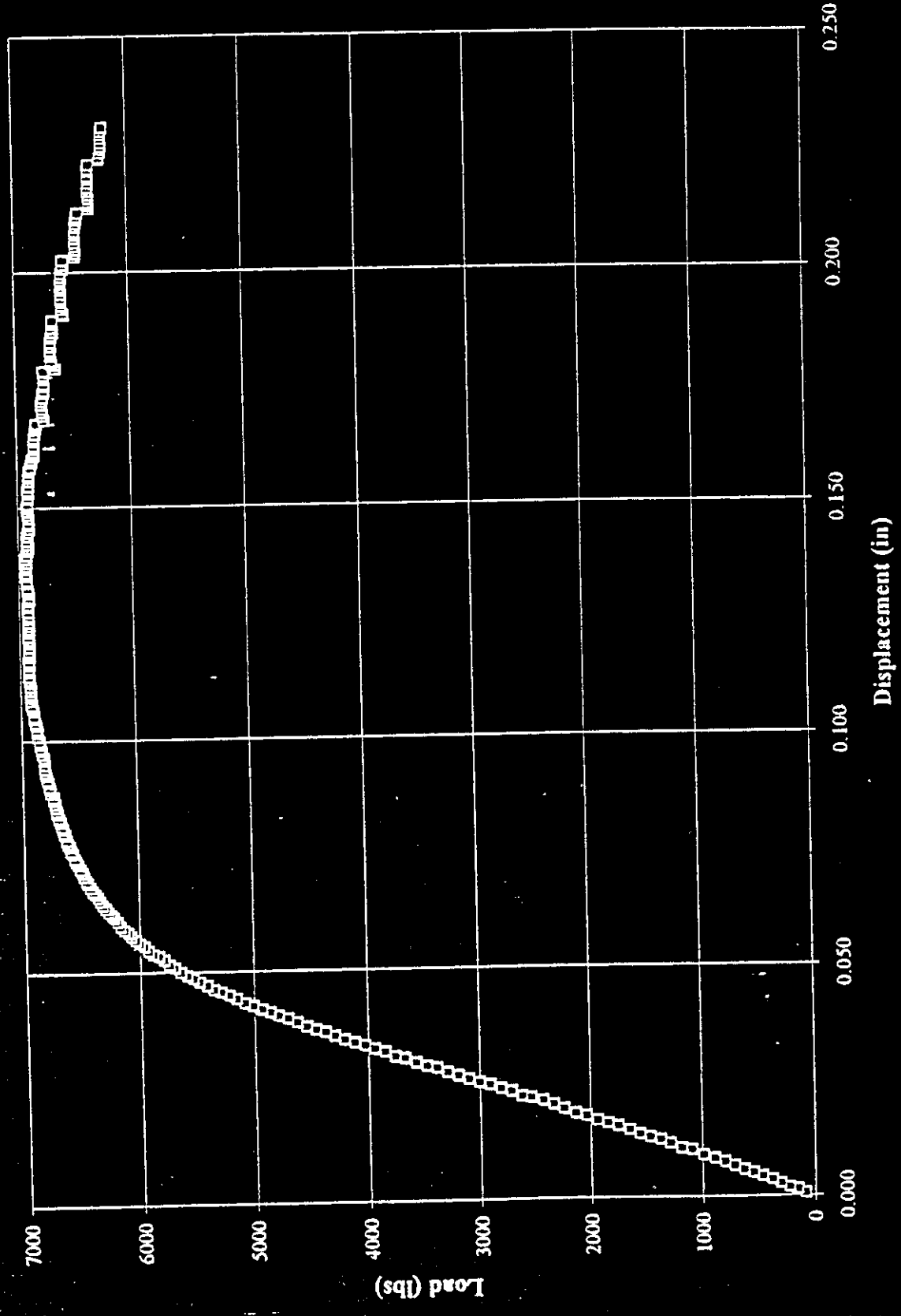
Load vs Displacement
Specimen TW1 @ 800°F
Load Rate = .05"/min.

308 SS R1
TA512

BEST AVAILABLE COPY

TA512

207910-2-2...S



Displacement (in)

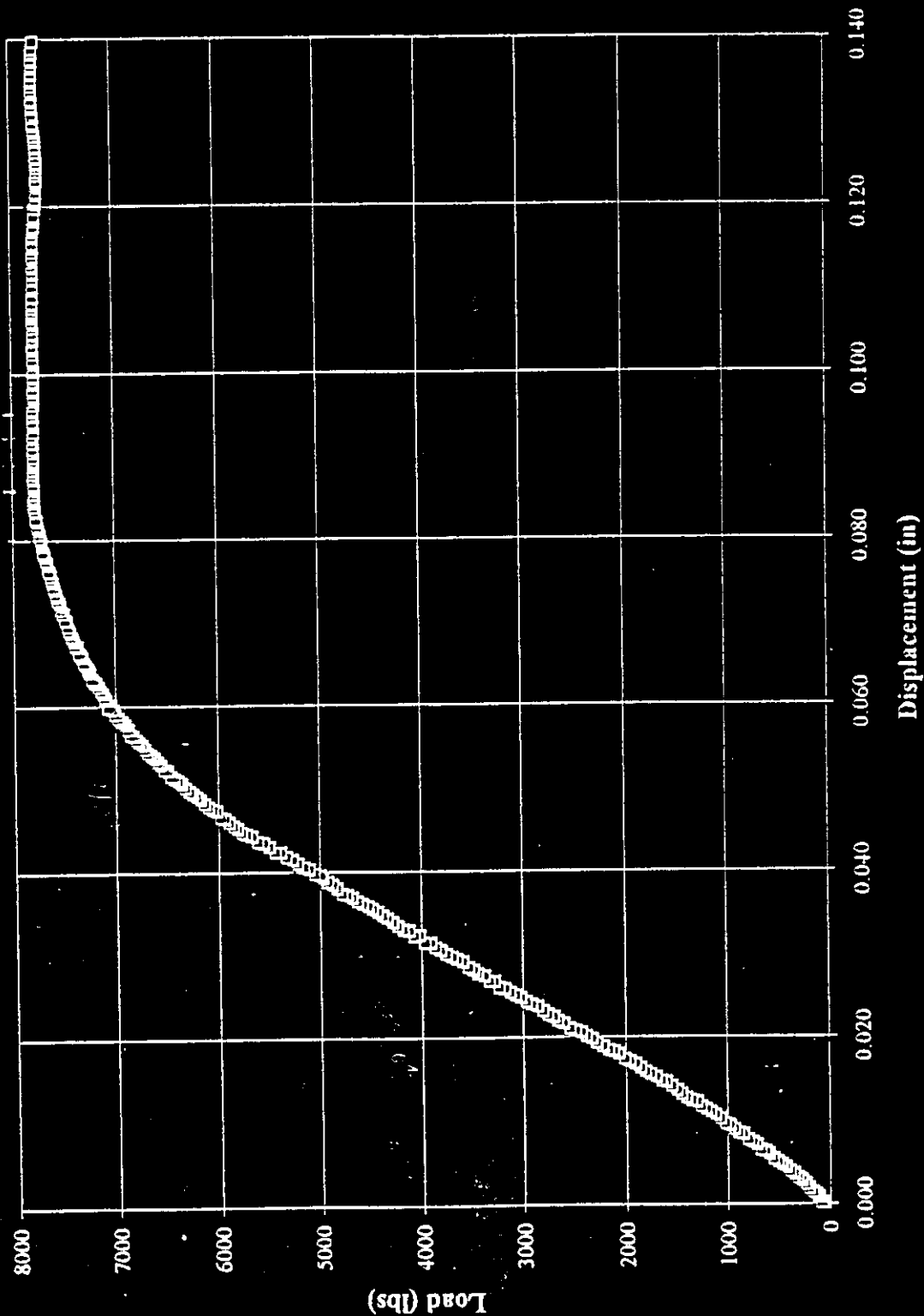
Load vs Displacement
Specimen TW2 @ 800°F
Load Rate = .05"/min.

Load (lbs)

308 SS R1
TA 513



207910-3-NLS



Load vs Displacement
Specimen TW3 @ 800°F
Load Rate = .05"/min.

30855 RV

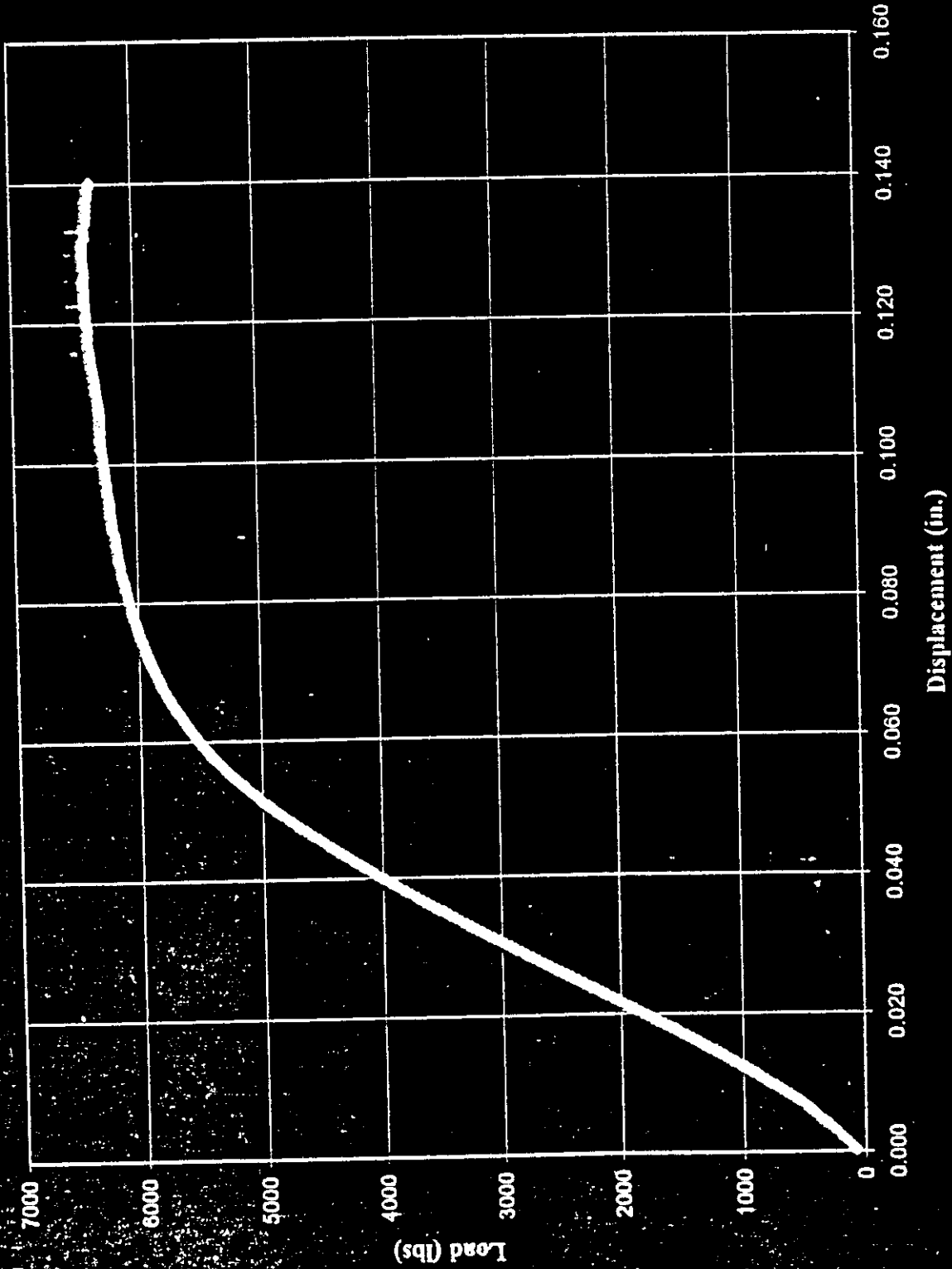
TA514

BEST AVAILABLE COPY



TA514

207910-4.XLS

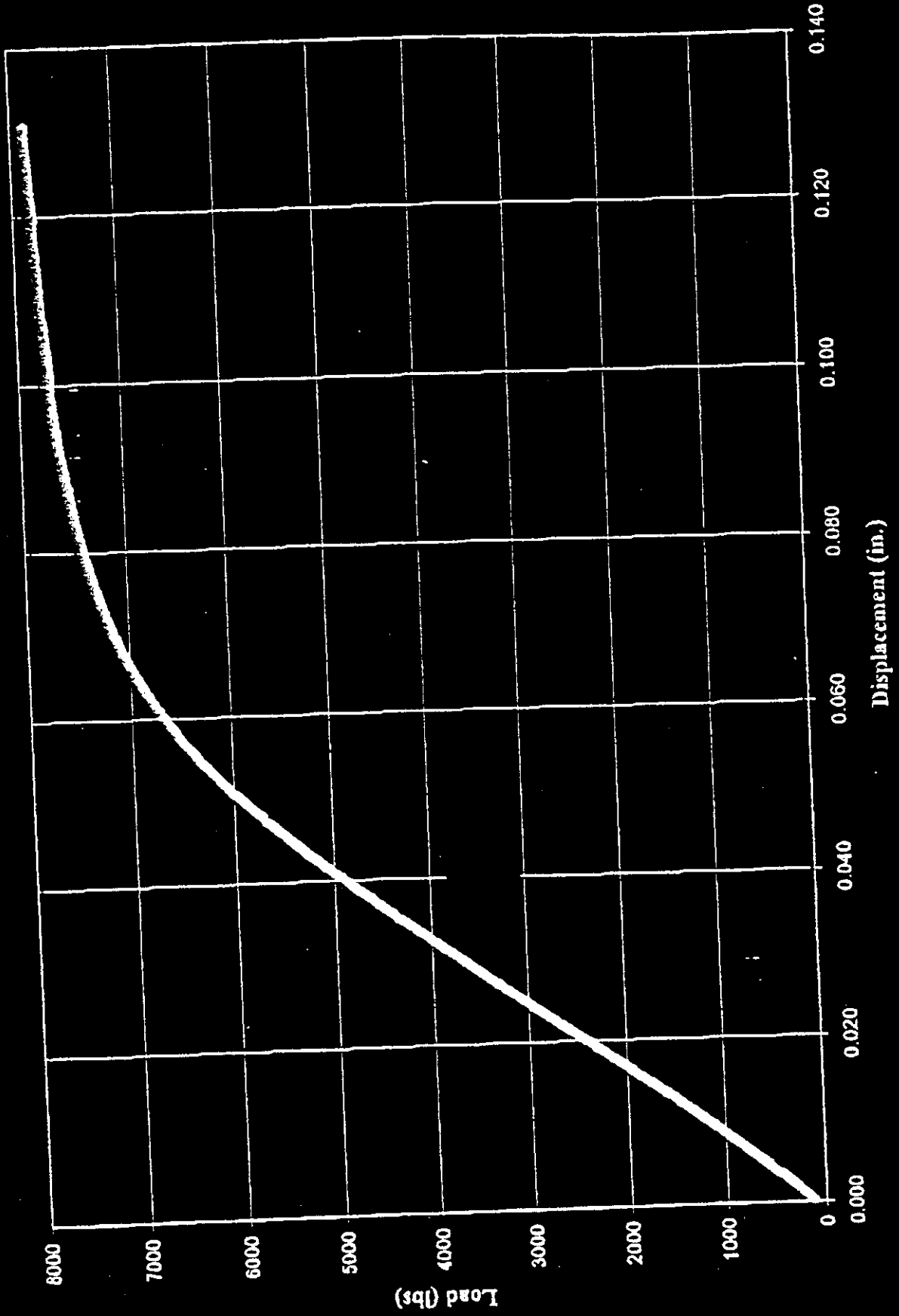


Load vs Displacement
Specimen TW4 @ 800°F
Load Rate = .05"/min.

308 SS RV
TA 515

TA 515

207910-5.XL.s



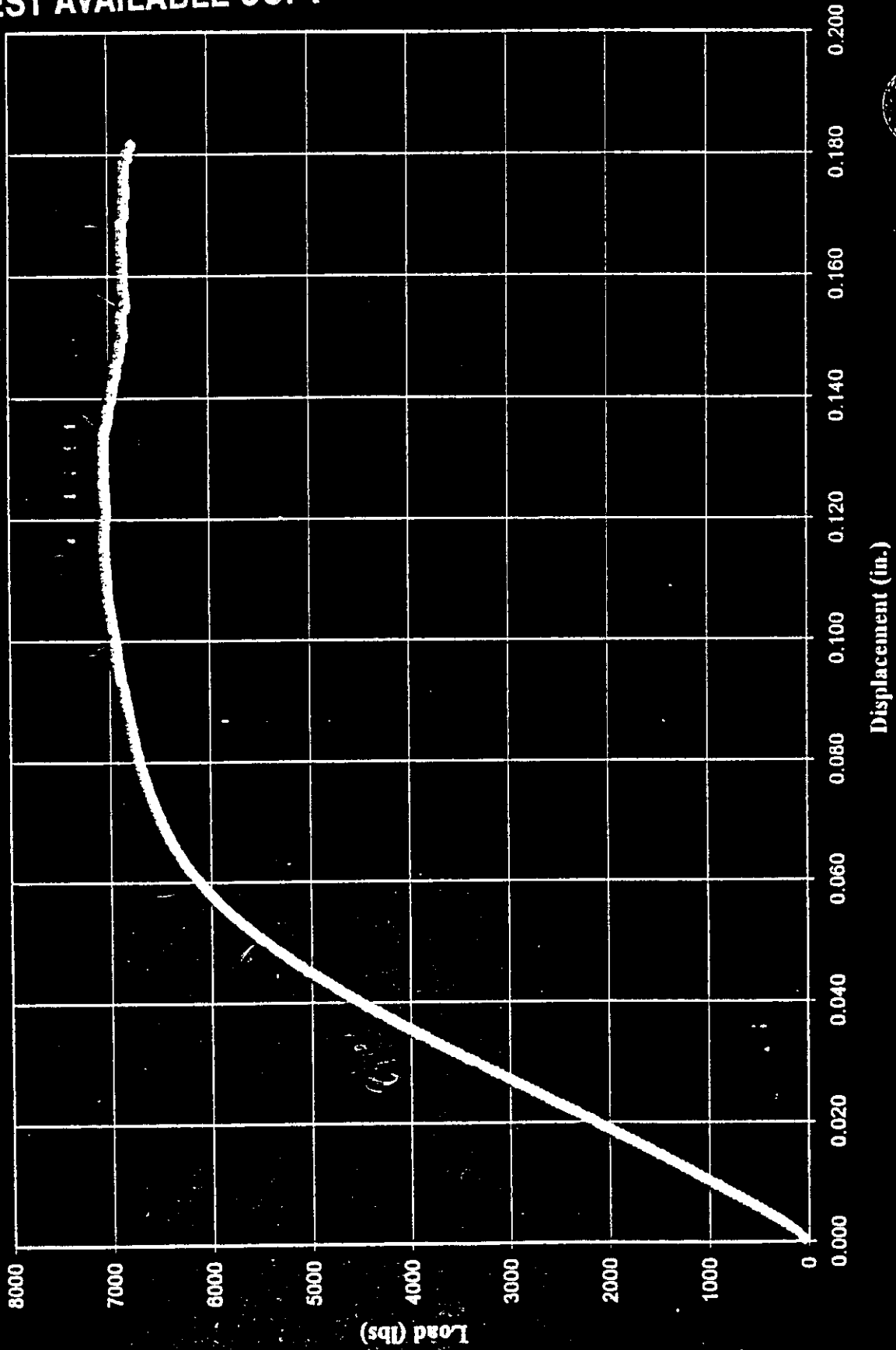
Load vs Displacement
Specimen TW5 @ 800°F
Load Rate = 0.05"/min.

TA516

BEST AVAILABLE COPY

207910-6-ALS

TA516



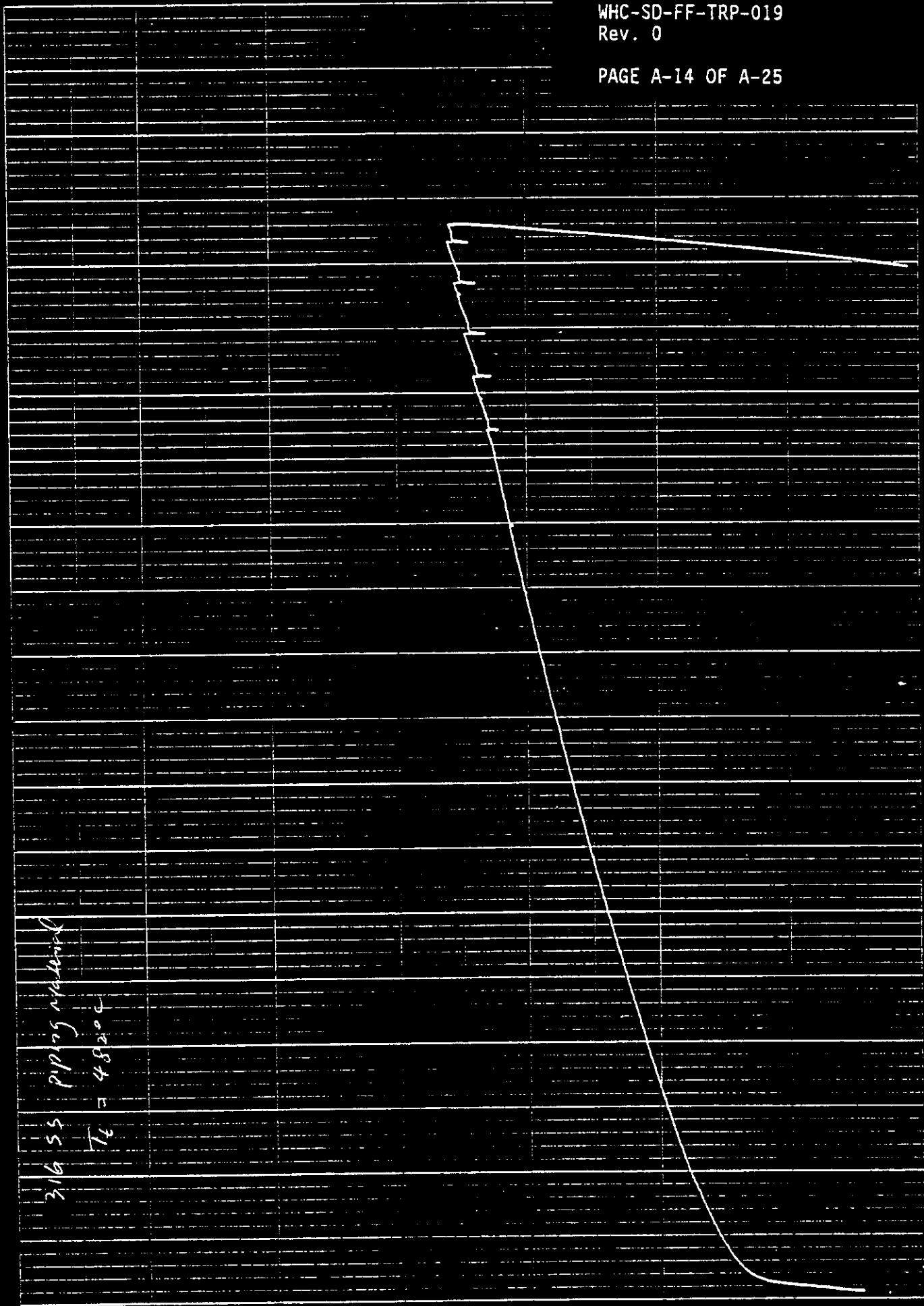
Load vs Displacement
Specimen TW6 @ 800°F
Load Rate = .05"/min.

