Research Report on Characterization and Monitoring of Cracking in Wet H_2S Service

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FOREWORD

In 1990 cracking of refinery process equipment in wet H_2S service was being widely reported. As a result, committees and task groups of industry organizations, including API, NACE and the Materials Properties Council, were actively seeking improved understanding of the phenomenon. Of particular concern were conditions leading to cracking and blistering, the incidence of cracking, the consequences of such damage, and the efficacy of NDE methods for detection and monitoring.

The Program reported herein was one of several significant industry-wide efforts on this subject. It was intended to supplement other activities by examining, in a large-scale test vessel, issues which could not be addressed satisfactorily either with conventional small-scale laboratory specimens or with in-situ exposures in refineries.

The construction of a welded steel pressure vessel with a replaceable "window" for test purposes was proposed by MPC to the API Subcommittee on Corrosion and Materials. Its Task Group on Materials and Corrosion Research developed the program to study the effect of variables on cracking and the capabilities of certain NDE monitoring methods. At that time, it was realized that the results would not be directly translatable to field application because the environment to be used would be extremely severe, and the thickness of the steel studied was limited to 0.5 inch. Nevertheless the guidance to be obtained would be valuable.

The results of the program have helped to provide validation of observations of conventional laboratory test specimens and clarify the roles of the variables considered. The work on acoustic emission monitoring was particularly enlightening. However, it must be realized that the information obtained is to be viewed in the context of specific service demands before application in the plant should be attempted. For example, pressure vessels usually have thicker shells than used in the test which will affect NDE capabilities, hydrogen permeation and material behavior.

A large measure of the credit for the success of this program goes to the members of the API Subcommittee and Task Group and the MPC Sponsor Committees who contributed their ideas and vast experience.

M. Prager

Research Report on Characterization and Monitoring of Cracking in Wet H_2S Service

M. S. Cayard, R. D. Kane, L. Kaley, and M. Prager

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1.0 Executive Summary

This report presents the experimental methods and findings of a research program of MPC entitled "Characterization and Monitoring of Cracking in Wet H_2S Service." The program was supported by the Refining Division of the American Petroleum Institute (API) and by The Materials Properties Council (MPC) and its Fitness-for-Service group-sponsored program.

The two main objectives of the program were to study the performance in wet H_2S of welded steel plate of various qualities and microstructures, and evaluate the effectiveness of NDE techniques to characterize and monitor the cracking. To accomplish these objectives, a series of large scale exposure tests were conducted with steel panels (referred to herein as "windows") containing welds and attachments welded into a fabricated steel vessel filled with a

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pressurized H_2S containing solution prepared in accordance with NACE Standard TM0177-90, Method A. Experiments were performed using windows comprised of conventional, low sulfur, ultra-low sulfur and advanced thermo-mechanically controlled processed (TMCP) steels per the ASTM A516-70 and A841 specifications using various weld fabrication methods.

Characterization and monitoring of internal cracks resulting from Hydrogen Induced Cracking (HIC), Stress Oriented Hydrogen Induced Cracking (SOHIC) and Sulfide Stress Cracking (SSC) was accomplished at various pressures, solution pH, H_2S content, and time. Methods utilized included: (1) manual and automated ultrasonic testing (UT), (2) wet fluorescent magnetic particle testing (WFMPT), and (3) acoustic emission (AE). The results of these nondestructive techniques were confirmed using metallographic sectioning following exposure.

It was found that resistance to blister-type HIC was greater in lower sulfur steels than in the higher sulfur conventional steels. Maximum resistance to HIC was found in ultra-low sulfur advanced steels produced by thermo-mechanically controlled processing (TMCP) with ultra-low sulfur contents (≤ 0.001 wt. percent) and processed to produce controlled homogeneous microstructures free from ferrite/pearlite banding.

Based on all materials evaluated in this program, the resistance to through-wall crack propagation also increased with decreasing sulfur content and decreasing microstructural banding. However, under very severe hydrogen charging conditions, i.e., two to three times the NACE TM0177 solution charging levels, all steels evaluated exhibited through-wall cracking to depths ranging from approximately 30–50% of the plate thickness irrespective of either the sulfur content or degree of banding. These data suggest that there is a threshold level of hydrogen charging above which the resistance of these materials, even those processed to optimize resistance to HIC, breaks down. At such severe hydrogen charging conditions, the use of stainless steel clad vessels may be more appropriate.

One of the most notable findings of this program was the significant impact of surface cleaning and removal of protective sulfide films on the subsequent cracking behavior of carbon steel equipment. It was found that removal of surface films on the internal surface of carbon steel equipment, using techniques typically used prior to WFMPT, increased the hydrogen flux and likelihood of wet H_2S cracking during operation prior to the reformation of a protective sulfide scale.

Nondestructive evaluation techniques (i.e., WFMPT, UT and AE) were useful to varying degrees in identifying and monitoring HIC, SOHIC and SSC. Automated ultrasonic testing (AUT) T-scan adequately identified in-plane, blister type cracking caused by HIC in a semi-quantitative manner which correlated reasonably well with metallographic sectioning. AUT P-scan was only able to qualitatively identify through-wall SOHIC. This may have, in part, been due to the relatively thin section size of the plate used in this study.

Manual UT was required to size through-wall flaws in plate specimens resulting from SOHIC and sulfide stress cracking (SSC). However, manual UT crack sizing measurements in the regions around nozzle attachment welds and surface crack indications obtained using WFMPT typically did not accurately identify areas of significant through-wall cracking from SOHIC as confirmed by metallographic sectioning. Many of the indications obtained from WFMPT were limited to surface cracks and imperfections.

AE monitoring was able to detect and characterize damage during periods of active cracking resulting from HIC, SOHIC and SSC. AE also differentiated cracking related to in-plane (blister-type) HIC growth from through-wall crack growth resulting from SOHIC and SSC. AE conducted during hydrotesting of HIC/SOHIC damaged material required relatively high levels of internal pressure, beyond the normal operating levels for the vessel, to produce a significant AE response.

In general, the observations of material behavior found in this study were consistent with the findings of the previously conducted laboratory testing conducted in the MPC group-sponsored Wet H_2S Research Program. The results of the present study validated the wet H_2S test methods developed previously in that work and showed their applicability to refinery wet H_2S service conditions.

2.0 Introduction

Presented herein is the final report for a research program conducted at CLI *International* as contractor to The Materials Properties Council, Inc. (MPC). The program was jointly funded by MPC, its Fitness-for-Service sponsor group and the Refining Division of the American Petroleum Institute (API). DNV Industry Inc. provided nondestructive services for WFMPT, UT and AE inspection as well as nondestructive test data analysis. Chicago Bridge and Iron fabricated the wet H_2S full-scale test vessel. This report contains a comprehensive summary of the test facilities and experimental methods, pertinent findings and analysis of the test results.

2.1 Background

Refinery equipment in wet H_2S service is characterized by exposure to aqueous process environments containing hydrogen sulfide. Systematic inspection programs conducted by petroleum companies have shown that wet H_2S refinery processes can provide conditions for hydrogen charging of steel and widespread cracking of carbon steel equipment.[1,2] The results of operating experience surveys and technical investigations have described situations where carbon steel equipment exposed to wet H_2S environments may be susceptible to cracking via hydrogen induced cracking (HIC), stress oriented hydrogen induced cracking (SOHIC) and/or sulfide stress cracking (SSC).[3–6] In some cases, cracking has been found to be minimal, resulting in no significant effect on equipment integrity or serviceability. In other cases, widespread cracking initiates and/or cracks propagate to a substantial degree thus limiting the residual load and pressure capabilities of the affected equipment.

Prior to the initiation of this program, MPC organized a research program on wet H_2S cracking of steels sponsored by more than twenty major petroleum companies, steel manufacturers and equipment fabricators. This program was aimed at (1) the development of screening procedures for evaluation of steels, (2) the determination of the influence of metallurgical processing and welding variables, and (3) the better understanding of the roles of stress, environment composition and temperature. It has provided valuable fundamental information which has improved both the awareness of the causes of wet H_2S cracking and potential solutions in terms of both new construction and repair and remediation of existing equipment. However, there was a desire to validate the findings and conclusions of that program and to explore the complex interrelations of variables that can affect the actual behavior of large scale equipment used in wet H_2S service.

The present study was conducted to provide important information regarding the serviceability of welded steel equipment in wet H_2S service. Specifically, situations exist in refinery operations where it is necessary to assess equipment based on the fitness for continued service versus repair or replacement because of wet H_2S damage. Such an assessment requires information regarding (1) the nature of wet H_2S crack propagation, (2) the operational conditions that may affect wet H_2S damage, and (3) the ability to use nondestructive methods to assess the degree of cracking in operating equipment.

2.2 Goal

The overall goal of this program was to demonstrate the ability to characterize and monitor various aspects of crack propagation in pressurized process equipment exposed to wet H_2S environments. Specific aspects of wet H_2S cracking and crack monitoring were closely examined, namely:

1. Identification of the mechanical/environmental effects such as the role of internal pressure, pressure cycling and environmental severity.
2. Identification of active cracking sites in pressurized equipment using nondestructive evaluation (NDE) methods.
3. Assessment of the relative abilities of various NDE methods such as acoustic emission (AE), ultrasonics (UT), automated ultrasonics (AUT) and wet florescent magnetic particle techniques (WFMPT) versus destructive examination methods such as metallography.
4. Evaluation of fabrication and repair techniques with regard to their ability to reduce or prevent wet H_2S cracking, and to identify any procedures which may increase the susceptibility to cracking.

2.3 Technical Approach

To accomplish the goal and objectives of this program, a series of large scale exposure tests were conducted with a fabricated steel vessel [36 in. (90 cm) nominal outer diameter; 6 ft (1.8 m) long] made to ASME design requirements. The tests conducted during this program utilized a novel approach involving test specimens or "windows" fabricated from steel plates, welds, fittings and attachments using typical practices utilized in the construction and maintenance of refinery equipment. These windows were welded into the test vessel which contained pressurized wet H_2S test media.

2.4 Terminology

2.4.1 Wet H_2S Cracking Mechanisms. Wet H_2S cracking is a complex and often misunderstood phenomenon involving several fundamental cracking mechanisms. The complexities involved in developing a global understanding of wet H_2S cracking revolve around the fact that each cracking mechanism has different controlling metallurgical and environmental parameters as well as specific modes of attack. To properly present and discuss the results of this program, it is first necessary to clearly set forth the basic terminology related to the various mechanisms of wet H_2S cracking.

Wet H_2S cracking involves four types of mechanisms:

1. Hydrogen Blistering
2. Hydrogen Induced Cracking (HIC)
3. Stress Oriented Hydrogen Induced Cracking (SOHIC)
4. Sulfide Stress Cracking (SSC)

A brief discussion of each of these cracking mechanisms is presented below.

2.4.1.1 Hydrogen Blistering. Hydrogen blistering is the development of internal blisters in a steel caused by the accumulation of molecular hydrogen. The blisters usually occur at sites of large nonmetallic inclusions, laminations or other large metallurgical discontinuities in the steel. The blisters are oriented parallel to the surfaces of the steel. The molecular hydrogen which acts to initiate and propagate these blisters arises from the absorption and diffusion of atomic hydrogen produced on the steel surface by the sulfide corrosion process. No externally applied stress is required to produce hydrogen blistering.

2.4.1.2 Hydrogen Induced Cracking (HIC). HIC is a form of internal hydrogen damage caused by the development of small cracks oriented parallel to the surfaces of the steel. These cracks tend to link up with other cracks due to a build-up of internal pressure in the hydrogen damage zones in the steel and the resultant stress fields around the zones. This link-up of the cracks tends to produce the characteristic stepwise crack appearance. Similar to hydrogen blistering, no externally applied stress is required for the formation of HIC.

The link-up of the small blister cracks on different planes in the steel is often referred to as "stepwise cracking" to describe the characteristics of the crack appearance. The stepwise linkage of these cracks can have a major or minor effect on reducing the load (pressure) capabilities of the equipment depending on the nature of the linkage. HIC is commonly found in steels with moderate to high impurity levels which have a high density of elongated sulfide inclusions often found in fully (Al-Si) killed steels.

2.4.1.3 Stress Oriented Hydrogen Induced Cracking (SOHIC). SOHIC is the development of arrays of short cracks which are linked in the through-thickness direction. These arrays of cracks are typically aligned perpendicular to the tensile stress which can be produced by both applied mechanical and residual tensile stresses. SOHIC is commonly observed to occur in the heat affected zone (HAZ) microstructures in the base metal associated with fabrication and attachment welds. They may also be produced at high stress concentration points such as crack-like flaws, the tip of cracks produced by SSC in hard HAZ's or where HIC intersects the weld HAZ area.

2.4.1.4 Sulfide Stress Cracking (SSC). SSC is brittle cracking produced by a form of hydrogen embrittlement cracking under the combined action of tensile stress and aqueous corrosion in the presence of hydrogen sulfide. SSC usually occurs in high strength steels or in high hardness regions of welds and HAZ's. SSC involves the interaction of the absorbed atomic hydrogen produced by the sulfide corrosion process with internal sites in the metal lattice. Such sites can be grain boundaries and inclusions. However, SSC is usually differentiated from HIC because it does not require the recombination of atomic hydrogen to form molecular hydrogen and the build-up of pressure at sites inside of the steel.

2.4.2 Steels. The present investigation involves the evaluation and testing of several types of steels which can be differentiated by the type of metallurgical processing which they receive during manufacturing. The following steels were tested:

1. Conventional Steel
2. Low Sulfur Conventional Steel
3. "HIC Resistant" Steel
4. Ultra-Low Sulfur Advanced Steel

The basic attributes of each of these steels is described below:

2.4.2.1 Conventional Steel. A conventional steel is a commercially produced steel which is either hot rolled or normalized (e.g., ASTM A516-70). It has generally moderate to high levels of impurities, particularly sulfur (i.e., ≥ 0.010 wt. percent sulfur). This type of material generally has a high susceptibility to HIC in most hydrogen charging environments even under moderate exposure conditions.

2.4.2.2 Low Sulfur Conventional Steel. A low sulfur conventional steel is a commercially produced material which contains lower than normal levels of sulfur (i.e., 0.003–0.010 wt. percent). This material can exhibit improved mechanical properties over conventional steels, but typically has not been processed to specifically exhibit high resistance to HIC. These steels can still show significantly high susceptibility to HIC even in moderate service environments.

2.4.2.3 "HIC Resistant" Steel. The term "HIC resistant" steel is used by manufacturers and users to denote conventional grades of steel (e.g., ASTM A516-70) which have been metallurgically processed to enhance their resistance to HIC. Such processing typically includes ultra-low sulfur levels (i.e., ≤ 0.002 wt. percent sulfur), normalizing heat treatments to modify the hot rolled microstructure and possibly Ca additions to produce sulfide shape control. Shape control is important in that it produces sulfides of spherical morphology which reduce localized stresses in the vicinity of the inclusion, compared to the elongated stringers found in conventional steels. These steels are often tested to evaluate HIC resistance using conventional or modified NACE TM0284 methods for the purposes of lot acceptance or for supplemental information. These steels typically have improved resistance to HIC as compared to conventional steels; however, they may still show some degree of susceptibility to HIC and SOHIC in severe wet H_2S service conditions.

2.4.2.4 Ultra-Low Sulfur Advanced Steels. Ultra-low sulfur advanced steels are those made by modern steelmaking and processing techniques. These steels typically have ultra-low levels of sulfur (e.g., ≤ 0.002 wt. percent sulfur) and low carbon equivalents compared to conventional steels of comparable tensile strengths (i.e., ASTM A516-70). Steels in this category are currently made to ASTM A841 by thermo-mechanically controlled processing (TMCP) and/or accelerated cooling techniques. Also, they have reduced carbon levels as compared to conventional steels to produce ferritic or ferritic/bainitic microstructures with little or no microstructural banding.

2.4.3 General Terminology. The following terms are used throughout the context of this report and are defined here for clarity.

2.4.3.1 Crack Length Ratio (CLR). The crack length ratio or CLR provides a measure of the materials resistance to HIC as defined in NACE Standard TM0284-87. CLR is determined by summing the lengths of each crack array and dividing by the section width and multiplying by 100 to express it as a percentage. This is shown schematically in Fig. 2-1.

2.4.3.2 Crack Thickness Ratio (CTR). The crack thickness ratio or CTR also provides a measure of the materials resistance to HIC as defined in NACE Standard TM0284-87. CTR is determined by summing the thicknesses of each crack array and dividing by the section thickness and multiplying by 100 to express it as a percentage. This is shown schematically in Fig. 2-1.

2.4.3.3 Crack Sensitivity Ratio (CSR). The crack sensitivity ratio or CSR also provides a measure of the materials resistance to HIC as defined in NACE Standard TM0284-87. CSR is determined by summing the products of the length and thicknesses of each crack array and dividing this sum by the product of the section length and thickness and multiplying this value by 100 to express it as a percentage. This is shown schematically in Fig. 2-1.

2.4.3.4 Longitudinal–Transverse (LT) Section. A longitudinal–transverse or LT section is a metallographic section in which the perpendicular to the polished face is parallel to the longitudinal or rolling direction.

2.4.3.5 Transverse–Longitudinal (TL) Section. A transverse–longitudinal or TL section is a metallographic section in which the perpendicular to the polished face is perpendicular to the longitudinal or rolling direction.

3.0 Experimental Procedures

The materials evaluated in this program along with specimen configurations, general conditions of exposure, and post-exposure evaluations conducted are summarized below. Specific conditions of exposure time, pressure, and environmental severity of each test are presented in the respective appendix (Appendices I–VI) for each particular vessel exposure.

3.1 Materials Evaluated

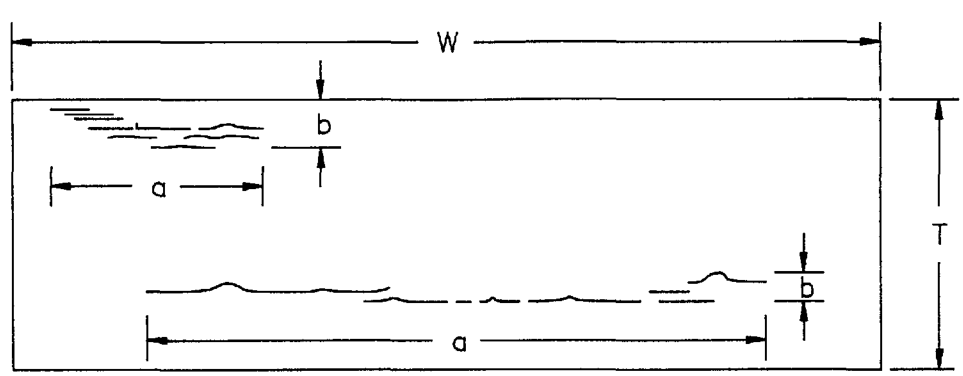
The present investigation involved the testing and evaluation of the following steels:

1. Conventional Steel
2. Low Sulfur Conventional Steel
3. "HIC Resistant" Steel
4. Ultra-Low Sulfur Advanced Steel
5. ASTM A53 ERW Pipe
6. ASTM A234 WPB Weld Cap
7. ASTM A105 Threadolets

The basic attributes of each of the first four steels listed were previously described in Section 2.3.2. The evaluation of the ASTM A53 ERW pipe, ASTM A234 WPB weld cap and ASTM A105 threadolet materials was limited to the final test to study the effect of nozzle attachments. The material compositions and mechanical property data for each of the base plate materials are presented in Table 3-1.

3.2 Specimen Configurations

As previously mentioned, the goals and objectives of this program were accomplished using a series of large scale tests on a 36 in. (90 cm) nominal diameter pressure vessel approximately 6 ft (1.8 m) long. The



$$\text{Crack Sensitivity Ratio, CSR} = \frac{\sum (a \times b)}{W \times T} \times 100$$

$$\text{Crack Length Ratio, CLR} = \frac{\sum a}{W} \times 100$$

$$\text{Crack Thickness Ratio, CTR} = \frac{\sum b}{T} \times 100$$

Method Of Measuring Stepwise Cracks

Fig. 2-1—HIC damage evaluation formulas given in NACE TM0284-87

Table 3-1—Material Summary

Steel No.	A	B	C	D	E	F	G
CLI#	2278	3201	2279	2098	3249	3250	2280
Grade	A516-70	A516-70	A516-70	A516-70	A841	A841	A516-70
C.E.	0.410	0.427	0.460	0.400	0.332	0.329	0.420
C	0.220	0.210	0.220	0.210	0.120	0.090	0.220
S	0.017	0.001	0.019	0.007	0.001	0.001	0.020
P	0.020	0.005	0.014	0.013	0.005	0.003	0.027
Mn	1.090	1.090	0.950	1.080	1.110	1.180	1.110
Cu	...	0.060	...	...	0.190	0.010	...
Ni	...	0.050	...	...	0.190	0.230	...
Cr	...	0.120	...	...	0.010	0.020	...
Mo	...	0.020	...	...	0.000	0.070	...
Ti	...	0.003	...	...	...	...	...
V	...	0.001	...	...	0.000	0.040	...
Nb	...	0.002	...	...	0.026	0.020	...
Si	0.260	0.260	0.190	0.210	0.270	0.250	0.270
Al	0.035	0.020	0.010	0.039	0.037	0.029	0.031
Ca							
Y.S.	48.2	49.6	57.3	47.6	61.4	67.0	52.0
U.T.S.	78.9	76.2	78.4	78.8	74.2	79.0	76.9
% Elong	25.0	27.0	23.0	45.0	26.0	25.0	42.0

vessel, shown in Fig. 3-1, was fabricated by Chicago Bridge and Iron (CBI Na-Con, Inc.) at its Houston location.

Each large scale test incorporated the use of a "window" specimen measuring approximately 2 ft by 2 ft (0.6 × 0.6 m). This approach is detailed schematically in Fig. 3-2. With the exception of the test window, the entire I.D. surface of the vessel was coated to protect the remaining vessel from damage. The coating chosen for this program was T31, ECTFE material. The T31 process is comprised of a primer and multiple topcoats of a partially fluorinated copolymer. The T31 coating is a true thermoplastic and was applied in this application in the thickness range of 0.015–0.025 in. (0.38–0.64 mm).

During insertion of the test window into the vessel, the coated area in the vicinity of the weld underwent localized damage. The weld around the window and any additional damage areas caused by excessive heat, arc strikes, etc., were repaired with a modified thermoplastic hand-applied coating. Both coatings utilized in this program were successful in protecting

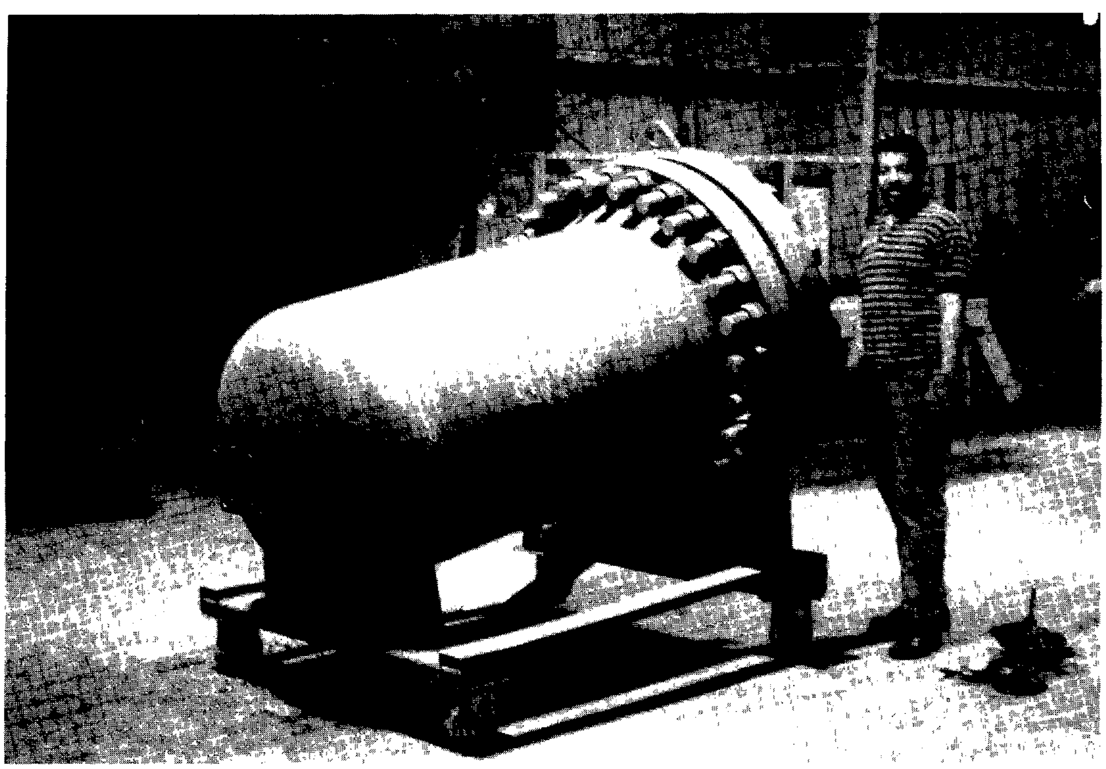


Fig. 3-1—Pressure vessel used for this study (PN 3040-1)

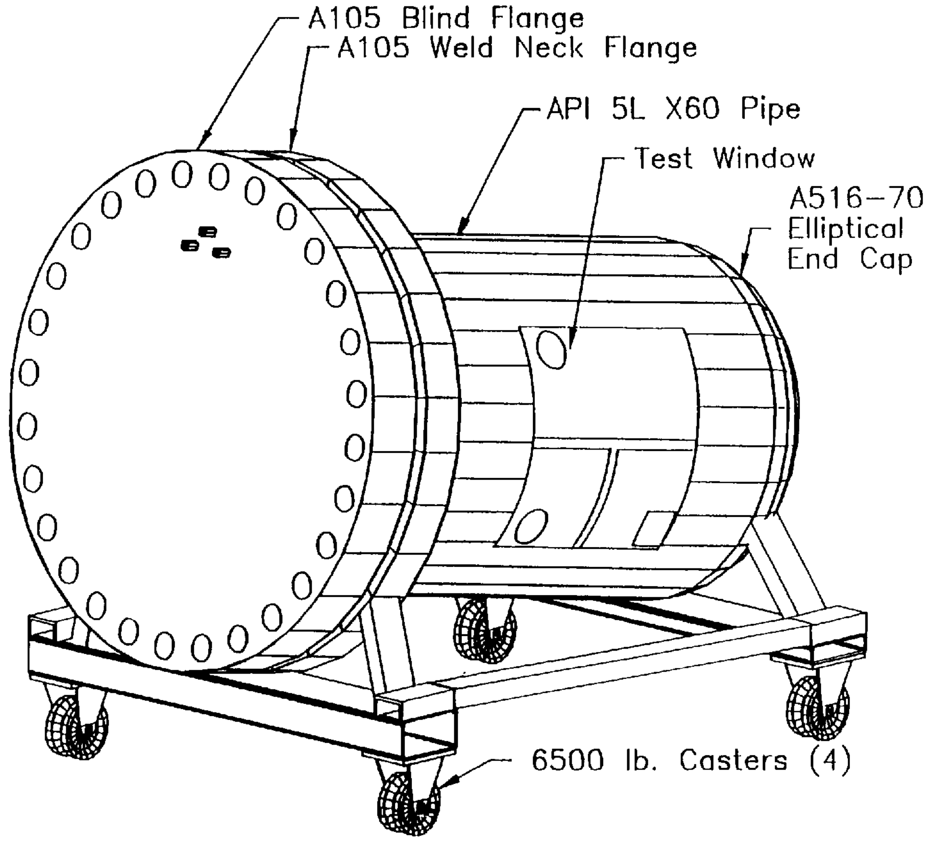


Fig. 3-2—Schematic of pressure vessel detailing materials used

the vessel from damage for the total duration of testing.