BEST AVAILABLE COPY

TAS21

316 SS piping material

TE = 482°C



DISPLACEMENT, in

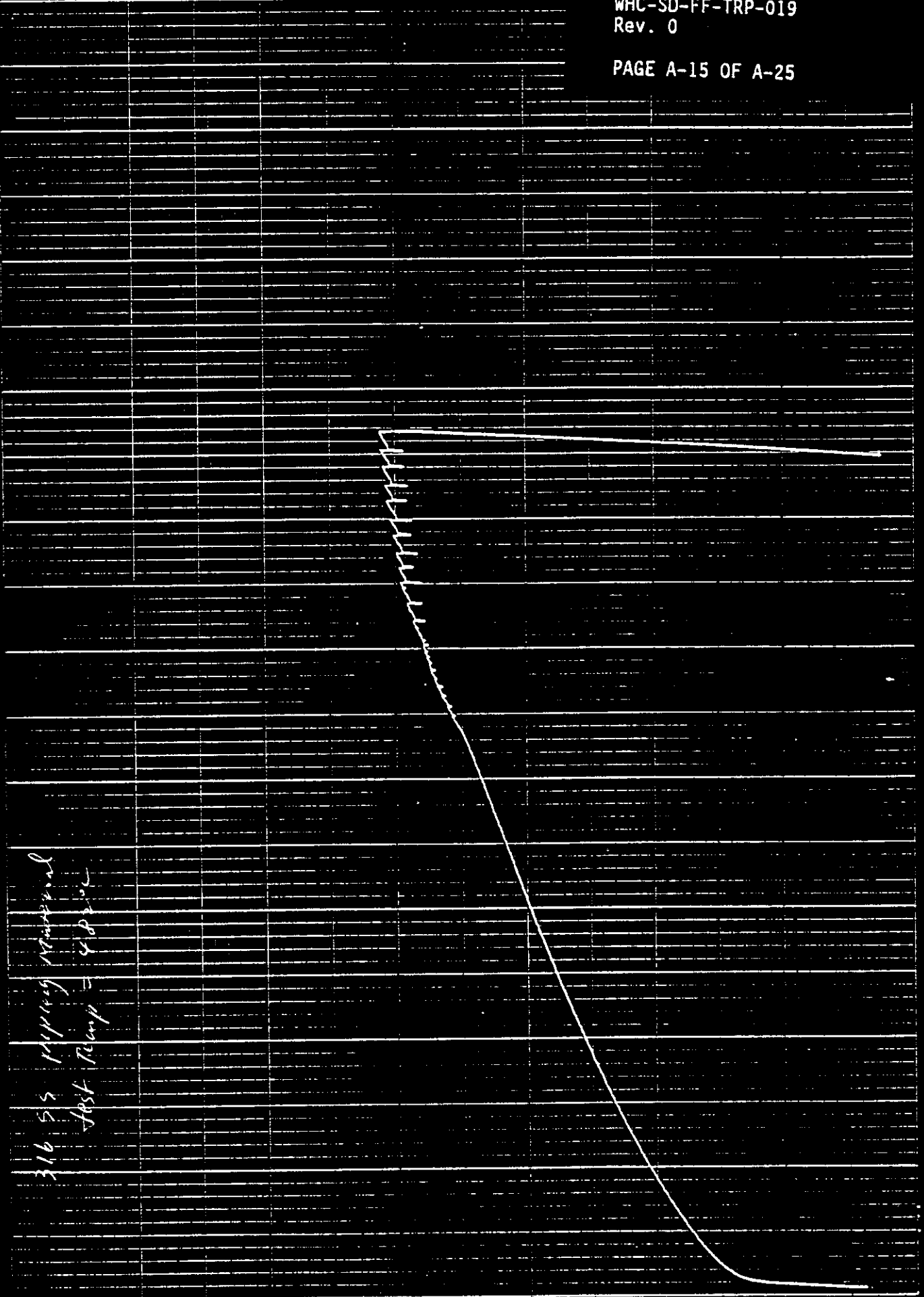
0.317 in

WELD, in

0.005 in

TAS22

316 SS Spring Material
Test Temp = 400°C



LOAD, lb

100 lb

DISPLACEMENT, in

.0594 in/lb

12/5/81

46 0780

BEST AVAILABLE COPY

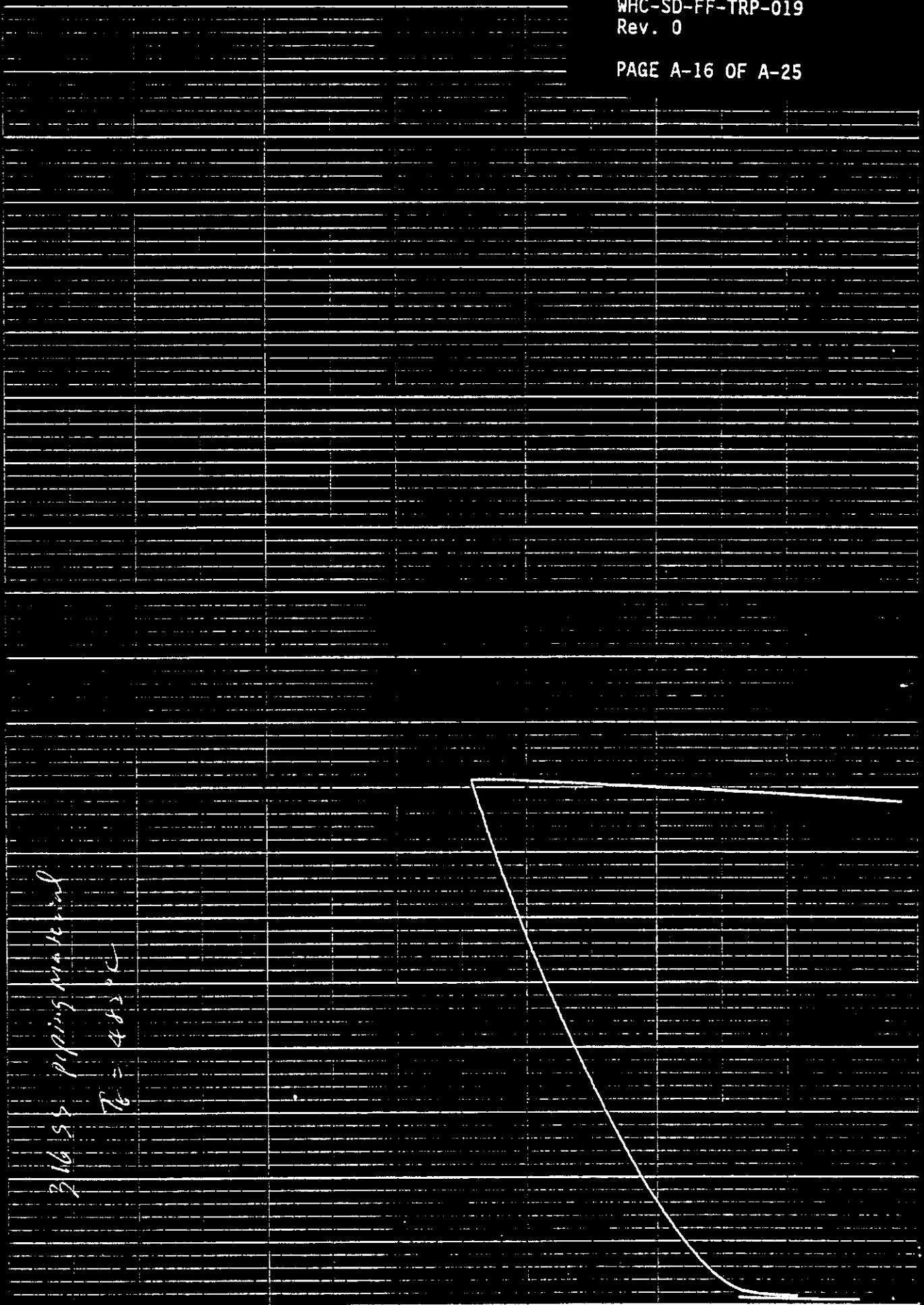
SCALE 10 X 10 TO THE RIGHT OF THE CURVE

TA523

316 SS piping material
 $T_E = 482 \text{ } ^\circ\text{C}$

200 #/C
LC47, 10

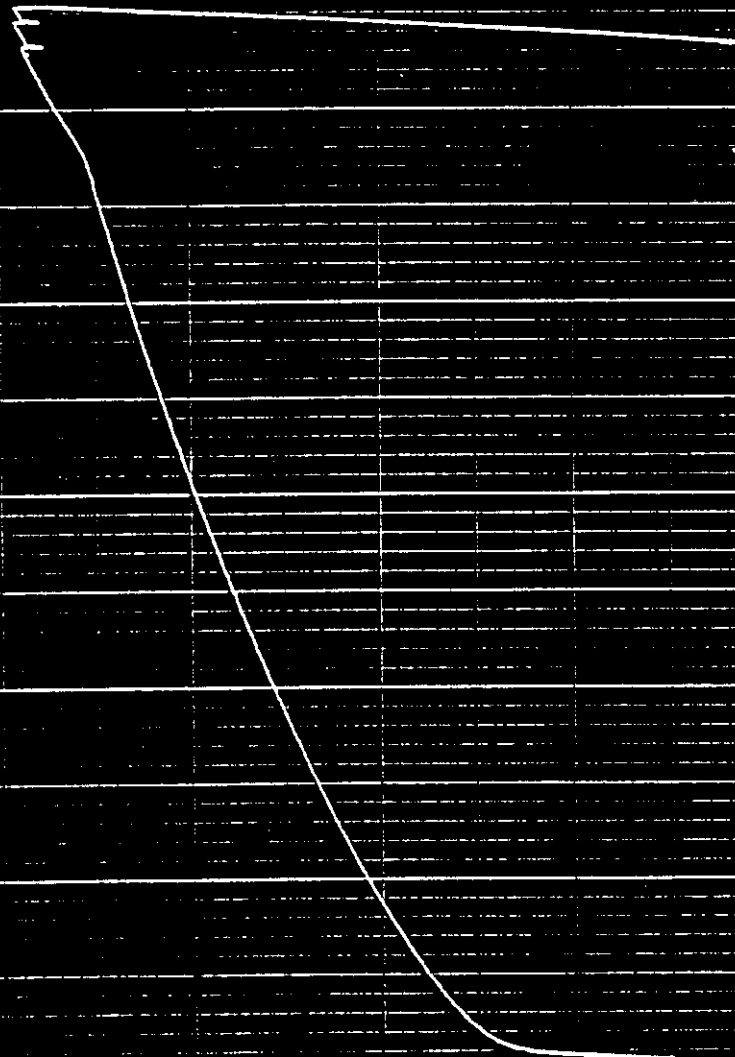
.6594"/in DISPLACEMENT, in



SEE 10 X 10 TO THE INCH 7 X 10 1/4 10 1/4
K&E NEUTRAL & ESSELEC CO. 1011 10 1/4

316 SS Piping material
T = 482°C

TAS24



DISPLACEMENT, in

0.594"/in

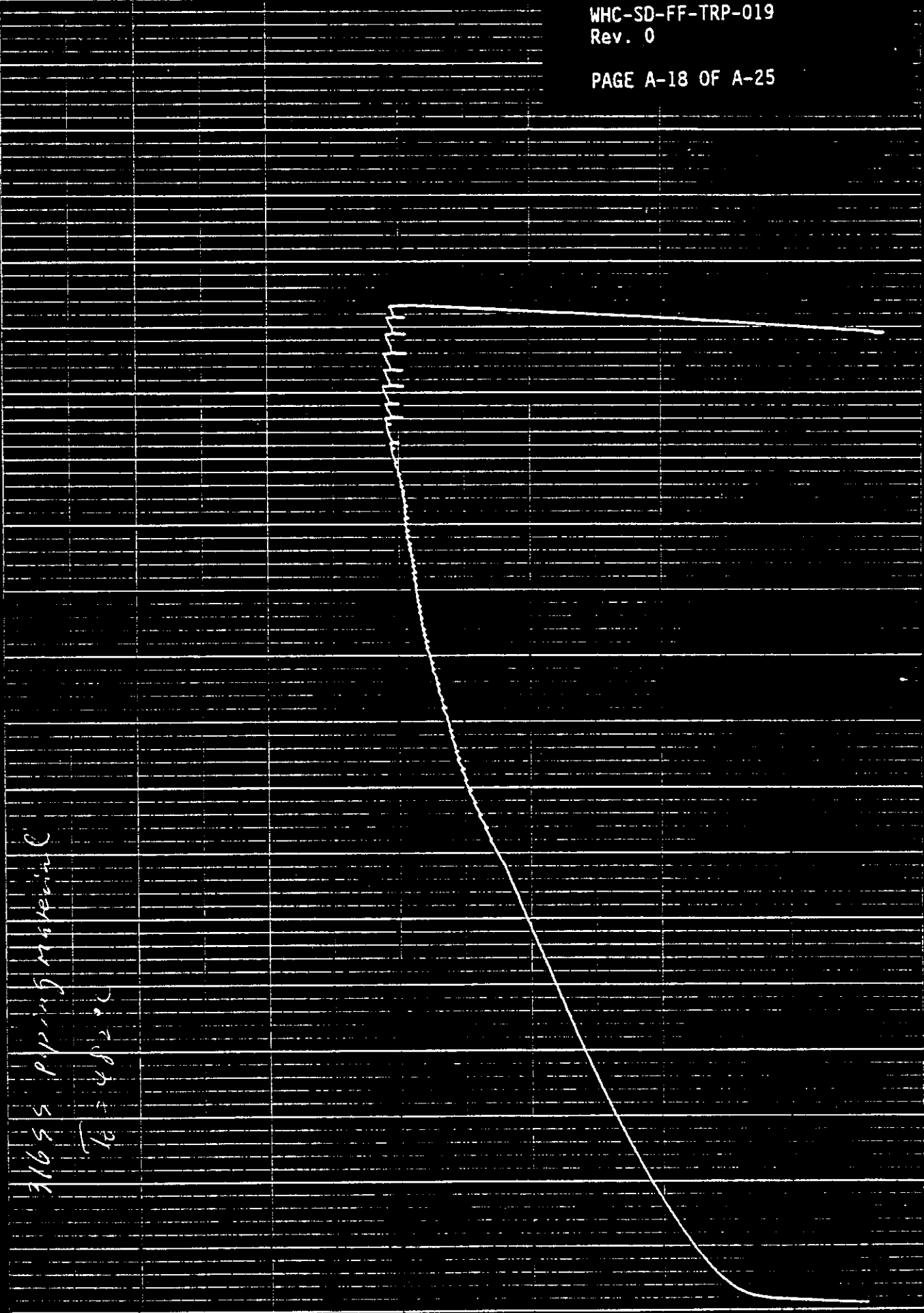
200 in

BEST AVAILABLE COPY

TAS25

3/65 Piping Movement

$T_0 = 482.0$



DISPLACEMENT, in

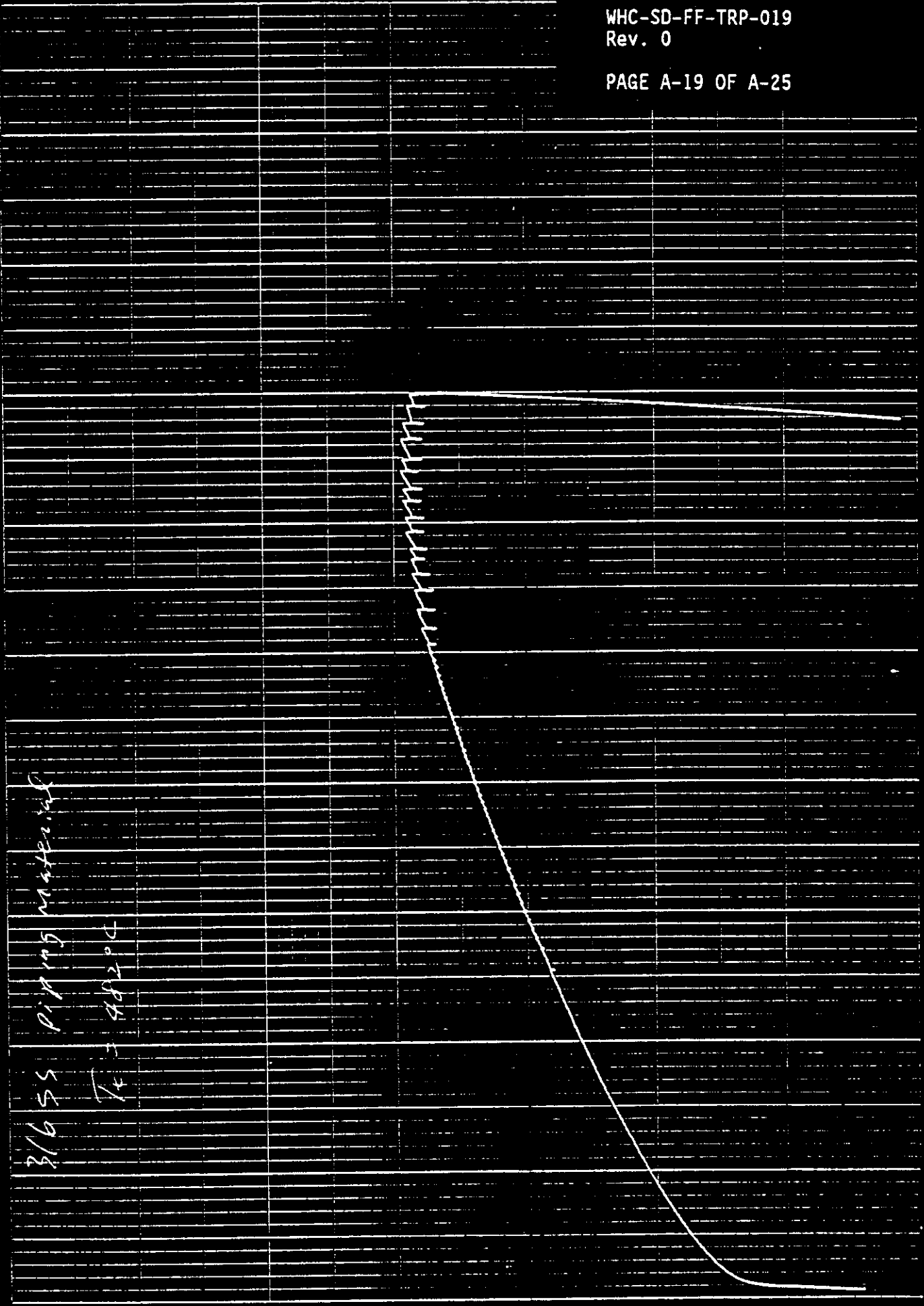
0.0594

97 12407

12702

TA526

3/6 SS PIPING MATERIAL
T_e = 98200



LOAD, lb

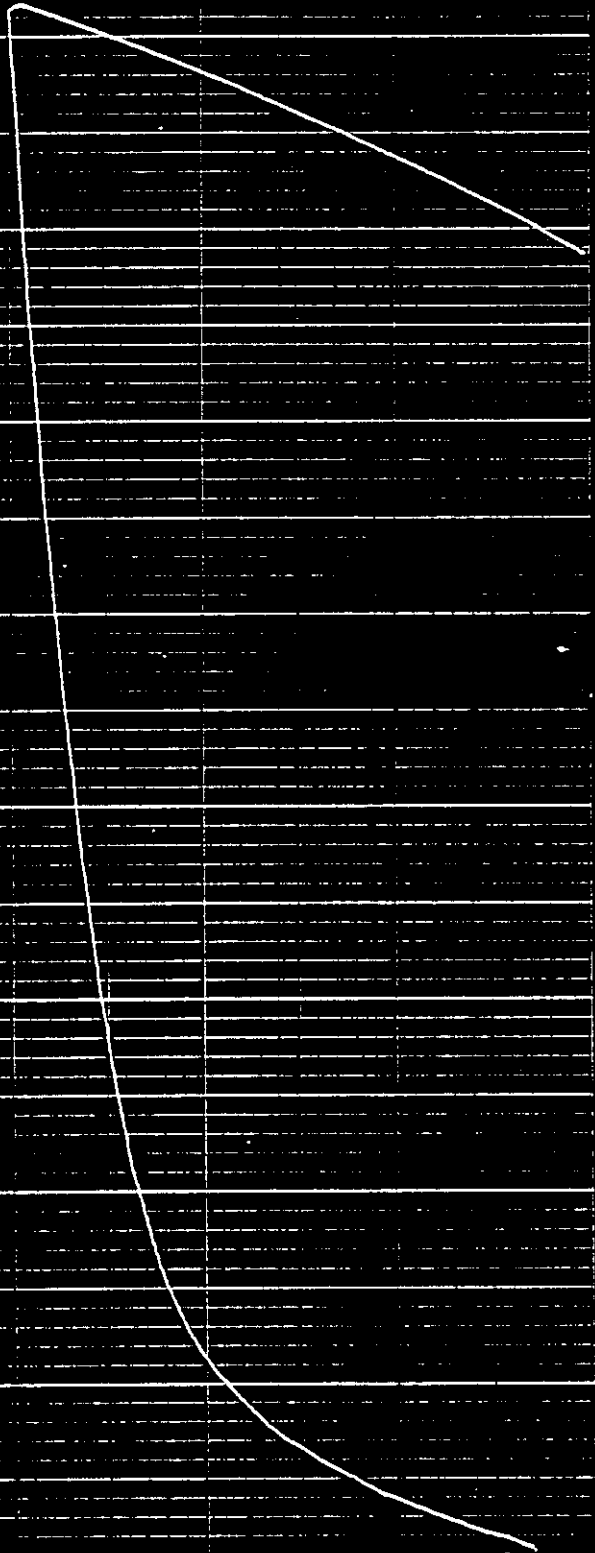
DISPLACEMENT, in

0.594 in

BEST AVAILABLE COPY

TAS31

16-8-2 SS Weld Piping Material
7-3-480°C



DISPLACEMENT, IN

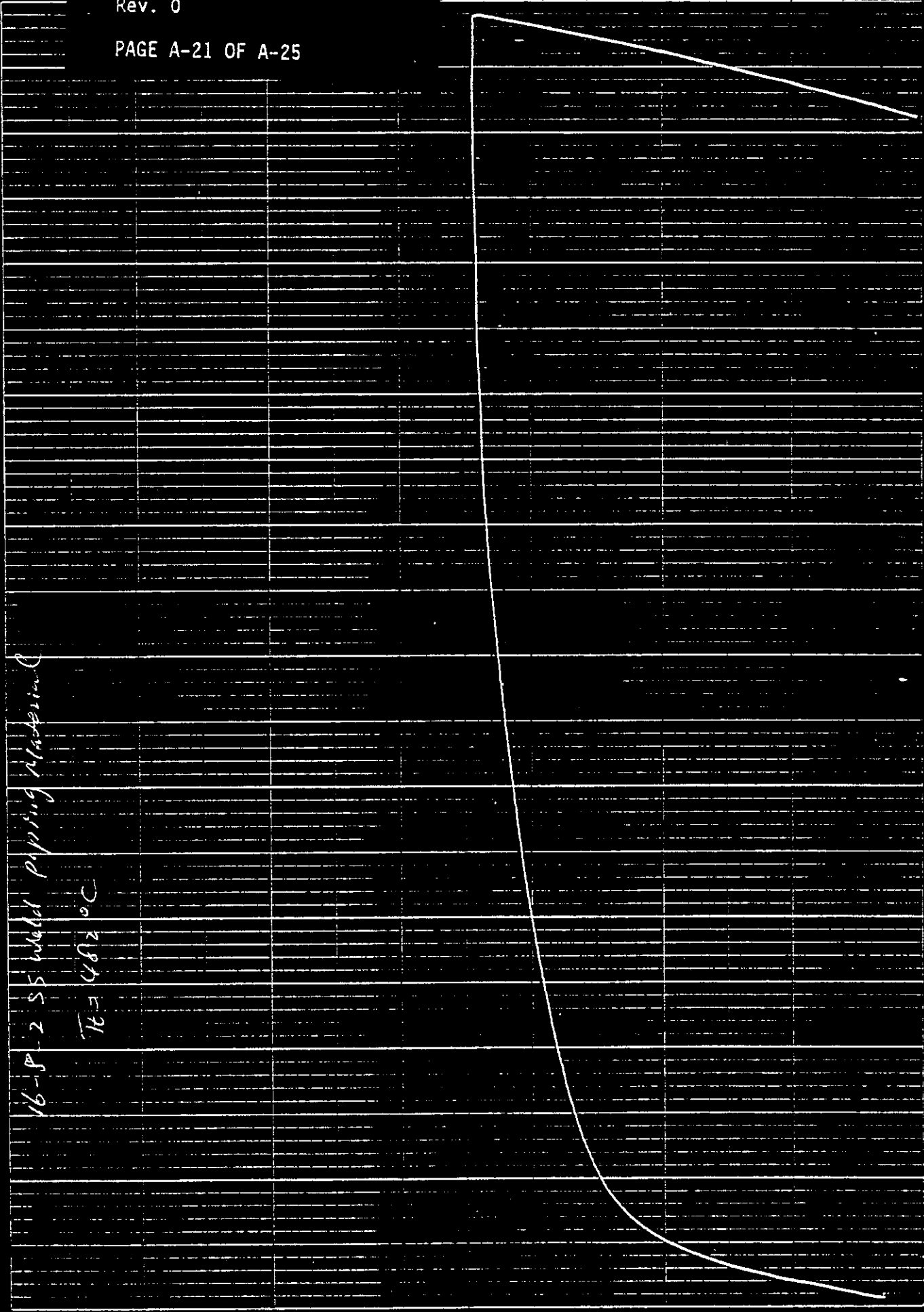
0.0792"/IN

200# - 100# LB

TA532

16-8-2 SS Weld Piping Material

TC = 4820C



200 lb
5 in

DISPLACEMENT, IN.

0.0158"/IN

46 0780

BEST AVAILABLE COPY

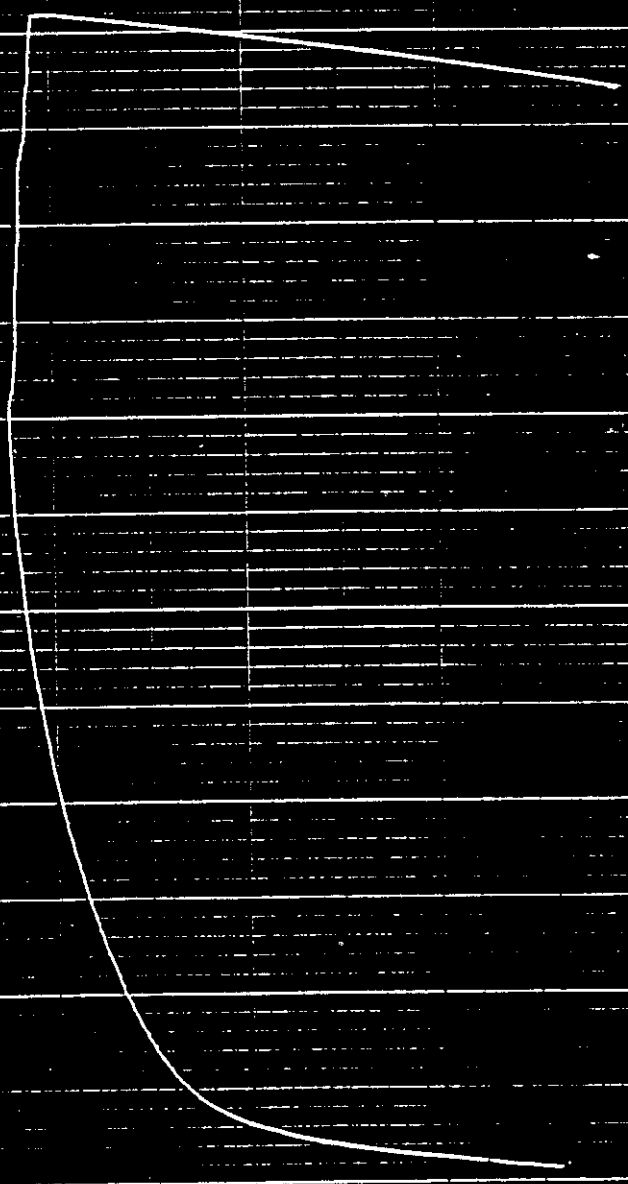
10 X 10 TO THE INCH
KEUFFEL & ESSER CO.

TA 533

16-8-2 SS Weld Piping Material
T = 482°C

WHC-SD-FF-TRP-019
Rev. 0

PAGE A-22 OF A-25



206 = 110
57.2

DISPLACEMENT, IN

0.317 "/in

TA534

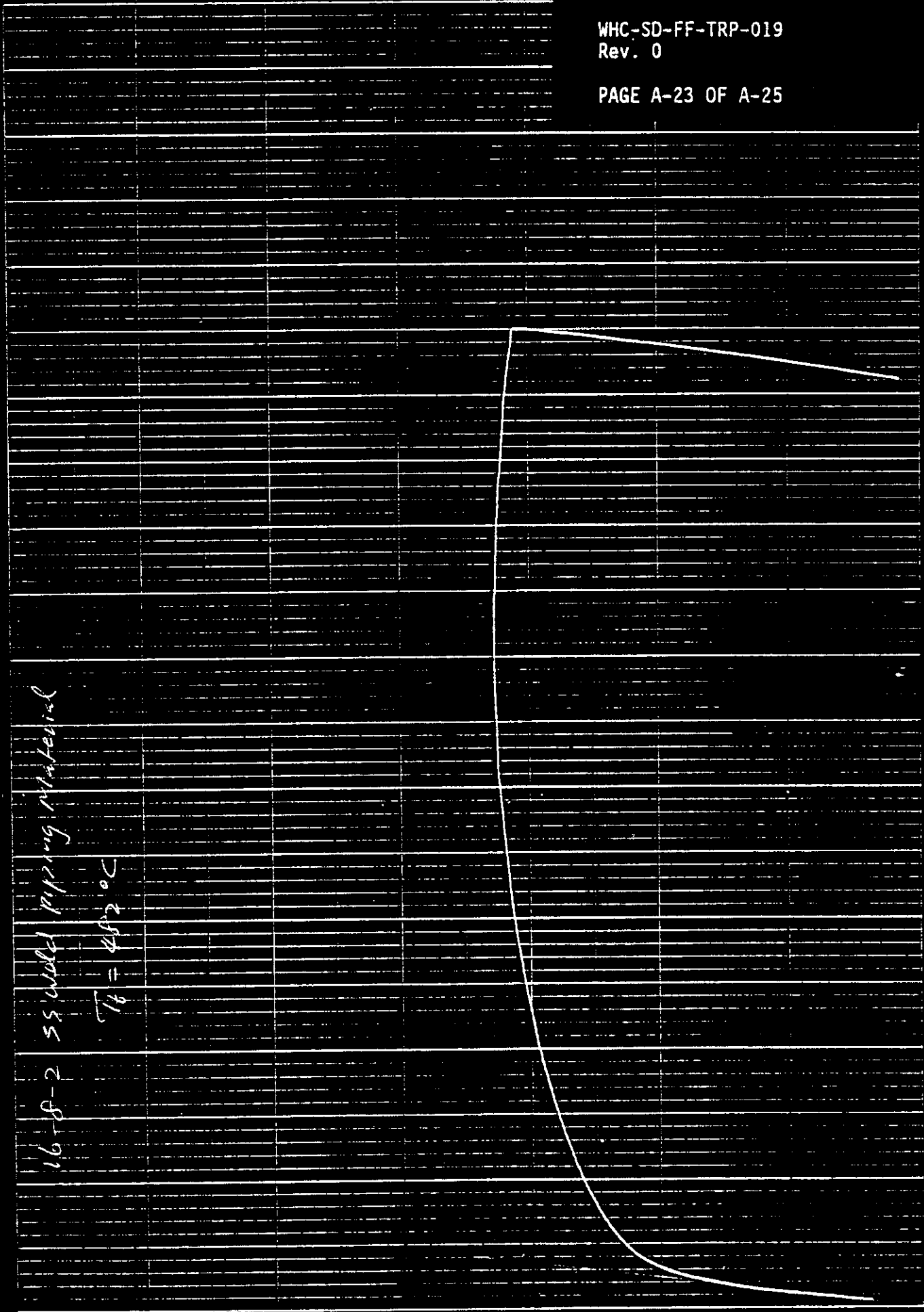
16-8-2 SS Weld Piping Material

$T_6 = 482^{\circ}C$

2cc = 1/4 inch
1000, lb

DISPLACEMENT, IN

.0317"/in



46 0780

BEST AVAILABLE COPY

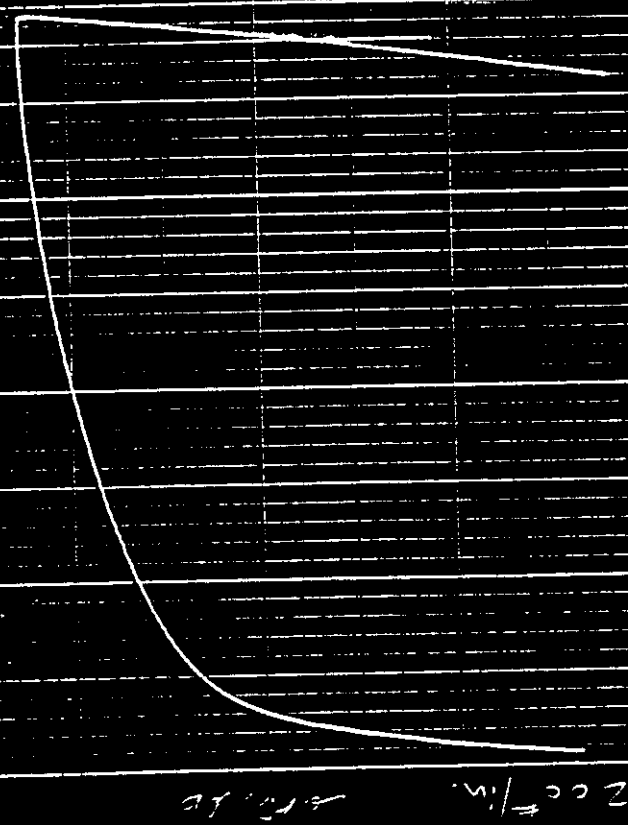
10 X 10 TO THE INCH 7 X 10 REELS
KEUFFEL & ESSER CO. MADE IN U.S.A.

TA 535

16-8-1 53 weld piping material
T_e = 442.5

WHC-SD-FF-TRP-019
Rev. 0

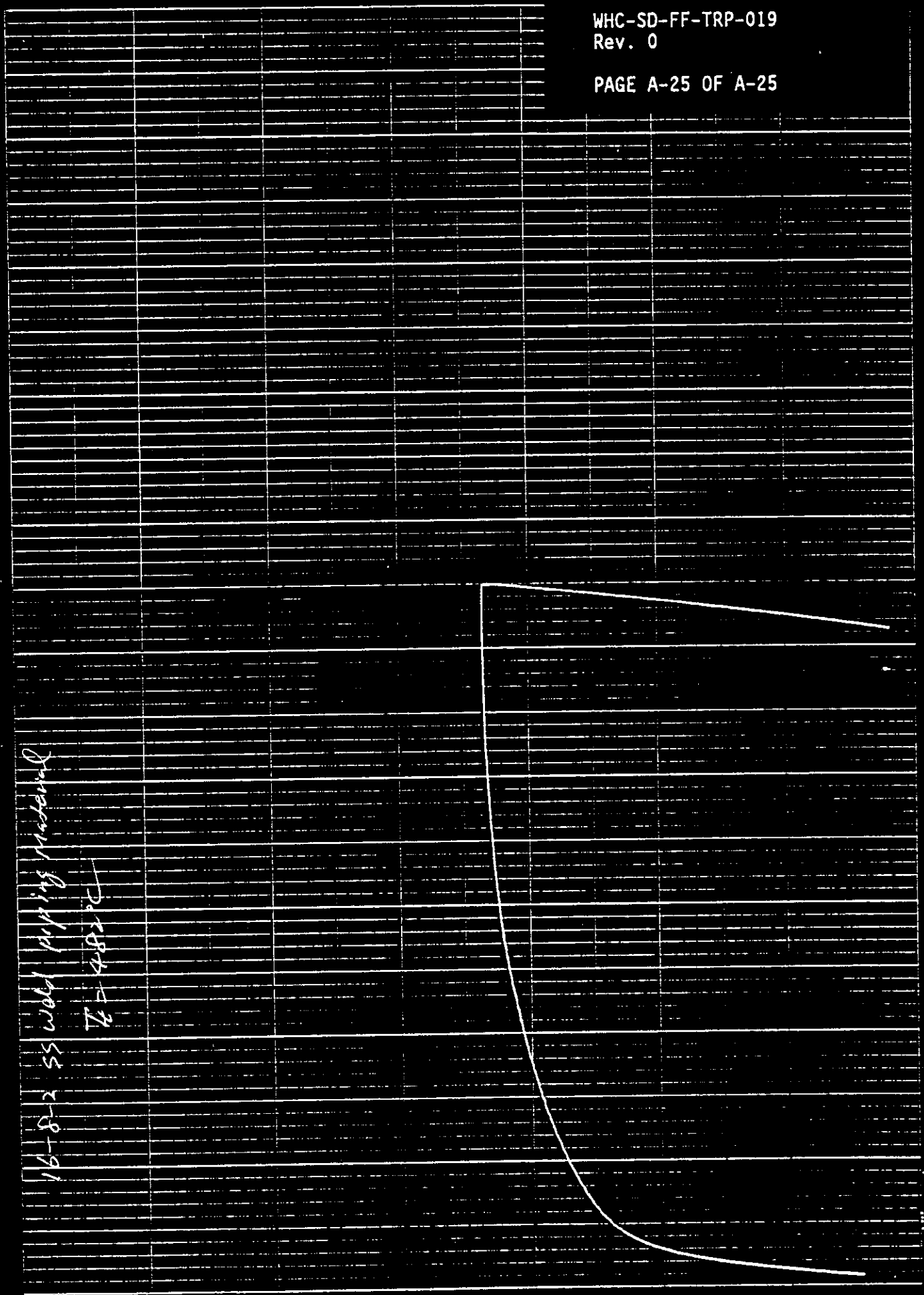
PAGE A-24 OF A-25



2000
TUSP/REGAT 30T 123

TA 536

16-8-2 SS weld piping material
21884-2



200 = 100
2000 = 1000

Displacement, in

0.317"/in

APPENDIX B

Additional Test Records for 316 Stainless Steel and
16-8-2 Stainless Steel Weld



LABORATORY REPORT

WHC-SD-FF-TRP-019
Rev. 0

PAGE B-2 OF B-64

TO: Westinghouse Hanford Company
ATTN: Bill Roberson
PSS Procurement
2355 Stevens Drive
Richland, WA 99352

PROJECT NO: 1665-62077-3
DATE: March 31, 1995
AUTHORIZATION: MWGSWV380208

PROJECT: Precracking and Fracture Toughness Testing of (12) Compact Tension Specimens Prepared by Metcut Research from Material with Necessary Identification Supplied by Westinghouse Hanford Company.


Material Identity: 16-8-2 Stainless Steel and 316 Stainless Steel
Test Specification: ASTM E813, Multiple Specimen Technique
Test Environment: 900°F, Laboratory Air
Nominal Specimen Size, (in.):

Depth, W:	1.154
Thickness, B:	0.300
Height, 2H:	1.385
Length, L:	1.443

Discussion: One group of 16-8-2 stainless steel specimens comprised of six specimens and another group of six 316 stainless steel specimens were to be tested per ASTM E813 using the multiple specimen technique. Test conditions were 900°F in laboratory air. Each specimen was to have digital recordings of Load, Machine Ram Displacement, and Specimen Load-Line Displacement. This was achieved by taking this information electronically at the rate of approximately six readings per second for the duration of the test. However, due to electronic malfunction, no data was obtained for specimens TA523 and TA532.

Please see the following pages for data presentation.


Thomas E. Arnold, Manager
Dynamics Testing


Kenneth G. Horner
Testing Specialist

NOTE: This report may only be duplicated or copied in its entirety.

Precracking Data Summary

Job Number 62077
 Customer
 Operator LR Bramlage
 Date 02-16-1995
 Material SS
 Specimen Type C(T)

Specimen ID TA521
 Machine 60076
 Extensometer 27189
 Clip Gage Cal (in/volt) 0.0020
 Load Cell Cal (lb/volt) 200.0
 Environment AIR
 Temperature RT

K Calibration Type	P
KCT	CT00
0 0.88600	1.00002
1 4.64000	-4.06320
2 -13.32000	11.24200
3 14.72000	-106.04000
4 -5.60000	464.32999
5 0.00000	-650.67999

Specimen Characteristics

Specimen Thickness (in)	B	0.300
Net Spec. Thickness (in)	Bn	0.300
Notch Depth (in)	h	0.501
Specimen Width (in)	W	1.156
Young's Modulus (10E6)	E	28.300

Test Parameters

Max Load for E adj. (lb)	300.0
Stress Ratio (R)	0.25
Initial a (in)	0.501
Final a (in)	0.771
Initial Kmax (ksi sqrt(in))	20.50
Final Kmax (ksi sqrt(in))	20.50
Initial Maximum Load (lb)	830.3
Final Maximum Load (lb)	362.5
K-Gradient (1/in)	0.000
Minimum Slope Level (%)	50.0
Number of Slopes	10.
Minimum Corr Coeff	0.990
Data on load or unload	LOAD AND UNLOAD
Final a/W	0.6670
a/W Increment for Printout	0.0050
Waveform Type	SINEWAVE
Frequency (Hz)	25.000

Command-Feedback Error
 Command-Feedback Error

Job Number 62077
Specimen ID TA521

N Number of cycles
a(in) Crack length measured from load line
a/W Ratio of crack length to specimen width
P(lb) Maximum force
dK(ksi $\sqrt{\text{in}}$) Cyclic stress intensity
EvB/P Normalized compliance
Snum Number of slopes for crack length determination
Corr Correlation coefficient
da/dN(in/cyc) Crack growth rate

N	a	a/W	P	dK	EvB/P	Snum	Corr	da/dN
2,783	0.5080	.439	300	5.65	27.560	10	0.9991	3.651E-04
3,341	0.5072	.439	300	5.64	27.476	10	0.9985	-4.473E-07

92,607	0.5123	.443	808	15.38	28.056	13	0.9996	-7.014E-08
103,564	0.5181	.448	855	16.50	28.736	13	0.9997	2.261E-07
113,970	0.5239	.453	843	16.50	29.432	16	0.9998	5.481E-07
121,036	0.5296	.458	877	17.40	30.136	13	0.9998	6.780E-07
127,540	0.5356	.463	864	17.40	30.906	13	0.9998	8.851E-07
134,698	0.5412	.468	852	17.40	31.638	13	0.9997	8.471E-07
141,210	0.5471	.473	839	17.40	32.429	13	0.9997	8.647E-07
148,376	0.5533	.479	826	17.40	33.288	13	0.9997	8.405E-07
154,246	0.5586	.483	815	17.40	34.051	10	0.9996	8.920E-07
160,282	0.5641	.488	804	17.40	34.858	10	0.9996	9.207E-07
167,334	0.5703	.493	791	17.40	35.784	10	0.9997	8.861E-07
174,408	0.5763	.499	778	17.40	36.732	10	0.9998	8.399E-07
181,453	0.5818	.503	767	17.40	37.613	10	0.9998	8.020E-07
187,523	0.5874	.508	775	17.85	38.548	10	0.9998	8.864E-07
193,049	0.5934	.513	762	17.85	39.574	10	0.9998	9.930E-07
198,069	0.5989	.518	751	17.85	40.538	10	0.9998	1.078E-06
203,607	0.6047	.523	739	17.85	41.600	10	0.9999	1.070E-06
209,643	0.6107	.528	726	17.85	42.741	10	0.9998	9.939E-07
215,172	0.6162	.533	715	17.85	43.810	10	0.9997	1.036E-06
220,708	0.6222	.538	703	17.85	45.013	10	0.9998	1.019E-06
226,744	0.6280	.543	691	17.85	46.222	10	0.9997	1.017E-06
233,169	0.6345	.549	678	17.85	47.623	10	0.9998	1.018E-06
238,216	0.6395	.553	668	17.85	48.736	10	0.9997	9.890E-07
244,250	0.6457	.559	656	17.85	50.175	10	0.9997	9.823E-07
249,786	0.6511	.563	645	17.85	51.464	10	0.9997	1.005E-06
255,334	0.6568	.568	634	17.85	52.882	10	0.9997	1.024E-06
261,383	0.6627	.573	622	17.85	54.409	10	0.9996	9.648E-07
267,432	0.6682	.578	611	17.85	55.868	10	0.9997	9.554E-07
273,982	0.6747	.584	599	17.85	57.673	10	0.9998	9.269E-07
279,522	0.6802	.588	588	17.85	59.266	10	0.9997	1.007E-06
285,064	0.6856	.593	578	17.85	60.881	10	0.9997	1.022E-06
290,606	0.6915	.598	566	17.85	62.728	10	0.9995	1.030E-06
296,155	0.6972	.603	555	17.85	64.557	10	0.9996	1.004E-06
302,731	0.7032	.608	544	17.85	66.580	10	0.9997	9.730E-07
308,287	0.7091	.613	533	17.85	68.647	10	0.9996	1.016E-06
313,455	0.7148	.618	522	17.85	70.739	10	0.9996	1.060E-06
318,514	0.7203	.623	512	17.85	72.831	10	0.9996	1.116E-06
324,578	0.7264	.628	501	17.85	75.267	10	0.9997	1.027E-06
330,143	0.7323	.633	490	17.85	77.688	10	0.9997	1.023E-06
335,699	0.7381	.639	479	17.85	80.239	10	0.9996	1.039E-06
340,754	0.7436	.643	469	17.85	82.709	10	0.9995	1.062E-06
346,310	0.7495	.648	459	17.85	85.526	10	0.9996	1.091E-06
351,879	0.7552	.653	449	17.85	88.345	10	0.9995	1.049E-06
356,934	0.7609	.658	438	17.85	91.300	10	0.9995	1.079E-06
362,511	0.7666	.663	428	17.85	94.391	10	0.9994	1.086E-06
Beyond final crack length .7716672								
368,107	0.7725	.668	418	17.85	97.762	10	0.9995	1.034E-06
372,669	0.7783	.673	408	17.85	101.187	8	0.9996	1.170E-06
377,631	0.7840	.678	398	17.85	104.806	8	0.9996	1.209E-06
Beyond final crack length .7849709								