The test windows were fabricated as follows. The plate steels were cold rolled to the appropriate radius, and tacked together with strips or "strong-back" welds. Each window typically had a 2 ft (0.6 m) longitudinal weld and a 1 ft (0.3 m) girth or circumferential weld. The parameters used for welding are documented in Table 3-2.

The various test windows also contained: (1) Charpy notches and low heat input weld beads to assist in initiating cracking, (2) Cu plating on the O.D. surface of the window to act as a hydrogen barrier, (3) external hydrogen charging, (4) penetrations to allow cathodic charging on the I.D. surface, and (5) nozzle attachments. The details of the individual test windows evaluated are presented in the six appendices attached to this report.

Limited experiments using standard NACE TM0177 SSC specimens (see Fig. 3-3) and one-side exposed 6 in. × 6 in. (15 × 15 cm) plate samples (see Fig. 3-4) were also utilized to assist in obtaining the characteristic cracking AE responses of SOHIC and HIC, respectively.

3.3 Experimental Overview

Several aspects of the experimental procedures are common to all of the experiments such as solution, temperature, etc. These common variables are first addressed followed by a brief discussion of the particular variables which are unique to each experiment.

The test solution for all but one of the evaluations corresponded to NACE TM0177-90, Method A solution (0.5 wt. percent glacial acetic acid, 5.0 wt. percent sodium chloride in distilled water). The solution was saturated with H_2S and maintained at a hydrogen sulfide concentration of approximately 1600–2000 ppm throughout the test duration. One of the evaluations conducted slowly increased the severity of the test environment in several stages by decreasing the pH and increasing the H_2S concentrations of the test solution. The details of this environment will be described later.

All of the evaluations were conducted at room temperature. The test durations ranged from less than 4 days for conditions of rapid failure to 5 weeks for the staged and prolonged experiments.

Efforts were made to measure the residual strain from initial window fabrication to insertion into the test vessel. However, problems with the strain gages during fabrication and welding of the windows prevented quantitative measures. Biaxial strain measurements were conducted on both the vessel and window during the hydrotest to calculate the corresponding outer fiber stresses of the window and the vessel.

The test pressure was applied hydrostatically. Operating pressures in the range of 0–850 psi were examined. H_2S concentration and solution pH were monitored throughout the test period. No depletion in H_2S concentration was observed during the tests due to the high ratio of solution volume to exposed

Table 3-2—Welding Summary

Procedure Specification

Material Specification	A516-70
Welding Process	FCAW/SAW/GMAW
Manual or Machine	Manual and Machine
Position of Welding	Flat
Filler Metal Specification	A5.29/A5.23
Filler Metal Classification[a]	E71T1/E76A6-EG-G/ER-705-2
Flux	Lincoln 880M
Shielding Gas	75% CO_2/25% AR
Flow Rate	40 cfh
Single or Multiple Pass	Multiple
Single or Multiple Arc	Single
Welding Current	DC
Polarity	RP
Welding Progression	N/A
Root Treatment	Back gouge/Grind to clean metal
Preheat or Interpass Temperature	100°F min.–150°F max.
Postheat Treatment	N/A

Welding Procedure

			Welding Current			
	Pass No.	*Electrode Size*	*Amperes*	*Volts*	*Travel Speed*	*Joint Detail*
Side 1	1–2	0.052	200	25	7.54 IPM	
	3–4	3/32	300	31	14 IPM	B-12C-2
Side 2	1	0.052	200	25	7.5 IPM	
10 KJ Weld	1–2	0.035	110	8	12	

[a] Applicable only when filler metal has no AWS classification: FCAW Trimark E71T1; SAW LA71 880 M; GMAW ER-705-2.

steel surface area used in these experiments. The solution pH on all but one of the exposures ranged from 2.7 at the initiation of the test to 3.5 at test completion. Hydrogen flux was monitored with a patch probe affixed to the vessel window.

The nondestructive evaluation services included AE, UT, AUT and WFMPT. The AE monitoring was used to assess cracking activity both in terms of locating active sites and distinguishing between blister cracking and through-wall cracking. Fig. 3-5

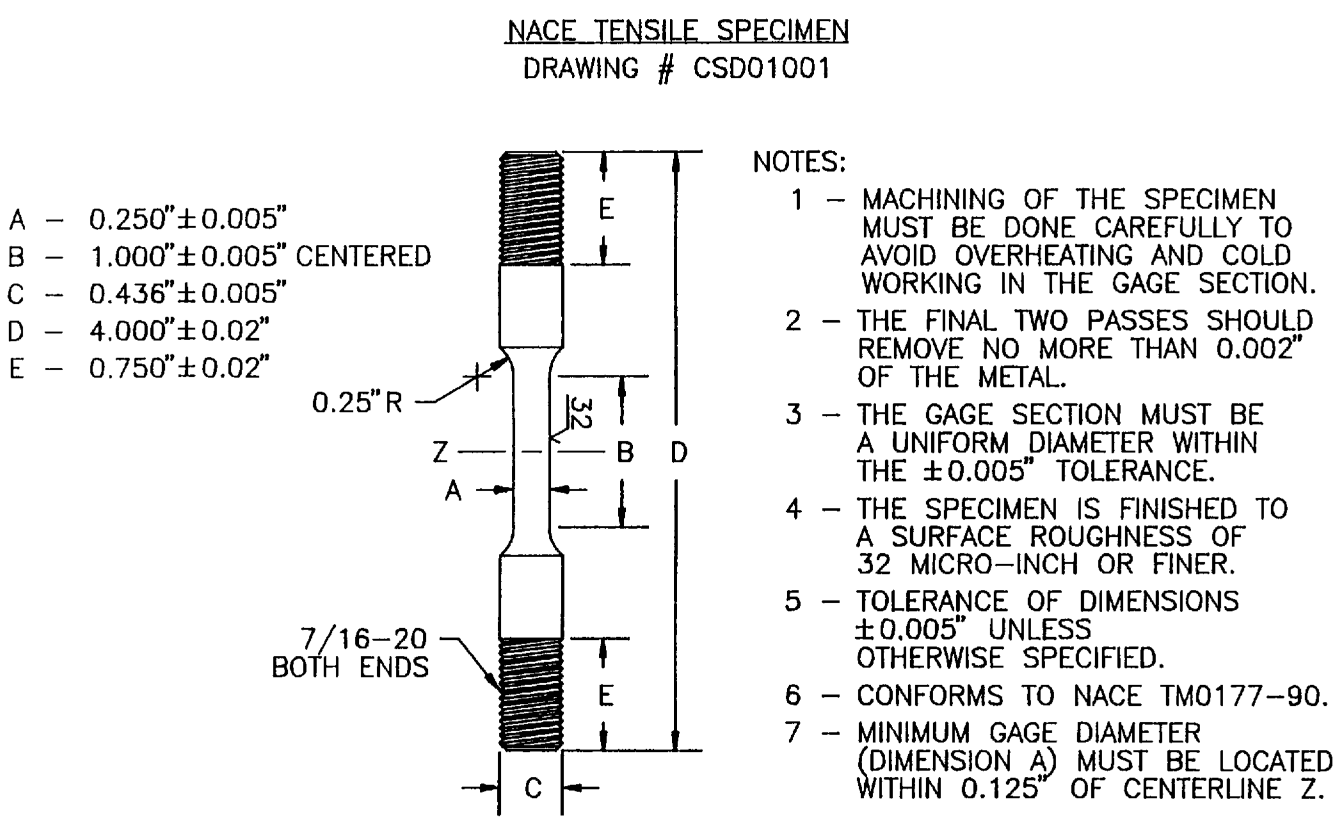


Fig. 3-3—Standard SSC specimen per NACE TM0177-90, Method A

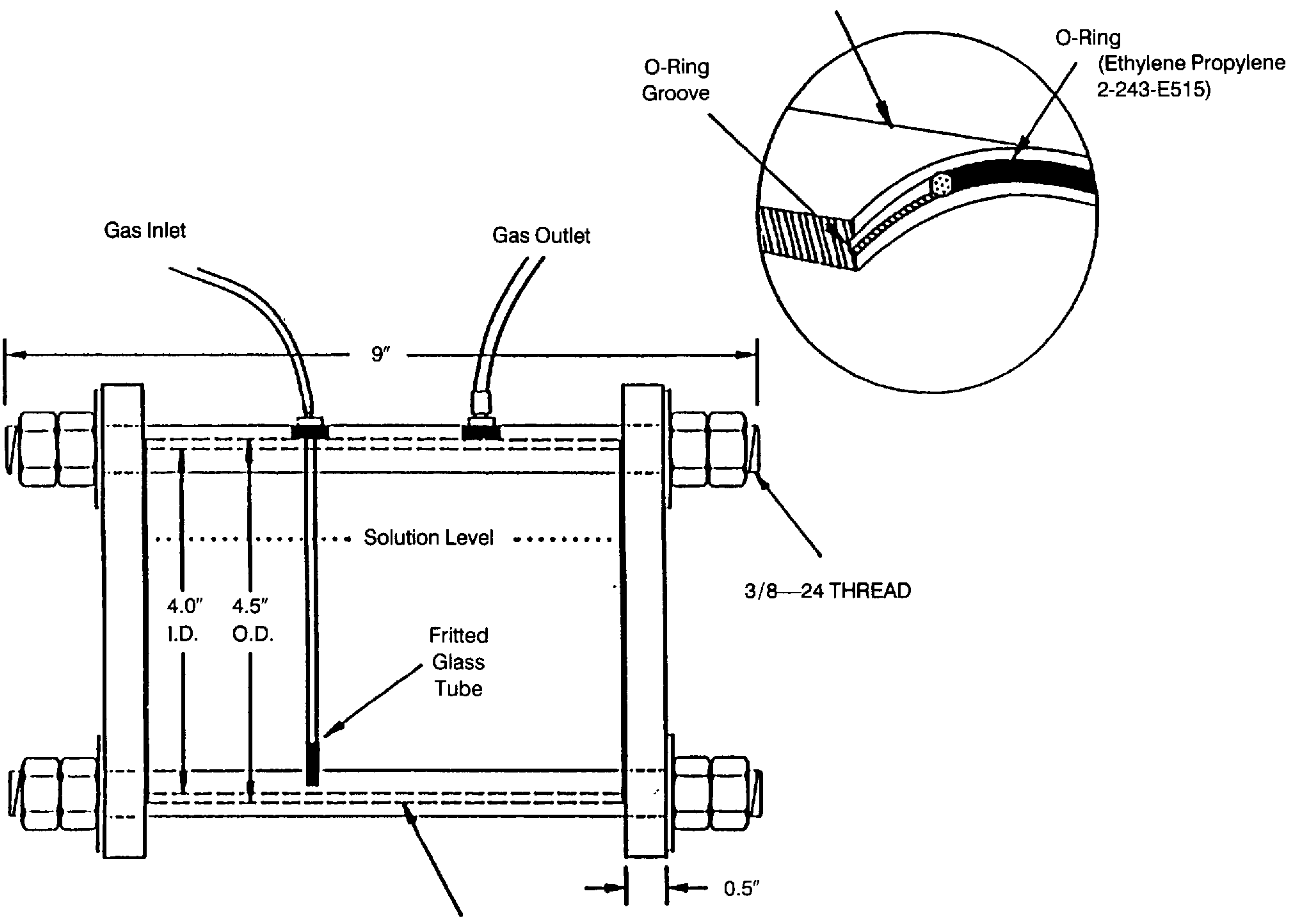


Fig. 3-4—Test fixture used to isolate HIC AE response

shows the AE instrumentation and external hydrogen patch probe used on the test window. Periodic inspection of the window with AUT (T-scan and P-scan) was also conducted to monitor the crack propagation in terms of affected area and through-wall severity. When necessary, crack sizing was conducted using manual sizing UT methods. WFMPT was conducted after cleaning the I.D. surface with a 60-grit flapper wheel to reveal surface crack indications.

Cathodic charging was utilized on two of the evaluations to further increase the severity of the hydrogen charging at the I.D. of the test window or to increase the hydrogen content at the O.D. surface of the test window. Using internal hydrogen charging, levels of charging were produced that were between two to three times those normally obtained in NACE TM0177-90, Method A solution.

3.3.1 Evaluation of Plate Containing Pre-existing HIC Damage. The test window used in this evaluation (see Appendix I) was pre-exposed for 30 days to NACE TM0177-90, Method A solution under one-side exposure conditions to produce pre-existing HIC damage prior to testing in the vessel configuration. The exposure was one-sided in nature and was successful in creating extensive HIC damage from the I.D. to mid-wall. Metallographic sections were taken from the edge of the pre-exposed window prior to insertion in the test vessel. These sections were evaluated for HIC damage using the formulas given in NACE TM0284 for the calculation of crack length ratio (CLR), crack thickness ratio (CTR) and crack sensitivity ratio (CSR) (see Fig. 2-1). Crack ratios were calculated and location codes given based on cracking observed in the full thickness, ⅔ thickness and ⅓ thickness as shown in Fig. 3-6 using techniques developed in prior MPC sponsored research.

Following exposure in the test vessel at pressures ranging from 400–800 psi over a period of 14 days, strips were sectioned from the plate for further metallography and to measure the remaining strength in both the longitudinal and hoop directions. The remainder of the test window was left intact for an ultrasonic round robin program to be conducted later.

3.3.2 Evaluation of Plate Containing Hard Welds (HRC 22-30). The test window used in this evaluation contained hard welds in both the longitudinal and hoop directions of a conventional steel plate. No pre-exposure was conducted prior to testing; consequently no pre-existing HIC damage was pre-

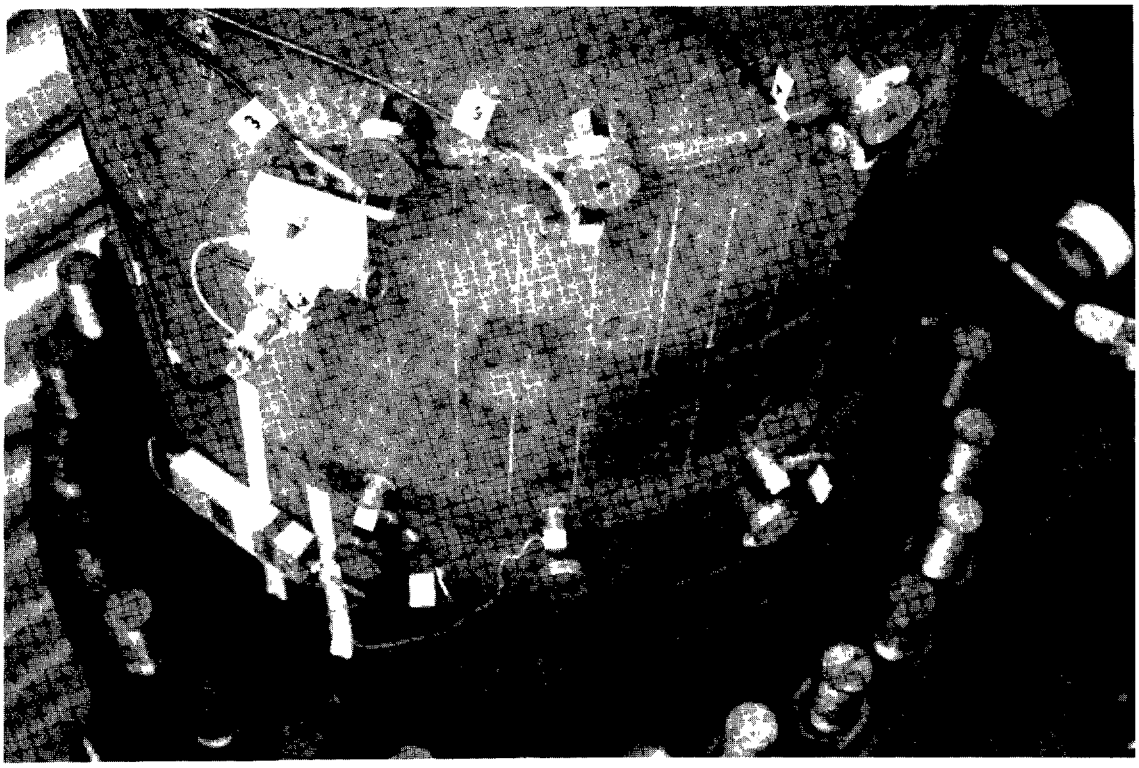


Fig. 3-5—AE instrumentation and external hydrogen patch probe

sent in the window. A schematic of the test window is presented in Appendix II.

The test was initiated and pressurized to 400 psi and allowed to hold for several days. In less than four days a crack emanated through-wall along the girth weld of the window. The crack was completely contained within the hard weld deposit.

A patch containing the full crack was removed and sectioned for metallographic examination and crack measurements. A failure analysis was conducted on the section.

3.3.3 Evaluation of the Repair of a HIC Damaged Vessel. In order to attain information on the repair of H_2S damaged steel vessels, a patch of "HIC resistant" steel, which was found to exhibit a limited degree of cracking susceptibility in prior laboratory tests, was welded into the previous window. The remaining longitudinal weld which was not contained within the removed patch was ground out ⅛ in. from the I.D. to remove the hard weld deposit and rewelded with E7018. The heat from this welding also served to temper and reduce the hardness of the remaining ⅜ in. of weld deposit. A schematic of this window is shown in Appendix III.

The window was exposed in the vessel for 28 days. Following the exposure of this window in the test vessel, the window was WFMPT to reveal any I.D. connected cracks. Extensive sectioning was also conducted to quantify the extent of cracking.

3.3.4 Simulation of the Cracking Behavior of Thick Plate. In order to simulate the effects of thicker material, an electroplated Cu patch was put on the window O.D. which should act as an external hydrogen barrier and increase the hydrogen concentration under the plating. The expectation was that this would allow HIC to progress past the mid-wall and potentially simulate the hydrogen gradient and cracking response of a thicker wall vessel. The materials chosen and window configuration are presented in Appendix IV.

This window was exposed in the vessel for 28 days. Following testing, the window was extensively sectioned and metallographically examined. Strip tensile and Charpy specimens were also removed and tested to determine residual properties.

3.3.5 Evaluation of HIC Resistant Plate/I.D. Surface Cleaning/Severe Hydrogen Charging Conditions. The window chosen for this evaluation is presented in Appendix V. The material chosen represents HIC resistant material, including a TMCP grade steel. The window also contained two electroplated Cu patches to simulate the behavior of thicker plate.

The environmental severity of this test was slowly increased over the 33 day test duration. The increase was conducted in eight stages. The solution ranged from pH 4.4 at the beginning of the exposure (Stage 1) to pH 3.0 at test conclusion (Stage 8). The test was interrupted between Stages 7 and 8 at which point the I.D. surface of the window was cleaned, WFMPT, and re-exposed to fresh TM0177-90, Method A test solution saturated with H_2S at ambient temperature and pressure. Extensive AUT and AE monitoring were conducted during this exposure sequence. Following the test, the window was extensively sectioned and metallographically examined.

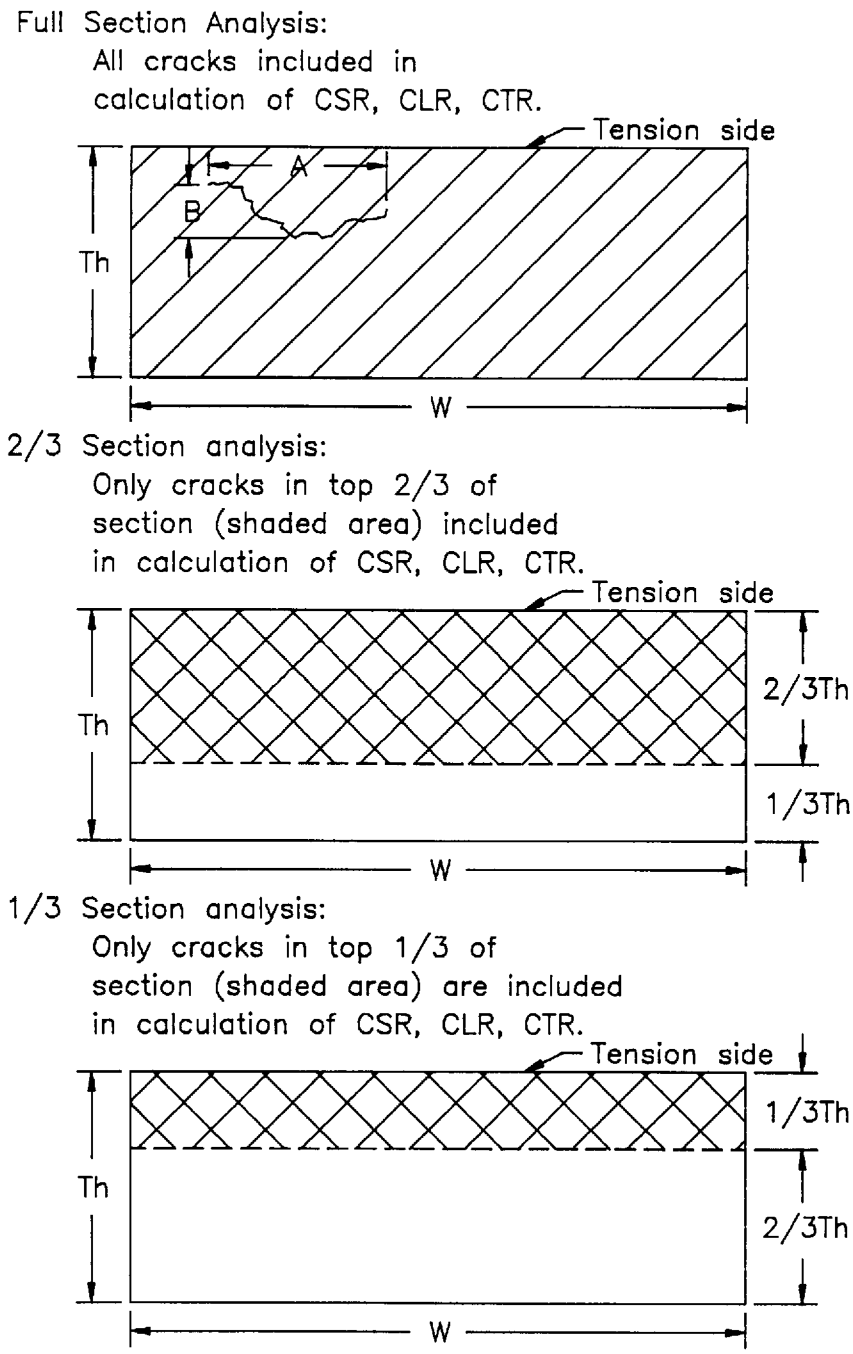


Fig. 3-6—Location coding used to present detailed HIC data

3.3.6 Evaluation of Nozzle Attachments/Effect of PWHT. The window chosen for this evaluation is presented in Appendix VI. This window incorporated several test variables including PWHT versus non-PWHT nozzle attachments, PWHT of the longitudinal seam weld, single-V versus double-V weld geometries of the nozzle attachments (see Fig. 3-7), and as-welded threadolets on the nozzles and weld caps. The environment corresponded to standard NACE TM0177-90, Method A solution. The test exposure lasted 24 days. Following testing, the window was WFMPT, manually sized for flaws using UT, and extensively sectioned for metallographic examination.