Test Status for Specimen ID# TA521

	Target Load		Command Signal		Actual Load		Clip Gage	
	#	%	#	%	#	%	mil	%
Max	397	19.8	100	5.0	106	5.3	3.19	16.1
Min	99	5.0	100	5.0	106	5.3	3.21	16.1

Slope #	Slope #	Corr	Kmax	Delta K	da/dN
8	8	0.9994	23.8	17.9	1.209E-06

Function Key Status
F5 F6 F7 F8

Function Generator Status	EvB/P	Count	a
Frequency (Hz) 31.000	105.411	378,452	0.7850
start run STOP	Beyond final crack length		0.785

WHC-SD-FF-TRP-019
Rev. 0

S/N TA521

MATERIAL : 316 STAINLESS STEEL

TEST TEMPERATURE : 900°F

FRACTURE FACE CRACK MEASUREMENTS

	<u>PRECRACK</u>	<u>POST-TEST</u>
SIDE 1	0.779	0.794
1/8 POINT	0.782	0.796
1/4 POINT	0.795	0.814
3/8 POINT	0.800	0.817
1/2 POINT	0.802	0.819
5/8 POINT	0.800	0.826
3/4 POINT	0.796	0.815
7/8 POINT	0.782	0.815
SIDE 2	0.776	0.796
AVERAGE	0.792	0.812

Precracking Data Summary

Job Number 62077
 Customer
 Operator L R Bramlage
 Date 02-16-1995
 Material SS
 Specimen Type CT

 Specimen ID TA522
 Machine 60056
 Extensometer 27209
 Clip Gage Cal (in/volt) 0.0020
 Load Cell Cal (lb/volt) 200.0
 Environment AIR
 Temperature RT

K Calibration Type P
 KCT CT00
 0 0.88600 1.00002
 1 4.64000 -4.06320
 2 -13.32000 11.24200
 3 14.72000 -106.04000
 4 -5.60000 464.32999
 5 0.00000 -650.67999

Specimen Characteristics

Specimen Thickness (in) B 0.299
 Net Spec. Thickness (in) Bn x299.000
 Notch Depth (in) h 0.502
 Specimen Width (in) W 1.155
 Young's Modulus (10E6) E 28.300

Test Parameters

Max Load for E adj. (lb) 750.0
 Stress Ratio (R) 0.25
 Initial a (in) 0.502
 Final a (in) 0.780
 Initial Kmax (ksi sqr[in]) 24.00
 Final Kmax (ksi sqr[in]) 24.00
 Initial Maximum Load (lb) 30520.8
 Final Maximum Load (lb) 12838.3
 K-Gradient (1/in) 0.000

 Minimum Slope Level (X) 50.0
 Number of Slopes 36.
 Minimum Corr Coeff 0.990
 Data on load or unload LOAD AND UNLOAD
 Final a/W 0.6790
 a/W Increment for Printout 0.0050
 Waveform Type SINEWAVE
 Frequency (Hz) 29.000

Job Number 62077
Specimen ID TAS22

PAGE B-II OF B-64

N Number of cycles
a(in) Crack length measured from load line
a/W Ratio of crack length to specimen width
P(lb) Maximum force
dK(ksi sqrt[in]) Cyclic stress intensity
EvB/P Normalized compliance
Snum Number of slopes for crack length determination
Corr Correlation coefficient
da/dN(in/cyc) Crack growth rate

N	a	a/W	P	dK	EvB/P	Snum	Corr	da/dN
51,455	0.5024	.435	750	14.00	26.989	45	0.9998	1.880E-05
69,516	0.5083	.440	812	15.38	27.650	57	0.9999	1.698E-07
81,899	0.5142	.445	840	16.13	28.325	71	0.9999	3.950E-07
91,844	0.5200	.450	866	16.88	29.019	71	0.9999	5.362E-07
101,698	0.5261	.455	854	16.88	29.754	71	0.9999	6.096E-07
110,833	0.5324	.461	863	17.33	30.555	71	0.9999	6.460E-07
115,769	0.5371	.465	853	17.33	31.160	57	0.9999	8.057E-07
122,383	0.5429	.470	840	17.33	31.926	57	0.9999	8.991E-07
129,007	0.5489	.475	828	17.33	32.742	57	0.9999	8.922E-07
135,339	0.5545	.480	834	17.70	33.519	45	0.9999	8.712E-07
141,519	0.5602	.485	822	17.70	34.355	45	0.9999	9.152E-07
148,032	0.5663	.490	809	17.70	35.261	45	0.9999	9.315E-07
154,515	0.5722	.495	796	17.70	36.161	45	0.9999	9.289E-07
161,017	0.5780	.500	784	17.70	37.076	45	0.9999	8.901E-07
167,507	0.5834	.505	773	17.70	37.962	45	0.9999	8.581E-07
174,587	0.5893	.510	760	17.70	38.958	45	0.9999	8.307E-07
181,073	0.5948	.515	749	17.70	39.911	45	0.9999	8.370E-07
187,607	0.6007	.520	737	17.70	40.967	45	0.9999	8.881E-07
194,123	0.6067	.525	725	17.70	42.078	45	0.9999	9.266E-07
200,660	0.6124	.530	713	17.70	43.158	45	0.9999	8.742E-07
206,770	0.6183	.535	707	17.85	44.333	36	0.9999	9.360E-07
212,915	0.6240	.540	696	17.85	45.498	36	0.9999	9.378E-07
219,074	0.6298	.545	684	17.85	46.719	36	0.9999	9.313E-07
225,259	0.6353	.550	673	17.85	47.920	36	0.9999	9.022E-07
231,873	0.6412	.555	661	17.85	49.249	36	0.9998	8.907E-07
238,053	0.6470	.560	650	17.85	50.621	36	0.9999	9.111E-07
244,353	0.6529	.565	638	17.85	52.048	36	0.9999	9.477E-07
250,543	0.6587	.570	626	17.85	53.510	36	0.9999	9.328E-07
256,746	0.6646	.575	615	17.85	55.051	36	0.9999	9.284E-07
262,486	0.6700	.580	604	17.85	56.519	36	0.9998	9.574E-07
268,948	0.6759	.585	593	17.85	58.193	36	0.9999	9.358E-07
275,132	0.6817	.590	582	17.85	59.873	36	0.9999	9.220E-07
280,879	0.6873	.595	571	17.85	61.590	36	0.9999	9.779E-07
287,514	0.6935	.600	559	17.85	63.544	36	0.9999	9.363E-07
293,628	0.6991	.605	549	17.85	65.382	36	0.9998	9.097E-07

313,365	0.7164	.620	516	17.85	71.563	45	0.9999	9.272E-07
319,974	0.7223	.625	505	17.85	73.877	45	0.9999	8.788E-07
325,980	0.7281	.630	495	17.85	76.188	45	0.9999	9.619E-07
331,924	0.7337	.635	484	17.85	78.553	45	0.9999	9.434E-07
337,879	0.7394	.640	474	17.85	81.073	45	0.9999	9.355E-07
344,117	0.7453	.645	463	17.85	83.820	45	0.9999	9.720E-07
350,096	0.7512	.650	453	17.85	86.641	45	0.9999	9.579E-07
355,495	0.7566	.655	443	17.85	89.371	45	0.9998	9.896E-07
361,444	0.7626	.660	433	17.85	92.524	45	0.9998	1.010E-06
366,867	0.7682	.665	423	17.85	95.645	45	0.9998	1.011E-06
372,309	0.7740	.670	413	17.85	99.041	45	0.9998	1.060E-06
377,732	0.7800	.675	403	17.85	102.703	36	0.9998	1.100E-06

Beyond final crack length .7843685

Test Status for Specimen ID# TA522

	Target Load		Command Signal		Actual Load		Clip Gage	
	#	%	#	%	#	%	mil	%
Max	395	19.8	100	5.0	123	6.2	1.98	9.9
Min	99	4.9	100	5.0	123	6.2	1.98	9.9

a/W	a	Last a	Next a	Count	Time	Date
.6791	0.7844	0.7796	0.7854	381,693	13:30:16	02-16-1995

Slope #	Slope #	Corr	Kmax	Delta K	da/dN
36	37	0.9998	23.8	17.9	1.100E-06

Function Key Status
F5 F6 F7 F8

Function Generator Status	EvB/P	Count	a
Frequency (Hz) 31.000	105.461	381,662	0.7844

start run STOP Beyond final crack length 0.784

WHC-SD-FF-TRP-019
Rev. 0

PAGE B-11 OF B-64

S/N TA522

MATERIAL : 316 STAINLESS STEEL

TEST TEMPERATURE : 900°F

FRACTURE FACE CRACK MEASUREMENTS

	<u>PRECRACK</u>	<u>POST-TEST</u>
SIDE 1	0.779	0.808
1/8 POINT	0.784	0.809
1/4 POINT	0.798	0.826
3/8 POINT	0.802	0.838
1/2 POINT	0.804	0.851
5/8 POINT	0.803	0.857
3/4 POINT	0.797	0.845
7/8 POINT	0.782	0.809
SIDE 2	0.777	0.804
AVERAGE	0.794	0.830

Precracking Data Summary

Job Number 62077
 Customer
 Operator L R Bramlage
 Date 02-15-1995
 Material SS
 Specimen Type CT

 Specimen ID TA523
 Machine 60056
 Extensometer 27209
 Clip Gage Cal (in/volt) 0.0040
 Load Cell Cal (lb/volt) 200.0
 Environment AIR
 Temperature RT

K Calibration Type		P
	KCT	CT00
0	0.88600	1.00002
1	4.64000	-4.06320
2	-13.32000	11.24200
3	14.72000	-106.04000
4	-5.60000	464.32999
5	0.00000	-650.67999

Specimen Characteristics

Specimen Thickness (in) B 0.300
 Net Spec. Thickness (in) Bn 0.300
 Notch Depth (in) h 0.500
 Specimen Width (in) W 1.155
 Young's Modulus (10E6) E 30.000

Test Parameters

Max Load for E adj. (lb) 300.0
 Stress Ratio (R) 0.25
 Initial a (in) 0.500
 Final a (in) 0.770
 Initial Kmax (ksi sqrt[in]) 11.60
 Final Kmax (ksi sqrt[in]) 11.60
 Initial Maximum Load (lb) 470.3
 Final Maximum Load (lb) 205.3
 K-Gradient (1/in) 0.000

 Minimum Slope Level (X) 50.0
 Number of Slopes 29.
 Minimum Corr Coeff 0.990
 Data on load or unload LOAD AND UNLOAD
 Final a/W 0.6670
 a/W Increment for Printout 0.0050
 Waveform Type SINEWAVE
 Frequency (Hz) 49.000

Test Status for Specimen ID# TA523

Max	#	%	#	%	"	"	"	"
	300	15.0	0	0.0	24	1.2	-0.04	-0.1
Min	75	3.8	0	0.0	24	1.2	-0.04	-0.1

a/W	a	Last a	Next a	Count	Time	Date
.0000	0.0000	0.0000	0.0000	0	11:43:13	02-15-1995

Slope #	Slope #	Corr	Kmax	Delta K	da/dN
29	0	0.0000	0.0	0.0	0.000E+00

Function Key Status
 F5 F6 F7 F8

Function Generator Status
 Frequency (Hz) 49.000

EvB/P	Count	a
0.000	0	0.0000

start run STOP

WHC-SD-FF-TRP-019
 Rev. 0

PAGE B-15 OF B-64

Test Status for Specimen ID# TA523

	Target Load		Command Signal		Actual Load		Clip Gage	
	#	%	#	%	#	%	mil	%
Max	750	37.5	733	36.6	750	37.5	2.73	13.6
Min	188	9.4	65	3.3	188	9.4	0.77	3.9

a/W	a	Last a	Next a	Count	Time	Date
.4555	0.5261	0.5232	0.5290	157,367	13:20:15	02-15-1995

Slope #	Slope #	Corr	Kmax	Delta K	da/dN
45	32	0.9999	19.7	14.8	1.854E-07

Function Key Status
F5 F6 F7 F8

Function Generator Status	EvB/P	Count	a
Frequency (Hz) 29.000	29.755	157,017	0.5261

start RUN stop

168,416 0.5291 .458 756 15.00 30.130 57 0.9998 2.450E-07

Test Status for Specimen ID# TA523

	Target Load		Command Signal		Actual Load		Clip Gage	
	#	%	#	%	#	%	mil	%
Max	750	37.5	735	36.8	751	37.6	2.81	14.1
Min	188	9.4	64	3.2	188	9.4	0.80	4.0

a/W	a	Last a	Next a	Count	Time	Date
.4607	0.5321	0.5290	0.5348	181,459	13:34:06	02-15-1995

Slope #	Slope #	Corr	Kmax	Delta K	da/dN
57	52	0.9999	20.0	15.0	2.450E-07

Function Key Status
F5 F6 F7 F8

Function Generator Status	EvB/P	Count	a
Frequency (Hz) 29.000	30.511	179,557	0.5321

start RUN stop

Test Status for Specimen ID# TA523

Target	Command	Actual	Clip Gage
--------	---------	--------	-----------

Min 197 9.8 69 3.4 196 9.8 0.85 4.3

a/W .4614 a 0.5329 Last a 0.5290 Next a 0.5348 Count 182,720 Time 13:34:50 Date 02-15-1995

Slope # 57 Slope # 45 Corr 0.9999 Kmax 21.0 Delta K 15.8 da/dN 2.450E-07 WHC-SD-FF-TRP-019 Rev. 0

Function Key Status
F5 F6 F7 F8

PAGE B-17 OF B-64

Function Generator Status EvB/P Count a
Frequency (Hz) 29.000 30.614 182,210 0.5329

start RUN stop

187,236	0.5348	.463	782	15.75	30.862	71	0.9999	2.798E-07
201,382	0.5407	.468	808	16.50	31.626	89	0.9999	3.483E-07
210,911	0.5465	.473	832	17.25	32.412	71	0.9999	5.188E-07

Input Parameters - Page 2 for Specimen ID# TA523

K Coeff	C Coeff	Specimen Thickness (in)	B	0.300
KCT	CT00	Net Spec. Thickness (in)	Bn	0.300
0 0.88600	1.00002	Notch Depth (in)	h	0.500
1 4.64000	-4.06320	Specimen Width (in)	W	1.155
2 -13.32000	11.24200	Required Final a/W		0.6670
3 14.72000	-106.04000	Young's Modulus (10E6)		28.300
4 -5.60000	464.32999			
5 0.00000	-650.67999			

Stress Parameters

Maximum Load (lbs)	750.0	Clip Gage Cal (in/volt)	0.0020
Stress Ratio (R)	0.25	Load Cell Cal (lb/volt)	200.0
Constant Load or K-Ctrl.	K-CONTROL	Initial a (in)	0.500
		Final a (in)	0.770
		Initial Kmax (ksi sqr[in])	23.00
		Final Kmax (ksi sqr[in])	23.00
		K-Gradient (1/in)	0.000

Data Acquisition Parameters

Minimum Slope Level (%)	50.0	Initial Maximum Load (lb)	932.5
Number of Slopes	71.	Final Maximum Load (lb)	407.1
Minimum Corr Coeff	0.990	Initial a/W	0.4780
Data on load or unload	LOAD AND UNLOAD	a/W Increment	0.0050

218,673	0.5521	.478	856	18.00	33.190	57	0.9999	6.907E-07
223,667	0.5580	.483	843	18.00	34.034	45	0.9999	9.022E-07
229,175	0.5642	.488	830	18.00	34.935	45	0.9999	1.126E-06
234,184	0.5700	.493	817	18.00	35.815	45	0.9999	1.118E-06
238,693	0.5753	.498	806	18.00	36.648	36	0.9999	1.173E-06
243,944	0.5811	.503	793	18.00	37.578	36	0.9999	1.127E-06
250,004	0.5869	.508	781	18.00	38.542	36	0.9999	1.038E-06
255,659	0.5925	.513	769	18.00	39.511	36	0.9999	9.802E-07
261,316	0.5983	.518	757	18.00	40.530	36	0.9999	1.006E-06
267,377	0.6044	.523	744	18.00	41.637	36	0.9999	1.008E-06
273,031	0.6101	.528	733	18.00	42.715	36	0.9999	1.003E-06
278,687	0.6159	.533	720	18.00	43.855	36	0.9999	1.012E-06
284,344	0.6215	.538	709	18.00	44.977	36	0.9999	1.010E-06
289,999	0.6272	.543	697	18.00	46.164	36	0.9998	1.009E-06
296,059	0.6330	.548	685	18.00	47.421	36	0.9999	1.006E-06

314,240	0.6506	.563	650	18.00	51.501	45	0.9999	9.445E-07
320,250	0.6563	.568	639	18.00	52.909	45	0.9999	9.453E-07
326,258	0.6623	.573	627	18.00	54.442	45	0.9998	9.841E-07
331,770	0.6677	.578	616	18.00	55.892	45	0.9998	9.812E-07
337,778	0.6735	.583	605	18.00	57.492	45	0.9999	9.702E-07
343,786	0.6794	.588	593	18.00	59.203	45	0.9999	9.745E-07
348,793	0.6850	.593	582	18.00	60.872	45	0.9999	1.055E-06
353,801	0.6907	.598	571	18.00	62.667	45	0.9999	1.124E-06
359,309	0.6967	.603	560	18.00	64.583	45	0.9998	1.107E-06
364,817	0.7027	.608	548	18.00	66.609	45	0.9999	1.099E-06
370,088	0.7081	.613	538	18.00	68.498	45	0.9999	1.038E-06
376,096	0.7142	.618	526	18.00	70.732	45	0.9999	1.023E-06
381,604	0.7198	.623	516	18.00	72.892	45	0.9999	1.017E-06
387,113	0.7254	.628	506	18.00	75.084	45	0.9999	1.028E-06
392,623	0.7313	.633	495	18.00	77.541	45	0.9999	1.028E-06

Test Status for Specimen ID# TA523

	Target Load		Command Signal		Actual Load		Clip Gage	
	#	%	#	%	#	%	mil	%
Max	493	24.7	40	2.0	69	3.5	1.35	6.7
Min	123	6.2	40	2.0	69	3.5	1.35	6.7

a/W	a	Last a	Next a	Count	Time	Date
.6337	0.7319	0.7311	0.7369	393,240	15:36:07	02-15-1995

Slope #	Slope #	Corr	Kmax	Delta K	da/dN	
45	10	0.9999	24.0	18.0	1.028E-06	WHC-SD-FF-TRP-019 Rev. 0

Function Key Status
F5 F6 F7 F8

PAGE B-18 OF B-64

Function Generator Status	EvB/P	Count	a
Frequency (Hz) 29.000	77.796	393,126	0.7319

start run STOP

397,692	0.7370	.638	484	18.00	80.022	45	0.9999	1.113E-06
403,200	0.7427	.643	474	18.00	82.610	45	0.9999	1.084E-06

Test Status for Specimen ID# TA523

	Target Load		Command Signal		Actual Load		Clip Gage	
	#	%	#	%	#	%	mil	%
Max	467	23.4	522	26.1	467	23.4	5.23	26.1
Min	117	5.8	-73	-3.7	117	5.9	1.77	8.8

a/W	a	Last a	Next a	Count	Time	Date
.6461	0.7463	0.7427	0.7484	406,861	09:20:57	02-16-1995

Slope #	Slope #	Corr	Kmax	Delta K	da/dN
45	37	0.9999	24.0	18.0	1.084E-06

Function Key Status
F5 F6 F7 F8

Function Generator Status	EvB/P	Count	a
Frequency (Hz) 29.000	84.279	406,456	0.7463

408,516	0.7485	.648	463	18.00	85.312	36	0.9998	1.080E-06
413,797	0.7545	.653	452	18.00	88.310	36	0.9998	1.091E-06
419,227	0.7604	.658	442	18.00	91.394	36	0.9998	1.130E-06
423,783	0.7660	.663	432	18.00	94.399	36	0.9998	1.149E-06
428,774	0.7717	.668	422	18.00	97.675	36	0.9998	1.172E-06
434,303	0.7775	.673	412	18.00	101.128	36	0.9999	1.095E-06
439,555	0.7835	.678	401	18.00	104.902	36	0.9998	1.076E-06

Beyond final crack length .7845098

Test Status for Specimen ID# TA523

	Target Load		Command Signal		Actual Load		Clip Gage	
	#	%	#	%	#	%	mil	%
Max	400	20.0	40	2.0	70	3.5	1.75	8.7
Min	100	5.0	40	2.0	70	3.5	1.76	8.8

a/W .6792 a 0.7845 Last a 0.7831 Next a 0.7889 Count 440,390 Time 09:40:23 Date 02-16-1995

Slope # 36 Slope # 37 Corr 0.9997 Kmax 24.0 Delta K 18.0 da/dN 1.076E-06 WHC-SD-FF-TRP-019 Rev. 0

Function Key Status
F5 F6 F7 F8

PAGE B-19 OF 8-64

Function Generator Status EvB/P Count a
Frequency (Hz) 29.000 105.553 440,366 0.7845

start run STOP Beyond final crack length 0.785

Input Parameters - Page 2 for Specimen ID# TA523

	K Coeff	C Coeff		
0	0.88600	1.00002	Specimen Thickness (in)	B 0.300
1	4.64000	-4.06320	Net Spec. Thickness (in)	Bn 0.300
2	-13.32000	11.24200	Notch Depth (in)	h 0.500
3	14.72000	-106.04000	Specimen Width (in)	W 1.155
4	-5.60000	464.32999	Required Final a/W	0.6790
5	0.00000	-650.67999	Young's Modulus (10E6)	28.300

Stress Parameters

Maximum Load (lbs)	750.0	Clip Gage Cal (in/volt)	0.0020
Stress Ratio (R)	0.25	Load Cell Cal (lb/volt)	200.0
Constant Load or K-Ctrl.	K-CONTROL	Initial a (in)	0.500
		Final a (in)	0.784
		Initial Kmax (ksi sqr[in])	24.00
		Final Kmax (ksi sqr[in])	24.00
		K-Gradient (1/in)	0.000