3.3.7 Verification of AE Signature for Hydrogen Blistering and SSC. In conjunction with the API full scale vessel testing, an additional experiment was conducted which measured the AE behavior of an unstressed plate material subjected to a sour environment. In this experiment, sections of plate steel similar to that used in the vessel experiments were exposed to NACE TM0177-90, Method A solution. This exposure was conducted on one side only with no applied stress. Under these conditions, the cracking should have been predominately HIC. The AE data from this experiment were compared to those obtained from previous vessel tests with applied stress. This analysis was used to help distinguish between

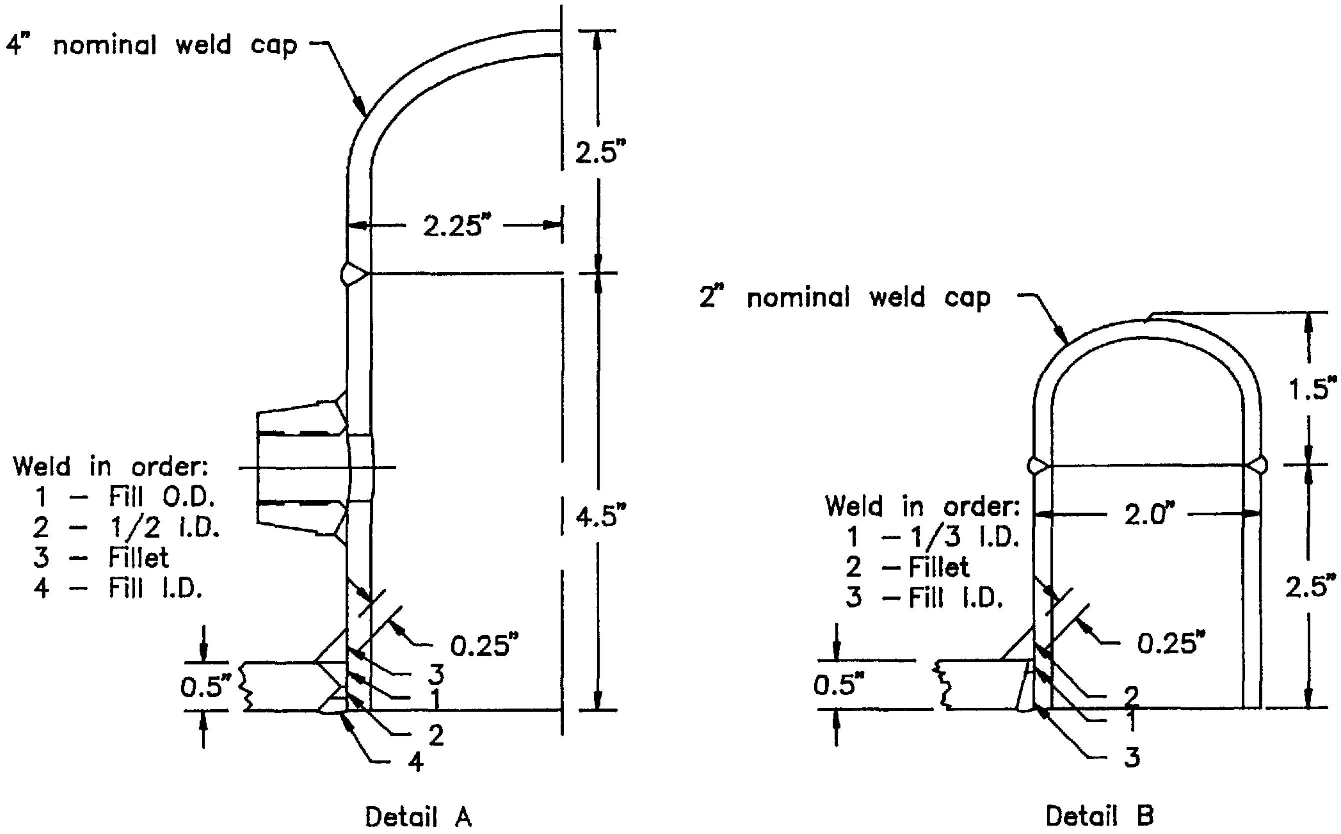


Fig. 3-7—Single-V and double-V attachment weld configurations

HIC and through-wall cracking by SOHIC. A schematic of the experimental set-up was previously shown in Fig. 3-4.

Another experiment was conducted to measure the AE behavior of SSC specimens subjected to an applied tensile stress and exposed to a NACE TM0177-90, Method A environment. The AE data from this experiment were compared to those obtained from previous vessel tests with applied stress.

4.0 Results and Discussion

The findings of this investigation have been evaluated based on their relevance to the serviceability of refinery wet H_2S equipment. For clarity, the test results and the findings they support have been separated into the following categories:

1. Materials Selection
2. Fabrication
3. Inspection
4. Vessel Design and Integrity

4.1 Materials Selection

4.1.1. Ultra-low sulfur steels (i.e., ASTM A516-70 and A841 with $\leq$0.002 wt. percent sulfur) exhibited higher resistance to HIC than conventional and low sulfur conventional steels.

It was shown that the ultra-low sulfur steels had generally fewer HIC indications, as observed by both AUT T-scan (Figs. 4-1a and 4-1b) and by metallographic sectioning (Appendix V and VI) than found in conventional steels which were very susceptible to HIC in the NACE TM0177 solution environment. The ultra-low sulfur ASTM A516-70 steel was found to have small isolated areas of HIC while the ASTM A841 steel produced by thermo-mechanically controlled processing (TMCP) was essentially free of HIC in the bulk plate. By comparison, the number of HIC indications found in low sulfur conventional ASTM A 516-70 steel was considerably greater. In conventional ASTM A516-70 steel with even higher sulfur content, the cracks produced by HIC were larger than in the lower sulfur materials.

4.1.2. The susceptibility of the base metal to HIC and SOHIC decreased with a corresponding decrease in sulfur content and decrease of microstructural banding. This was observed at the standard NACE TM0177 hydrogen charging conditions and at very severe hydrogen charging conditions, i.e., two to three times NACE TM0177 levels. The exposure to very severe hydrogen charging conditions did produce substantial SOHIC adjacent to the welds in all materials including the ultra-low sulfur steels. This is further discussed in Sections 4.2.6 and 4.4.3.

Fig. 4-2 shows the percent CTR as a function of steel type, sulfur content and banding index in accordance with ASTM E1268. While two data points were not available to complete the spectrum, there still exists a strong correlation amongst the variables. The maximum base metal CTR values observed decreased with a corresponding decrease in sulfur content and decrease of microstructural banding at both the standard NACE TM0177 hydrogen charging conditions and at very severe hydrogen charging conditions, i.e., two to three times NACE TM0177 levels. The maximum resistance to cracking was observed in the TMCP A841 steels with a sulfur content of 0.001 wt. percent and banding index of 0.20.

The above mentioned trends only represent the behavior of the base metal at stress levels ranging from 60–80% of the specified minimum yield strengths. The behavior of the steels at areas of high residual tensile stress such as at weldments or areas containing local stress concentrations may in many situations produce more severe cracking with respect to SOHIC. Fig. 4-3, obtained from the literature,[7] shows the effect of sulfur content on the time-to-failure of linepipe steels under various levels of applied tensile stress. It indicates that the susceptibility to SOHIC, as determined by time-to-failure, increases with decreasing sulfur content, in particular at the higher applied stress levels. Therefore, the lower sulfur content, while decreasing susceptibility to HIC, may under very severe environments and high applied or residual tensile stress produce an increased susceptibility to SOHIC. This topic is addressed further in Sections 4.2.6 and 4.4.3.

4.1.3. Based on both UT and metallographic sectioning, the only steels to exhibit no HIC in the base metal were the TMCP steels (i.e., ASTM A841). Both low sulfur and ultra-low sulfur A516-70 steel exhibited low levels of HIC which increased with sulfur content.

As previously shown in Figs. 4-1a and 4-1b, supported by metallographic sectioning results (Appendix V and VI), the TMCP appears to resist HIC even under very severe conditions of hydrogen charging. Under similar conditions, the HIC resistant and low sulfur conventional steels exhibited significant levels of HIC.

4.1.4. ASTM A 53 ERW pipe used in the nozzles did not exhibit HIC. However, the ASTM A234 WPB weld cap material did exhibit substantial HIC.

Fig. 4-4 shows the nature of the HIC observed in the ASTM A234 WPB weld cap. The cracking was at a significantly high level as determined by metallographic sectioning (Appendix VI), but had a different character than the HIC found in conventional steels made to similar impurity levels. The HIC was not restricted to planar cracks as commonly observed in plate materials. Due to the variations typically found in the ASTM A 53 steels, the crack-free behavior of the ASTM A 53 evaluated in this study may not be typical of all materials made to this specification.

4.2 Fabrication

4.2.1. Welds made with low heat input (i.e., single pass welds made with heat input ≤ 10 kJ/in.) were found to increase the presence of SOHIC in the HAZ of the base metal adjacent to the low heat input welds.

In the present study, through-thickness cracking resulting from SOHIC was predominantly found to occur in the base metal adjacent to the weld in the heat affected zone rather than in the bulk plate material. Where low heat input welds were tested without PWHT, an increase in susceptibility to SOHIC was observed. Fig. 4-5 shows the comparison of the cracking severity in terms of CTR values in the vicinity of the low heat input welds on the I.D. of the specimen versus that observed for the fabrication weld without the low heat input weld. The CTR value on the I.D. ⅓ section of the plate in the area of the low heat input weld was over eight times greater than the value in the comparable location without the low heat input weld. The reason for this increase appears to be related to at least two factors: (1) the locally high hardness which can produce a stress concentrator resulting from SSC, and (2) the locally high residual tensile stress which can also exist in the area of the low heat input weld.

4.2.2. SSC initiating from localized hard weld zones on the exposed surface of conventional steels was found to propagate into the softer base metal via SOHIC. However, these cracks only propagated to the extent of the HAZ.

Fig. 4-6 shows an example of the situation mentioned above. As represented in Fig. 4-6, many instances of cracking were observed where low heat input welding initiated cracks on the I.D. of the vessel as a result of SSC. However, the extent of subsequent propagation of these cracks in conventional steels by SOHIC was generally limited to a region within the HAZ of the base metal adjacent to the weld.

4.2.3. SSC initiating from localized hard zones on the exposed surface of "HIC Resistant" and TMCP steels was also found to propagate into the softer base metal via SOHIC. However, in these steels the cracks generally propagated *past* the extent of the HAZ.

Ultra-low sulfur steels (i.e., "HIC Resistant" A516-70 and A841 TMCP Steels) tested in this program also exhibited propagation of SSC cracks from low heat input welds. However, in contrast to the cracking behavior for conventional steels mentioned previously (Section 4.2.2), subsequent crack growth via SOHIC in these materials propagated beyond the extent of the HAZ (See Fig. 4-7).

4.2.4. When hard welds (i.e., >22 HRC or >240 BHN) were used in the vessel fabrication, the cracking mechanism which led to complete through-wall failure was SSC. Cracking occurred rapidly (<4 days) without producing SOHIC.

In one experiment, the test window was fabricated by a procedure which produced a hard weld metal deposit. The hardnesses were in the range of HRC 22–30. As shown in Fig. 4-8, complete through-wall cracking was observed which was completely confined to the weld metal. Crack propagation by SSC was rapid at relatively low levels of internal vessel pressure (i.e., 400 psi), and resulted in loss of pressure of the H_2S containing solution. This is the only case in the present study where a through-wall crack was obtained. No through-wall cracking was observed in other tests even where (1) substantial amounts of

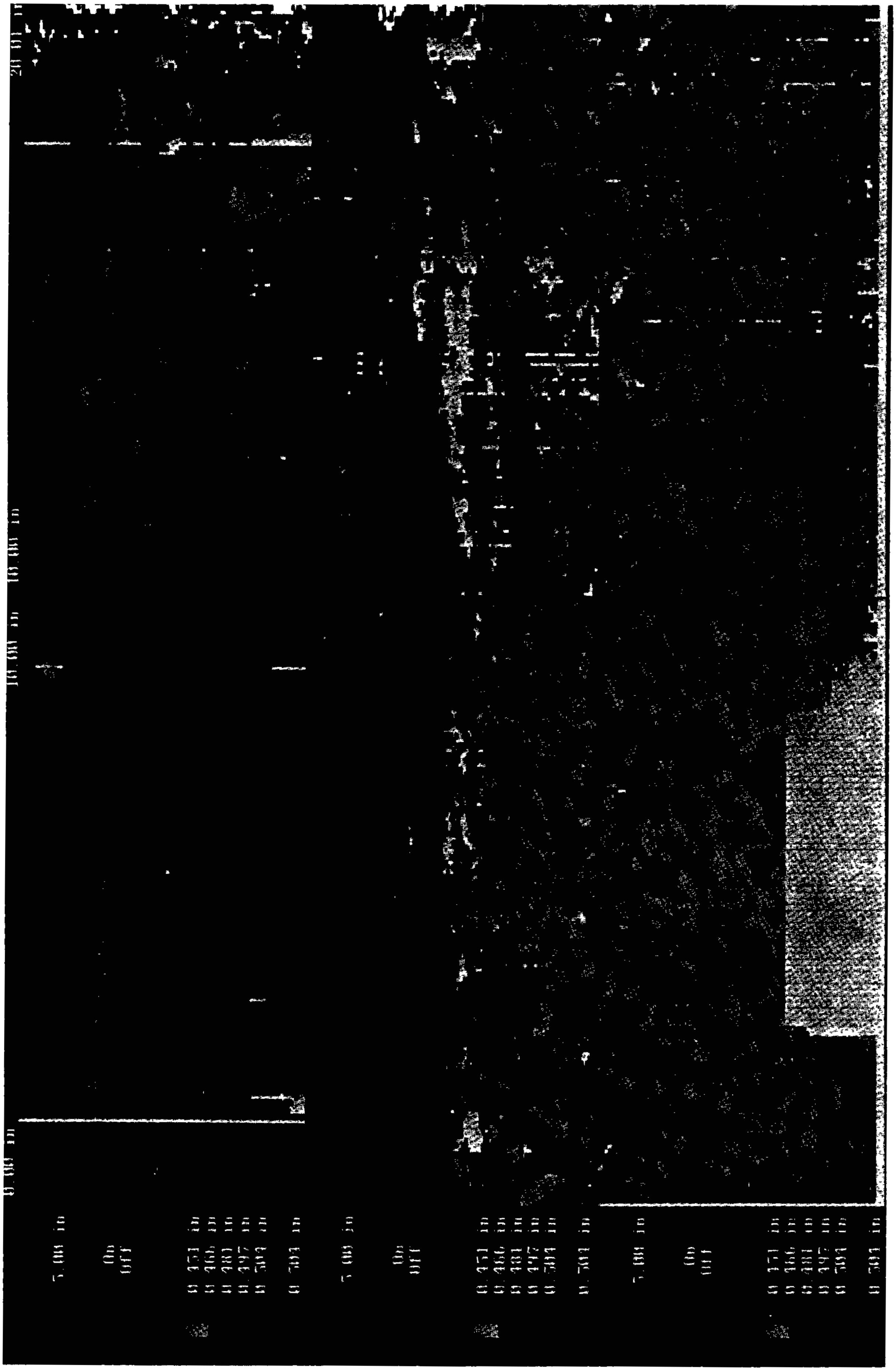


Fig. 4-1a—AUT T-scan data taken after Stage 7 of the environmental staging experiment

AUT T-SCANS

The print-outs of the AUT T-scans shown
in Figures 4-1a, 4-1b, and 4-15
are shown in full color on the following three pages.

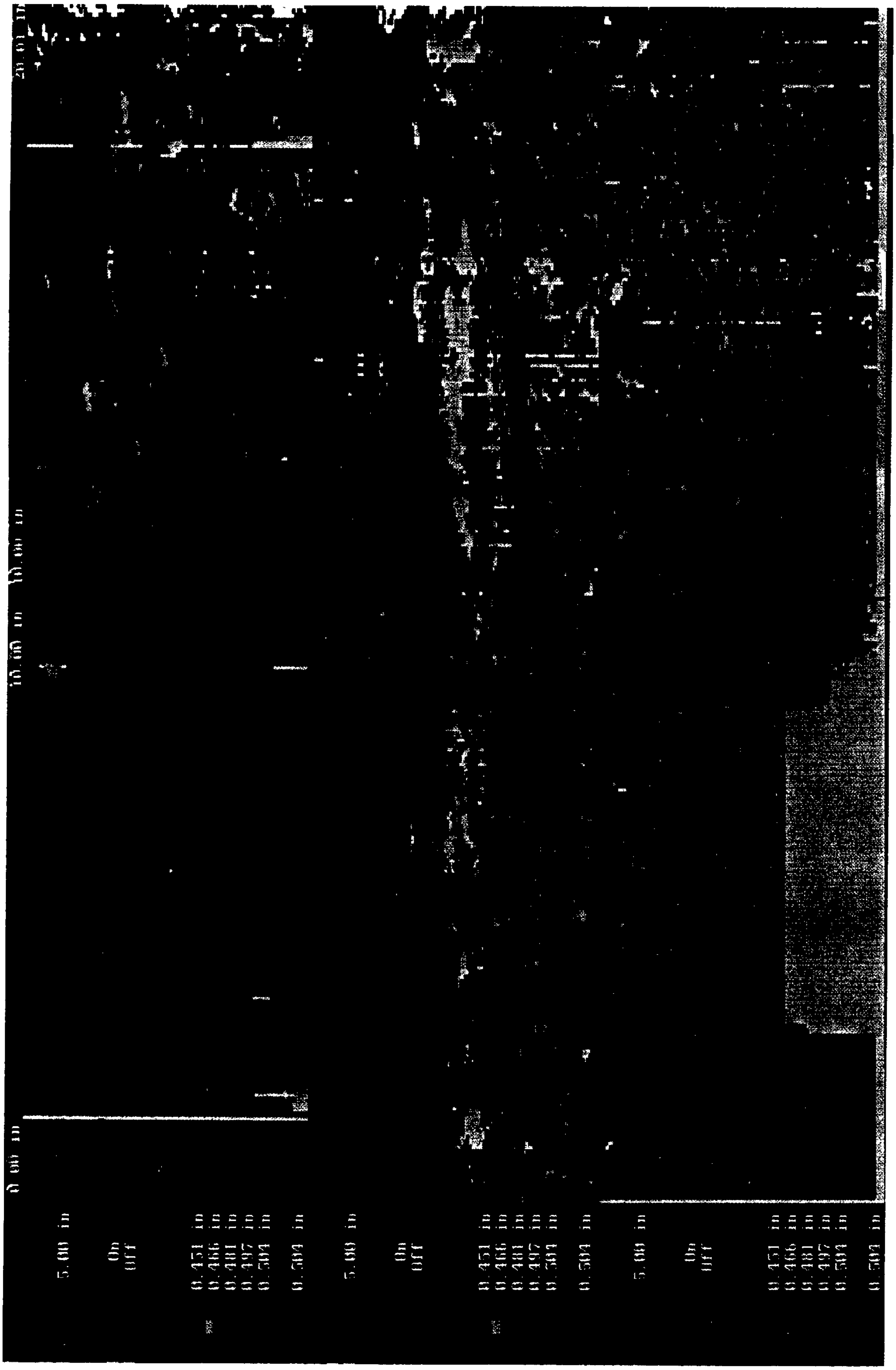


Fig. 4-1a—AUT T-Scan Data Taken After Stage 7 of the Environmental Staging Experiment

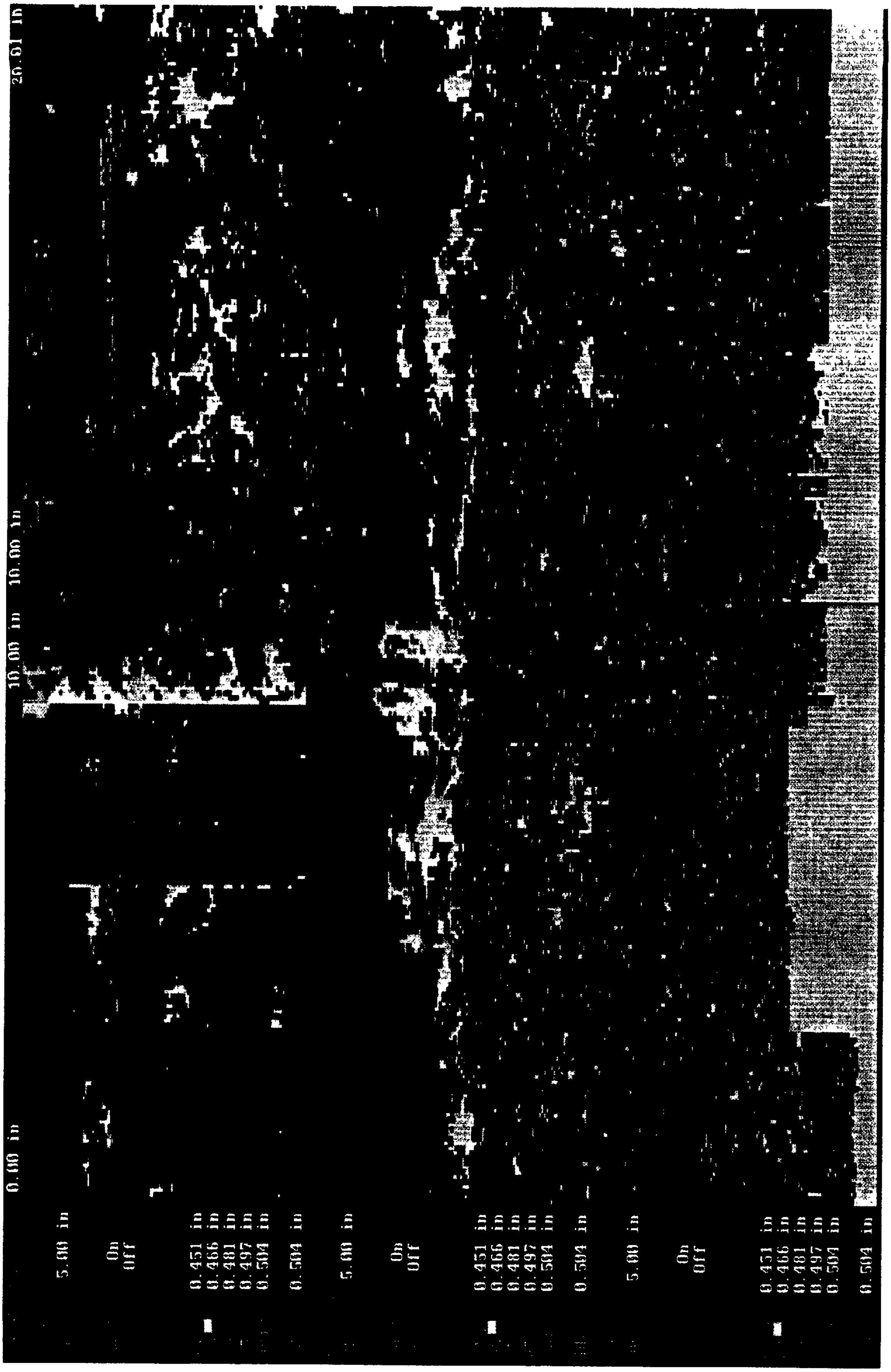


Fig. 4-1b—AUT T-Scan Data Taken After Stage 8 of the Environmental Staging Experiment

Fig. 4-15—AUT T-Scan Data Taken at the Conclusion of the Simulation of Thick Plate Behavior Evaluation

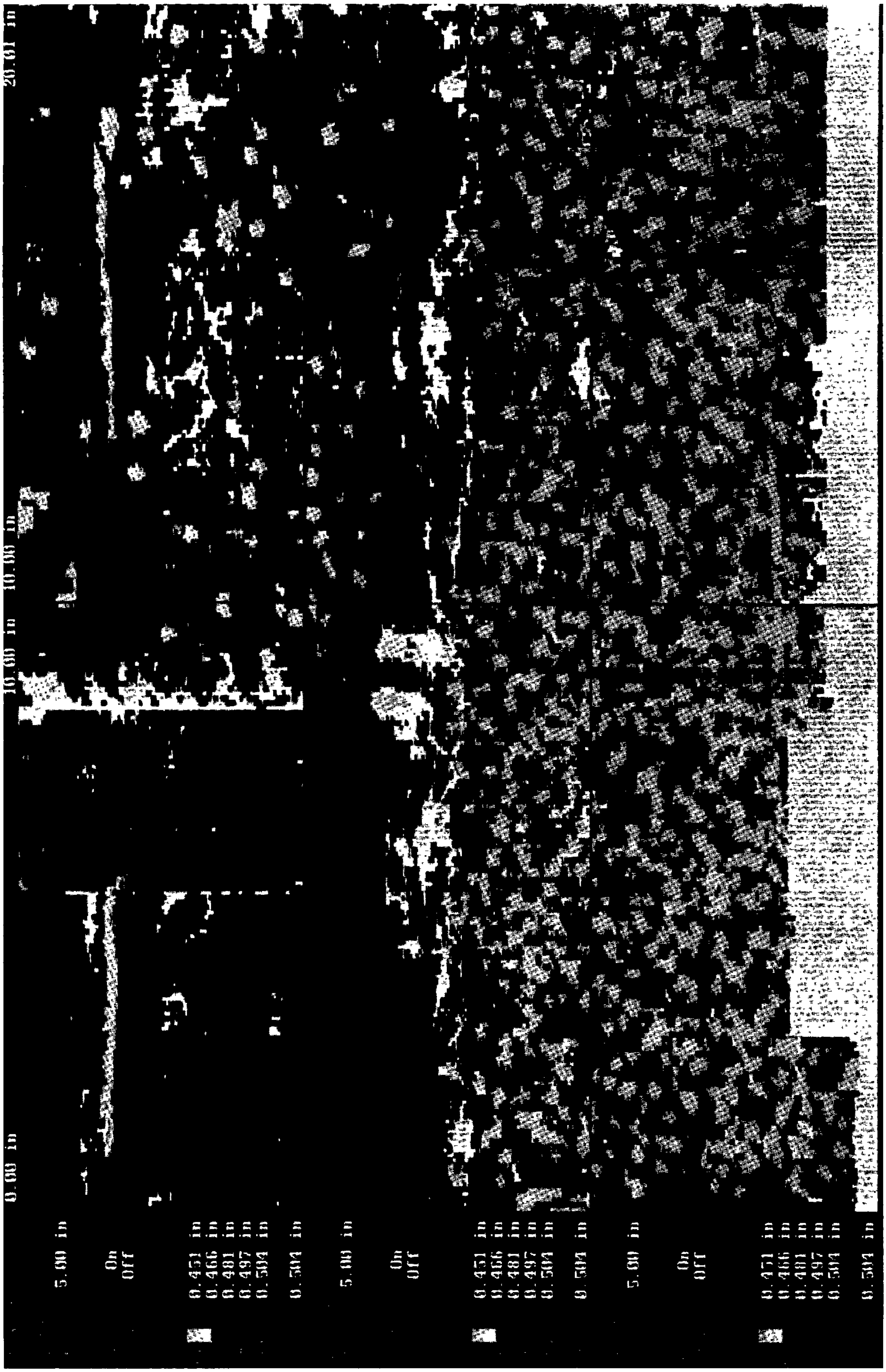


Fig. 4-1b—AUT T-scan data taken after Stage 8 of the environmental staging experiment

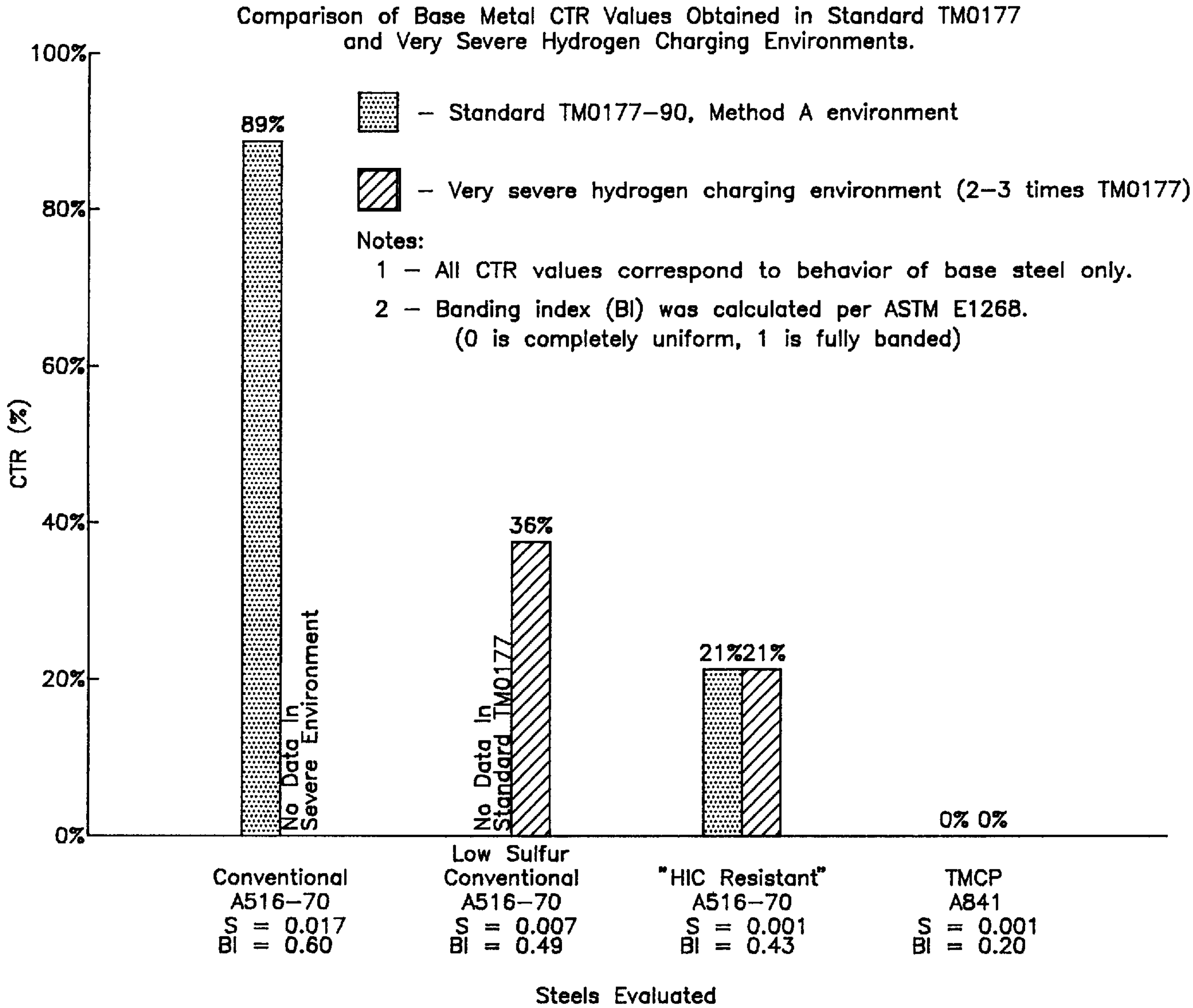


Fig. 4-2—Comparison of base metal CTR values obtained in standard NACE TM0177 and very severe hydrogen charging environments

HIC and SOHIC (i.e., up to 60% of the wall thickness) were noted, and (2) high levels of internal vessel pressure (i.e., 850 psi) were combined with severe hydrogen charging levels during exposure.