Data Acquisition Parameters

Minimum Slope Level (%)	50.0	Initial Maximum Load (lb)	973.0
Number of Slopes	36	Final Maximum Load (lb)	400.4
Minimum Corr Coeff	0.990	Initial a/W	0.6830
Data on load or unload	LOAD AND UNLOAD	a/W Increment	0.0050

S/N TA523

MATERIAL : 316 STAINLESS STEEL

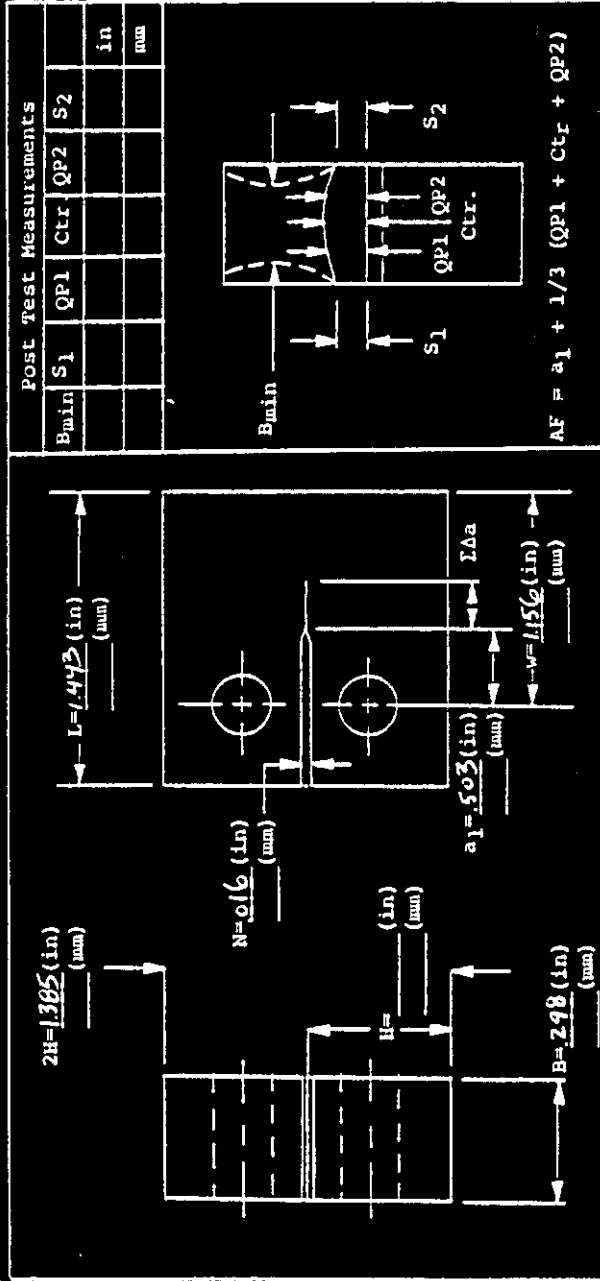
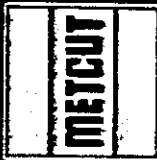
TEST TEMPERATURE : 900°F

FRACTURE FACE CRACK MEASUREMENTS

	<u>PRECRACK</u>	<u>POST-TEST</u>
SIDE 1	0.772	0.784
1/8 POINT	0.773	0.789
1/4 POINT	0.786	0.797
3/8 POINT	0.795	0.811
1/2 POINT	0.798	0.816
5/8 POINT	0.799	0.813
3/4 POINT	0.797	0.808
7/8 POINT	0.785	0.800
SIDE 2	0.777	0.789
AVERAGE	0.788	0.803

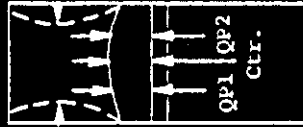
FRACTURE TOUGHNESS PER ASTM E399

PROJECT DATA		TEST DATA		PRECRACK DATA	
Project No.	1665-62077-06-21-01	Material	316 SS	Test No.	S
Specimen No.	TAS24	Modulus ($\times 10^6$ psi)		Pre-crack Ratio	R = 0.25
Operator	LRB	0.2% Yield Strength		Frequency (Hz)	31
Checker	K. J. [Signature]	Crack Plane Orientation		LCF Test No.	23095
Temp.	RT	Relative Humidity (%)	44	Temp. Indicator No.	
Machine	60076	LCF Test No.	24304	Recorder No.	
Date	2-16-95	X-Y	90023	Slide Cath. No.	
		Clip Gage	27209	Oscilloscope No.	



Post Test Measurements

B _{min}	S ₁	QP1	Ctr	QP2	S ₂



$$AF = a_1 + 1/3 (QP1 + Ctr + QP2)$$

K	P	Load/Volts			Cycles ($\times 10^3$)	ΔN	N _f	Δa	a	a/W	f(ΔW)	Side Δa		Set Point	
		Max	Mean	Min								S-1	S-2		

Precracking Data Summary

Job Number 62077
Customer
Operator L R Bramlage
Date 02-16-1995
Material SS
Specimen Type CT

Specimen ID TA524
Machine 60056
Extensometer 27209
Clip Gage Cal (in/volt) 0.0020
Load Cell Cal (lb/volt) 200.0
Environment AIR
Temperature RT

K Calibration Type P
KCT CT00
0 0.88600 1.00002
1 4.64000 -4.06320
2 -13.32000 11.24200
3 14.72000 -106.04000
4 -5.60000 464.32999
5 0.00000 -650.67999

Specimen Characteristics

Specimen Thickness (in) B 0.298
Net Spec. Thickness (in) Bn 0.298
Notch Depth (in) h 0.503
Specimen Width (in) W 1.156
Young's Modulus (10E6) E 28.300

Test Parameters

Max Load for E adj. (lb) 350.0
Stress Ratio (R) 0.25
Initial a (in) 0.503
Final a (in) 0.785
Initial Kmax (ksi sqrt[in]) 20.50
Final Kmax (ksi sqrt[in]) 20.50
Initial Maximum Load (lb) 820.9
Final Maximum Load (lb) 339.4
K-Gradient (1/in) 0.000

Minimum Slope Level (X) 50.0
Number of Slopes 10.
Minimum Corr Coeff 0.990
Data on load or unload LOAD AND UNLOAD
Final a/W 0.6810
a/W Increment for Printout 0.0050
Waveform Type SINEWAVE
Frequency (Hz) 31.000

Job Number 62077
Specimen ID TA524

N Number of cycles
a(in) Crack length measured from load line
a/W Ratio of crack length to specimen width
P(lb) Maximum force
dK(ksi sqr[in]) Cyclic stress intensity
EvB/P Normalized compliance
Snum Number of slopes for crack length determination
Corr Correlation coefficient
da/dN(in/cyc) Crack growth rate

N	a	a/W	P	dK	EvB/P	Snum	Corr	da/dN
4,589	0.5029	.435	750	14.04	26.993	13	0.9998	2.005E-04
55,696	0.5088	.440	829	15.75	27.650	16	0.9999	8.164E-08
72,227	0.5144	.445	818	15.75	28.304	20	0.9999	1.953E-07
80,900	0.5203	.450	883	17.25	29.001	24	0.9999	4.699E-07
88,196	0.5261	.455	890	17.63	29.704	31	0.9999	7.472E-07
94,722	0.5319	.460	877	17.63	30.428	38	0.9999	8.461E-07
101,547	0.5377	.465	865	17.63	31.174	38	0.9999	8.709E-07
107,936	0.5435	.470	852	17.63	31.934	38	0.9999	8.766E-07
113,898	0.5492	.475	840	17.63	32.717	38	0.9999	9.431E-07
120,792	0.5553	.480	827	17.63	33.565	38	0.9999	9.232E-07
127,681	0.5611	.485	815	17.63	34.402	38	0.9999	8.390E-07
134,095	0.5668	.490	813	17.85	35.260	38	0.9999	8.570E-07
139,622	0.5724	.495	801	17.85	36.116	38	0.9999	9.774E-07
145,629	0.5783	.500	789	17.85	37.041	38	0.9999	9.913E-07
152,070	0.5842	.505	776	17.85	38.009	38	0.9999	9.524E-07
158,505	0.5898	.510	765	17.85	38.958	38	0.9999	8.911E-07
164,475	0.5957	.515	753	17.85	39.966	38	0.9999	9.377E-07
170,464	0.6011	.520	741	17.85	40.945	38	0.9999	9.225E-07
176,938	0.6073	.525	729	17.85	42.083	38	0.9999	9.370E-07
182,934	0.6129	.530	717	17.85	43.160	38	1.0000	9.430E-07
189,424	0.6188	.535	705	17.85	44.322	38	0.9999	9.278E-07
195,420	0.6244	.540	694	17.85	45.457	38	0.9999	9.116E-07
201,887	0.6303	.545	682	17.85	46.708	38	0.9999	9.266E-07
207,897	0.6360	.550	671	17.85	47.964	38	0.9998	9.399E-07
214,372	0.6417	.555	659	17.85	49.245	38	0.9999	9.143E-07
220,847	0.6478	.560	647	17.85	50.666	38	0.9999	8.874E-07
226,848	0.6535	.565	636	17.85	52.073	38	0.9999	9.596E-07
233,302	0.6593	.570	624	17.85	53.537	38	0.9999	9.382E-07
239,307	0.6650	.575	613	17.85	55.008	38	0.9999	9.125E-07
245,314	0.6706	.580	602	17.85	56.541	38	0.9999	9.595E-07
251,324	0.6763	.585	591	17.85	58.144	38	0.9999	9.280E-07
257,321	0.6821	.590	580	17.85	59.837	38	0.9999	9.444E-07
263,320	0.6879	.595	569	17.85	61.588	38	0.9999	9.930E-07
270,258	0.6939	.600	558	17.85	63.499	38	0.9998	9.029E-07
276,855	0.6997	.605	547	17.85	65.375	38	0.9999	8.655E-07
283,331	0.7056	.610	536	17.85	67.395	38	0.9999	8.844E-07

301,925	0.7228	.625	504	17.85	73.812	38	0.9998	9.438E-07
307,473	0.7284	.630	494	17.85	76.068	38	0.9998	9.923E-07
313,495	0.7342	.635	483	17.85	78.532	38	0.9998	1.011E-06
319,188	0.7399	.640	473	17.85	81.024	38	0.9998	9.657E-07
325,218	0.7459	.645	462	17.85	83.795	38	0.9998	1.013E-06
330,766	0.7515	.650	452	17.85	86.466	38	0.9998	9.842E-07
336,320	0.7572	.655	442	17.85	89.369	38	0.9999	1.021E-06
341,912	0.7630	.660	432	17.85	92.403	38	0.9998	1.029E-06
347,456	0.7689	.665	422	17.85	95.662	38	0.9998	1.045E-06
352,980	0.7746	.670	412	17.85	98.963	38	0.9998	1.049E-06
358,569	0.7804	.675	402	17.85	102.514	38	0.9998	1.035E-06
364,160	0.7863	.680	392	17.85	106.285	38	0.9998	1.067E-06

Beyond final crack length .7884377

Test Status for Specimen ID# TA524

	Target Load		Command Signal		Actual Load		Clip Gage	
	#	%	#	%	#	%	mil	x
Max	388	19.4	100	5.0	118	5.9	2.50	12.5
Min	97	4.9	100	5.0	118	5.9	2.50	12.5

a/W	a	Last a	Next a	Count	Time	Date
.6820	0.7884	0.7861	0.7919	366,216	16:59:45	02-16-1995

Slope #	Slope #	Corr	Kmax	Delta K	da/dN
38	39	0.9997	23.8	17.9	1.067E-06

Function Key Status
F5 F6 F7 F8

Function Generator Status	EvB/P	Count	a
Frequency (Hz) 31.000	107.694	366,201	0.7884

start run STOP Beyond final crack length 0.788

WHC-SD-FF-TRP-019
Rev. 0

PAGE B-24 OF B-64

S/N TA524

MATERIAL : 316 STAINLESS STEEL

TEST TEMPERATURE : 900°F

FRACTURE FACE CRACK MEASUREMENTS

	<u>PRECRACK</u>	<u>POST-TEST</u>
SIDE 1	0.783	0.805
1/8 POINT	0.785	0.805
1/4 POINT	0.799	0.827
3/8 POINT	0.805	0.831
1/2 POINT	0.805	0.841
5/8 POINT	0.805	0.836
3/4 POINT	0.798	0.827
7/8 POINT	0.787	0.813
SIDE 2	0.782	0.805
AVERAGE	0.796	0.823

Precracking Data Summary

Job Number 62077
Customer
Operator LR Bramlage
Date 02-16-1995
Material SS
Specimen Type C(T)

Specimen ID TA525
Machine 60076
Extensometer 27189
Clip Gage Cal (in/volt) 0.0020
Load Cell Cal (lb/volt) 200.0
Environment AIR
Temperature RT

K Calibration Type		P
	KCT	CT00
0	0.88600	1.00002
1	4.64000	-4.06320
2	-13.32000	11.24200
3	14.72000	-106.04000
4	-5.60000	464.32999
5	0.00000	-650.67999

Specimen Characteristics

Specimen Thickness (in)	B	0.300
Net Spec. Thickness (in)	Bn	0.300
Notch Depth (in)	h	0.500
Specimen Width (in)	W	1.155
Young's Modulus (10E6)	E	28.300

Test Parameters

Max Load for E adj. (lb)	350.0
Stress Ratio (R)	0.25
Initial a (in)	0.500
Final a (in)	0.785
Initial Kmax (ksi sqrt[in])	20.60
Final Kmax (ksi sqrt[in])	20.60
Initial Maximum Load (lb)	835.2
Final Maximum Load (lb)	342.2
K-Gradient (1/in)	0.000
Minimum Slope Level (%)	50.0
Number of Slopes	8.
Minimum Corr Coeff	0.990
Data on load or unload	LOAD AND UNLOAD
Final a/W	0.6790
a/W Increment for Printout	0.0050
Waveform Type	SINEWAVE
Frequency (Hz)	31.000

Job Number 62077
Specimen ID TA525

N Number of cycles
a(in) Crack length measured from load line
a/W Ratio of crack length to specimen width
P(lb) Maximum force
dK(ksi $\sqrt{\text{in}}$) Cyclic stress intensity
EvB/P Normalized compliance
Snum Number of slopes for crack length determination
Corr Correlation coefficient
da/dN(in/cyc) Crack growth rate

N	a	a/W	P	dK	EvB/P	Snum	Corr	da/dN
7,480	0.5002	.433	750	13.88	26.739	6	0.9996	9.437E-05
62,124	0.5060	.438	750	14.08	27.392	15	0.9996	1.677E-07
83,003	0.5117	.443	812	15.45	28.035	19	0.9997	1.752E-07
94,197	0.5181	.449	901	17.40	28.786	19	0.9997	3.907E-07
103,654	0.5236	.453	888	17.40	29.456	19	0.9998	6.135E-07
111,342	0.5291	.458	895	17.77	30.132	15	0.9998	6.477E-07
118,538	0.5353	.463	882	17.77	30.925	12	0.9998	8.053E-07
125,159	0.5407	.468	870	17.77	31.625	12	0.9998	7.805E-07
132,484	0.5464	.473	858	17.77	32.403	12	0.9997	8.238E-07
139,900	0.5528	.479	844	17.77	33.279	12	0.9998	8.219E-07
146,510	0.5585	.484	832	17.77	34.098	12	0.9998	8.343E-07
153,719	0.5639	.488	820	17.77	34.898	12	0.9997	8.111E-07
160,340	0.5695	.493	808	17.77	35.741	12	0.9998	7.974E-07
168,172	0.5760	.499	794	17.77	36.765	12	0.9998	8.320E-07
174,201	0.5813	.503	783	17.77	37.611	12	0.9998	8.509E-07
181,428	0.5869	.508	771	17.77	38.548	12	0.9997	8.376E-07
188,049	0.5929	.513	759	17.77	39.566	12	0.9997	8.582E-07
194,078	0.5987	.518	747	17.77	40.603	12	0.9997	9.337E-07
200,707	0.6046	.523	735	17.77	41.673	12	0.9997	9.081E-07
206,715	0.6100	.528	723	17.77	42.708	12	0.9998	8.892E-07
213,337	0.6158	.533	712	17.77	43.824	12	0.9997	8.973E-07
220,553	0.6218	.538	699	17.77	45.046	12	0.9997	8.589E-07
226,570	0.6272	.543	689	17.77	46.162	12	0.9996	8.610E-07
233,185	0.6330	.548	677	17.77	47.425	12	0.9997	8.913E-07
239,808	0.6392	.553	664	17.77	48.812	12	0.9997	9.139E-07
245,839	0.6449	.558	653	17.77	50.132	12	0.9997	9.277E-07
251,870	0.6507	.563	642	17.77	51.505	12	0.9997	9.415E-07
258,504	0.6567	.569	630	17.77	53.012	12	0.9998	9.113E-07
265,136	0.6623	.573	619	17.77	54.464	12	0.9997	8.804E-07
271,158	0.6679	.578	608	17.77	55.942	12	0.9997	9.079E-07
277,796	0.6736	.583	597	17.77	57.539	12	0.9997	8.856E-07
284,427	0.6794	.588	586	17.77	59.214	12	0.9997	8.582E-07
291,063	0.6853	.593	574	17.77	60.973	12	0.9997	8.874E-07
297,097	0.6909	.598	564	17.77	62.725	12	0.9997	9.441E-07
302,527	0.6965	.603	553	17.77	64.522	10	0.9996	9.524E-07

321,209	0.7139	.618	520	17.77	70.644	10	0.9996	9.508E-07
327,280	0.7199	.623	509	17.77	72.932	10	0.9996	9.750E-07
332,831	0.7254	.628	499	17.77	75.102	10	0.9995	9.914E-07
339,390	0.7316	.633	488	17.77	77.663	10	0.9996	9.211E-07
344,948	0.7370	.638	478	17.77	80.019	10	0.9996	9.924E-07
350,507	0.7430	.643	467	17.77	82.754	10	0.9996	1.034E-06
356,067	0.7485	.648	457	17.77	85.334	10	0.9996	9.942E-07
362,646	0.7547	.653	446	17.77	88.410	10	0.9997	9.873E-07
367,711	0.7601	.658	437	17.77	91.185	10	0.9996	1.014E-06
373,287	0.7660	.663	427	17.77	94.388	10	0.9994	1.032E-06
378,864	0.7719	.668	416	17.77	97.791	10	0.9996	1.064E-06
384,432	0.7778	.673	406	17.77	101.329	10	0.9995	1.063E-06
389,494	0.7833	.678	397	17.77	104.748	10	0.9995	1.087E-06

Beyond final crack length .7845087

Test Status for Specimen ID# TA525

	Target Load		Command Signal		Actual Load		Clip Gage	
	#	%	#	%	#	%	mil	%
1ax	395	19.7	120	6.0	139	7.0	2.53	12.7
1in	99	4.9	120	6.0	141	7.0	2.53	12.7

a/W	a	Last a	Next a	Count	Time	Date
.6792	0.7845	0.7831	0.7889	390,544	07:18:07	02-16-1995

Slope #	Slope #	Corr	Kmax	Delta K	da/dN
10	10	0.9995	23.7	17.8	1.087E-06

Function Key Status
F5 F6 F7 F8

Function Generator Status	EvB/P	Count	a
Frequency (Hz) 31.000	105.552	390,514	0.7845

start run STOP Beyond final crack length 0.785

WHC-SD-FF-TRP-019
Rev. 0

PAGE B-29 OF B-64

S/N TA525

MATERIAL : 316 STAINLESS STEEL
TEST TEMPERATURE : 900°F

FRACTURE FACE CRACK MEASUREMENTS

	<u>PRECRACK</u>	<u>POST-TEST</u>
SIDE 1	0.775	0.825
1/8 POINT	0.778	0.826
1/4 POINT	0.794	0.840
3/8 POINT	0.799	0.868
1/2 POINT	0.802	0.868
5/8 POINT	0.800	0.877
3/4 POINT	0.795	0.859
7/8 POINT	0.781	0.831
SIDE 2	0.780	0.831
AVERAGE	0.791	0.850

Precracking Data Summary

Job Number	62077
Customer	
Operator	LR Bramlage
Date	02-17-1995
Material	SS
Specimen Type	C(T)
Specimen ID	TA526
Machine	60076
Extensometer	27189
Clip Gage Cal (in/volt)	0.0020
Load Cell Cal (lb/volt)	200.0
Environment	AIR
Temperature	RT

K Calibration Type	P	
	KCT	
	CT00	
0	0.88600	1.00002
1	4.64000	-4.06320
2	-13.32000	11.24200
3	14.72000	-106.04000
4	-5.60000	464.32999
5	0.00000	-650.67999

Specimen Characteristics

Specimen Thickness (in)	B	0.298
Net Spec. Thickness (in)	Bn	0.298
Notch Depth (in)	h	0.503
Specimen Width (in)	W	1.156
Young's Modulus (10E6)	E	28.300

Test Parameters

Max Load for E adj. (lb)	350.0
Stress Ratio (R)	0.25
Initial a (in)	0.503
Final a (in)	0.787
Initial Kmax (ksi sqrt[in])	20.60
Final Kmax (ksi sqrt[in])	20.60
Initial Maximum Load (lb)	824.9
Final Maximum Load (lb)	338.2
K-Gradient (1/in)	0.000
Minimum Slope Level (%)	50.0
Number of Slopes	15.
Minimum Corr Coeff	0.990
Data on load or unload	LOAD AND UNLOAD
Final a/W	0.6810
a/W Increment for Printout	0.0050
Waveform Type	SINEWAVE
Frequency (Hz)	31.000

Job Number 62077
 Specimen ID TA526

N Number of cycles
 a(in) Crack length measured from load line
 a/W Ratio of crack length to specimen width
 P(lb) Maximum force
 dK(ksi sqrt(in)) Cyclic stress intensity
 EvB/P Normalized compliance
 Snum Number of slopes for crack length determination
 Corr Correlation coefficient
 da/dN(in/cyc) Crack growth rate