4.2.5. Short cracks produced by SSC and regions of residual tensile stresses were found to be effective initiation sites for SOHIC.

The most significant areas in terms of susceptibility to through-wall crack propagation from SOHIC were regions immediately adjacent to low heat input welds (See Fig. 4-5). SOHIC easily initiates from these low heat input weld locations. Factors which cause this phenomenon are related to (1) the formation of small cracks from SSC in hard weld zones and (2) the tensile residual stresses in these regions.

4.2.6. SOHIC initiated from low heat input welds in the conventional, low sulfur conventional, "HIC Resistant," and TMCP steels at the standard NACE TM0177 hydrogen charging conditions and at very severe hydrogen charging conditions, i.e., two to three times NACE TM0177 levels. The absolute through-wall crack penetration observed at the standard NACE TM0177 hydrogen charging conditions decreased with a decrease in sulfur content and decrease in microstructural banding. However, under very severe hydrogen charging conditions, the low sulfur conventional, "HIC Resistant," and TMCP steels exhibited through-wall crack penetrations ranging from approximately 30–50%, irrespective of the sulfur content or degree of microstructural banding.

Fig. 4-9 compares the through-wall crack penetration observed at both the standard NACE TM0177 hydrogen charging conditions and very severe hydrogen charging conditions, i.e., two to three times NACE TM0177 levels. All of the values represent cracking along the longitudinal seam weld at low heat input weld bead locations, except the "HIC Resistant" steel in the standard NACE TM0177 environment which corresponded to the longitudinal weld only. At the standard NACE TM0177 hydrogen charging conditions, a decrease in the through-wall crack penetration is observed with a decrease in sulfur content and decrease in microstructural banding. However, under the very severe conditions of hydro-

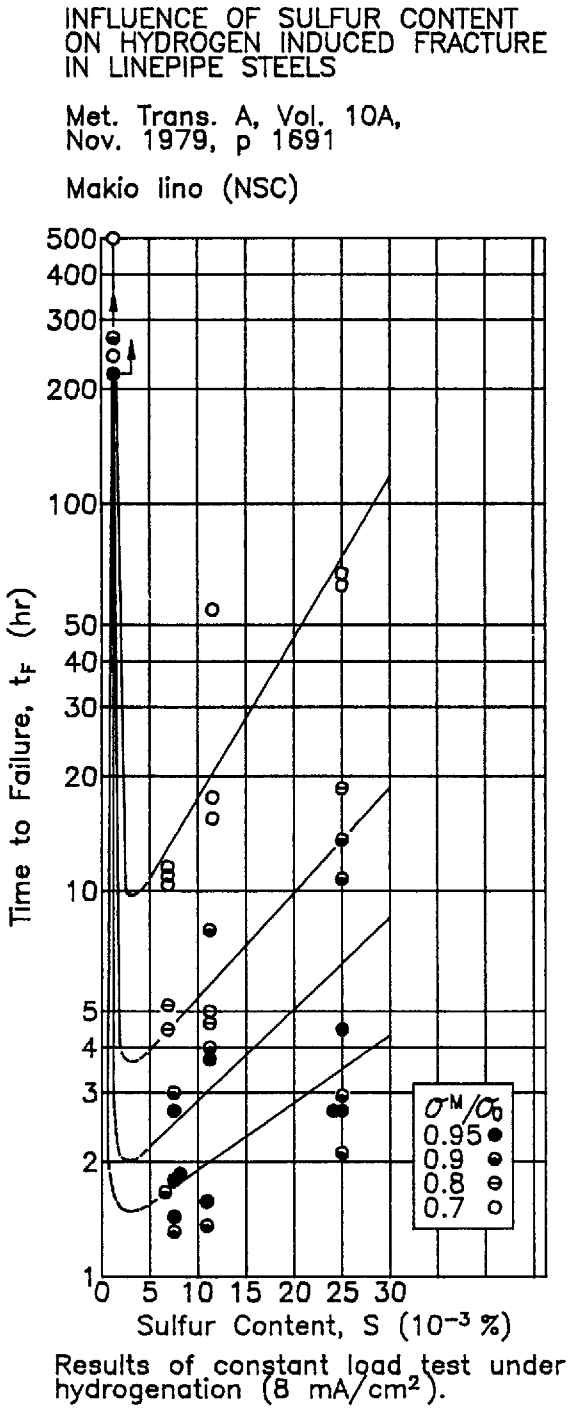


Fig. 4-3—Results of constant load tests under hydrogenation showing time to failure as a function of sulfur content

gen charging, no relationship was observed between the sulfur content, degree of microstructural banding, and through-wall crack penetration. Through-wall cracks were observed to penetrate approximately 30–50% in the low sulfur conventional, "HIC Resistant" and TMCP steels.

Additional factors which may control the depth of HIC and SOHIC in wet H_2S environments include (1) the differences in threshold hydrogen concentrations in the various steels to produce cracking and (2) the natural hydrogen concentration gradient in the steel resulting from the I.D. exposure of the vessel to the wet H_2S environment. This situation is shown schematically in Fig. 4-10. The hydrogen concentration in the steel is a maximum at the I.D. surface exposed to the test solution resulting from the charging of hydrogen produced by the sulfide corrosion reaction. At the O.D. surface, the hydrogen concentration is zero because there is no barrier to the egress of hydrogen from the steel on this surface.

The depth to which cracking can occur in the steel is dependent on the hydrogen gradient through the wall of the vessel. Once the hydrogen concentration becomes less than the threshold hydrogen concentration to produce cracking, the cracks will tend to arrest unless the driving force (i.e., stress or hydrogen concentration) is increased further. The results of this program show that the threshold hydrogen concentration to produce cracking in the ultra-low sulfur advanced steels is higher than for conventional steels. Therefore, the depth of cracking is restricted to varying degrees as shown in Fig. 4-10. The relationship is not simply linear, but is complicated by the changes in cracking susceptibility through the thickness of the material caused by microstructural differences such as centerline segregation or banding. In these cases, cracks can develop and propagate, in particular steels to a further extent than indicated in the figure.

4.2.7. No difference was observed in the cracking behavior of attachment welds using single-V and double-V weld configurations made per ASME specifications. Both were very resistant to cracking in this study even in the severe NACE TM0177 environment. Therefore, weld configuration did not appear to have a significant effect on susceptibility to cracking.

As shown in Appendix VI, the results from metallographic sectioning of attachment welds did not show significant SOHIC susceptibility using either single-V or double-V welds under what was considered to be severe conditions of hydrogen charging. While these welds showed AE responses and manual UT indications of potential cracking, no through-wall cracks were found in these regions by the metallographic sectioning (See Section 4.3.3.).

4.3 Inspection

4.3.1. Wet Fluorescent Magnetic Particle Testing (WFMPT) was able to identify HIC and SOHIC which intersected the I.D. surface of the plates. HIC indications were located in the bulk plate material whereas SOHIC was primarily found in the HAZ region of the base metal. In most cases examined, the depths of the surface cracking identified by WFMPT were shallow and not associated with SOHIC of significant through-wall extension.

Metallographic sectioning was performed in regions inspected by WFMPT that were found either to have crack indications or no crack indications. Fig. 4-11 gives the results of these examinations. It can be seen that WFMPT was able to identify surface cracking as evidenced by the high CTR values in the ⅓

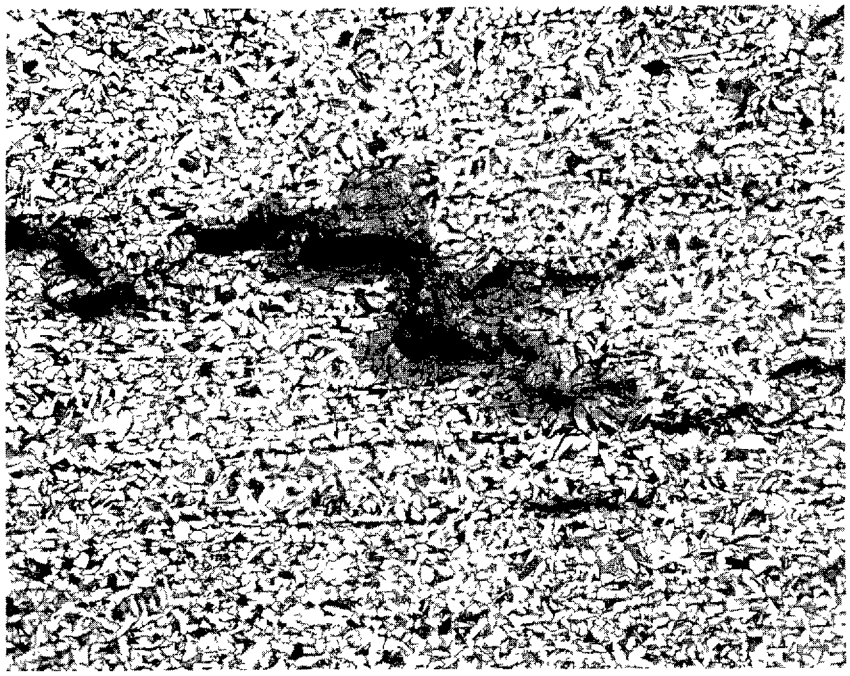


Fig. 4-4—Morphology of typical HIC observed in the ASTM A234 WPB material; magnification 100× (PN 3343-13)

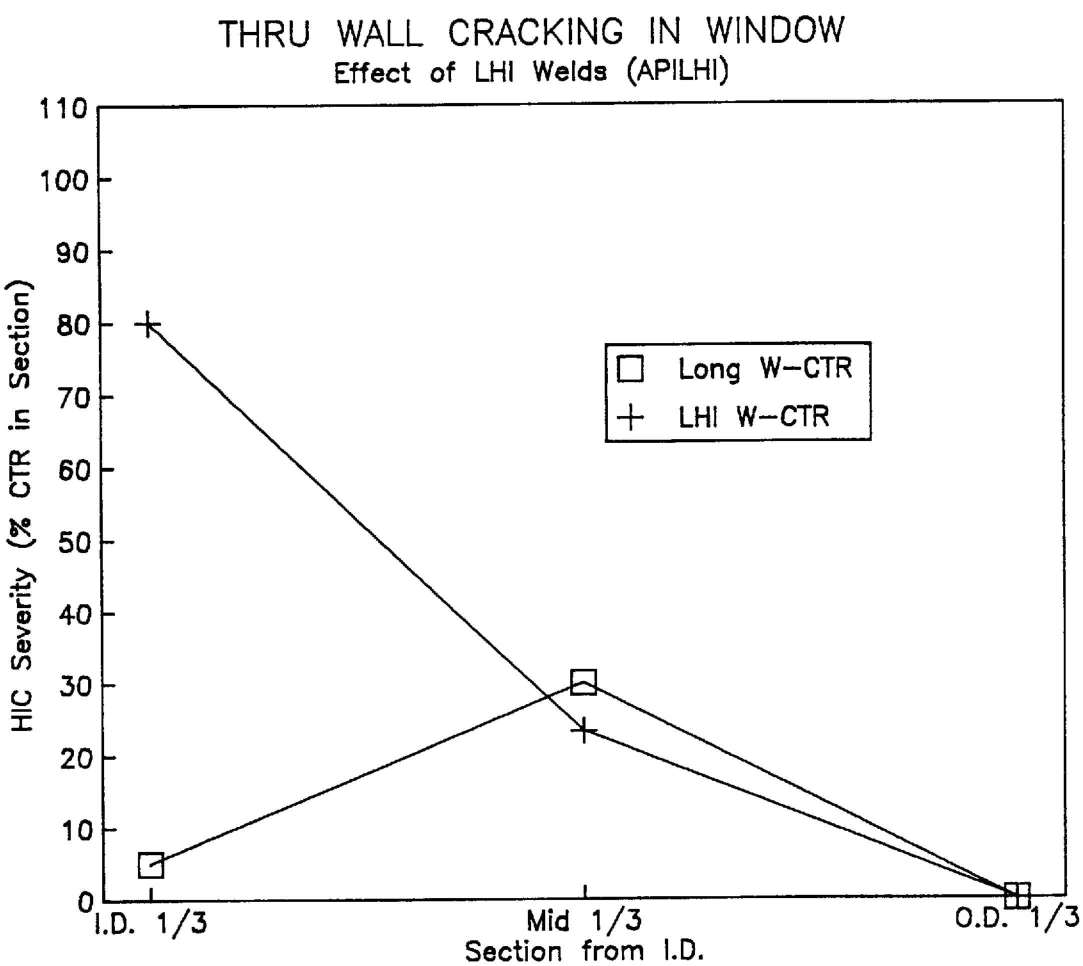


Fig. 4-5—Through-wall cracking at LHI weld locations along longitudinal weld seam

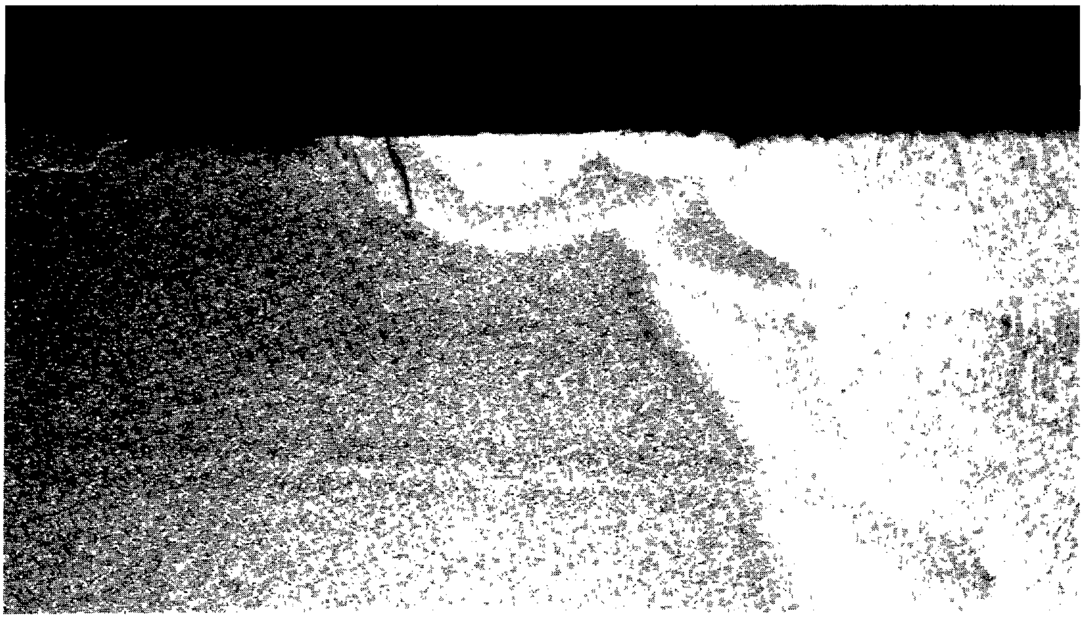


Fig. 4-6—Photograph of SSC at LHI weld in conventional steel: crack arrests at extent of HAZ (PN 3343-3)

thickness from the I.D. surface. The indications in the bulk plate were from HIC which intersected the I.D. surface while the indications in the weld area were more likely to be related to cracks from SSC and SOHIC. However, in most cases, the WFMPT indications were associated with limited surface cracking and not with regions of substantial through-wall cracking via SOHIC.

4.3.2. I.D. surface cleaning required for WFMPT resulted in an increase in SOHIC upon re-exposure of the vessel to the wet H_2S environment. This appeared to be caused by the removal of the protective sulfide films by cleaning and surface preparation prior to WFMPT.

An experiment specifically designed to observe the effect of surface cleaning on cracking susceptibility was conducted. The results are shown in Figs. 4-1a and 4-1b (AUT), Fig. 4-12 and Appendix V. In this experiment, a test window was exposed to an increasingly more severe environment using the sequence given in Table 4-1. Upon completion of the seventh exposure sequence, the test was stopped, the solution drained from the vessel and the I.D. surface of the window cleaned for WFMPT. The I.D. surface was found to have a thick sulfide scale which was removed prior to inspection. Upon completion of the cleaning and inspection, the test was restarted with fresh NACE TM0177 solution saturated with H_2S at ambient temperature and pressure.

Immediately upon restarting the test, it was apparent that an increase in cracking was occurring. As shown in Fig. 4-12, the upper band AE response, typical of SSC and SOHIC, was more active than in the previous exposure sequences of this test. Additionally, AUT P-scans conducted after this eighth exposure sequence showed more through-wall cracking oriented adjacent to both the longitudinal and transverse fabrication welds in the window than was found in previous scans. However, the extent of HIC extension, as determined by AUT T-scan, did not appear to increase noticeably between the seventh and eighth exposure periods.

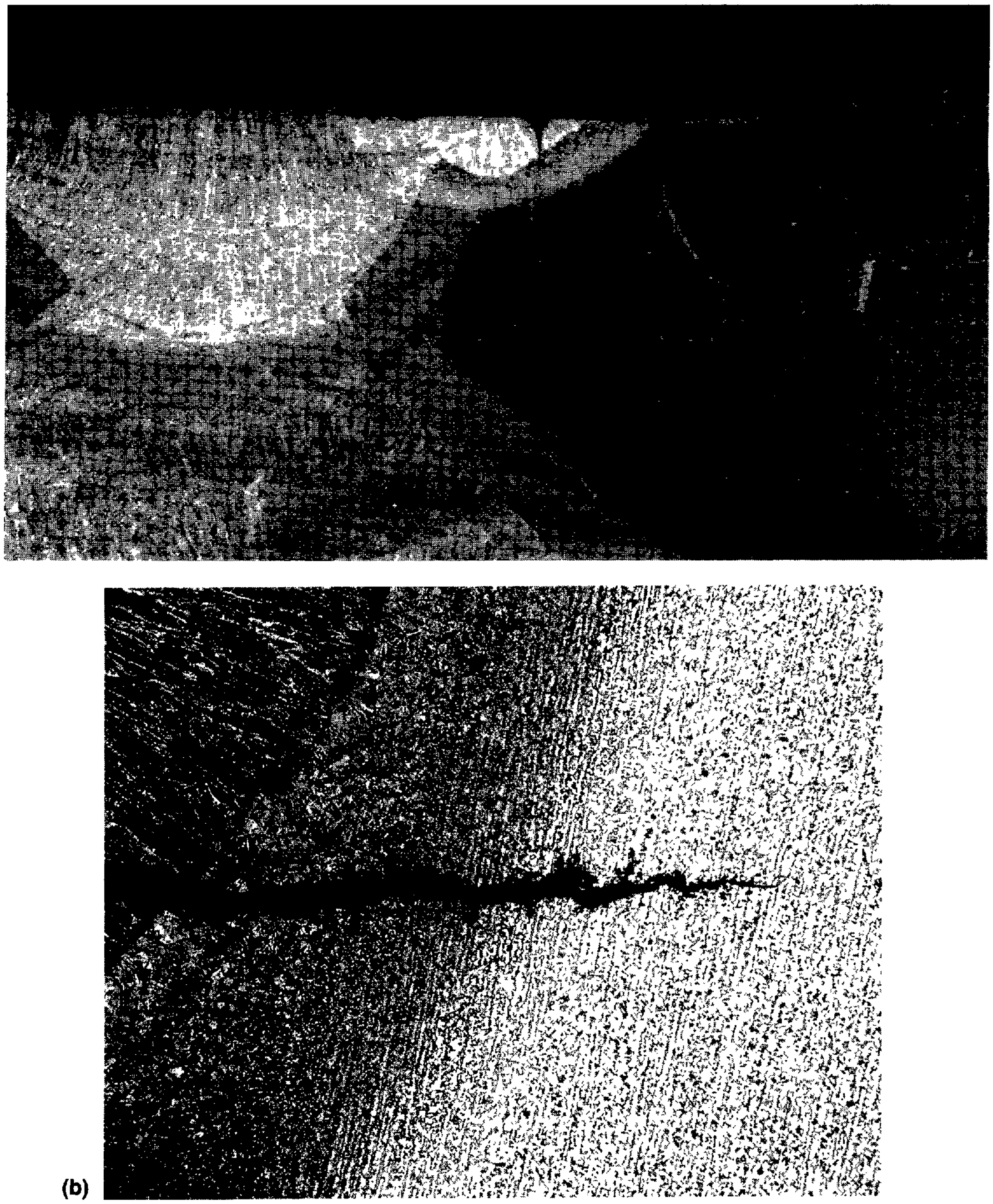
The increase in through-wall oriented cracking was confirmed by metallographic sectioning. It was identified to be caused primarily by SOHIC.

4.3.3. SOHIC locations with through-wall extension that were not revealed by WFMPT were found by automated shear wave (P-scan) ultrasonic testing. Manual relative arrival time UT methods were used for sizing of defects in the bulk plate areas and were confirmed by metallographic sectioning. Neither manual UT or WFMPT proved to be fully reliable for the identification of cracks in attachment welds for nozzle penetrations as revealed by metallographic sectioning.

Table 4-1—Environmental Staging Description

Stage	*Number of Days*	*H_2S Conc. (ppm)*	*Solution pH*	*Acetic Acid (wt. %)*	*HCL (wt. %)*	*Current Density (μA)*
1[a]	5	325	4.4	—	—	—
2[a]	6	2100	4.2	—	—	—
3	1	2100	4.2	0.05	—	—
4[a]	5	2100	4.1	0.50	—	—
5[a]	7	2100	4.2	0 50	—	55
6	3	2100	4.2	0.50	—	145
7[a]	6	2100	2.9	0.50	0.02	145
Solution was removed and the exposed surface of the window was cleaned. A new batch of standard NACE TM0177 solution was immediately added.						
8[a]	11	2100	3.0	0.50	—	145

[a]An AUT scan was conducted at the conclusion of the stage.
The pressure was maintained at 50 to 500 psi throughout the first seven stages. The pressure varied from 500 to 850 psi during stage 8.



(a)

(b)

Fig. 4-7—SSC in advanced steel. Crack propagates past extent of HAZ: (a) 35 mm photograph (PN 3343-10); (b) micrograph, magnification 50× (PN 3343-15)

In several cases, AUT shear wave examination conducted on the O.D. of the test window was able to identify indications in the plate which were associated with internal SOHIC with a through-wall orientation. In some cases, these crack indications were not identified by subsequent WFMPT on the I.D. surface in the same location. Fig. 4-13 shows the O.D. view of the WFMPT conducted on one of the windows prior to sectioning (See Appendix V). It shows the locations of many surface crack indications due to (1) HIC near the I.D. surface, (2) SSC associated with low heat input welds, and (3) SOHIC in the HAZ area of the base metal.

The results of the WFMPT, however, did not reflect the extent of the through-wall oriented cracking from SOHIC in the longitudinal seam weld, particularly on the side(s) of the weld bordered by the ultra-low sulfur steels. By comparison, AUT P-scan was able to detect the presence of through-wall oriented cracking in the longitudinal weld HAZ extending nearly the entire length of this weld. As shown in Appendix V, the metallographic sectioning confirmed the presence of these cracks.