N	a	a/W	P	dK	EvB/P	Snum	Corr	da/dN
30,364	0.5030	.435	750	14.05	27.001	11	0.9997	2.960E-05
68,156	0.5088	.440	750	14.24	27.652	14	0.9997	1.193E-07
92,701	0.5147	.445	802	15.45	28.330	18	0.9997	1.865E-07
102,626	0.5207	.450	883	17.25	29.048	18	0.9998	3.777E-07
109,801	0.5260	.455	871	17.25	29.695	14	0.9996	7.120E-07
117,301	0.5322	.460	858	17.25	30.464	14	0.9997	7.285E-07
125,537	0.5383	.466	845	17.25	31.254	14	0.9998	7.898E-07
132,128	0.5439	.470	851	17.63	31.990	11	0.9997	8.099E-07
138,738	0.5495	.475	839	17.63	32.758	11	0.9997	8.283E-07
144,745	0.5550	.480	828	17.63	33.535	11	0.9998	9.097E-07
151,960	0.5608	.485	815	17.63	34.367	11	0.9997	8.510E-07
159,777	0.5671	.491	802	17.63	35.305	11	0.9996	8.166E-07
166,993	0.5726	.495	791	17.63	36.139	11	0.9996	7.777E-07
174,225	0.5783	.500	779	17.63	37.042	11	0.9997	7.676E-07
180,533	0.5842	.505	776	17.85	38.013	9	0.9997	8.699E-07
185,981	0.5899	.510	765	17.85	38.971	9	0.9997	9.618E-07
192,788	0.5955	.515	753	17.85	39.934	9	0.9997	8.942E-07
199,595	0.6015	.520	741	17.85	41.015	9	0.9997	8.815E-07
205,940	0.6071	.525	729	17.85	42.056	9	0.9997	9.037E-07
212,464	0.6128	.530	717	17.85	43.146	9	0.9998	8.881E-07
218,826	0.6185	.535	706	17.85	44.256	9	0.9997	8.411E-07
225,628	0.6243	.540	694	17.85	45.454	9	0.9996	8.838E-07
231,978	0.6302	.545	682	17.85	46.688	9	0.9996	9.108E-07
238,804	0.6360	.550	671	17.85	47.953	9	0.9997	8.759E-07
245,158	0.6418	.555	659	17.85	49.265	9	0.9997	8.948E-07
251,058	0.6474	.560	648	17.85	50.580	9	0.9997	9.135E-07
257,420	0.6532	.565	636	17.85	51.999	9	0.9996	9.385E-07
263,334	0.6593	.570	625	17.85	53.522	9	0.9996	9.569E-07
269,692	0.6649	.575	614	17.85	54.998	9	0.9996	9.472E-07
276,496	0.6709	.580	602	17.85	56.608	9	0.9997	8.789E-07
283,310	0.6768	.585	591	17.85	58.272	9	0.9997	8.676E-07
289,680	0.6823	.590	580	17.85	59.876	9	0.9996	8.841E-07
296,496	0.6880	.595	569	17.85	61.635	9	0.9997	8.423E-07
303,316	0.6940	.600	558	17.85	63.517	9	0.9996	8.669E-07
309,694	0.6996	.605	547	17.85	65.344	9	0.9997	8.835E-07
315,604	0.7052	.610	537	17.85	67.288	9	0.9997	9.048E-07
322,435	0.7113	.615	525	17.85	69.451	9	0.9995	8.927E-07
328,803	0.7168	.620	515	17.85	71.494	9	0.9997	8.896E-07
334,712	0.7228	.625	504	17.85	73.825	9	0.9997	9.588E-07
340,182	0.7283	.630	494	17.85	76.035	9	0.9997	1.022E-06
346,096	0.7342	.635	483	17.85	78.527	9	0.9996	9.805E-07
351,560	0.7399	.640	473	17.85	81.003	9	0.9997	1.024E-06
357,929	0.7461	.645	462	17.85	83.896	9	0.9997	9.994E-07
363,394	0.7517	.650	452	17.85	86.583	9	0.9996	1.053E-06

375,251	0.7635	.650	421	17.85	95.894	9	0.9991	9.840E-07
381,164	0.7693	.665	421	17.85	95.894	9	0.9991	9.840E-07
386,632	0.7752	.671	411	17.85	99.307	9	0.9995	1.036E-06
391,650	0.7807	.675	401	17.85	102.691	9	0.9995	1.123E-06
397,114	0.7861	.680	392	17.85	106.179	9	0.9996	1.037E-06

beyond final crack length .7879345

Test Status for Specimen ID# TA526

	Target Load		Command Signal		Actual Load		Clip Gage	
	#	%	#	%	#	%	mil	%
max	389	19.5	100	5.0	128	6.4	2.47	12.4
min	97	4.9	100	5.0	128	6.4	2.47	12.4

a/W	a	Last a	Next a	Count	Time	Date
.6816	0.7879	0.7861	0.7919	398,528	11:08:11	02-17-1995

Slope #	Slope #	Corr	Kmax	Delta K	da/dN
9	9	0.9996	23.8	17.9	1.037E-06

Function Key Status
 F5 F6 F7 F8

Function Generator Status
 Frequency (Hz) 31.000

EvB/P	Count	a
107.358	398,488	0.7879

start run STOP Beyond final crack length 0.788

WHC-SD-FF-TRP-019
 Rev. 0

S/N TA526

MATERIAL : 316 STAINLESS STEEL

TEST TEMPERATURE : 900°F

FRACTURE FACE CRACK MEASUREMENTS

	<u>PRECRACK</u>	<u>POST-TEST</u>
SIDE 1	0.784	0.836
1/8 POINT	0.796	0.852
1/4 POINT	0.805	0.868
3/8 POINT	0.808	0.876
1/2 POINT	0.808	0.873
5/8 POINT	0.799	0.852
3/4 POINT	0.789	0.830
7/8 POINT	0.786	0.836
SIDE 2	0.785	0.822
AVERAGE	0.797	0.852

Precracking Data Summary

Job Number	62077
Customer	
Operator	L R Bramlage
Date	02-17-1995
Material	SS
Specimen Type	CT
Specimen ID	TA531
Machine	60056
Extensometer	27209
Clip Gage Cal (in/volt)	0.0020
Load Cell Cal (lb/volt)	200.0
Environment	AIR
Temperature	RT
K Calibration Type	P
	KCT CT00
0	0.88600 1.00002
1	4.64000 -4.06320
2	-13.32000 11.24200
3	14.72000 -106.04000
4	-5.60000 464.32999
5	0.00000 -650.67999

Specimen Characteristics

Specimen Thickness (in)	B	0.300
Net Spec. Thickness (in)	Bn	0.300
Notch Depth (in)	h	0.504
Specimen Width (in)	W	1.156
Young's Modulus (10E6)	E	28.300

Test Parameters

Max Load for E adj. (lb)	350.0
Stress Ratio (R)	0.25
Initial a (in)	0.504
Final a (in)	0.788
Initial Kmax (ksi sqrt[in])	20.60
Final Kmax (ksi sqrt[in])	20.60
Initial Maximum Load (lb)	828.5
Final Maximum Load (lb)	339.0
K-Gradient (1/in)	0.000
Minimum Slope Level (%)	50.0
Number of Slopes	9.
Minimum Corr Coeff	0.990
Data on load or unload	LOAD AND UNLOAD
Final a/W	0.6820
a/W Increment for Printout	0.0050
Waveform Type	SINEWAVE
Frequency (Hz)	31.000

Command-Feedback Error
Command-Feedback Error

Job Number 62077
Specimen ID TAS31

N Number of cycles
a(in) Crack length measured from load line
a/W Ratio of crack length to specimen width
P(lb) Maximum force
dK(ksi sqrt(in)) Cyclic stress intensity
EvB/P Normalized compliance
Snum Number of slopes for crack length determination
Corr Correlation coefficient
da/dN(in/cyc) Crack growth rate

N	a	a/W	P	dK	EvB/P	Snum	Corr	da/dN
50,216	0.5042	.436	750	13.99	27.136	11	0.9998	1.905E-05
62,621	0.5099	.441	750	14.19	27.778	14	0.9998	2.442E-07
70,662	0.5157	.446	750	14.39	28.453	18	0.9998	5.864E-07
77,059	0.5214	.451	750	14.59	29.129	22	0.9998	8.114E-07
Load has exceeded full scale 2070.084								
Load has exceeded full scale 2070.084 <i>did not run at this level</i>								
83,376	0.5273	.456	741	14.63	29.850	13	0.9998	8.842E-07
88,005	0.5330	.461	731	14.63	30.562	16	0.9998	1.100E-06
93,621	0.5392	.466	720	14.63	31.374	20	0.9998	1.167E-06
98,765	0.5448	.471	710	14.63	32.111	24	0.9998	1.155E-06
104,693	0.5503	.476	689	14.40	32.863	31	0.9998	9.721E-07
111,223	0.5564	.481	678	14.40	33.724	38	0.9972	9.045E-07
116,088	0.5624	.487	668	14.40	34.603	38	0.9998	1.142E-06
121,618	0.5679	.491	658	14.40	35.427	38	0.9997	1.082E-06
128,010	0.5736	.496	639	14.18	36.297	25	0.9997	9.034E-07
133,963	0.5792	.501	629	14.18	37.190	31	0.9998	8.922E-07
139,641	0.5850	.506	619	14.18	38.144	31	0.9998	1.024E-06
146,128	0.5909	.511	610	14.18	39.143	39	0.9998	9.674E-07
153,323	0.5974	.517	599	14.18	40.267	39	0.9998	8.010E-07
158,004	0.6023	.521	591	14.18	41.166	39	0.9998	1.084E-06
164,549	0.6082	.526	569	13.88	42.260	39	0.9998	9.904E-07
172,108	0.6140	.531	559	13.88	43.381	49	0.9997	7.947E-07
178,947	0.6198	.536	550	13.88	44.521	49	0.9997	8.145E-07
185,418	0.6255	.541	541	13.88	45.693	49	0.9997	8.438E-07
192,250	0.6315	.546	532	13.88	46.964	49	0.9997	9.008E-07
197,954	0.6371	.551	523	13.88	48.203	49	0.9998	9.359E-07
205,367	0.6430	.556	514	13.88	49.548	49	0.9997	8.577E-07
211,639	0.6487	.561	505	13.88	50.901	49	0.9997	8.350E-07
218,097	0.6549	.567	496	13.88	52.406	49	0.9997	9.542E-07
223,936	0.6606	.571	487	13.88	53.861	39	0.9996	9.840E-07
230,014	0.6662	.576	478	13.88	55.330	39	0.9997	9.404E-07
236,565	0.6718	.581	470	13.88	56.874	39	0.9998	8.726E-07
242,635	0.6775	.586	461	13.88	58.477	39	0.9997	8.872E-07
248,748	0.6836	.591	452	13.88	60.287	39	0.9998	9.816E-07
254,348	0.6893	.596	443	13.88	62.018	39	0.9997	1.014E-06
260,884	0.6951	.601	435	13.88	63.859	39	0.9997	9.298E-07
266,948	0.7009	.606	426	13.88	65.795	39	0.9997	9.205E-07
272,548	0.7064	.611	418	13.88	67.707	39	0.9997	9.847E-07
278,609	0.7125	.616	409	13.88	69.882	39	0.9997	9.755E-07
284,202	0.7182	.621	401	13.88	72.018	39	0.9997	1.033E-06
289,796	0.7238	.626	393	13.88	74.203	39	0.9996	1.003E-06
296,027	0.7295	.631	385	13.88	76.546	39	0.9997	9.699E-07
300,232	0.7355	.636	376	13.88	79.072	31	0.9996	1.066E-06
306,306	0.7413	.641	368	13.88	81.662	39	0.9996	1.090E-06

326,448	0.7644	.561	336	13.88	93.192	39	0.9995	1.178E-06
331,586	0.7700	.566	328	13.88	96.300	39	0.9995	1.149E-06
337,267	0.7761	.671	320	13.88	99.896	39	0.9996	1.122E-06
342,925	0.7817	.676	313	13.88	103.330	39	0.9995	9.847E-07
348,547	0.7874	.681	305	13.88	106.976	39	0.9994	9.678E-07

Beyond final crack length .7888314

Test Status for Specimen ID# TA531

	Target Load		Command Signal		Actual Load		Clip Gage	
	#	%	#	%	#	%	mil	%
Max	304	15.2	100	5.0	151	7.6	2.09	10.5
Min	76	3.8	100	5.0	151	7.6	2.09	10.5

a/W	a	Last a	Next a	Count	Time	Date
.6824	0.7888	0.7872	0.7930	350,017	13:06:11	02-17-1995

Slope #	Slope #	Corr	Kmax	Delta K	da/dN
39	40	0.9994	18.5	13.9	9.678E-07

Function Key Status
F5 F6 F7 F8

Function Generator Status
Frequency (Hz) 31.000

EvB/P	Count	a
107.957	350,017	0.7888

start run STOP

Beyond final crack length 0.789

Machine shut down

WHB-SD-FF-TRP-019
Rev. 0

PAGE B-39 OF B-64

S/N TA531

MATERIAL : 16-8-2 STAINLESS STEEL

TEST TEMPERATURE : 900°F

FRACTURE FACE CRACK MEASUREMENTS

	<u>PRECRACK</u>	<u>POST-TEST</u>
SIDE 1	0.800	0.805
1/8 POINT	0.815	0.819
1/4 POINT	0.818	0.826
3/8 POINT	0.814	0.823
1/2 POINT	0.810	0.819
5/8 POINT	0.803	0.812
3/4 POINT	0.790	0.794
7/8 POINT	0.774	0.778
SIDE 2	0.754	0.757
AVERAGE	0.800	0.807

Precracking Data Summary

Job Number 62077
 Customer
 Operator LR Bramlage
 Date 02-17-1995
 Material SS
 Specimen Type C(T)
 Specimen ID TA532
 Machine 60076
 Extensometer 27189
 Clip Gage Cal (in/volt) 0.0020
 Load Cell Cal (lb/volt) 200.0
 Environment AIR
 Temperature RT

K Calibration Type		P
	KCT	CT00
0	0.88600	1.00002
1	4.64000	-4.06320
2	-13.32000	11.24200
3	14.72000	-106.04000
4	-5.60000	464.32999
5	0.00000	-650.67999

Specimen Characteristics

Specimen Thickness (in)	B	0.300
Net Spec. Thickness (in)	Bn	0.300
Notch Depth (in)	h	0.502
Specimen Width (in)	W	1.155
Young's Modulus (10E6)	E	28.300

Test Parameters

Max Load for E adj. (lb)	750.0
Stress Ratio (R)	0.25
Initial a (in)	0.502
Final a (in)	0.786
Initial Kmax (ksi sqrt(in))	18.50
Final Kmax (ksi sqrt(in))	18.50
Initial Maximum Load (lb)	746.5
Final Maximum Load (lb)	306.0
K-Gradient (1/in)	0.000
Minimum Slope Level (%)	50.0
Number of Slopes	12.
Minimum Corr Coeff	0.990
Data on load or unload	LOAD AND UNLOAD
Final a/W	0.6810
a/W Increment for Printout	0.0050
Waveform Type	SINEWAVE
Frequency (Hz)	31.000

Job Number 62077
Specimen ID TA532

N Number of cycles
a(in) Crack length measured from load line
a/W Ratio of crack length to specimen width
P(lb) Maximum force
dK(ksi $\sqrt{\text{in}}$) Cyclic stress intensity
EvB/P Normalized compliance
Snum Number of slopes for crack length determination
Corr Correlation coefficient
da/dN(in/cyc) Crack growth rate

N	a	a/W	P	dK	EvB/P	Snum	Corr	da/dN
68,946	0.5025	.435	750	13.96	27.002	15	0.9995	1.339E-05
90,814	0.5086	.440	750	14.16	27.678	19	0.9995	1.907E-07
103,053	0.5142	.445	750	14.36	28.330	19	0.9996	3.491E-07
113,406	0.5202	.450	750	14.57	29.038	19	0.9995	5.348E-07
122,255	0.5258	.455	705	13.88	29.725	15	0.9995	6.370E-07
130,466	0.5314	.460	695	13.88	30.422	15	0.9995	6.106E-07
140,246	0.5371	.465	685	13.88	31.158	15	0.9995	6.316E-07
149,945	0.5434	.470	675	13.88	31.992	15	0.9996	6.065E-07
158,156	0.5489	.475	665	13.88	32.743	15	0.9995	6.827E-07
169,033	0.5546	.480	656	13.88	33.533	15	0.9996	6.045E-07
176,719	0.5605	.485	646	13.88	34.394	15	0.9994	6.092E-07
184,951	0.5660	.490	637	13.88	35.210	15	0.9996	6.867E-07
194,673	0.5723	.496	626	13.88	36.181	15	0.9995	6.404E-07
202,159	0.5778	.500	617	13.88	37.055	15	0.9995	7.198E-07
208,883	0.5833	.505	608	13.88	37.941	12	0.9996	7.939E-07
216,675	0.5896	.510	598	13.88	39.006	12	0.9995	7.935E-07
223,286	0.5948	.515	589	13.88	39.914	12	0.9996	7.761E-07
231,681	0.6008	.520	580	13.88	40.973	12	0.9996	7.357E-07
Below minimum correlation coeff .9799776								
239,204	0.6065	.525	570	13.88	42.028	12	0.9995	7.568E-07
247,003	0.6122	.530	561	13.88	43.123	12	0.9995	7.452E-07
256,012	0.6180	.535	552	13.88	44.266	12	0.9995	6.846E-07
263,792	0.6242	.540	542	13.88	45.543	12	0.9995	7.083E-07
270,386	0.6297	.545	534	13.88	46.693	12	0.9995	8.180E-07
278,184	0.6356	.550	524	13.88	47.999	12	0.9995	8.135E-07
285,393	0.6413	.555	515	13.88	49.278	12	0.9994	7.756E-07
293,219	0.6471	.560	506	13.88	50.635	12	0.9995	7.219E-07
300,466	0.6530	.565	497	13.88	52.070	12	0.9994	7.761E-07
308,314	0.6586	.570	489	13.88	53.499	12	0.9995	7.841E-07
315,560	0.6648	.576	479	13.88	55.123	12	0.9995	7.781E-07
322,190	0.6700	.580	471	13.88	56.529	12	0.9996	8.357E-07
328,831	0.6760	.585	462	13.88	58.220	12	0.9993	8.400E-07
336,089	0.6818	.590	454	13.88	59.923	12	0.9992	8.368E-07
342,765	0.6873	.595	445	13.88	61.590	12	0.9993	8.529E-07
351,230	0.6933	.600	436	13.88	63.491	12	0.9993	7.571E-07
357,873	0.6992	.605	428	13.88	65.443	12	0.9993	7.514E-07
365,137	0.7050	.610	419	13.88	67.416	12	0.9994	8.569E-07
371,797	0.7109	.616	411	13.88	69.526	12	0.9993	8.248E-07
377,247	0.7163	.620	403	13.88	71.523	10	0.9994	9.495E-07
384,349	0.7222	.625	394	13.88	73.815	10	0.9994	8.550E-07
390,936	0.7277	.630	386	13.88	76.040	10	0.9996	8.486E-07
397,022	0.7334	.635	378	13.88	78.456	10	0.9995	9.163E-07
403,675	0.7393	.640	370	13.88	81.021	10	0.9994	9.073E-07
411.238	0.7452	.645	362	13.88	83.767	10	0.9994	3.309E-07

424,751	0.7569	.655	345	13.88	89.511	10	0.9994	8.385E-07
431,772	0.7626	.660	337	13.88	92.567	10	0.9992	8.462E-07
438,297	0.7682	.665	330	13.88	95.651	10	0.9993	9.155E-07
444,824	0.7743	.670	322	13.88	99.196	10	0.9993	9.362E-07
450,368	0.7798	.675	314	13.88	102.573	10	0.9993	9.362E-07

Test Status for Specimen ID# TA532

	Target Load		Command Signal		Actual Load		Clip Gage	
	#	%	#	%	#	%	mil	%
Max	313	15.6	100	5.0	112	5.6	1.47	7.3
Min	78	3.9	100	5.0	112	5.6	1.47	7.3

a/W	a	Last a	Next a	Count	Time	Date
.6761	0.7809	0.7796	0.7854	452,040	10:29:46	02-18-1995

Slope #	Slope #	Corr	Kmax	Delta K	da/dN
10	2	0.9991	18.5	13.9	9.362E-07

Function Key Status
F5 F6 F7 F8

Function Generator Status
Frequency (Hz) 31.000

EvB/P	Count	a
103.270	451,956	0.7809

start run STOP

WHB-SD-FF-TRP-019
Rev. 0

PAGE B-44 OF B-64

S/N TA532

MATERIAL : 16-8-2 STAINLESS STEEL

TEST TEMPERATURE : 900°F

FRACTURE FACE CRACK MEASUREMENTS

	<u>PRECRACK</u>	<u>POST-TEST</u>
SIDE 1	0.786	0.802
1/8 POINT	0.797	0.816
1/4 POINT	0.803	0.831
3/8 POINT	0.803	0.846
1/2 POINT	0.804	0.845
5/8 POINT	0.801	0.836
3/4 POINT	0.795	0.812
7/8 POINT	0.783	0.792
SIDE 2	0.765	0.769
AVERAGE	0.795	0.820

Precracking Data Summary

Job Number 62077
Customer
Operator L R Bramlage
Date 02-17-1995
Material SS
Specimen Type CT

Specimen ID TA533
Machine 60056
Extensometer 27209
Clip Gage Cal (in/volt) 0.0020
Load Cell Cal (lb/volt) 200.0
Environment AIR
Temperature RT

K Calibration Type P
KCT CT00
0 0.88600 1.00002
1 4.64000 -4.06320
2 -13.32000 11.24200
3 14.72000 -106.04000
4 -5.60000 464.32999
5 0.00000 -650.67999

Specimen Characteristics

Specimen Thickness (in) B 0.298
Net Spec. Thickness (in) Bn 0.298
Notch Depth (in) h 0.502
Specimen Width (in) W 1.155
Young's Modulus (10E6) E 28.300

Test Parameters

Max Load for E adj. (lb) 380.0
Stress Ratio (R) 0.25
Initial a (in) 0.502
Final a (in) 0.786
Initial Kmax (ksi sqrt[in]) 18.50
Final Kmax (ksi sqrt[in]) 18.50
Initial Maximum Load (lb) 741.5
Final Maximum Load (lb) 304.0
K-Gradient (1/in) 0.000

Minimum Slope Level (%) 50.0
Number of Slopes 10.
Minimum Corr Coeff 0.990
Data on load or unload LOAD AND UNLOAD
Final a/W 0.6810
a/W Increment for Printout 0.0050
Waveform Type SINEWAVE
Frequency (Hz) 31.000

333,796	0.7881	.665	337	14.25	93.382	38	0.9995	1.207E-06
359,303	0.7740	.670	328	14.25	99.038	38	0.9995	1.169E-06
364,479	0.7799	.675	320	14.25	102.599	38	0.9995	1.100E-06
369,551	0.7856	.680	313	14.25	106.259	31	0.9995	1.196E-06

Test Status for Specimen ID# TA533

	Target Load		Command Signal		Actual Load		Clip Gage	
	#	%	#	%	#	%	mil	%
Max	310	15.5	20	1.0	53	2.6	-0.18	-0.9
Min	77	3.9	20	1.0	53	2.6	-0.18	-0.9

a/W	a	Last a	Next a	Count	Time	Date
.6820	0.7877	0.7854	0.7912	371,536	10:58:07	02-18-1995

Slope #	Slope #	Corr	Kmax	Delta K	da/dN
31	14	0.9995	19.0	14.3	1.196E-06

Function Key Status

F5 F6 F7 F8

Function Generator Status
 Frequency (Hz) 31.000

EvB/P	Count	a
107.685	371,367	0.7877

start run STOP

WHB-SD-FF-TRP-019
 Rev. 0

PAGE B-48 OF B-64

S/N TA533

MATERIAL : 16-8-2 STAINLESS STEEL
TEST TEMPERATURE : 900°F

FRACTURE FACE CRACK MEASUREMENTS

	<u>PRECRACK</u>	<u>POST-TEST</u>
SIDE 1	0.787	0.833
1/8 POINT	0.797	0.843
1/4 POINT	0.809	0.866
3/8 POINT	0.815	0.871
1/2 POINT	0.812	0.869
5/8 POINT	0.805	0.850
3/4 POINT	0.800	0.820
7/8 POINT	0.786	0.805
SIDE 2	0.776	0.797
AVERAGE	0.801	0.842