One limiting aspect of the AUT P-scan was its inability to quantitatively indicate the extent of through-wall crack propagation. The extent of through-wall cracking adjacent to the longitudinal seam weld, observed under severe hydrogen charging

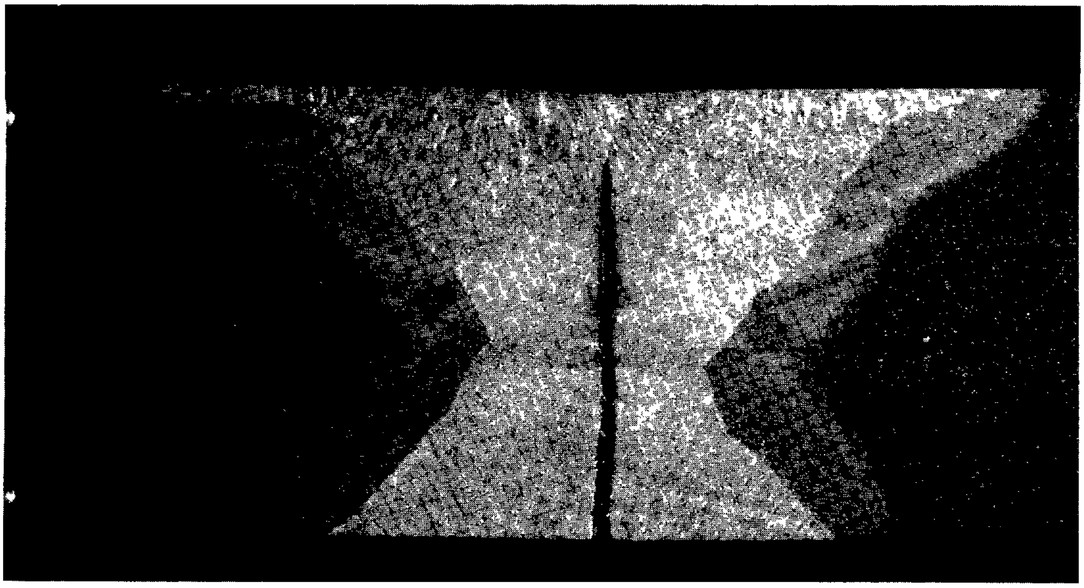


Fig. 4-8—Micrograph of SSC just adjacent to through-wall crack in conventional steel (PN 3343-3)

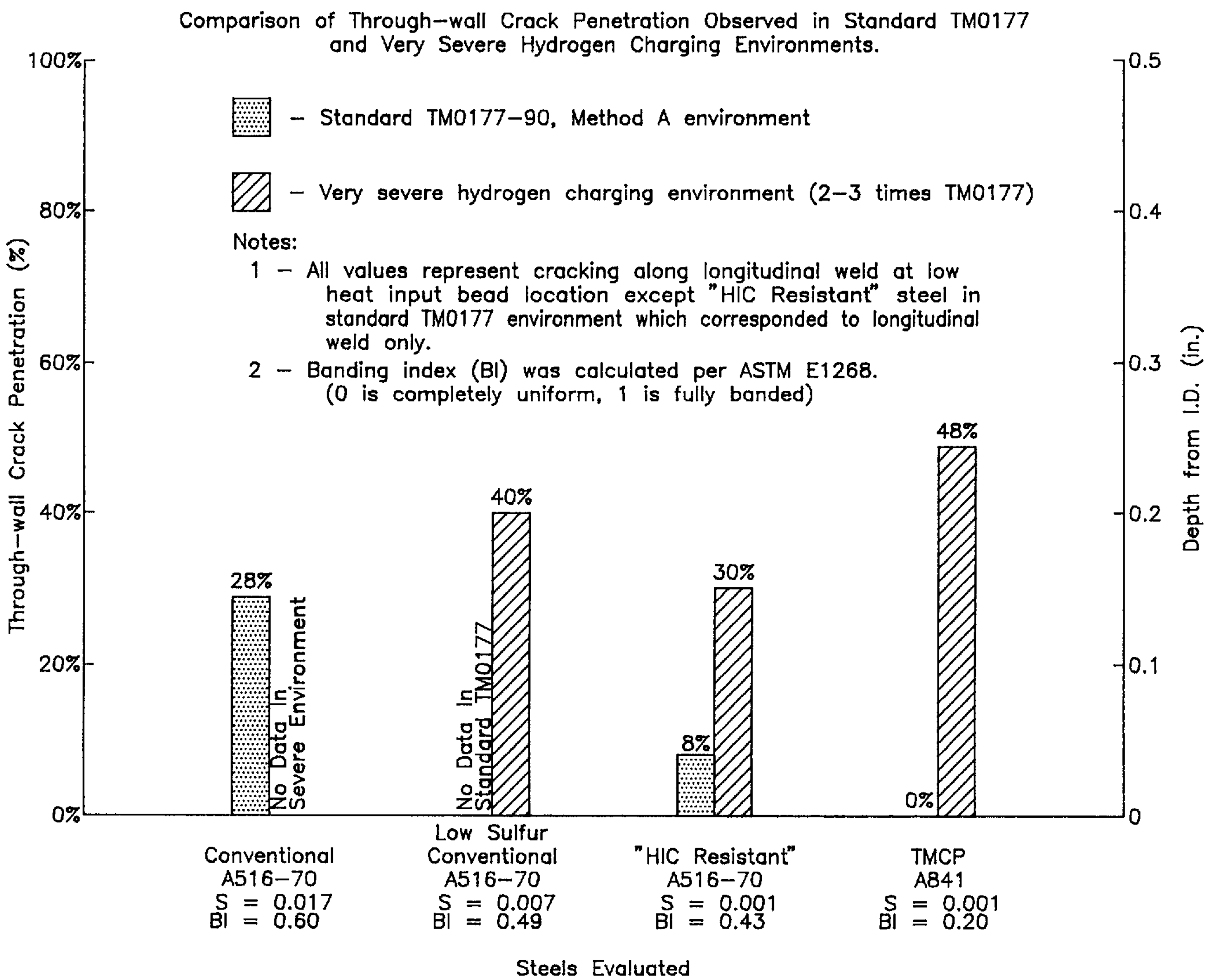


Fig. 4-9—Comparison of through-wall crack penetration observed in standard NACE TM0177 and very severe hydrogen charging environments

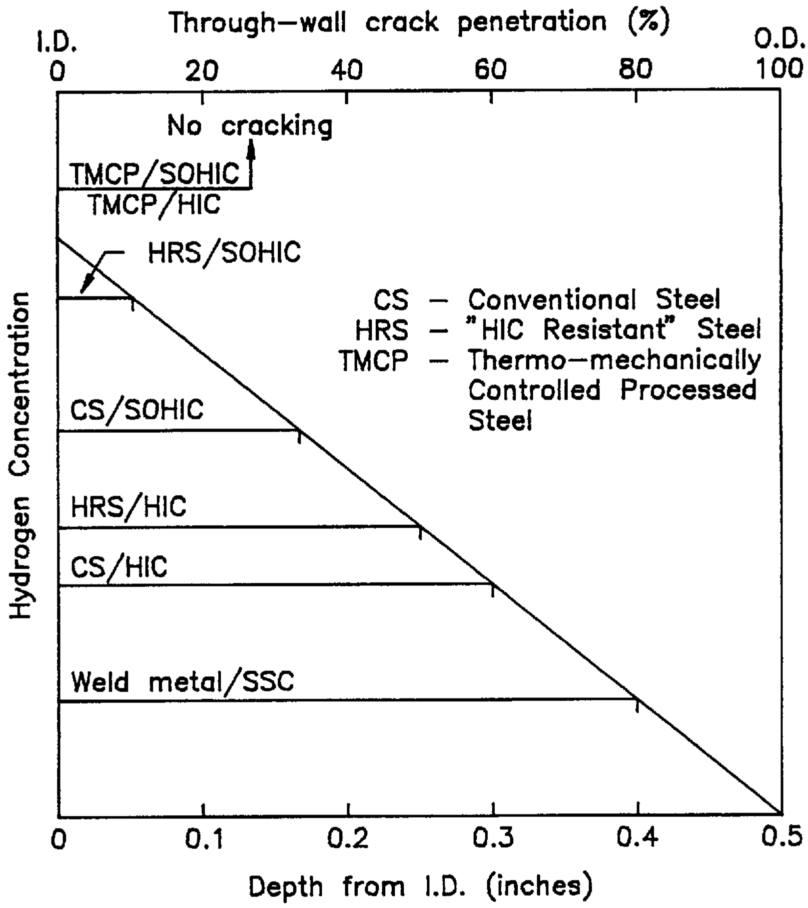


Fig. 4-10—Critical hydrogen concentrations required for cracking in the steels evaluated

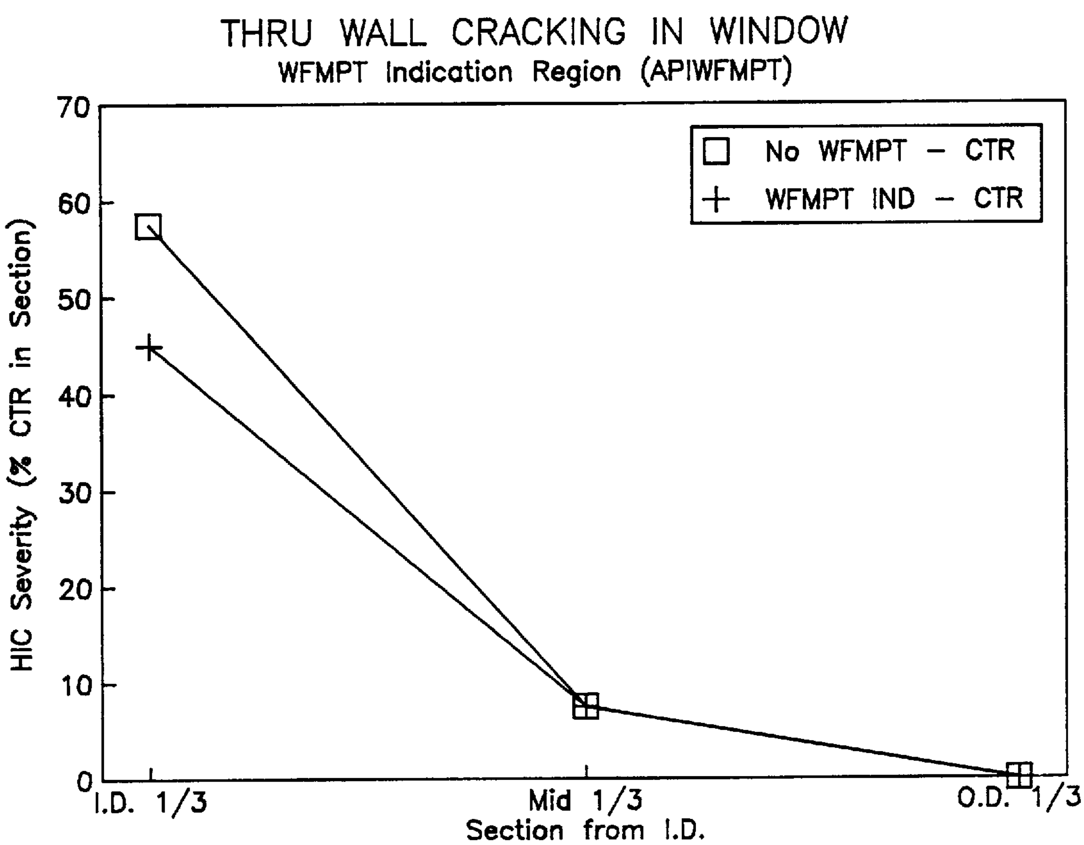
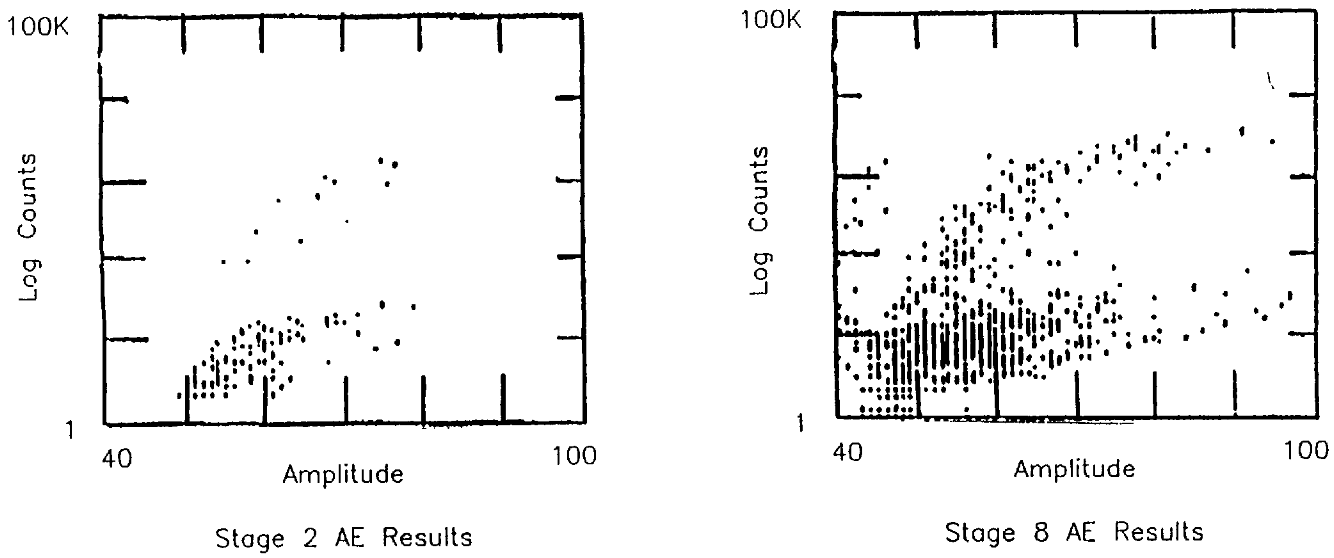
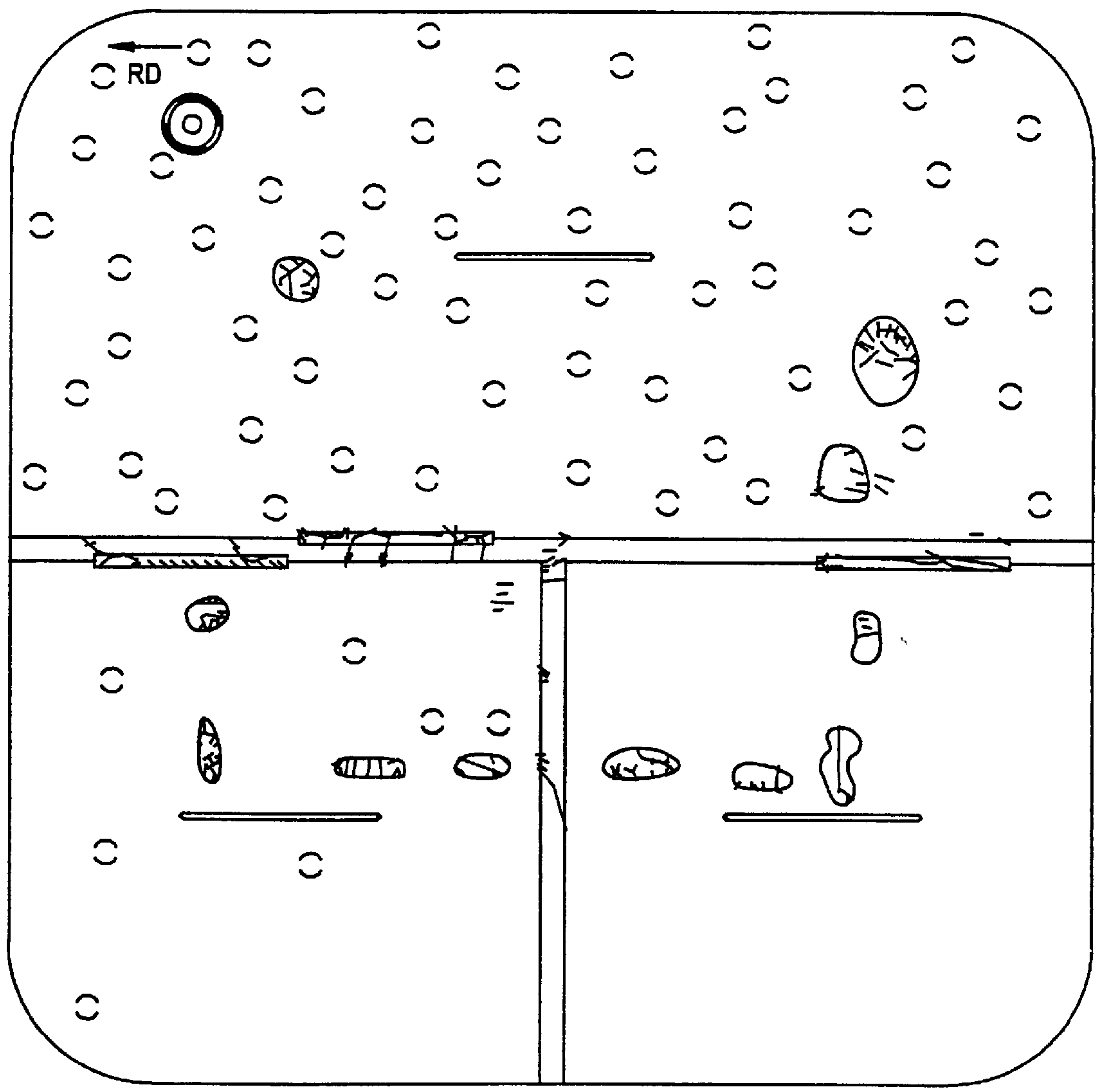


Fig. 4-11—Sectioning results based on positive WFMPT regions and regions of no WFMPT indications



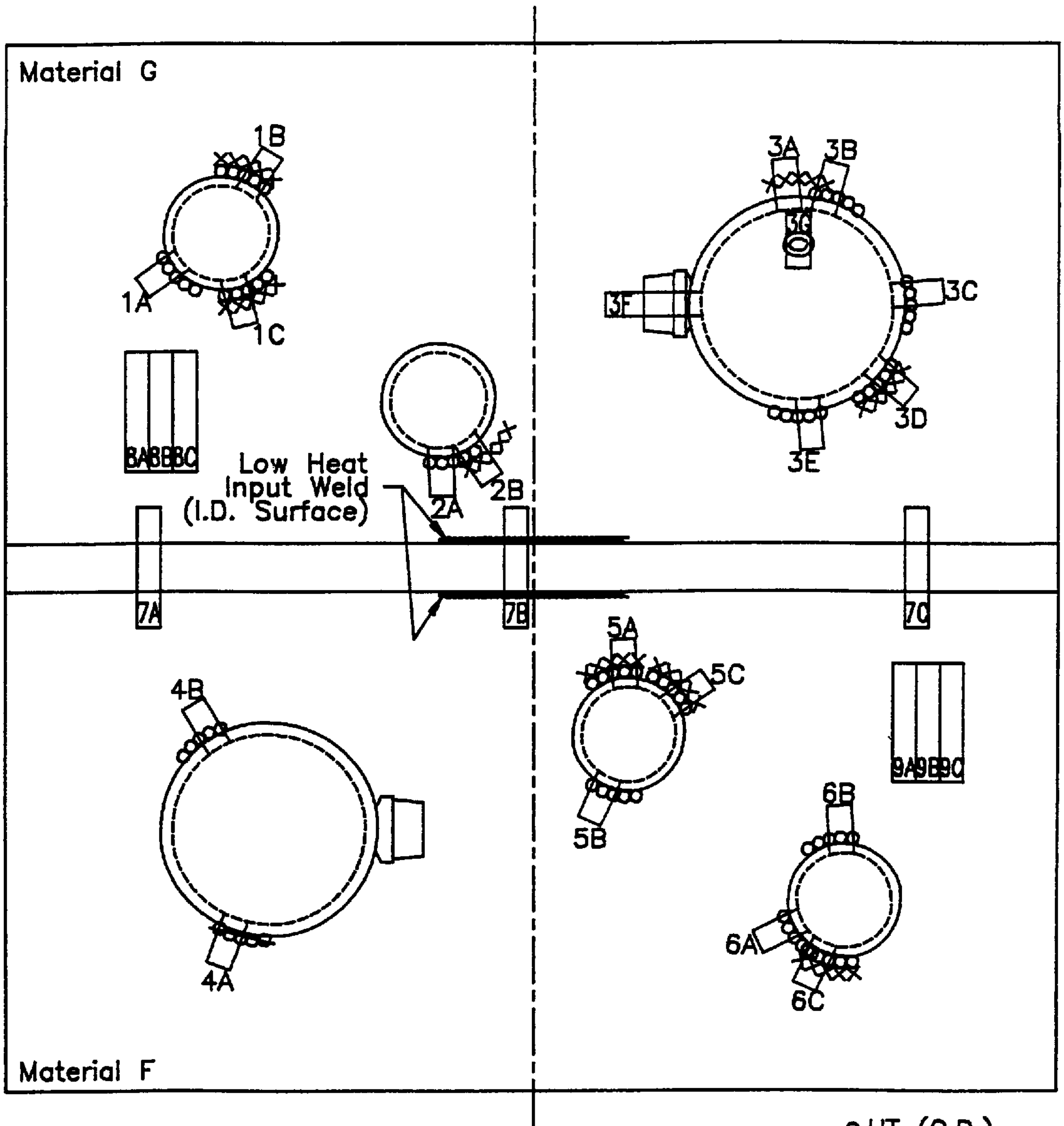
Note: High level of AE response after cleaning and solution renewal. Upper band AE response was characteristic of through-wall cracking.

Fig. 4-12—AE counts versus amplitude data taken during stages 2 and 8 of the environmental staging/effect of cleaning evaluation



O.D. view for comparison to AUT data. All WFMT cracking is on I.D. surface.

Fig. 4-13—O.D. view of the WFMPT conducted on the I.D. of the environmental staging/effect of cleaning evaluation



Material F: A841
CLI Number: 3250
Chemistry: C=0.09, P=0.003, S=0.001
Material Condition: TMCP
Mechanical Properties: Yield=67.0ksi, UTS=79.0ksi, % elongation=25.0

Material G: A516 Grade 70
CLI Number: 2280
Chemistry: C=0.22, P=0.027, S=0.020
Material Condition: Normalized
Mechanical Properties: Yield=52.0ksi, UTS=76.9ksi, % elongation=42.0

Fig. 4-14—Crack locations based on WFMPT and manual UT on the evaluation of nozzle attachments/PWHT

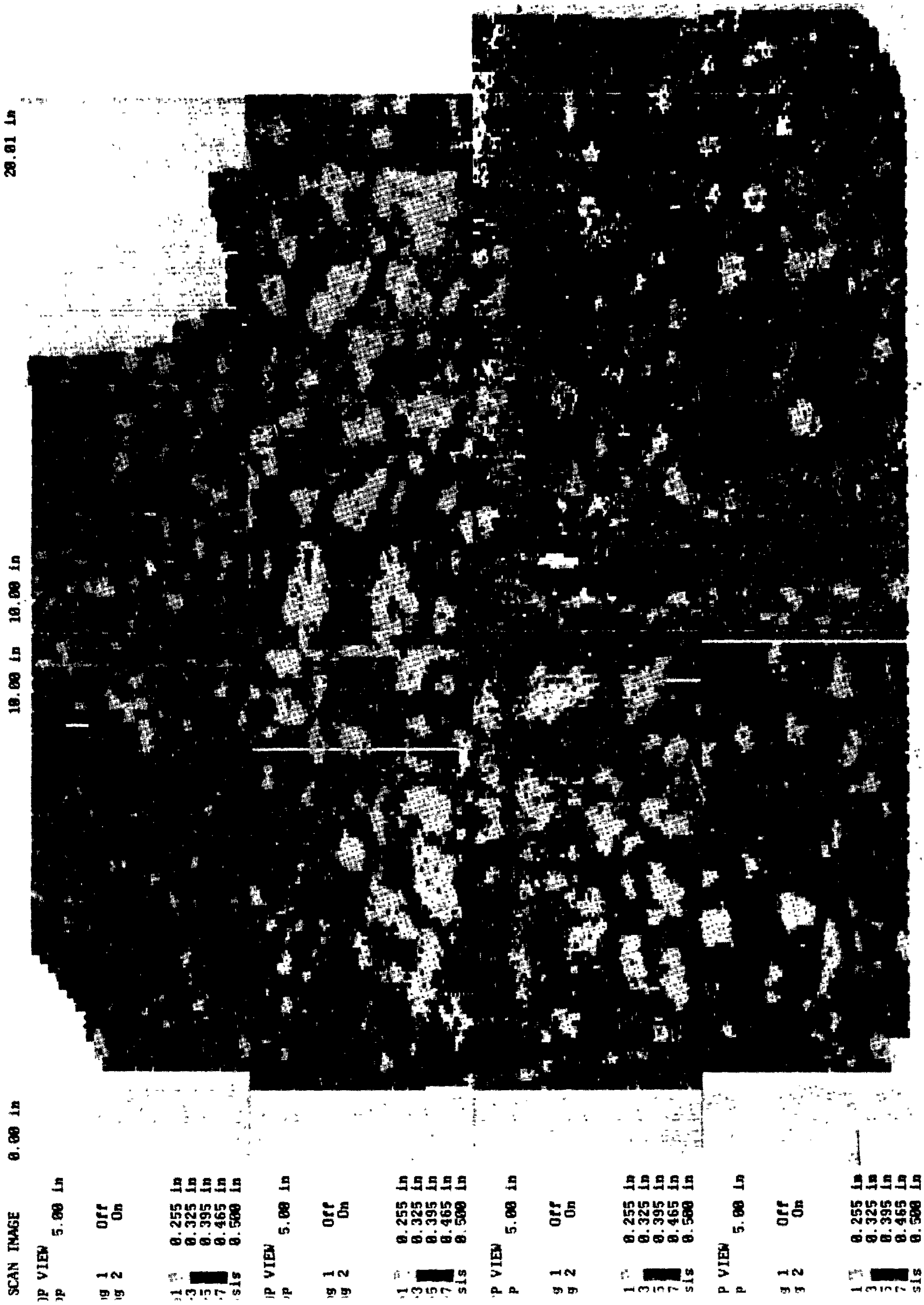


Fig. 4-15—AUT T-scan data taken at the conclusion of the simulation of thick plate behavior evaluation. For full-color version, see insert following p. 14

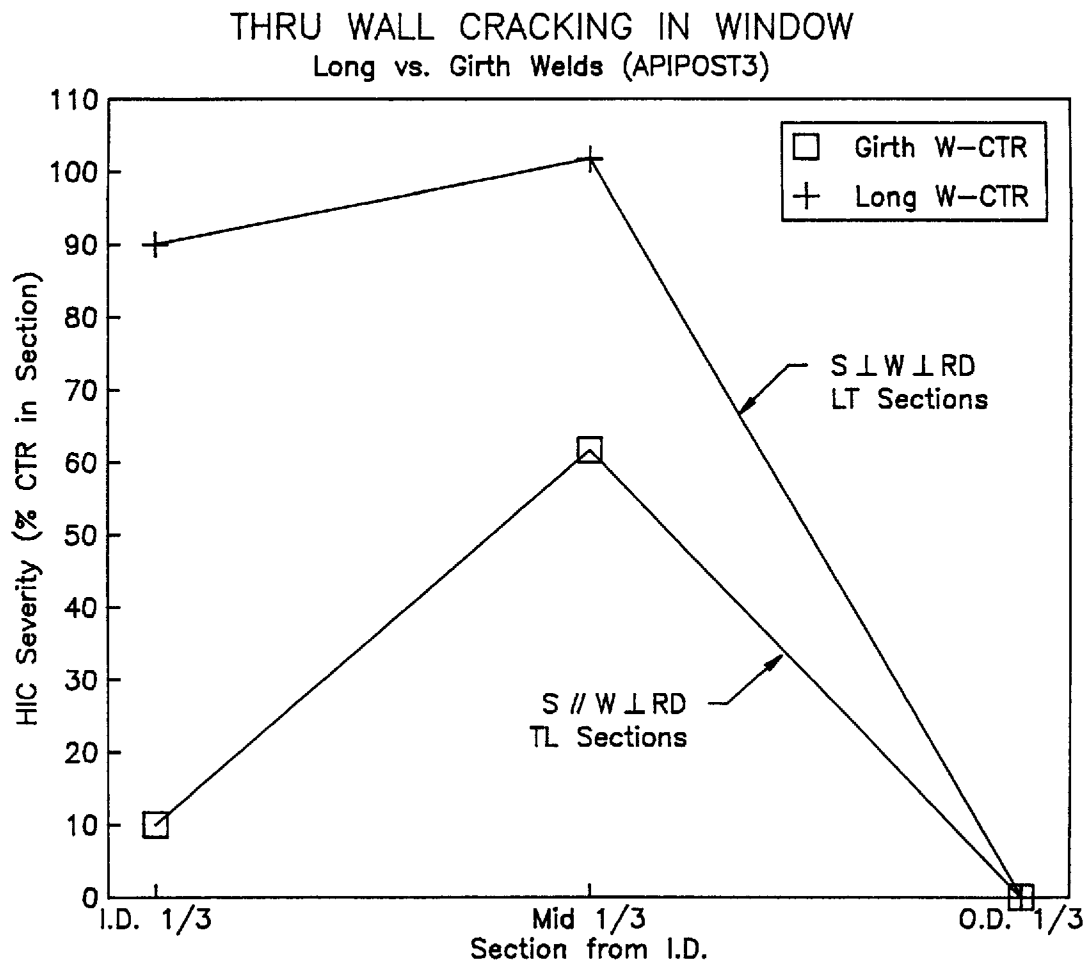


Fig. 4-16—Increased severity of SOHIC as characterized by increased CTR values associated with LT sections

conditions, was 50% of the wall thickness in the "HIC Resistant" steel and 30% of the wall thickness in the low sulfur conventional steel. These cracks gave similar cracking indications with the amplitude based AUT (P-scan) system. The AUT P-scan system is able to detect and determine the extent of through-wall cracking using automated time of flight diffraction (TOFD) techniques. However, these techniques become limited when applied to thin shells such as those used in this research program.