Precracking Data Summary

Job Number 62077
Customer
Operator LR Bramlage
Date 02-18-1995
Material SS
Specimen Type C(T)

Specimen ID TA534
Machine 60076
Extensometer 27189
Clip Gage Cal (in/volt) 0.0020
Load Cell Cal (lb/volt) 200.0
Environment AIR
Temperature RT

K Calibration Type P
KCT CT00
0 0.88600 1.00002
1 4.64000 -4.06320
2 -13.32000 11.24200
3 14.72000 -106.04000
4 -5.60000 464.32999
5 0.00000 -650.67999

Specimen Characteristics

Specimen Thickness (in) B 0.298
Net Spec. Thickness (in) Bn 0.298
Notch Depth (in) h 0.501
Specimen Width (in) W 1.154
Young's Modulus (10E6) E 28.300

Test Parameters

Max Load for E adj. (lb) 380.0
Stress Ratio (R) 0.25
Initial a (in) 0.501
Final a (in) 0.781
Initial Kmax (ksi sqrt[in]) 18.50
Final Kmax (ksi sqrt[in]) 18.50
Initial Maximum Load (lb) 742.2
Final Maximum Load (lb) 309.5
K-Gradient (1/in) 0.000

Minimum Slope Level (%) 50.0
Number of Slopes 10.
Minimum Corr Coeff 0.988
Data on load or unload LOAD AND UNLOAD
Final a/W 0.6770
a/W Increment for Printout 0.0050
Waveform Type SINEWAVE
Frequency (Hz) 31.000

347,890	0.7608	.659	339	13.95	91.916	10	0.9994	1.053E-06
353,975	0.7665	.664	331	13.95	95.066	10	0.9995	9.735E-07
359,060	0.7721	.669	323	13.95	98.260	10	0.9993	1.086E-06
364,758	0.7783	.674	315	13.95	102.066	10	0.9994	1.067E-06

beyond final crack length .7814187

Test Status for Specimen ID# TA534

	Target Load		Command Signal		Actual Load		Clip Gage	
	#	%	#	%	#	%	mil	%
x	311	15.5	100	5.0	118	5.9	1.42	7.1
n	78	3.9	100	5.0	118	5.9	1.42	7.1

a/W	a	Last a	Next a	Count	Time	Date
.6771	0.7814	0.7778	0.7836	367,392	14:07:25	02-18-1995

Slope #	Slope #	Corr	Kmax	Delta K	da/dN
10	10	0.9996	18.6	13.9	1.067E-06

Function Key Status
 F5 F6 F7- F8

Function Generator Status	Frequency (Hz)	EvB/P	Count	a
	31.000	103.999	367,375	0.7814

start run STOP Beyond final crack length 0.781

WHB-SD-FF-TRP-019
 Rev. 0

PAGE B-52 OF B-64

S/N TA534

MATERIAL : 16-8-2 STAINLESS STEEL

TEST TEMPERATURE : 900°F

FRACTURE FACE CRACK MEASUREMENTS

	<u>PRECRACK</u>	<u>POST-TEST</u>
SIDE 1	0.765	0.773
1/8 POINT	0.779	0.812
1/4 POINT	0.791	0.831
3/8 POINT	0.797	0.845
1/2 POINT	0.806	0.863
5/8 POINT	0.805	0.877
3/4 POINT	0.806	0.862
7/8 POINT	0.798	0.852
SIDE 2	0.788	0.845
AVERAGE	0.795	0.844

Precracking Data Summary

Job Number 62077
Customer
Operator L R Bramlage
Date 02-18-1995
Material SS
Specimen Type CT

Specimen ID TA535
Machine 60056
Extensometer 27209
Clip Gage Cal (in/volt) 0.0020
Load Cell Cal (lb/volt) 200.0
Environment AIR
Temperature RT

K Calibration Type		P
	KCT	CT00
0	0.88600	1.00002
1	4.64000	-4.06320
2	-13.32000	11.24200
3	14.72000	-106.04000
4	-5.60000	464.32999
5	0.00000	-650.67999

Specimen Characteristics

Specimen Thickness (in)	B	0.298
Net Spec. Thickness (in)	Bn	0.298
Notch Depth (in)	h	0.501
Specimen Width (in)	W	1.155
Young's Modulus (10E6)	E	28.300

Test Parameters

Max Load for E adj. (lb)	380.0
Stress Ratio (R)	0.25
Initial a (in)	0.501
Final a (in)	0.785
Initial Kmax (ksi sqr[in])	18.50
Final Kmax (ksi sqr[in])	18.50
Initial Maximum Load (lb)	743.3
Final Maximum Load (lb)	305.3
K-Gradient (1/in)	0.000
Minimum Slope Level (%)	50.0
Number of Slopes	10.
Minimum Corr Coeff	0.990
Data on load or unload	LOAD AND UNLOAD
Final a/W	0.6800
a/W Increment for Printout	0.0050
Waveform Type	SINEWAVE
Frequency (Hz)	31.000

S/N TA535

MATERIAL : 16-8-2 STAINLESS STEEL

TEST TEMPERATURE : 900°F

FRACTURE FACE CRACK MEASUREMENTS

	<u>PRECRACK</u>	<u>POST-TEST</u>
SIDE 1	0.775	0.787
1/8 POINT	0.794	0.805
1/4 POINT	0.802	0.825
3/8 POINT	0.803	0.830
1/2 POINT	0.805	0.829
5/8 POINT	0.803	0.824
3/4 POINT	0.796	0.810
7/8 POINT	0.785	0.794
SIDE 2	0.770	0.779
AVERAGE	0.795	0.813

Precracking Data Summary

Job Number 62077
Customer
Operator LR Bramlage
Date 02-19-1995
Material SS
Specimen Type C(T)

Specimen ID TA536
Machine 60076
Extensometer 27189
Clip Gage Cal (in/volt) 0.0020
Load Cell Cal (lb/volt) 200.0
Environment AIR
Temperature RT

K Calibration Type P
KCT CT00
0 0.88600 1.00002
1 4.64000 -4.06320
2 -13.32000 11.24200
3 14.72000 -106.04000
4 -5.60000 464.32999
5 0.00000 -650.67999

Specimen Characteristics

Specimen Thickness (in) B 0.300
Net Spec. Thickness (in) Bn 0.300
Notch Depth (in) h 0.502
Specimen Width (in) W 1.155
Young's Modulus (10E6) E 28.300

Test Parameters

Max Load for E adj. (lb) 380.0
Stress Ratio (R) 0.25
Initial a (in) 0.502
Final a (in) 0.782
Initial Kmax (ksi sqrt[in]) 18.60
Final Kmax (ksi sqrt[in]) 18.60
Initial Maximum Load (lb) 750.5
Final Maximum Load (lb) 313.0
K-Gradient (1/in) 0.000

Minimum Slope Level (%) 50.0
Number of Slopes 10.
Minimum Corr Coeff 0.989
Data on load or unload LOAD AND UNLOAD
Final a/W 0.6770
a/W Increment for Printout 0.0050
Waveform Type SINEWAVE
Frequency (Hz) 31.000

S/N TA536

MATERIAL : 16-8-2 STAINLESS STEEL

TEST TEMPERATURE : 900°F

FRACTURE FACE CRACK MEASUREMENTS

	<u>PRECRACK</u>	<u>POST-TEST</u>
SIDE 1	0.768	0.802
1/8 POINT	0.775	0.801
1/4 POINT	0.790	0.813
3/8 POINT	0.797	0.826
1/2 POINT	0.801	0.836
5/8 POINT	0.802	0.849
3/4 POINT	0.800	0.847
7/8 POINT	0.792	0.820
SIDE 2	0.785	0.804
AVERAGE	0.792	0.824



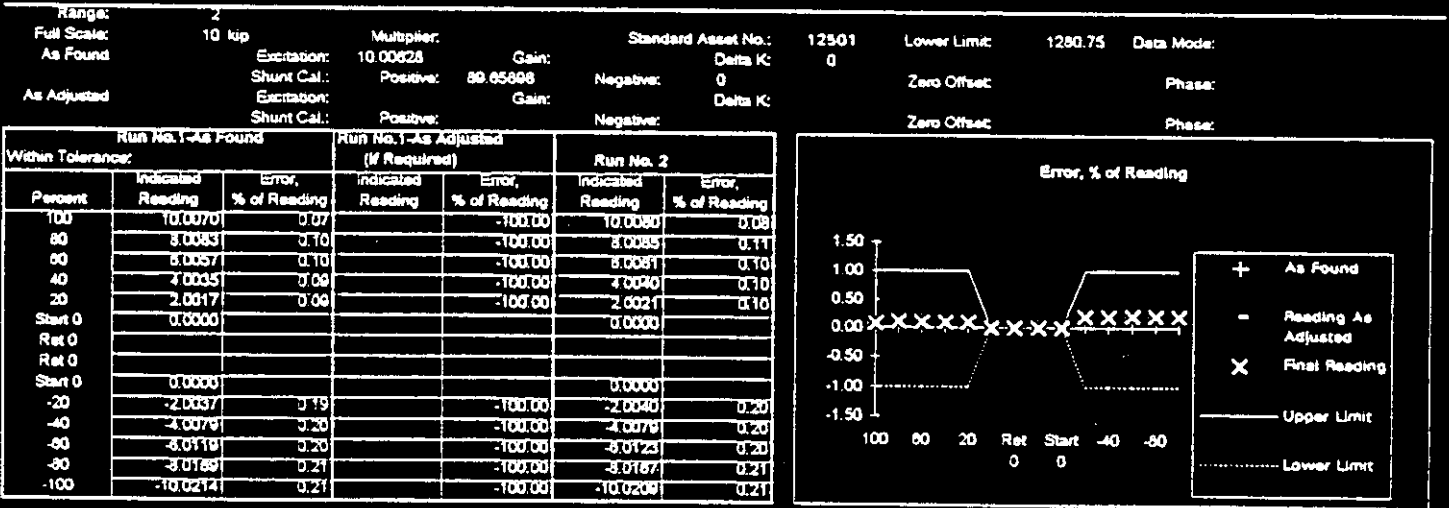
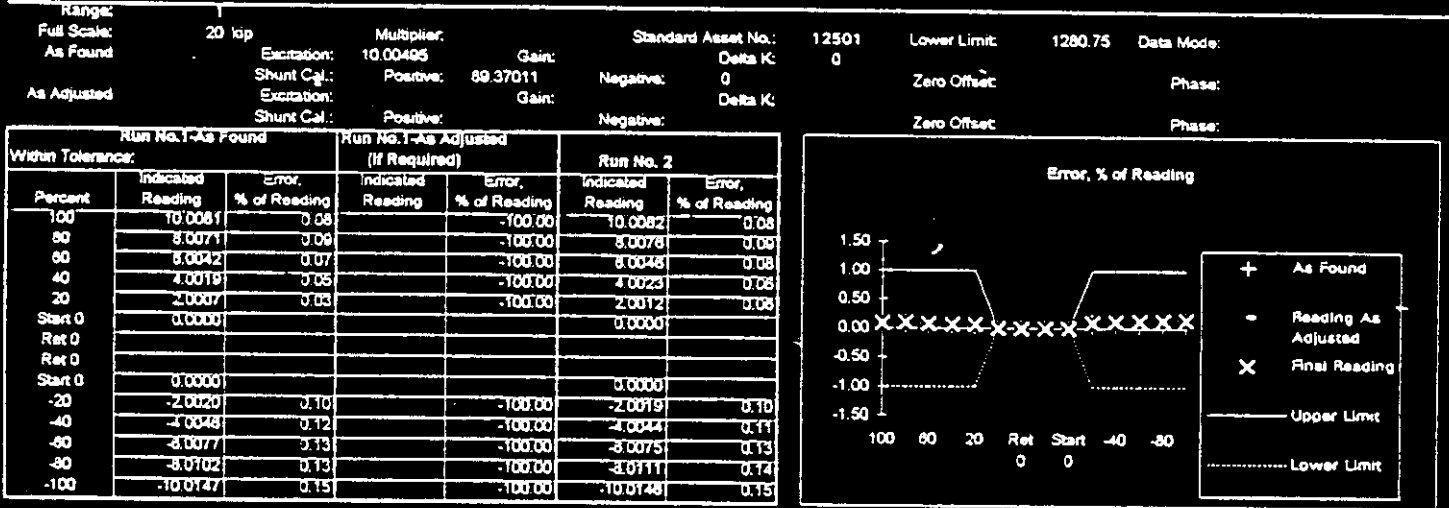
MTS Systems Corporation
14000 Technology Drive
Eden Prairie, MN 55344-221

Calibration Report

Customer Name: Metcut Research Associates System: 304.15G Page: 1 of 3
System ID: 60076 Location: Site: C53163-M01

Equipment Device Type: Force Transducer Model No.: 6.61E-01 Serial No.: V53427
Calibration Data File Name:
Controller/Conditioner Model: 458.11 Serial No.: 103021
Readout Device Model: 458.11 Serial No.: 103021 Channel:

Procedure MTS Procedure No.: MTS 1234-A
Calibration has been performed in accordance with ASTM practice: (none)
Calibration Equipment Asset No.
Computer: HighLevel Board: 13494 LowLevel Board: 13185
Temperature Readout: 12649 Additional Equipment
Conditions Ambient Temperature: 73.1 °F Polarity(+): Bidirectional:



MTS Systems Corporation Measurement Standards are Traceable to the National Institute of Standards and Technology

Notes:

Performed By: David B. Hauer

Date: 26-Jul-94

Signature:

Next Recommended Calibration Due Date: 26-Jul-95



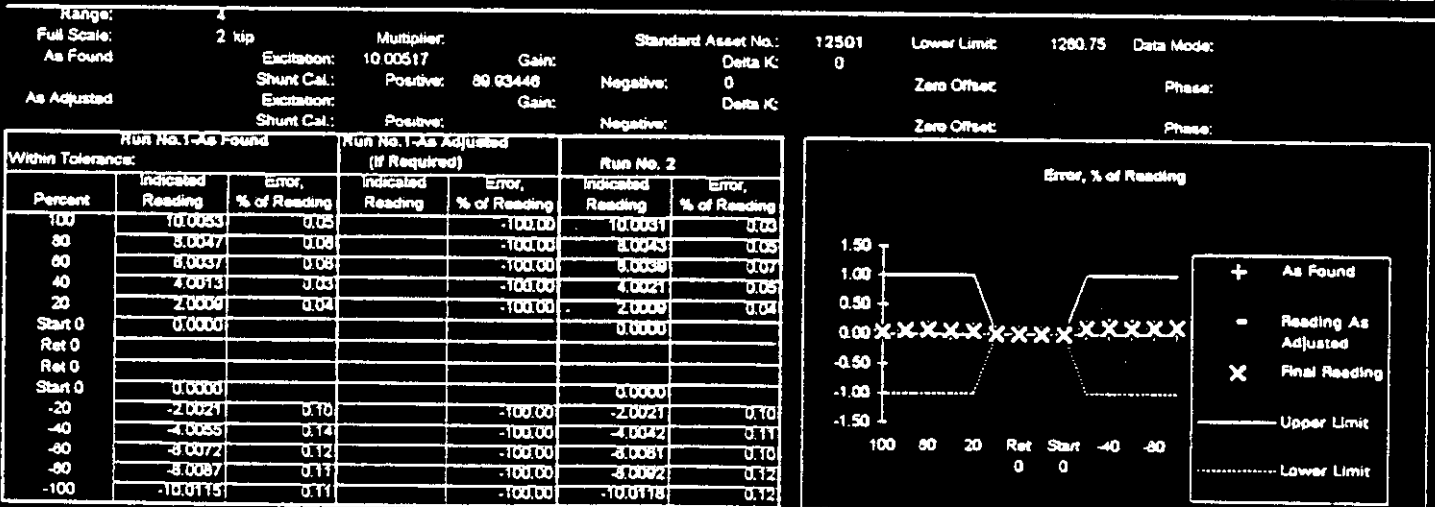
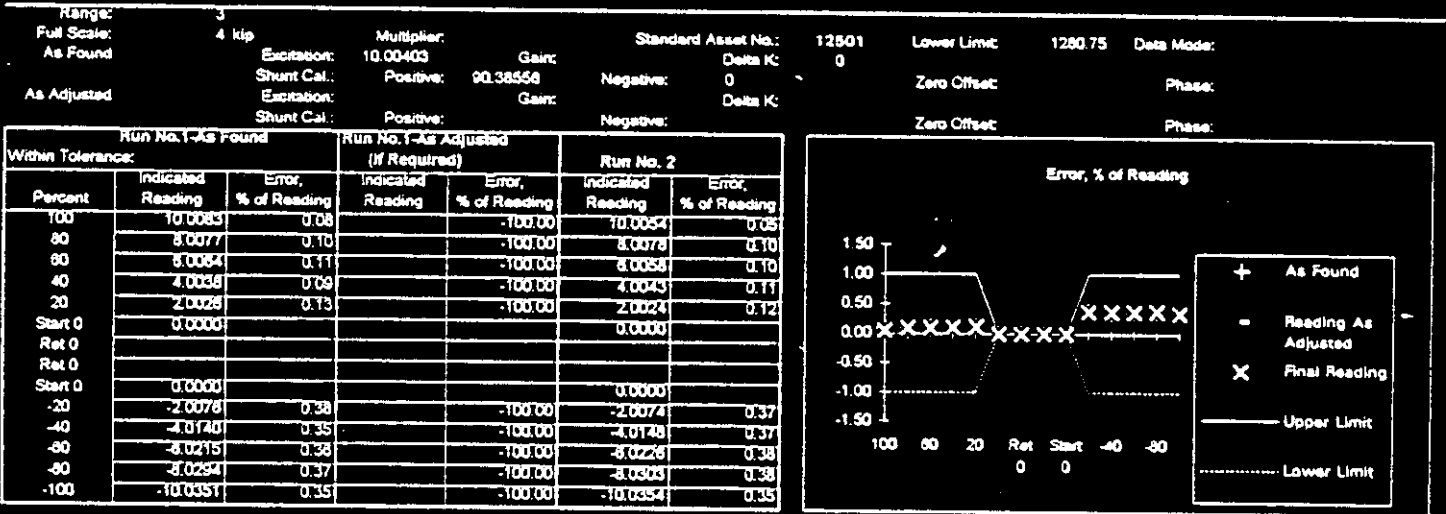
MTS Systems Corporation
14000 Technology Drive
Eden Prairie, MN 55344-2200

Calibration Report

Customer Name: Metcut Research Associates System: 304.15G Page: 2 of 3
System ID: 60076 Location: Site: C53163-M01

Equipment Device Type: Force Transducer Model No.: 6.61E-01 Serial No.: V53427
Calibration Data File Name:
Controller/Conditioner Model: 458.11 Serial No.: 103021
Readout Device Model: 458.11 Serial No.: 103021 Channel:

Procedure MTS Procedure No.: MTS 1234-A
Calibration has been performed in accordance with ASTM practice: (none)
Calibration Equipment Asset No.
Computer: HighLevel Board: 13494 LowLevel Board: 13185
Temperature Readout: 12649 Additional Equipment
Conditions Ambient Temperature: 73.1 °F Polarity(+): Bidirectional:



MTS Systems Corporation Measurement Standards are Traceable to the National Institute of Standards and Technology

Notes:

Performed By: David B. Hauer

Date: 26-Jul-94

Signature:

Next Recommended Calibration Due Date: 25-Jul-95



MTS Systems Corporation
14000 Technology Drive
Eden Prairie, MN 55344-2290

Calibration Report

Customer Name: Metcut Research Associates System: 304.15G Page: 3 of 3
System ID: 60076 Location: Site: C53163-M01

Equipment

Device Type: Force Transducer Model No.: 6.61E-01 Serial No.: V53427

Calibration Data File Name:

Controller/Conditioner Model: 458.11 Serial No.: 103021

Readout Device Model: 458.11 Serial No.: 103021 Channel:

Procedure

MTS Procedure No.: MTS 1234-A

Calibration has been performed in accordance with ASTM practice: (none)

Calibration Equipment Asset No.