Manual UT relative arrival time techniques proved to be reliable for crack sizing in the simple plate specimens used in this program. Manual UT techniques were used to determine both the lateral and through-wall extent of crack propagation in the hard weld study. Metallographic sectioning showed good agreement with the results of manual UT sizing results (See Appendix II). Additionally, the depth of HIC in the plate, as determined by manual UT, was also found to agree very closely with the value found by metallographic sectioning.

The only cases where manual UT crack sizing was not found to be accurate were in determinations made in the attachment areas of the nozzles. In this case, many crack indications were found in these areas using manual UT (See Fig. 4-14). However, when these areas were metallographically sectioned, no cracks were identified which corresponded to the indicated crack sites (See Appendix VI for both manual UT report and metallographic crack measurement data).

4.3.4. AUT longitudinal wave (T-scan) techniques were able to locate regions of internal planar HIC cracking. However, extensive HIC which produced overlapping cracks led to oversizing of the HIC indications based on AUT T-scan alone. Additionally, metallographic sectioning alone could produce non-conservative results due to chance sectioning. The best combination for quantitative HIC sizing was found to be destructive sectioning based on AUT T-scan measurements.

The results of comparative AUT (T-scan) and metallographic sectioning are shown in Fig. 4-15 and in Appendix IV, respectively. The AUT data indicated distinct areas of HIC within the plate specimen and an indication of the HIC depth within the plate. However, when comparing the crack sizes from the AUT scan and the metallographic sections from similar sections, it was found that the overlapping areas of HIC made the HIC regions appear larger on the AUT scan than was found with metallography.

Similarly, due to the isolated nature of HIC in some areas in the plate, it appeared possible to grossly under-estimate the degree of HIC if the metallographic sections were made by chance sectioning through regions of low HIC density. The best assessment of HIC severity was found when AUT was used as the basis for selecting sites for metallographic sections. In this manner, appropriate sites could be selected for sectioning. In these cases, the crack measurements made from the AUT scans were in close agreement with the crack measurements made on the metallographic sections.

4.3.5. Metallographic evaluations in conventional steels conducted on LT sections resulted in more severe SOHIC indications than for similar evaluations made on TL sections.

Fig. 4-16 shows increased severity of SOHIC as characterized by increased CTR values associated with LT sections. This effect appears to be related to the orientation of the weld, maximum tensile stress and rolling direction of the steel. When the maximum tensile stress direction is perpendicular to the welding direction and the rolling direction, CTR values tend to be maximized. The cracking was limited to the inner ⅔ region (i.e., I.D. ⅓ and middle ⅓ regions) of the plate thickness. The values of CTR in this region are consistently greater than those found for welds where the welding direction is perpendicular to the rolling direction and parallel to the direction of maximum tensile stress as was the case for the girth weld in the window specimen.

4.3.6. Acoustic Emission (AE) monitoring showed separate and identifiable acoustic responses for through-wall (i.e., SOHIC and SSC) and in-plane cracking (i.e., HIC). On-line AE measurements were able to detect the onset of HIC and SOHIC and could be used to provide an indication of the activity of each type of cracking.

As described in Section 4.3.2, AE monitoring was able to provide a direct indication of the extent of active cracking resulting from planar HIC cracking and through-wall SSC and SOHIC. Fig. 4-12 showed the increase in SOHIC activity, demonstrated by an increased amount of upper band activity observed in the AE correlation plot of log counts versus amplitude. By comparison, planar HIC cracking was found to be associated with the lower band on this AE correlation plot.

Additional evidence of the upper/lower band relationship is shown in Fig. 4-17. This figure illustrates the variation of internal test pressure, peak AE amplitude and average amplitude plotted as a function of test duration. The peak amplitude appeared to vary with the internal pressure in the vessel. Without internal pressure, cracking in the test window was found to be primarily of a planar nature resulting from HIC. With the application of the pressure stress in the test window a significant increase in CTR and through-wall oriented crack growth was observed (See Fig. 4-18). Since the peak amplitude was typically associated with the upper band on the AE correlation plot, it was suggested that the upper AE band was most likely related to the formation of through-thickness oriented cracks (i.e., SSC and SOHIC).

The average AE amplitude appears to be relatively constant throughout the test period in Fig. 4-17. The AUT data from this same test showed that the increase in HIC cracking also increased in a relatively constant manner during this period. Therefore, since the average amplitude is most heavily dependent on the lower AE band of the correlation plot, it was suggested that the lower band was most indicative of

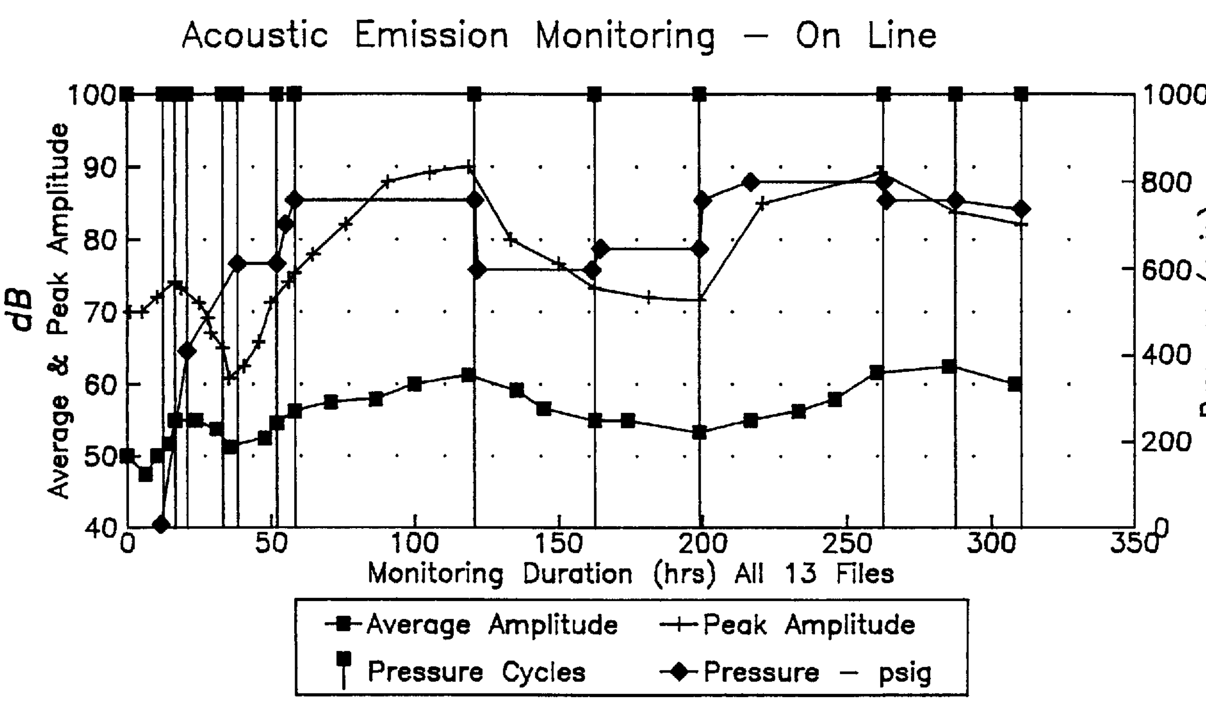


Fig. 4-17—Variation of internal test pressure, peak AE amplitude and average amplitude

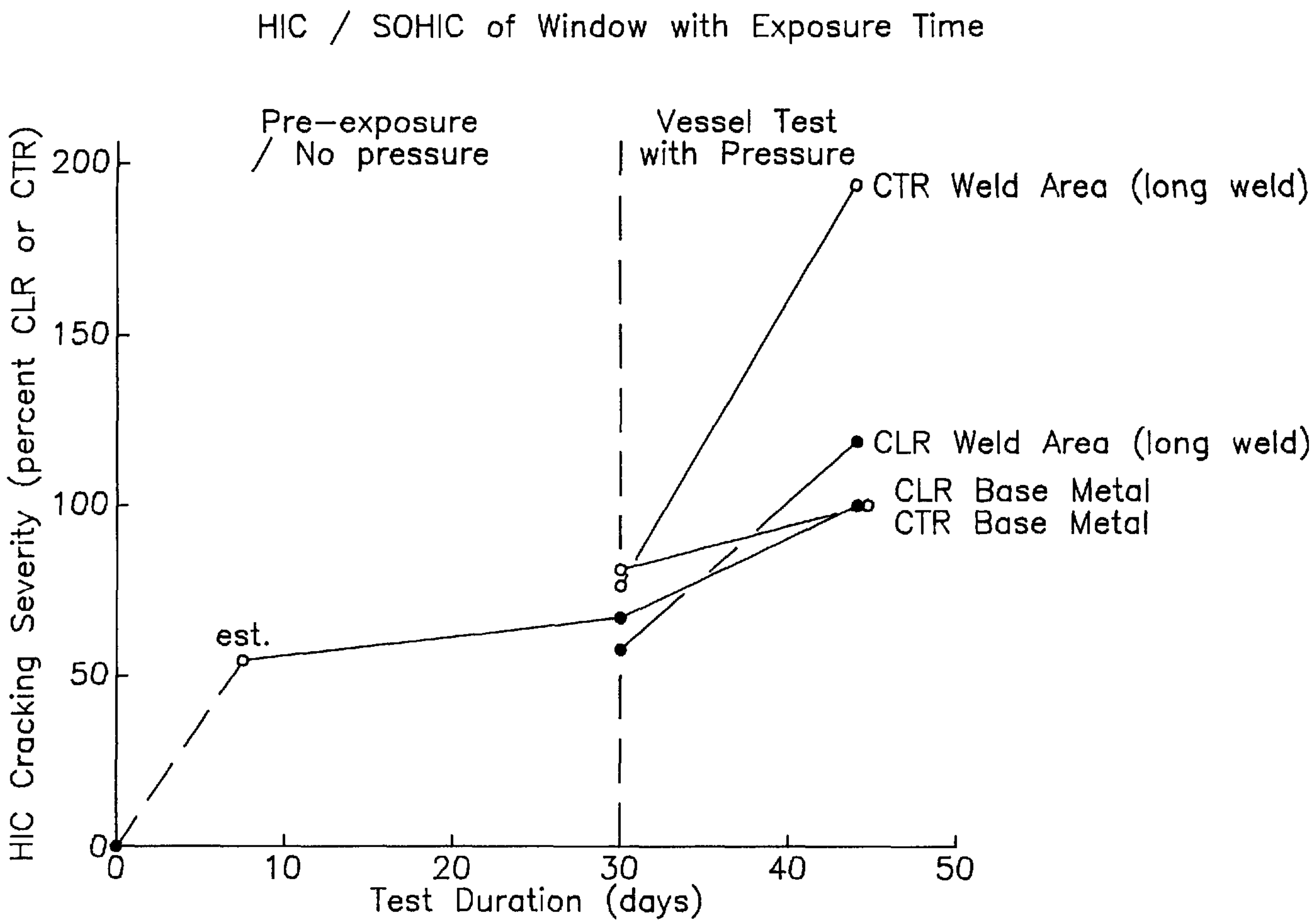


Fig. 4-18—Increase in CTR values after subjecting material to a pressure stress in the test vessel

the planar HIC cracking taking place in the test window. Observations made on subsequent test windows such as those shown in Fig. 4-18 appeared to confirm these early findings.

4.3.7. Based on AE monitoring and metallographic sectioning, the rate of HIC was not dependent on changes in the internal pressure of the test vessel. By comparison, SOHIC was found to be directly related to the internal pressure (i.e., increased SOHIC with increasing pressure), presence of low heat input welds, and severity of hydrogen charging.

Figs. 4-12 and 4-18 indicate that HIC in susceptible steels can occur under conditions with no stress and increase only slightly for conditions of increased operating pressure up to stress levels beyond normal operating limits for such equipment. However, severity of SOHIC depends on the operating stress levels. The results of AE monitoring suggest that SOHIC increases with operating pressure. Operating situations which increased tendencies for SOHIC were: (1) high operating pressures, (2) presence of non-stress relieved, low heat input welds (with high hardness and local residual tensile stress), (3) lack of PWHT, and (4) hydrogen charging severity of the environment. The results shown in Appendix V and VI support these findings.

4.4 Vessel Design and Integrity

4.4.1. The residual strengths of tensile specimens taken from the conventional steel plate containing substantial HIC damage were 95 to > 100% of the 70 ksi specified minimum tensile strength for ASTM A516-70. Measured elongations, however, ranged from 40–85% of specified minimum values. Specimens removed across the welds exhibited greater degradation in mechanical strength than base metal specimens. Maximum degradation was found to correlate with the regions of maximum SOHIC extension. These areas were in the HAZ of the welds which were perpendicular to the hoop stress in the vessel.

Following one-side exposure to NACE TM0177 solution under internal pressure, samples were cut from a test window to allow for determination of the residual mechanical properties of the A516-70 steel plate material. The samples were stored for several weeks at room temperature to allow for loss of diffusible hydrogen from the specimens. Fig. 4-19 shows the actual tensile strengths and elongations for specimens taken in the orientations indicated with the following codes:

1. 516 Specified Minimum Values per ASTM A516-70
2. PRE Pre-Test Values for Actual Plate Material

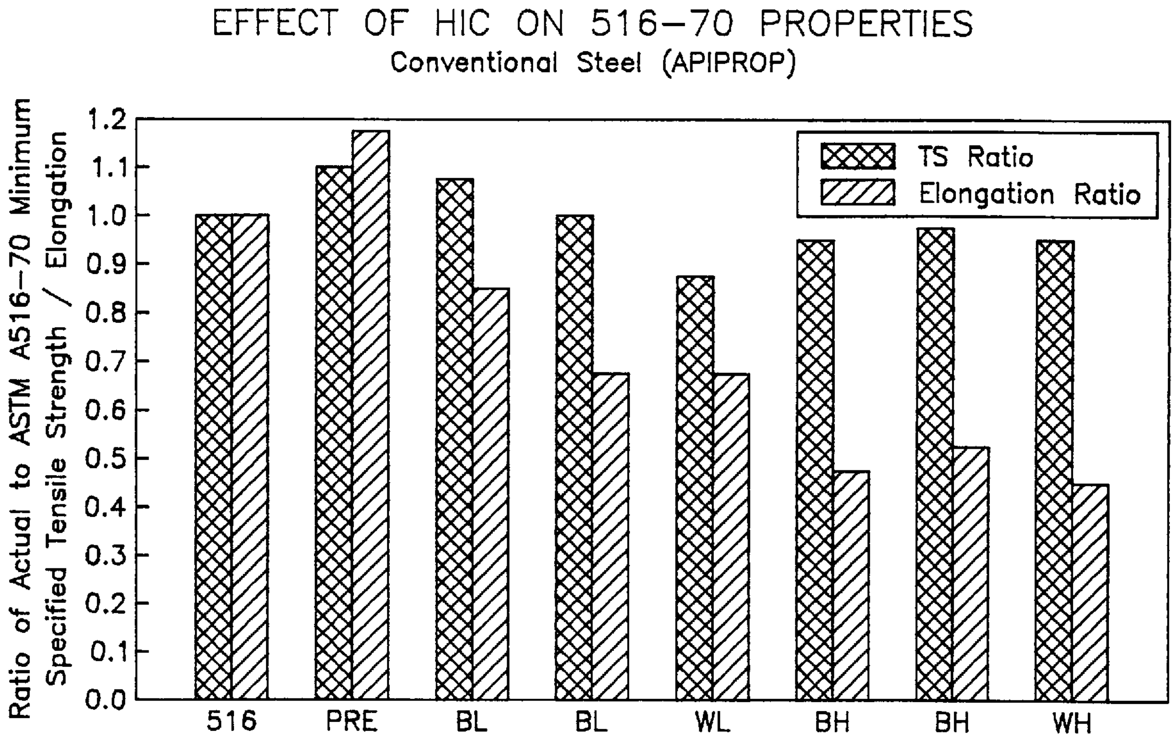


Fig. 4-19—Effect of HIC/SOHIC on mechanical properties of ASTM A516-70

3. BL Base Metal—Longitudinal Direction
4. WL Weldment—Longitudinal Direction
5. BH Base Metal—Hoop Direction
6. WH Weldment—Hoop Direction

As can be seen in this figure, the residual strengths of the specimens tested were all greater than 85% of the 70 ksi minimum specified tensile strength for A516-70. No relationship was observed between the orientation or location from which the test specimen was taken and the residual tensile strength after exposure in the pressure vessel configuration. The elongations of the specimens taken from the exposed material, however, were all less than the minimum specified values for A516-70. Maximum reductions in elongation were observed on tensile specimens oriented in the circumferential direction, particularly those taken across the longitudinal weld. Based on evaluation of the tensile specimens after testing, the severe reduction in elongation was attributed to the presence of SOHIC in the base metal HAZ adjacent to the longitudinal weld.

Base metal Charpy impact specimens were also taken from the base plate in both the longitudinal and transverse directions. Average longitudinal and transverse Charpy impact energy values following exposure were 60 and 34 ft-lb, respectively, at room temperature. The transverse values were essentially the same as those obtained for the A516-70 plate prior to exposure whose average value was 36 ft-lb. It should be cautioned that these values of strength, elongation and Charpy energy are residual values *without* hydrogen; values in the presence of hydrogen could be lower depending on the conditions of exposure and testing.

4.4.2. HIC in the conventional steels tested in NACE TM0177 solution was confined to the ⅔ thickness (from the I.D.). HIC in the "HIC Resistant" steels tested was limited to the I.D. 20% of the wall thickness except for isolated small regions of centerline cracking. HIC did not occur in A841 base metal in NACE TM0177 tests or in very severe accelerated tests using cathodic charging in NACE TM0177. When HIC reached these depths, it was not possible to obtain further HIC.

Figs. 4-9 and 4-10 indicate typical results with regard to depth of HIC for conventional, "HIC Resistant" A516-70 and A841 steels tested in this program. These data suggest that the critical hydrogen concentration for HIC increases with decreasing sulfur content in the steel and with the application of modern steelmaking and processing techniques. However, if problems such as centerline segregation exist they can limit the overall HIC performance of the steels in wet H_2S service.

Efforts were made to continue HIC beyond the depths indicated above in the experiments conducted in this program using prolonged exposures and external hydrogen barriers and external charging. None of these methods proved to be significant in terms of producing an increase in HIC size or depth of cracking.

4.4.3. SOHIC in the "HIC-Resistant" (A516-70) and ultra-low sulfur advanced steels (A841) tested in the standard NACE TM0177 solution showed lower susceptibility to through-wall cracking by SOHIC than conventional steels based on absolute crack depths. SOHIC was produced to a maximum of approximately 8% of the wall thickness in these steels.

As previously shown in Fig. 4-9, the results for through-wall SOHIC in the various steels tested in this program indicate that in NACE TM0177 solution, SOHIC was produced in the conventional steel to a depth of approximately 30% of the wall thickness, while the "HIC Resistant" steel exhibited SOHIC to a depth of approximately 10%. No SOHIC was produced in the A841 steel exposed to the NACE TM0177 solution in this study. However, in accelerated charging tests which had two to three times the hydrogen charging levels of NACE TM0177, the TMCP A841 steel did exhibit SOHIC to a depth of approximately 50% of the wall thickness in regions around weldments.

The data presented above and in Sections 4.1.2 and 4.2.6 suggest that decreased levels of sulfur content and decreased microstructural banding reduce the susceptibility to HIC and SOHIC. However, in very severe hydrogen charging environments these same steels, irrespective of sulfur content or degree of banding, may be susceptible to SOHIC. Therefore, to optimize cracking resistance in wet H_2S refinery equipment, it appears that issues related to all wet H_2S cracking mechanisms (i.e., HIC, SOHIC and SSC) must be addressed and the limitations of the specific carbon steels identified. Alternative methods such as the use of stainless steel clad vessels may be needed for very severe environments.

4.4.4. Based on AE monitoring and metallographic sectioning, the rate of HIC was not dependent on changes in the internal pressure of the test vessel. By comparison, SOHIC was found to be directly related to the internal pressure (i.e., increased SOHIC with increasing pressure), the presence of low heat input welds and severity of hydrogen charging.

Figs. 4-12 and 4-18 indicate that HIC in susceptible steels can occur under conditions of no stress, and increase only slightly for conditions of increased operating pressure up to stress levels beyond normal operating limits for such equipment. However, severity of SOHIC depends on the operating stress levels. The results of AE monitoring suggest that SOHIC increases with operating pressure. Operating situations which increased tendencies for SOHIC were: (1) high operating pressures, (2) presence of non-stress relieved, low heat input welds (with high hardness and local residual tensile stress), (3) lack of PWHT, and (4) hydrogen charging severity of the environment. The results shown in Appendix V and VI support these findings.

4.4.5. For conventional and "HIC Resistant" steels, the threshold hydrogen flux for HIC does not vary with sulfur content in the steel or susceptibility to HIC. The main difference between HIC susceptible steels and more resistant steels is the number of HIC initiation sites and the extent of HIC.

The results shown in Figs. 4-1a and 4-1b and Appendix V indicate that conventional and "HIC-Resistant" A516-70 steels initiated HIC at the same level of hydrogen charging during the sequence of increased hydrogen charging severity. This suggests that differences in the HIC performance of the steels is not related to the increase in resistance of individual sites to HIC initiation in the steels but to (1) reducing the number of HIC initiation sites and (2) the extent of HIC propagation. In the present study, the only material not found to have a HIC threshold hydrogen flux (or concentration) was the A841 steel which was not susceptible to HIC even in the most severe hydrogen charging environment.

4.4.6. PWHT was found to be effective in reducing the SOHIC in the area of the longitudinal seam weld which also contained low heat input welds. However, no effect of PWHT was found for SOHIC of nozzle attachment weldments.

The benefit of PWHT was observed in this study when comparing the results of SOHIC in the longitudinal seam welds containing low heat input welds with and without PWHT in NACE TM0177 solution (See Appendix IV and VI). In this case, SOHIC was observed in non-PWHT longitudinal seam welds containing low heat input welds. SOHIC was located in the HAZ region of the base metal (Appendix IV). Appendix VI shows the results of testing similar longitudinal seam welds containing low heat input welds which received PWHT prior to testing. In this case, no SOHIC was observed to occur in either conventional steel or ultra-low sulfur advanced steel.

As shown in Appendix VI, SOHIC was not observed in the nozzle attachment welds in either conventional (A516-70) or ultra-low sulfur advanced steels (A841). Neither of these attachment welds experienced SOHIC in this investigation in both the PWHT and no PWHT conditions tested in NACE TM0177 solution.