Computer: HighLevel Board: 13494 LowLevel Board: 13185

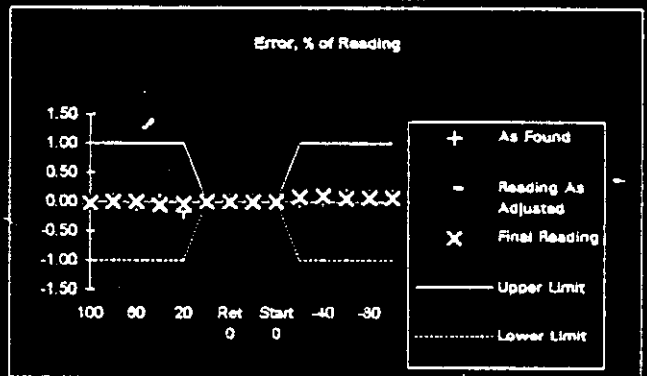
Temperature Readout: 12649 Additional Equipment:

Conditions

Ambient Temperature: 73.1 °F Polarity(+): Bidirectional:

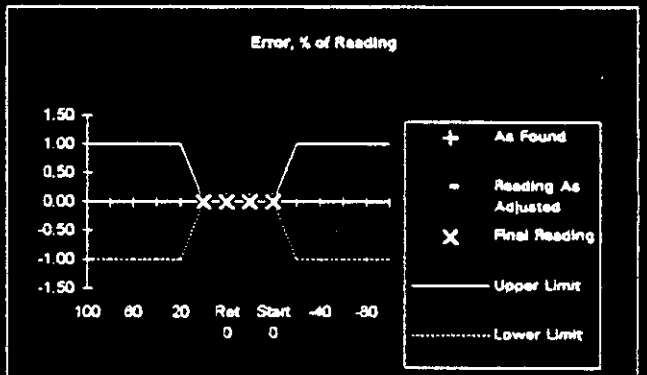
Range: 5 Full Scale: 1 kip Multiplier: 10.00389 Standard Asset No.: 12501 Lower Limit: 1280.75 Data Mode: 0
As Found Excitation: Gain: Delta K: 0
Shunt Cal.: Positive: 89.69157 Negative: 0 Zero Offset: Phase:
As Adjusted Excitation: Gain: Delta K: 0
Shunt Cal.: Positive: Negative: Zero Offset: Phase:

Run No. 1-As Found			Run No. 1-As Adjusted (If Required)			Run No. 2		
Percent	Indicated Reading	Error, % of Reading	Indicated Reading	Error, % of Reading	Indicated Reading	Error, % of Reading	Indicated Reading	Error, % of Reading
100	9.9952	-0.05	-100.00	-100.00	9.9982	-0.02	9.9982	-0.02
80	7.9998	-0.01	-100.00	-100.00	8.0002	0.00	8.0002	0.00
60	5.9990	-0.03	-100.00	-100.00	5.9999	0.00	5.9999	0.00
40	4.0001	0.00	-100.00	-100.00	3.9979	-0.05	3.9979	-0.05
20	1.9987	-0.17	-100.00	-100.00	1.9993	-0.04	1.9993	-0.04
Start 0	0.0000				0.0000		0.0000	
Ret 0								
Ret 0								
Start 0	0.0000				0.0000		0.0000	
-20	-2.0007	0.03	-100.00	-100.00	-2.0018	0.09	-2.0018	0.09
-40	-4.0029	0.07	-100.00	-100.00	-4.0040	0.10	-4.0040	0.10
-60	-6.0050	0.08	-100.00	-100.00	-6.0033	0.08	-6.0033	0.08
-80	-8.0083	0.08	-100.00	-100.00	-8.0057	0.07	-8.0057	0.07
-100	-10.0071	0.07	-100.00	-100.00	-10.0072	0.07	-10.0072	0.07



Range: 5 Full Scale: 1 kip Multiplier: 10.00389 Standard Asset No.: 12501 Lower Limit: 1280.75 Data Mode: 0
As Found Excitation: Gain: Delta K: 0
Shunt Cal.: Positive: 89.69157 Negative: 0 Zero Offset: Phase:
As Adjusted Excitation: Gain: Delta K: 0
Shunt Cal.: Positive: Negative: Zero Offset: Phase:

Run No. 1-As Found			Run No. 1-As Adjusted (If Required)			Run No. 2		
Percent	Indicated Reading	Error, % of Reading	Indicated Reading	Error, % of Reading	Indicated Reading	Error, % of Reading	Indicated Reading	Error, % of Reading
100		-100.00		-100.00		-100.00		-100.00
80		-100.00		-100.00		-100.00		-100.00
60		-100.00		-100.00		-100.00		-100.00
40		-100.00		-100.00		-100.00		-100.00
20		-100.00		-100.00		-100.00		-100.00
Start 0								
Ret 0								
Ret 0								
Start 0								
-20		-100.00		-100.00		-100.00		-100.00
-40		-100.00		-100.00		-100.00		-100.00
-60		-100.00		-100.00		-100.00		-100.00
-80		-100.00		-100.00		-100.00		-100.00
-100		-100.00		-100.00		-100.00		-100.00



MTS Systems Corporation Measurement Standards are Traceable to the National Institute of Standards and Technology

Notes:

Performed By: David B. Hauer

Date: 26-Jul-94

Signature:

Next Recommended Calibration Due Date: 26-Jul-95



MTS Systems Corporation
14000 Technology Drive
Eden Prairie, Minnesota 5534

WHB-SD-AFF-TRP-019
Rev. 0

PAGE B-63 OF B-64

BEST AVAILABLE COPY

**TRANS-DUCER -
TRANS-DUCER CONDITIONER
CALIBRATION REPORT**

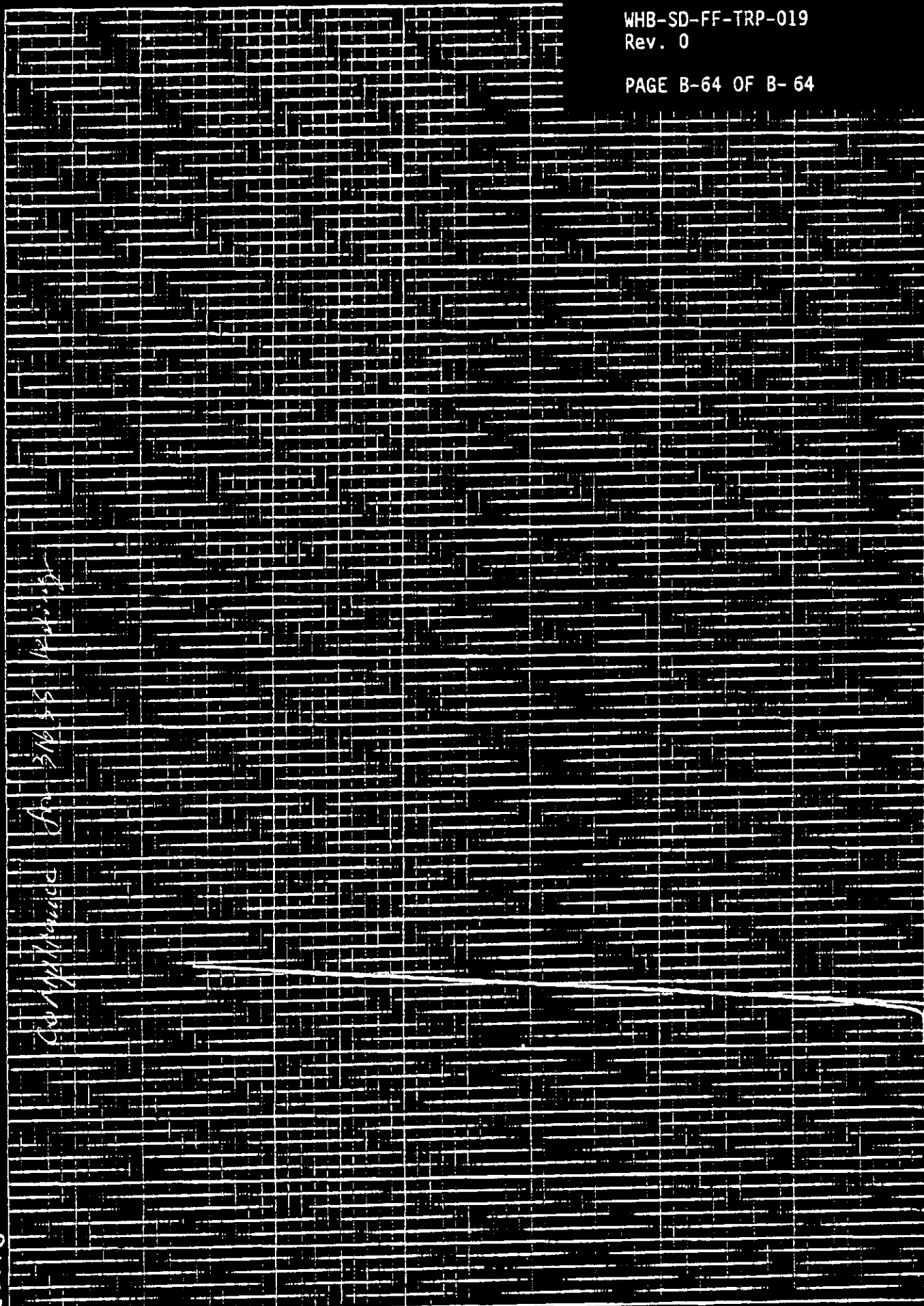
CUSTOMER Marent Kaszani N554 SYSTEM NO. 60076 SERIAL NO. 99785 CONDITIONER MODEL 4158.13 SERIAL NO. 101972
 TRANSDUCER TYPE LUOT INDICATOR UNIT I.D. NO. 10578 STANDARDIZER I.D. NO. 101972 LAB TEMP. 72.1
 THERM SUP 2 CAL FACTOR INITIAL 1.000 CAL FACTOR FINAL 1.000
 EXTRACTION POS NEG ADDITIONAL EQUIPMENT Temp Probe 12549 458AC CAL FAC SW ON OFF

RANGE #, FULL SCALE	MODULE OUTPUT		ERROR % OF READING	ADJUSTMENT <input type="checkbox"/> REQUIRED <input checked="" type="checkbox"/> NOT REQUIRED	MODULE OUTPUT		ERROR % OF READING
	INITIAL CAL DATA	FINAL CAL DATA			INITIAL CAL DATA	FINAL CAL DATA	
1 ± 5.0"	100%	—		<input type="checkbox"/> REQUIRED <input checked="" type="checkbox"/> NOT REQUIRED	100%		
	80%	—			80%		
	60%	+5.983			60%		
	40%	+4.015			40%		
	20%	+2.011			20%		
	0%	0.000			0%		
	-20%	-2.034			-20%		
	-40%	-4.014			-40%		
	-60%	-6.010			-60%		
	-80%	—			-80%		
	-100%	—			-100%		
2 ± 1.0"	100%	+7.710		<input checked="" type="checkbox"/> REQUIRED <input type="checkbox"/> NOT REQUIRED <i>INITIAL</i>	100%		
	80%	+8.000			80%		
	60%	+6.012			60%		
	40%	+4.018			40%		
	20%	+2.010			20%		
	0%	0.000			0%		
	-20%	-2.013			-20%		
	-40%	-4.015			-40%		
	-60%	-6.011			-60%		
	-80%	-8.001			-80%		
	-100%	-7.985			-100%		
3 ± 0.5"	100%	+6.799		<input type="checkbox"/> REQUIRED <input checked="" type="checkbox"/> NOT REQUIRED	100%		
	80%	+8.004			80%		
	60%	+6.008			60%		
	40%	+4.007			40%		
	20%	+2.000			20%		
	0%	0.000			0%		
	-20%	-2.011			-20%		
	-40%	-4.017			-40%		
	-60%	-6.017			-60%		
	-80%	-8.015			-80%		
	-100%	-10.004			-100%		
4 FULL SCALE	100%			<input type="checkbox"/> REQUIRED <input type="checkbox"/> NOT REQUIRED	100%		
	80%				80%		
	60%				60%		
	40%				40%		
	20%				20%		
	0%				0%		
	-20%				-20%		
	-40%				-40%		
	-60%				-60%		
	-80%				-80%		
	-100%				-100%		

BEST AVAILABLE COPY

WHB-SD-FF-TRP-019
Rev. 0

PAGE B-64 OF B-64



46 0780

NOTE 10 X 10 TO THE INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

60076

Copy/Handed to 516 SS JADWIN

.0125"/in

APPENDIX C

Additional Test Records for 304 Stainless Steel and
308 Stainless Steel Weld

TENSILE DATA

Material: 304 Stainless steel
Specimen blank number: 3-380-8-4K
Test temperature: 800°F

TYS @ 0.2% OFF		TENSILE STRENGTH		ELONG (4D)		RED. OF AREA	
LBS	KSI	LBS	KSI	IN	%	FIN. DIM.	%
545.8	27.0	1334	66.0	0.305	47.7	.092 D	67.3
447.7	22.2	1323	65.5	0.295	46.1	.087 D	70.8
				.640G			

TENSILE DATA

Material: 308 Stainless steel
Specimen blank number: AA-8-4K
Test temperature: 800°F

TYS @ 0.2% OFF		TENSILE STRENGTH		ELONG (4D)		RED. OF AREA	
LBS	KSI	LBS	KSI	IN	%	FIN. DIM.	%
2415	49.2	3452	70.3	0.240	24.0	.180 D	48.3
2424	49.0	3403	68.7	0.270	27.0	.178 D	49.7
				1.0G			

Test Parameters						
Specimen ID	TA501	TA502	TA503	TA504	TA505	TA506
Mach #	673	673	673	673	673	673
Yield (ksi)	36.0	36.0	36.0	36.0	36.0	36.0
Modulus	24.4	24.4	24.4	24.4	24.4	24.4
Temp'F	800	800	800	800	800	800
% R Humidity	35	35	35	35	35	35
Dimensions						
Notch (a/n)	0.859	0.854	0.859	0.853	0.859	0.86
B	1.006	1.005	1.005	1.005	1.004	1.006
W	2.004	1.998	2.005	1.997	2.003	2.006
Precrack						
Total Cycles	593095	561961	573636	490406	557871	643632
Aspect Ratio	0.599	0.578	0.599	0.601	0.599	0.598
Final P max	1790	1940	1790	1770	1780	1800
Final K max	17.1	17.1	17.1	17.1	17.1	17.1
A1	1.14	1.124	1.15	1.144	1.137	1.153
A2	1.121	1.156	1.177	1.192	1.18	1.184
A3	1.186	1.182	1.196	1.212	1.203	1.198
A4	1.193	1.194	1.202	1.218	1.214	1.2
A5	1.192	1.194	1.201	1.216	1.212	1.201
A6	1.187	1.193	1.2	1.211	1.209	1.194
A7	1.18	1.18	1.192	1.199	1.199	1.188
A8	1.162	1.158	1.171	1.185	1.175	1.168
A9	1.123	1.121	1.154	1.125	1.134	1.148
Static Testing						
Loading Rate	0.0016	0.0016	0.0016	0.0016	0.0008	0.0003
A1	1.152	1.215	1.174	1.177	1.162	1.158
A2	1.19	1.254	1.196	1.236	1.21	1.184
A3	1.205	1.314	1.239	1.271	1.235	1.205
A4	1.214	1.359	1.255	1.284	1.247	1.207
A5	1.218	1.359	1.255	1.289	1.247	1.203
A6	1.212	1.341	1.244	1.301	1.241	1.199
A7	1.204	1.316	1.227	1.27	1.219	1.191
A8	1.189	1.244	1.199	1.239	1.188	1.171
A9	1.144	1.212	1.173	1.193	1.153	1.151

Respectfully Submitted: 
Richard Green
Manager of Dynamic Test

BEST AVAILABLE COPY

AMS Lab: 207910

PAGE C-5 OF C-9

Test Parameters	TAS11	TAS12	TAS13	TAS14	TAS15	TAS16
Specimen ID	TW1	TW2	TW3	TW4	TW5	TW6
Mach #	676	676	676	676	676	676
Yield (ksi)	42.0	42.0	42.0	42.0	42.0	42.0
Modulus	24.4	24.4	24.4	24.4	24.4	24.4
Temp/F	800	800	800	800	800	800
% R Humidity	32	32	32	32	32	32
Dimensions						
Notch (a/n)	0.858	0.859	0.854	0.858	0.860	0.855
B	0.975	1.004	1.004	1.004	1.007	1.003
W	2.002	2.000	1.998	2.000	2.004	2.001
Precrack						
Total Cycles	1,364,617	782,198	1,261,863	855,930	1,009,028	1,151,663
Aspect Ratio	0.58	0.59	0.57	0.61	0.58	0.59
Final P max	1700	1700	1700	1700	1700	1700
Final K max						
A1	1.123	1.123	1.113	1.158	1.126	1.12
A2	1.178	1.202	1.173	1.224	1.167	1.195
A3	1.216	1.244	1.203	1.274	1.203	1.243
A4	1.23	1.256	1.202	1.297	1.217	1.256
A5	1.224	1.258	1.19	1.308	1.205	1.249
A6	1.217	1.249	1.174	1.312	1.2	1.241
A7	1.184	1.232	1.159	1.293	1.18	1.213
A8	1.143	1.194	1.133	1.237	1.151	1.167
A9	1.121	1.132	1.109	1.152	1.118	1.123
Average A	1.160	1.181	1.144	1.216	1.156	1.172
Static Testing						
Load Rate("/min)	0.05	0.05	0.05	0.05	0.05	0.05
A1	1.133	1.207	1.13	1.225	1.129	1.148
A2	1.182	1.258	1.196	1.252	1.187	1.229
A3	1.229	1.375	1.265	1.333	1.244	1.325
A4	1.259	1.439	1.303	1.364	1.271	1.369
A5	1.27	1.437	1.294	1.396	1.253	1.39
A6	1.248	1.425	1.274	1.393	1.247	1.374
A7	1.199	1.353	1.219	1.328	1.204	1.296
A8	1.153	1.269	1.147	1.251	1.164	1.219
A9	1.131	1.202	1.143	1.164	1.144	1.186
Average A	1.176	1.285	1.190	1.263	1.180	1.241
Crack Extension	0.016	0.104	0.046	0.046	0.025	0.068
Command Disp.	0.100	0.250	0.150	0.135	0.125	0.175



Respectfully Submitted: *Richard Green*
Richard Green
Manager of Dynamic Test

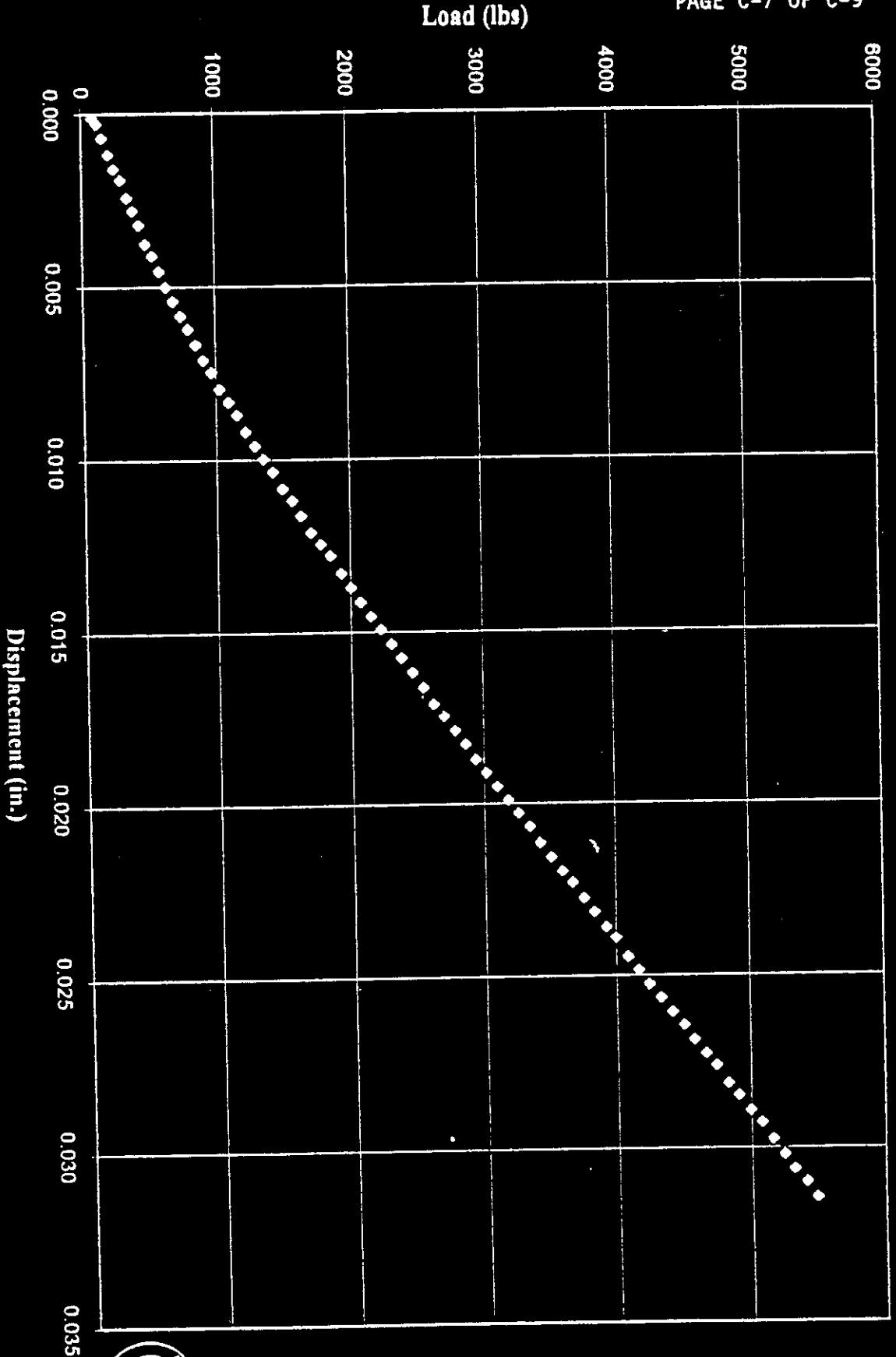
FRACTURE TOUGHNESS TEST # <u>800</u>	
LAB #: <u>203930</u>	DATE: <u>7/20/71</u>
SPECIMEN I.D.: <u>Compliance</u>	
MICROMETER/CALIPER I.D.: _____	
RECORDER I.D.: <u>458</u>	DISP (IN/IN): <u>30.5</u>
LOAD RATE: _____	RANGE: <u>1000</u>
LBS/MIN: _____	MAGN: _____
TEMP: <u>800</u>	HUMIDITY: <u>25</u>

0.5"

1000 lbs

30WAL 10 X 10 TO THE INCH AS 9007-61

GRAPHIC PAPER GRAPHIC CONTROLS CORPORATION Buffalo, New York Printed in U.S.A.



Load vs Displacement
Compliance of 676 @ 800F
Load Rate = .05"/min.



PRECRACK INFORMATION

Material: 308 Stainless steel
Specimen blank number: AA-8-4K
Test freq.: 30 Hz
R ratio: 0.25
Control mode: stroke

Specimen ID	W	Notch Length	Thickness	Max Stress ksi	Max Load lbs	Min Load lbs	Cycles
TW #1 TA511	2.002	0.858	0.975	15.5	1700	425	1,364,617
TW #2 TA512	2.000	0.859	1.004	15.8	1700	425	782,198
TW #3 TA513	1.998	0.854	1.004	14.8	1700	425	1,261,863
TW #4 TA514	2.000	0.858	1.004	16.9	1700	425	855,930
TW #5 TA515	2.004	0.860	1.007	14.9	1700	425	1,009,028
TW #6 TA516	2.001	0.855	1.003	15.5	1700	425	1,151,663

ACCURATE METALLURGICAL SERVICES, INC.

Extensometer Calibration Data (LTP V-A) (Form Rev. 7/94)

Extensometer Identification

Gage I.D.: 673 Range Card: 5.0"
 Gage S/N: _____ System I.D.: _____

Calibration Equipment Identification

DVM I.D.: 882 Calibration Due Date: 6/30/95
 Linear Calibrator: 830 Calibration Due Date: 6/9/95

Displacement Precalibration				Adjustment				Req. <input type="checkbox"/> Not Req. <input checked="" type="checkbox"/> 2nd Run							
Step	Std.	DVM	DC Ctl	A-D	Error	Std.	DVM	DC Ctl	A-D	Error	Std.	DVM	DC Ctl	A-D	Error
10%	.03	.06	.0303	.06		.03	.06	.0303	.06		.03	.06	.0303	.06	
20%	.06	.12	.0600	.11		.06	.12	.0600	.11		.06	.12	.0600	.11	
30%	.09	.18	.0900	.17		.09	.18	.0900	.17		.09	.18	.0900	.17	
40%	.12	.24	.1200	.23		.12	.24	.1200	.23		.12	.24	.1200	.23	
50%	.15	.30	.1495	.29		.15	.30	.1495	.29		.15	.30	.1495	.29	
60%	.18	.36	.1795	.35		.18	.36	.1795	.35		.18	.36	.1795	.35	
70%	.21	.42	.2090	.41		.21	.42	.2090	.41		.21	.42	.2090	.41	
80%	.24	.48	.2400	.47		.24	.48	.2400	.47		.24	.48	.2400	.47	
90%	.27	.54	.2695	.53		.27	.54	.2695	.53		.27	.54	.2695	.53	
100%	.30	.60	.2985	.59		.30	.60	.2985	.59		.30	.60	.2985	.59	
-10%															

Summary

Average % Error: _____
 Conforms to Class: _____
 Specification: MIL-STD-45662A
 ASTM E83-93

Shunt Cal Voltage: _____

Performed by: RG
 Date: 1/22/95
 Next Due Date (6 months): _____
 Approved for use by: RG