The differences in the behavior of the longitudinal seam welds containing low heat input welds and the nozzle attachment welds highlight the apparent importance of the low heat input welds in the initiation of SOHIC. The combination of the high local hardness and residual stress associated with the low heat input welds provides an excellent initiator or promoter for the initiation of SOHIC. Once these are reduced or eliminated through PWHT, the tendency for the initiation of SOHIC is significantly lessened. These results suggest that if the effect of low heat input welds would be superimposed on the nozzle attachment welds a similar effect of PWHT would be exhibited. The results from this study may indicate why the effect of PWHT on SOHIC has not always been found in wet H_2S refinery experience.

4.4.7. The observations of material behavior found in this study were consistent with the findings of the previously conducted laboratory testing conducted in the MPC Wet H_2S Research Program. The results of the present study validated the wet H_2S cracking test methods developed previously and showed their applicability to refinery wet H_2S environments.

Prior to the initiation of this program, MPC organized a research program on wet H_2S cracking of steels sponsored by more than twenty major petroleum companies, steel manufacturers and equipment fabricators. The data were collected using standard small scale laboratory tests such as the NACE TM0177 tensile test, the NACE TM0284 HIC test and the double beam test developed during the MPC program.[8] The data provided valuable fundamental information which has improved both the awareness of the causes of wet H_2S cracking and potential remedies in terms of both new construction and repair of existing equipment. However, there was a desire to validate the findings and conclusions of that program and to explore the complex interrelations of variables that can affect the actual behavior of large scale equipment used in wet H_2S service. The present study, which characterized the full-scale behavior of refinery equipment in wet H_2S service, assisted in bridging this gap. In general, the observations of material behavior found in this study were consistent with the findings of the previous laboratory testing conducted in the MPC Wet H_2S Research Program. The results of the present study validated the wet H_2S test methods developed previously and showed their applicability to refinery wet H_2S environments.

5.0 References

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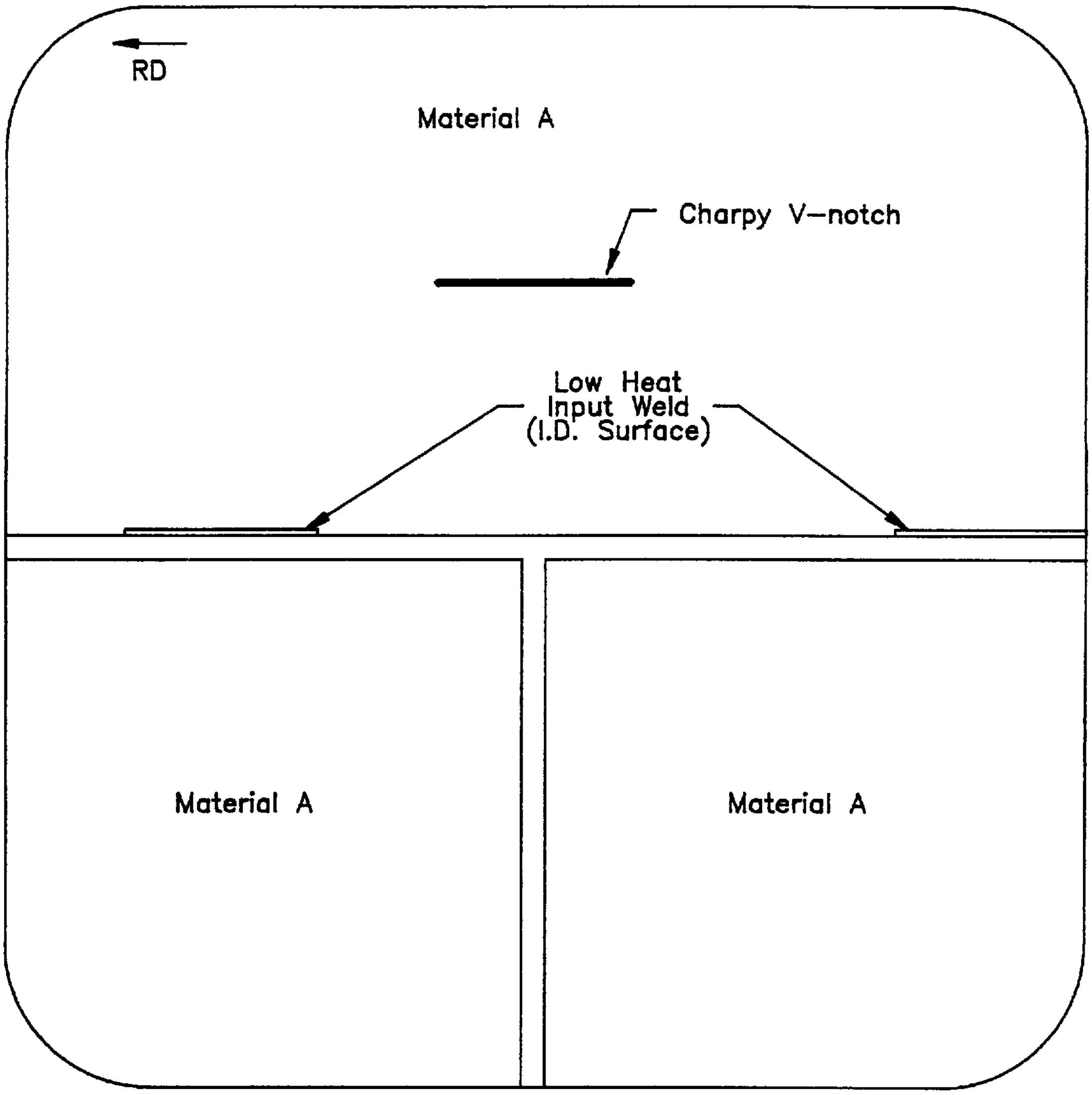
8. Kane, R. D. and Cayard, M. S., "Test Procedures for the Evaluation of Resistance of Steels to Cracking in Wet H_2S Environments," Paper No. 519, CORROSION/94, NACE, Baltimore, Maryland, Feb., 1994.

APPENDIX I

SERVICEABILITY OF HIC DAMAGED STEEL

APPENDIX I - FIGURE 1

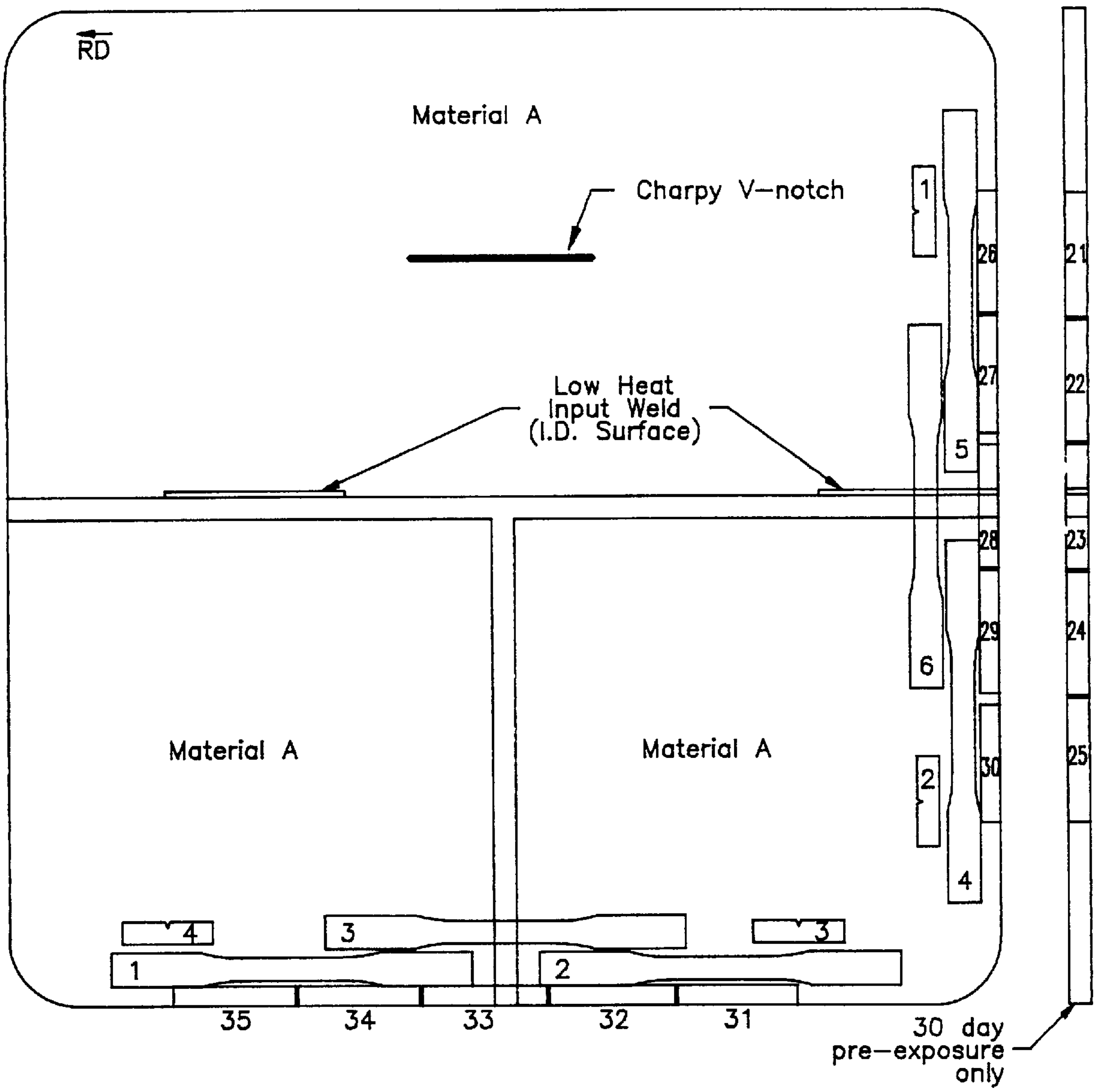


Material A: A516 Grade 70
CLI Number: 2278
Chemistry: C=0.22, P=0.020, S=0.017
Material Condition: As Rolled
Mechanical Properties: Yield=48.2ksi, UTS=78.9ksi, % elongation=25.0

O.D. View

Date: 9/2/93	Project #: L902103KT
Disk #: L500-1	File #: 2209
Scale:	Drawn By: K. Koenig

APPENDIX I - FIGURE 2



Material A: A516 Grade 70
CLI Number: 2278
Chemistry: C=0.22, P=0.020, S=0.017
Material Condition: As Rolled
Mechanical Properties: Yield=48.2ksi, UTS=78.9ksi, % elongation=25.0

Note:
Bulk of plate was left unsectioned for future round robin UT study.

O.D. View

Date: 9/2/93	Project #: L912151KT
Disk #: AMG-11	File #: 2151
Scale:	Drawn By: K. Koenig

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test NACE Per TM0284-87

Sponsor : API / MPC
Material : A516 Grade 70
Window # : 1
Condition : Cold Rolled

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.75
pH (FINL) : 3.5

Project # : L912151KT
CLI : 2278
Section : 21,22,25
File # : 1W212225.WK1
Date : 9/22/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
21	Top 1/3	0.0689	0.0413	2.723	0.513	BT	5.32	40.56	39.60
	Mid 1/3	0.5728	0.0984			BM			
		0.0354	0.0059			BM			
		0.1417	0.0102			BM			
		0.2854	0.0472			BM			
	Bot. 1/3	0.0000	0.0000						
22	Top 1/3	0.1575	0.0925	2.685	0.512	BT	9.68	56.75	67.90
		0.1772	0.0709			BT			
		0.1260	0.0630			BT			
	Mid 1/3	0.0866	0.0228			BM			
		0.9764	0.0984			BM			
	Bot. 1/3	0.0000	0.0000						
25	Top 1/3	0.0630	0.0551	2.754	0.515	BT	17.87	109.75	139.90
		0.0886	0.0807			BT			
		0.0331	0.0220			BT			
		0.1220	0.0374			BT			
		0.0945	0.0827			BT			
	Mid 1/3	0.0846	0.0374			BM			
		0.2815	0.0492			BM			
		0.3839	0.0827			BM/BT			
		0.8543	0.1122			BM			
		0.0441	0.0039			BM			
		0.1870	0.0551			BM			
		0.7579	0.0984			BM/BT			
	Bot. 1/3	0.0280	0.0035			BC			

Full Thickness Averages of All Three Sections

Avg. CSR =	10.96	Std. Dev. =	2.06
Avg. CLR =	69.02	Std. Dev. =	9.86
Avg. CTR =	82.47	Std. Dev. =	6.87

2/3 Thickness Averages of All Three Sections

Avg. CSR =	10.96	Std. Dev. =	2.13
Avg. CLR =	68.68	Std. Dev. =	10.04
Avg. CTR =	82.24	Std. Dev. =	6.26

1/3 Thickness Averages of All Three Sections

Avg. CSR =	1.48	Std. Dev. =	0.31
Avg. CLR =	11.42	Std. Dev. =	1.65
Avg. CTR =	35.41	Std. Dev. =	4.34

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

Comments

- Base metal LT section
- 30 day pre-exposure/No vessel test

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test NACE Per TM0284-87

Sponsor : API / MPC
Material : A516 Grade 70
Window # : 1
Condition : Cold Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.75
pH (FINL) : 3.5

Project # : L912151KT
CLI : 2278
Section : 23
File # : 1W23.WK1
Date : 9/22/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
23 WELD	Top 1/3	0.1516	0.0492	2.731	0.491	BT	10.23	58.07	79.06
		0.1909	0.1319			H2T/H1T			
		0.0583	0.0299			BT			
	Mid 1/3	0.4075	0.0945			BM			
		0.7776	0.0827			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Average

Avg. CSR =	10.23	Std. Dev. =	1.71
Avg. CLR =	58.07	Std. Dev. =	9.62
Avg. CTR =	79.06	Std. Dev. =	8.86

2/3 Thickness Average

Avg. CSR =	10.23	Std. Dev. =	1.68
Avg. CLR =	58.07	Std. Dev. =	9.41
Avg. CTR =	79.06	Std. Dev. =	7.25

1/3 Thickness Average

Avg. CSR =	2.56	Std. Dev. =	0.74
Avg. CLR =	14.68	Std. Dev. =	2.04
Avg. CTR =	42.98	Std. Dev. =	9.01

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Weld metal LT section
- 30 day pre-exposure only/No vessel test

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test NACE Per TM0284-87

Sponsor : API / MPC
Material : A516 Grade 70
Window # : 1
Condition : Cold Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.75
pH (FINL) : 3.5

Project # : L912151KT
CLI : 2278
Section : 26,27,30
File # : 1W262730.WK1
Date : 9/22/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
26	Top 1/3	0.1083	0.0512	2.659	0.489	BS/BT/BS	12.52	70.54	65.38
		0.0409	0.0134			BS			
		0.0669	0.0205			BS			
		0.3209	0.0315			BS/BT/BS			
		0.0256	0.0177			BT			
	Mid 1/3	0.1988	0.0472			BM			
		0.0433	0.0122			BM			
		1.0709	0.1260			BM/BT/BM			
	Bot. 1/3	0.0000	0.0000						
27	Top 1/3	0.0768	0.0276	2.601	0.503	BS	15.65	129.05	87.74
		0.0709	0.0110			BT			
		0.0504	0.0165			BS			
		0.0732	0.0205			BS/BT			
		0.0945	0.0354			BS			
		0.0559	0.0213			BS			
		0.1122	0.0295			BS			
		0.0531	0.0138			BT			
	Mid 1/3	1.5945	0.0846			BM			
		0.1122	0.0335			BM			
		0.5925	0.0689			BM/BT/BM			
		0.1496	0.0197			BM			
		0.2028	0.0177			BM			
		0.1181	0.0413			BM			
	Bot. 1/3	0.0000	0.0000						

Page 1 of 2

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test NACE Per TM0284-87

Sponsor : API / MPC
Material : A516 Grade 70
Window # : 1
Condition : Cold Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.75
pH (FINL) : 3.5

Project # : L912151KT
CLI : 2278
Section : 26,27,30
File # : 1W262730.WK1
Date : 9/22/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
30	Top 1/3	0.0567	0.0228	2.588	0.492	BS	16.48	95.49	79.62
		0.1142	0.0236			BT			
		0.0197	0.0142			BS			
		0.0276	0.0028			BS			
		0.0795	0.0126			BT			
		0.0654	0.0449			BS/BT			
		0.0150	0.0134			BS/BT			
		0.0984	0.0433			BT			
	Mid 1/3	0.5531	0.0689			BM			
		0.0126	0.0016			BM			
		1.3504	0.1161			BM/BT/BM			
		0.0787	0.0276			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR	14.89	Std. Dev. =	3.00
Avg. CLR =	98.36	Std. Dev. =	13.97
Avg. CTR =	77.58	Std. Dev. =	5.89

2/3 Thickness Averages of All Three Sections

Avg. CSR	14.89	Std. Dev. =	3.11
Avg. CLR =	98.36	Std. Dev. =	14.36
Avg. CTR =	77.58	Std. Dev. =	5.83

1/3 Thickness Averages of All Three Sections

Avg. CSR	1.15	Std. Dev. =	0.18
Avg. CLR =	20.71	Std. Dev. =	2.32
Avg. CTR =	32.82	Std. Dev. =	2.46

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Base metal LT section
- 30 day pre-exposure
- 14 day test

Page 2 of 2

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test NACE Per TM0284-87

Sponsor : API / MPC
Material : A516 Grade 70
Window # : 1
Condition : Cold Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.75
pH (FINL) : 3.5

Project # : L912151KT
CLI : 2278
Section : 28
File # : 1W28.WK1
Date : 9/22/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
28	Top 1/3	0.0925	0.0335	2.687	0.476	BT	23.63	113.51	191.89
WELD		0.0531	0.0217			BT			
		0.0276	0.0449			BT			
		0.0984	0.0197			BT			
		0.0689	0.0610			H1S/H2S/BT			
		0.0236	0.0630			H1T/H2T			
		0.0866	0.0276			BT			
		0.2657	0.0787			BT			
		0.2697	0.0768			BT			
	Mid 1/3	0.1476	0.0925			H1T/H2T/H2M/BM			
		0.7421	0.1398			BM/BT/BM			
		0.0394	0.0213			BM			
		0.1929	0.0433			BM/H2M/H1M			
		0.1240	0.0374			BM			
		0.7697	0.1476			H2M/BM/BT			
		0.0480	0.0047			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Average

Avg. CSR :	23.63	Std. Dev. =	2.65
Avg. CLR :	113.51	Std. Dev. =	8.33
Avg. CTR :	191.89	Std. Dev. =	8.69

2/3 Thickness Average

Avg. CSR :	23.63	Std. Dev. =	2.70
Avg. CLR :	113.51	Std. Dev. =	8.41
Avg. CTR :	191.89	Std. Dev. =	8.47

1/3 Thickness Average

Avg. CSR :	4.47	Std. Dev. =	0.61
Avg. CLR :	36.70	Std. Dev. =	3.28
Avg. CTR :	89.66	Std. Dev. =	4.59

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Weld metal LT section
- 30 day pre-exposure
- 14 day test

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test NACE Per TM0284–87

Sponsor : API / MPC
Material : A516 Grade 70
Window # : 1
Condition : Cold Rolled, Welded

Solution : TM0177–90
Exposure : One–sided
pH (INIT) : 2.75
pH (FINL) : 3.5

Project # : L912151KT
CLI : 2278
Section : 31,32,35
File # : 1W313235.WK1
Date : 9/22/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
31	Top 1/3	0.0083	0.0004	2.644	0.508	BT	22.15	104.25	82.62
		0.1299	0.0217			BT			
		0.4587	0.1417			BT			
	Mid 1/3	0.5157	0.1693			BM/BT			
		1.6437	0.0866			BM			
	Bot. 1/3	0.0000	0.0000						
32	Top 1/3	0.0295	0.0087	2.780	0.506	BT	15.52	117.05	115.54
		0.1673	0.0315			BT			
		0.0886	0.0197			BT			
		0.1713	0.0217			BT			
		0.1378	0.0453			BT			
		0.0787	0.0433			BT			
		0.3091	0.0433			BT			
	Mid 1/3	0.0394	0.0012			BM			
		0.5728	0.0689			BM/BT/BM			
		0.1772	0.0689			BT/BM			
		0.1555	0.0472			BM			
		0.8740	0.0984			BM/BT			
		0.4528	0.0866			BM/BT			
	Bot. 1/3	0.0000	0.0000						

Page 1 of 2

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test NACE Per TM0284–87

Sponsor : API / MPC
Material : A516 Grade 70
Window # : 1
Condition : Cold Rolled, Welded

Solution : TM0177–90
Exposure : One–sided
pH (INIT) : 2.75
pH (FINL) : 3.5

Project # : L912151KT
CLI : 2278
Section : 31,32,35
File # : 1W313235.WK1
Date : 9/22/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
35	Top 1/3	0.0787	0.0098	2.679	0.506	BT	22.36	123.19	82.71
		0.0142	0.0228			BT			
		0.0177	0.0020			BT			
		0.0728	0.0236			BS/BT			
		0.0094	0.0024			BS/BT			
		0.0228	0.0087			BS/BT			
		0.1122	0.0138			BT			
		0.1673	0.0276			BT			
		0.2441	0.0591			BT			
	Mid 1/3	0.0287	0.0012			BM			
		0.0315	0.0016			BM			
		0.0130	0.0028			BM			
		0.0228	0.0012			BM			
		0.1083	0.0039			BM			
		0.0339	0.0039			BM			
		0.4823	0.1122			BT/BM			
		1.8406	0.1220			BM/BT/BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	20.01	Std. Dev. =	3.37
Avg. CLR =	114.83	Std. Dev. =	15.10
Avg. CTR =	93.62	Std. Dev. =	8.66

2/3 Thickness Averages of All Three Sections

Avg. CSR =	20.01	Std. Dev. =	3.47
Avg. CLR =	114.83	Std. Dev. =	15.49
Avg. CTR =	93.62	Std. Dev. =	8.74

1/3 Thickness Averages of All Three Sections

Avg. CSR =	3.07	Std. Dev. =	1.07
Avg. CLR =	28.50	Std. Dev. =	4.23
Avg. CTR =	35.98	Std. Dev. =	6.10

Crack Location Codes

B–Base Metal
H1–Heat Affected Zone 1
H2–Heat Affected Zone 2
W–Weld
WC–Weld Cap
WR–Weld Root
S–Surface
T–Tension
M–Middle
C–Compression

Comments

- Base metal TL section
- 30 day pre–exposure
- 14 day test

Page 2 of 2

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test NACE Per TM0284-87

Sponsor : API / MPC
Material : A516 Grade 70
Window # : 1
Condition : Cold Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.75
pH (FINL) : 3.5

Project # : L912151KT
CLI : 2278
Section : 33
File # : 1W33.WK1
Date : 9/22/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
33	Top 1/3	0.0232	0.0055	2.727	0.477	BT	14.57	104.35	74.70
		0.1850	0.0197			BT			
		0.0492	0.0197			BT			
		0.0394	0.0039			BT			
	Mid 1/3	0.8858	0.1181			BM/BT/BM/BT/BM			
		0.0724	0.0142			BM			
		0.6339	0.0571			BM/H2M/H1M			
		0.2776	0.0177			H1M/H2M/BM			
		0.5118	0.0610			BM			
		0.1673	0.0394			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Average

Avg. CSR =	14.57	Std. Dev. =	2.32
Avg. CLR =	104.35	Std. Dev. =	10.26
Avg. CTR =	74.70	Std. Dev. =	7.00

2/3 Thickness Average

Avg. CSR =	14.57	Std. Dev. =	2.40
Avg. CLR =	104.35	Std. Dev. =	10.29
Avg. CTR =	74.70	Std. Dev. =	6.99

1/3 Thickness Average

Avg. CSR =	0.38	Std. Dev. =	0.11
Avg. CLR =	10.89	Std. Dev. =	2.37
Avg. CTR =	10.23	Std. Dev. =	1.57

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

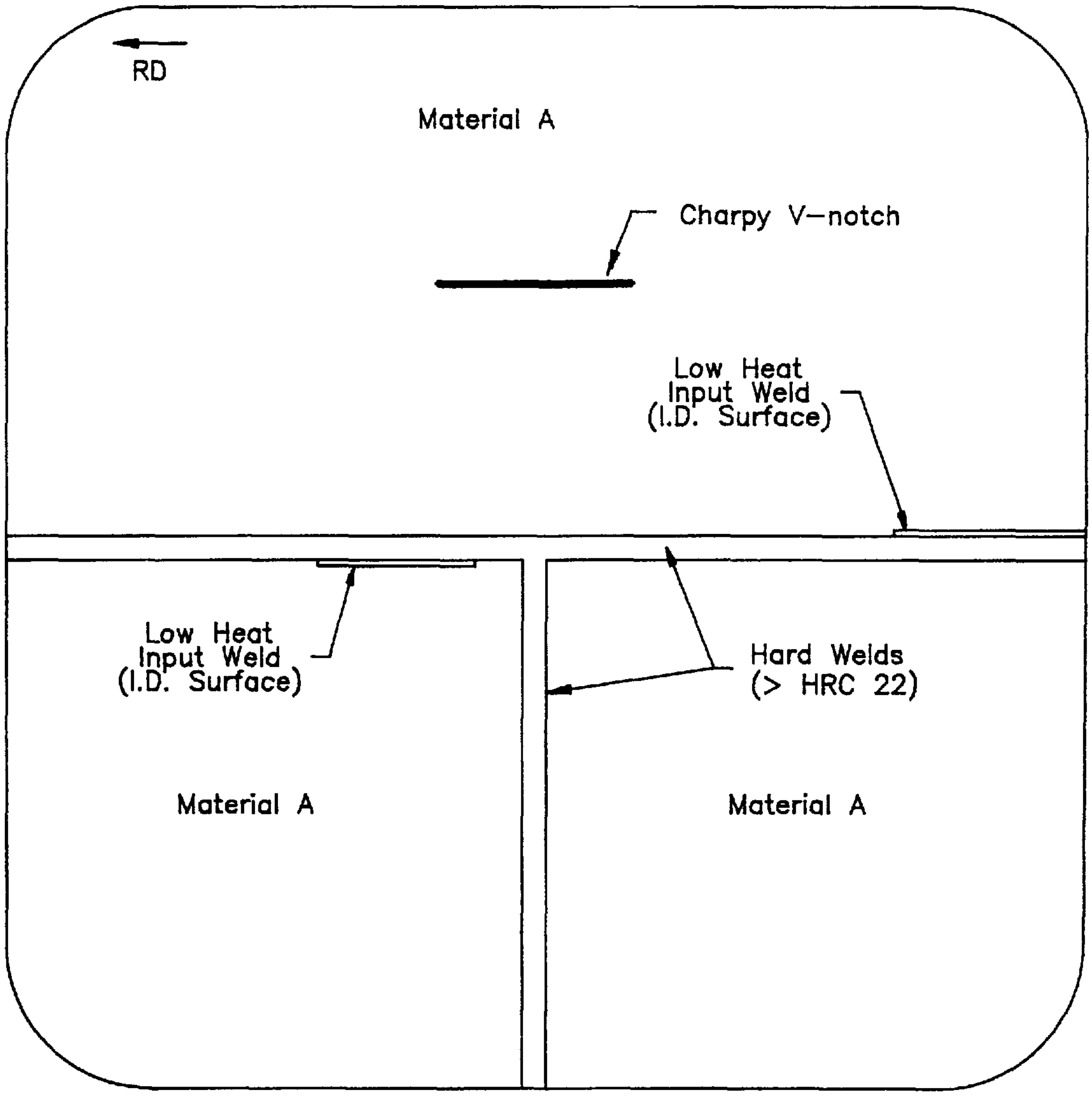
Comments

- Weld metal TL section
- 30 day pre-exposure
- 14 day test

APPENDIX II

SERVICEABILITY OF HARD WELDS

APPENDIX II - FIGURE 1

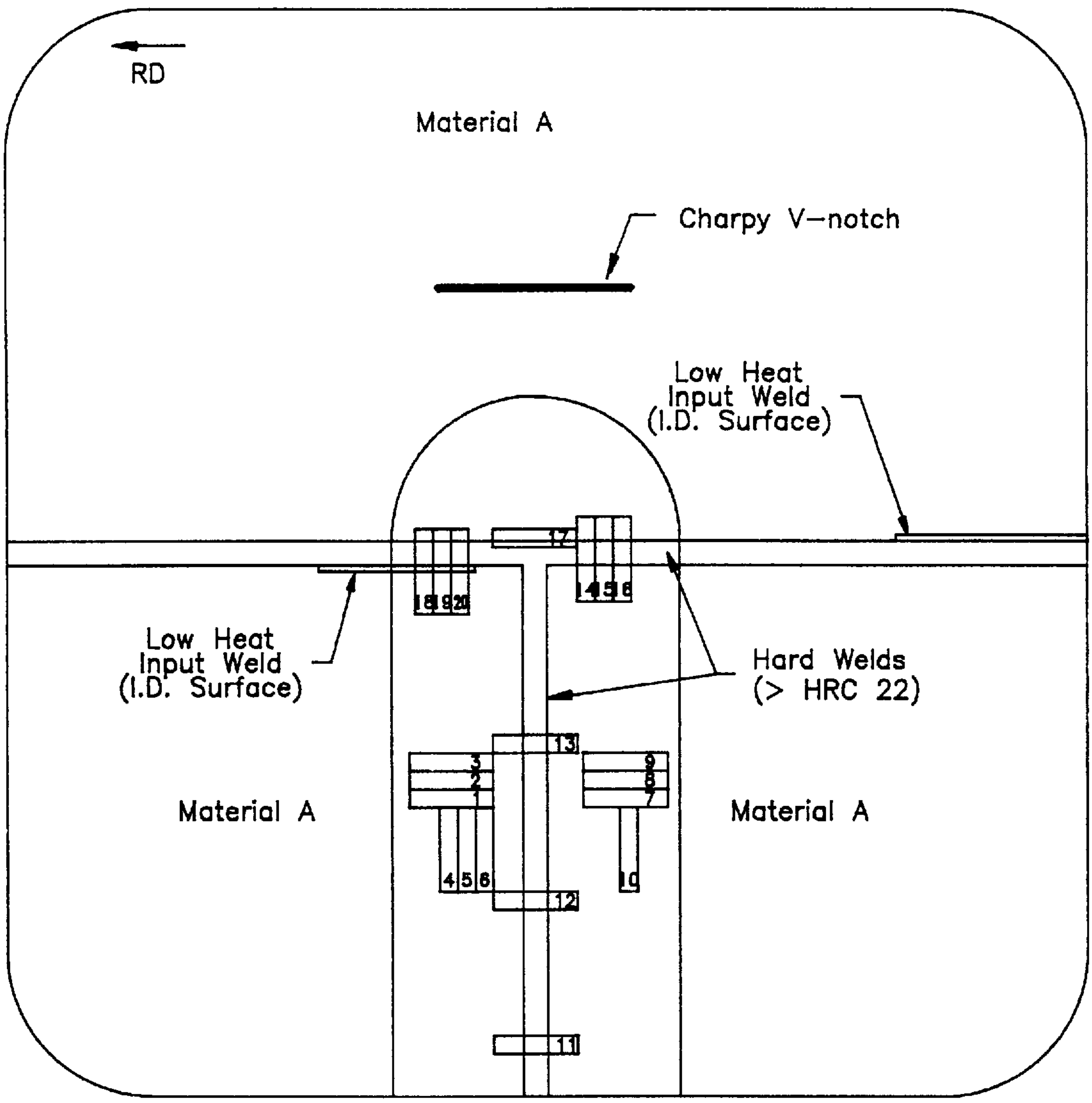


Material A: A516 Grade 70
CLI Number: 2278
Chemistry: C=0.22, P=0.020, S=0.017
Material Condition: As Rolled
Mechanical Properties: Yield=48.2ksi, UTS=78.9ksi, % elongation=25.0

O.D. View

Date: 9/2/93	Project #: L902103KT
Disk #: L500-1	File #: 2209
Scale:	Drawn By: K. Koenig

APPENDIX II - FIGURE 2



Material A: A516 Grade 70
CLI Number: 2278
Chemistry: C=0.22, P=0.020, S=0.017
Material Condition: As Rolled
Mechanical Properties: Yield=48.2ksi, UTS=78.9ksi, % elongation=25.0

O.D. View

Date: 9/2/93	Project #: L902103KT
Disk #: L500-1	File #: 2209
Scale:	Drawn By: K. Koenig

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516 Grade 70
Window # : 2
Condition : Cold Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.1

Project # : L912152KT
CLI : 2278
Section : 1,2,3
File # : 2W123.WK1
Date : 9/21/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
1	Top 1/3	0.2323	0.0374	2.036	0.500	BT	5.83	68.38	37.24
		0.1594	0.0472			BS/BT/BS			
	Mid 1/3	0.6516	0.0551			BM			
		0.0142	0.0067			BM			
		0.0098	0.0004			BM			
		0.2067	0.0276			BM			
		0.1181	0.0118			BM			
	Bot. 1/3	0.0000	0.0000						
2	Top 1/3	0.1220	0.0354	2.082	0.500	BS	6.66	81.18	34.41
	Mid 1/3	0.0602	0.0028			BM			
		0.1398	0.0256			BM			
		0.2126	0.0138			BM			
		0.4921	0.0256			BM			
		0.6634	0.0689			BM			
	Bot. 1/3	0.0000	0.0000						
3	Top 1/3	0.3012	0.0512	2.116	0.495	BT	5.19	76.38	42.55
	Mid 1/3	0.0728	0.0236			BM			
		0.1693	0.0315			BM			
		0.2736	0.0354			BM			
		0.2736	0.0315			BM			
		0.4075	0.0315			BM			
		0.1181	0.0059			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	5.89	Std. Dev. =	1.09
Avg. CLR =	75.31	Std. Dev. =	9.12
Avg. CTR =	38.07	Std. Dev. =	3.85

2/3 Thickness Averages of All Three Sections

Avg. CSR =	5.89	Std. Dev. =	1.12
Avg. CLR =	75.31	Std. Dev. =	8.89
Avg. CTR =	38.07	Std. Dev. =	3.58

1/3 Thickness Averages of All Three Sections

Avg. CSR =	1.16	Std. Dev. =	0.38
Avg. CLR =	13.11	Std. Dev. =	3.23
Avg. CTR =	11.45	Std. Dev. =	1.35

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

Comments

- Base metal TL section
- No pre-exposure/4 day test

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516 Grade 70
Window # : 2
Condition : Cold Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) . 3.1

Project # : L912152KT
CLI : 2278
Section : 4,5,6
File # : 2W456.WK1
Date · 9/22/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
4	Top 1/3	0.1693	0.0512	2.069	0.495	BS/BT	18.78	105.63	108.09
		0.0236	0.0173			BS			
		0.0189	0.0016			BT			
		0.0768	0.0315			BT			
		0.0610	0.0374			BT			
	Mid 1/3	0.0209	0.0016			BM			
		0.0217	0.0083			BM			
		0.2835	0.0669			BM			
		0.0071	0.0008			BM			
		0.0138	0.0016			BM			
		0.2480	0 0492			BM			
		0.4528	0.1043			BT/BM			
		0 0264	0 0335			BM			
		0.7618	0.1299			BT/BM			
	Bot. 1/3	0 0000	0.0000						
5	Top 1/3	0.0453	0.0118	2 056	0.500	BT	5.44	63.44	41.81
	Mid 1/3	0 0496	0 0063			BM			
		0 0374	0 0079			BM			
		0.4803	0 0827			BM/BT/BM			
		0.1969	0 0177			BM			
		0.1831	0.0138			BM			
		0.0161	0 0016			BM			
		0.0811	0.0134			BM			
		0.0472	0.0039			BM			
		0 0098	0 0008			BM			
		0.1575	0.0492			BM			
	Bot. 1/3	0.0000	0.0000						
6	Top 1/3	0 0000	0.0000	2.045	0.507		7.30	65.98	39.14
	Mid 1/3	0 6634	0.0728			BM			
		0.1004	0.0059			BM			
		0 0319	0 0122			BM			
		0.0472	0 0331			BM			
		0 3937	0.0610			BM			
		0.0339	0 0063			BM			
		0.0787	0 0071			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg CSR ·	10 50	Std Dev =	1 94
Avg CLR :	78.35	Std. Dev. =	9.14
Avg CTR :	63 01	Std Dev. =	6.46

2/3 Thickness Averages of All Three Sections

Avg. CSR	10.50	Std. Dev. =	2.01
Avg. CLR :	78.35	Std. Dev. =	9.33
Avg. CTR :	63.01	Std. Dev. =	6.54

1/3 Thickness Averages of All Three Sections

Avg. CSR	0 47	Std. Dev =	0.28
Avg CLR :	6.37	Std. Dev. =	2.52
Avg CTR :	10.15	Std. Dev. =	3.59

Crack Location Codes

B - Base Metal
H1 - Heat Affected Zone 1
H2 - Heat Affected Zone 2
W - Weld
WC - Weld Cap
WR - Weld Root
S - Surface
T - Tension
M - Middle
C - Compression

Comments

- Base metal LT section
- No pre-exposure/4 day test

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516 Grade 70
Window # : 2
Condition : Cold Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.1

Project # : L912152KT
CLI : 2278
Section : 7,8,9
File # : 2W789.WK1
Date : 9/22/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
7	Top 1/3	0.0748	0.0134	1.888	0.500	BT	4.06	66.83	22.20
	Mid 1/3	0.0512	0.0059			BM			
		0.0138	0.0012			BM			
		0.6358	0.0374			BM			
		0.2303	0.0157			BM			
		0.2559	0.0374			BM			
	Bot. 1/3	0.0000	0.0000						
8	Top 1/3	0.0039	0.0354	1.800	0.500	H1S/H2S	3.01	60.59	24.02
	Mid 1/3	0.0886	0.0157			BM			
		0.0925	0.0157			BM			
		0.4528	0.0177			BM			
		0.4528	0.0354			BM			
	Bot. 1/3	0.0000	0.0000						
9	Top 1/3	0.2402	0.0728	1.789	0.500	BT/BS	4.41	37.08	25.28
	Mid 1/3	0.4134	0.0531			BM			
		0.0098	0.0004			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	3.83	Std. Dev. =	0.90
Avg. CLR =	54.83	Std. Dev. =	10.65
Avg. CTR =	23.83	Std. Dev. =	4.11

2/3 Thickness Averages of All Three Sections

Avg. CSR =	3.83	Std. Dev. =	0.93
Avg. CLR =	54.83	Std. Dev. =	10.65
Avg. CTR =	23.83	Std. Dev. =	3.99

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.69	Std. Dev. =	0.89
Avg. CLR =	5.87	Std. Dev. =	5.56
Avg. CTR =	8.11	Std. Dev. =	4.91

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Base metal TL section
- No pre-exposure/4 day test
- Through I.D. surface indicaitons

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API / MPC	Solution : TM0177-90	Project # : L912152KT
Material : A516 Grade 70	Exposure : One-sided	CLI : 2278
Window # : 2	pH (INIT) : 2.7	Section : 10
Condition : Cold Rolled, Welded	pH (FINL) : 3.1	File # : 2W10.WK1
		Date : 9/22/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
10	Top 1/3	0.0413	0.0157	2.155	0.500	BT	6.23	57.97	53.78
	Mid 1/3	0.0866	0.0276			BM			
		0.5906	0.0787			BT/BM			
		0.0465	0.0035			BM			
		0.1201	0.0236			BM			
		0.1280	0.0394			BM			
		0.0291	0.0016			BM			
		0.1441	0.0567			BM			
		0.0630	0.0220			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Average

Avg. CSR =	2.08	Std. Dev. =	1.25
Avg. CLR =	19.32	Std. Dev. =	7.49
Avg. CTR =	17.93	Std. Dev. =	4.82

2/3 Thickness Average

Avg. CSR =	2.08	Std. Dev. =	1.30
Avg. CLR =	19.32	Std. Dev. =	7.63
Avg. CTR =	17.93	Std. Dev. =	4.71

1/3 Thickness Average

Avg. CSR =	0.02	Std. Dev. =	0.06
Avg. CLR =	0.64	Std. Dev. =	1.92
Avg. CTR =	1.05	Std. Dev. =	3.15

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

Comments

- Base metal LT section
- No pre-exposure/4 day test

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API / MPC
Material : A516 Grade 70
Window # : 2
Condition : Cold Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.1

Project # : L912152KT
CLI : 2278
Section : 11,12,13
File # : 2W111213.WK1
Date : 9/22/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
11	Top 1/3	0 0000	0.0000	2 145	0 480		0 50	17.27	11 32
	Mid 1/3	0 0709	0.0157			BM			
		0 0091	0.0012			BM			
		0 0563	0 0118			BM			
		0.1850	0 0157			BM			
		0.0492	0.0098			BM			
	Bot. 1/3	0 0000	0 0000						
12	Top 1/3	0 0606	0.0354	2 115	0.485	BT	4 88	80.02	40.59
		0 0748	0.0354			BS/BT			
		0 0236	0.0059			BT			
		0 0295	0 0059			BT			
	Mid 1/3	0.5256	0 0433			BM			
		0.2677	0 0157			BM			
		0 4134	0 0138			BM			
		0 2972	0 0413			H2M/BM/BT/BM/BT/BM			
	Bot 1/3	0 0000	0.0000						
13	Top 1/3	0 0492	0 0039	1.970	0.475	BT	16.22	87.23	38 96
	Mid 1/3	0.7815	0.0866			BM/BT/BM/H2M/H1M			
		0.8878	0 0945			H2M/BM			
	Bot. 1/3	0 0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR	7.20	Std. Dev =	2.41
Avg. CLR :	61.51	Std Dev. =	13.01
Avg. CTR :	30 29	Std Dev. =	5 61

2/3 Thickness Averages of All Three Sections

Avg CSR	7.20	Std. Dev. =	2 57
Avg CLR :	61.51	Std. Dev. =	13 47
Avg CTR :	30.29	Std. Dev =	5 72

1/3 Thickness Averages of All Three Sections

Avg CSR	0.17	Std. Dev =	0.11
Avg. CLR :	3.80	Std Dev =	1 19
Avg. CTR ·	5.96	Std Dev =	3 09

Crack Location Codes

B - Base Metal
H1 - Heat Affected Zone 1
H2 - Heat Affected Zone 2
W - Weld
WC - Weld Cap
WR - Weld Root
S - Surface
T - Tension
M - Middle
C - Compression

Comments

- Weld metal TL section
- No pre-exposure/4 day test

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284–87

Sponsor : API / MPC
Material : A516 Grade 70
Window # : 2
Condition : Cold Rolled, Welded

Solution : TM0177–90
Exposure : One–sided
pH (INIT) : 2.7
pH (FINL) : 3.1

Project # : L912152KT
CLI : 2278
Section : 14,15,16
File # : 2W141516.WK1
Date : 9/22/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
14	Top 1/3	0.0827	0.0335	2.084	0.486	BS	3.04	37.27	23.33
	Mid 1/3	0.4646	0.0551			BM			
		0.0189	0.0024			BM			
		0.0126	0.0008			BM			
		0.0661	0.0079			BM			
		0.1319	0.0138			BM			
	Bot. 1/3	0.0000	0.0000						
15	Top 1/3	0.0236	0.0240	2.088	0.485	WS	3.10	54.74	55.04
		0.0150	0.0496			WT			
		0.0394	0.0110			WT			
		0.0610	0.0177			BT			
	Mid 1/3	0.1693	0.0492			BM/BT/BM			
		0.1201	0.0413			BM			
		0.0402	0.0024			BM			
		0.0610	0.0197			BM			
		0.0102	0.0012			BM			
		0.0079	0.0004			BM			
		0.0106	0.0012			BM			
		0.1791	0.0059			BM			
		0.0551	0.0079			H2M/H1M/WM			
		0.3504	0.0354			BM			
	Bot. 1/3	0.0000	0.0000						
16	Top 1/3	0.0827	0.0780	2.095	0.475	WS/WT/H1T	5.33	50.50	58.10
		0.0354	0.0039			BT			
	Mid 1/3	0.2382	0.0453			BM/BT			
		0.0146	0.0012			BM			
		0.3780	0.0571			BM			
		0.1594	0.0512			BM			
		0.1496	0.0394			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	3.82	Std. Dev. =	0.64
Avg. CLR =	47.50	Std. Dev. =	5.72
Avg. CTR =	45.49	Std. Dev. =	4.70

2/3 Thickness Averages of All Three Sections

Avg. CSR =	3.82	Std. Dev. =	0.65
Avg. CLR =	47.50	Std. Dev. =	5.72
Avg. CTR =	45.49	Std. Dev. =	4.65

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.40	Std. Dev. =	0.21
Avg. CLR =	5.42	Std. Dev. =	1.21
Avg. CTR =	15.08	Std. Dev. =	4.97

Crack Location Codes

B–Base Metal	WR–Weld Root
H1–Heat Affected Zone 1	S–Surface
H2–Heat Affected Zone 2	T–Tension
W–Weld	M–Middle
WC–Weld Cap	C–Compression

Comments

– Weld metal LT section
– No pre–exposure/4 day test
– No LHI weld at HAZ

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API / MPC
Material : A516 Grade 70
Window # : 2
Condition : Cold Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.1

Project # : L912152KT
CLI : 2278
Section : 17
File # : 2W17.WK1
Date : 9/22/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
17	Top 1/3	0.0039	0.0465	1.963	0.465	WT	3.19	15.92	387.10
		0.0331	0.0465			WT			
		0.0150	0.0591			WT			
		0.0055	0.0236			WT			
		0.0118	0.1299			WS/WT			
		0.0031	0.0307			WS			
		0.0079	0.0965			WS/WT			
		0.0295	0.1102			WS/WT			
		0.0055	0.0299			WS/WT			
		0.0047	0.0465			WS/WT			
		0.0094	0.0701			WS/WT			
		0.0098	0.0709			WS/WT			
		0.0118	0.0417			WS/WT			
		0.0138	0.1181			WS/WT			
		0.0118	0.0551			WS/WT			
		0.0098	0.1181			WS/WT			
		0.0217	0.0728			WS/WT			
		0.0138	0.0846			WS/WT			
		0.0157	0.0728			WS/WT			
		0.0059	0.0787			WS/WT			
		0.0098	0.0512			WS/WT			
		0.0295	0.1732			WS/WT			
	Mid 1/3	0.0295	0.1732			WS/WT/WM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

2/3 Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

Comments

- Weld metal LT section
- No pre-exposure/4 day test

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API / MPC
Material : A516 Grade 70
Window # : 2
Condition : Cold Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.1

Project # : L912152KT
CLI : 2278
Section : 18,19,20
File # : 2W181920.WK1
Date : 9/22/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
18	Top 1/3	0.0299	0.0669	1.871	0.485	WS/WT	7.81	57.17	120.14
		0.0102	0.0701			WS/WT			
		0.0492	0.0886			WS/WT			
		0.0610	0.1004			WT			
		0.0217	0.0205			BS			
		0.1240	0.0413			SB/BT/BS			
		0.1220	0.0433			BT			
	Mid 1/3	0.3563	0.0335			BM			
		0.2953	0.1181			BM/BT			
	Bot. 1/3	0.0000	0.0000						
19	Top 1/3	0.0252	0.0520	1.860	0.487	WS/WT	7.23	45.11	117.38
		0.0209	0.0228			WS			
		0.0047	0.0335			WS			
		0.0331	0.0488			WS/WT			
		0.0051	0.0169			WS			
		0.0945	0.2283			WS/WT			
		0.0925	0.0551			BS/BT/BS			
	Mid 1/3	0.3878	0.0787			BM			
		0.1358	0.0335			BM			
		0.0394	0.0020			BM			
	Bot. 1/3	0.0000	0.0000						
20	Top 1/3	0.0598	0.0646	1.845	0.490	WS/H1S/H2S/H2T	4.90	39.20	74.16
		0.0118	0.0728			WS/WT			
		0.0236	0.0669			WS/WT			
		0.0295	0.0827			WS/WT			
	Mid 1/3	0.5551	0.0630			BM			
		0.0433	0.0134			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	6.65	Std. Dev. =	1.14
Avg. CLR =	47.16	Std. Dev. =	7.27
Avg. CTR =	103.89	Std. Dev. =	9.40

2/3 Thickness Averages of All Three Sections

Avg. CSR =	6.65	Std. Dev. =	1.18
Avg. CLR =	47.16	Std. Dev. =	7.47
Avg. CTR =	103.89	Std. Dev. =	9.07

1/3 Thickness Averages of All Three Sections

Avg. CSR =	2.32	Std. Dev. =	0.53
Avg. CLR =	14.65	Std. Dev. =	2.01
Avg. CTR =	80.47	Std. Dev. =	9.38

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

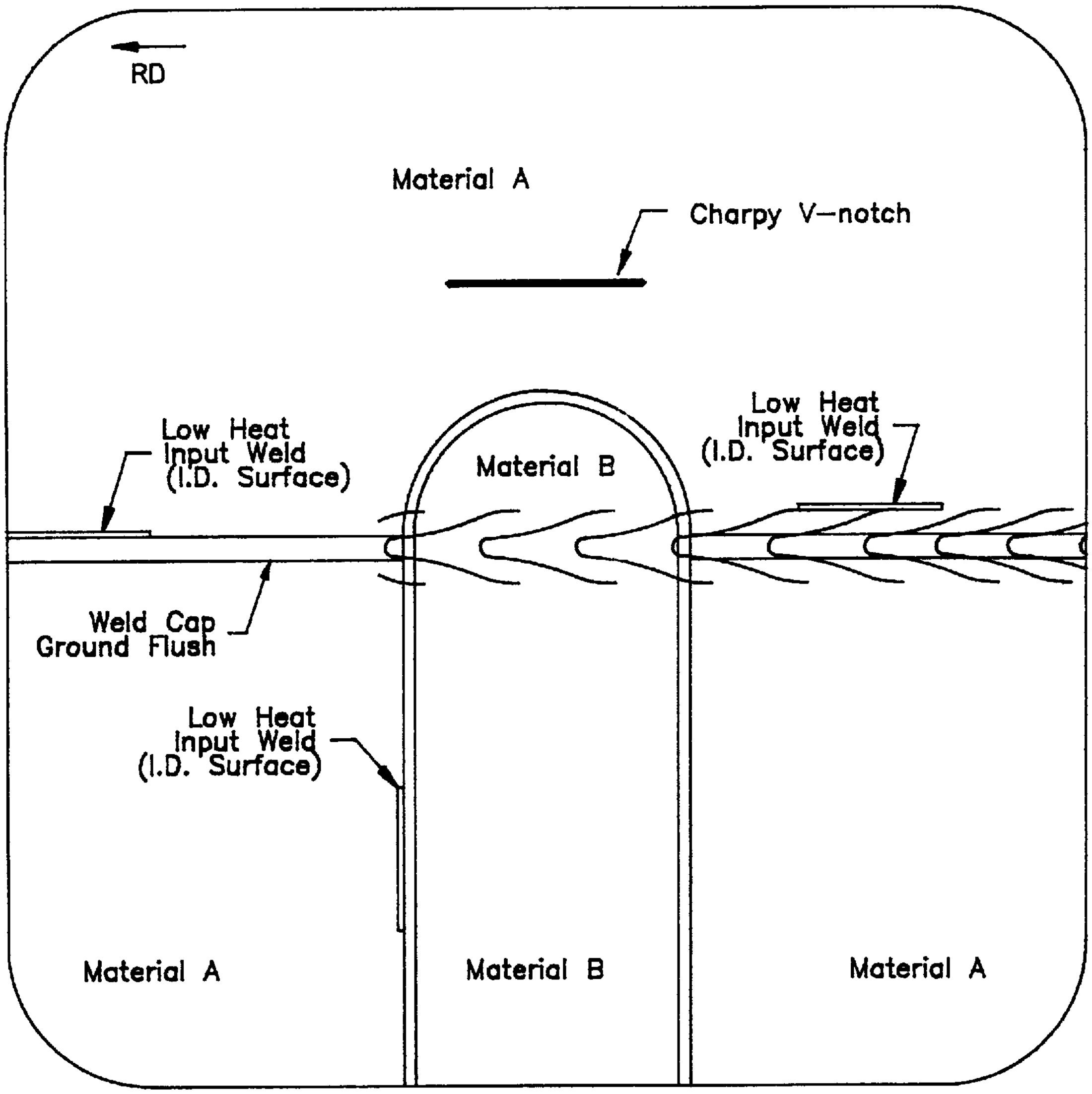
Comments

- Weld metal LT section
- No pre-exposure/4 day test
- LHI weld at HAZ

APPENDIX III

EVALUATION OF WELD REPAIR/PWHT

APPENDIX III - FIGURE 1



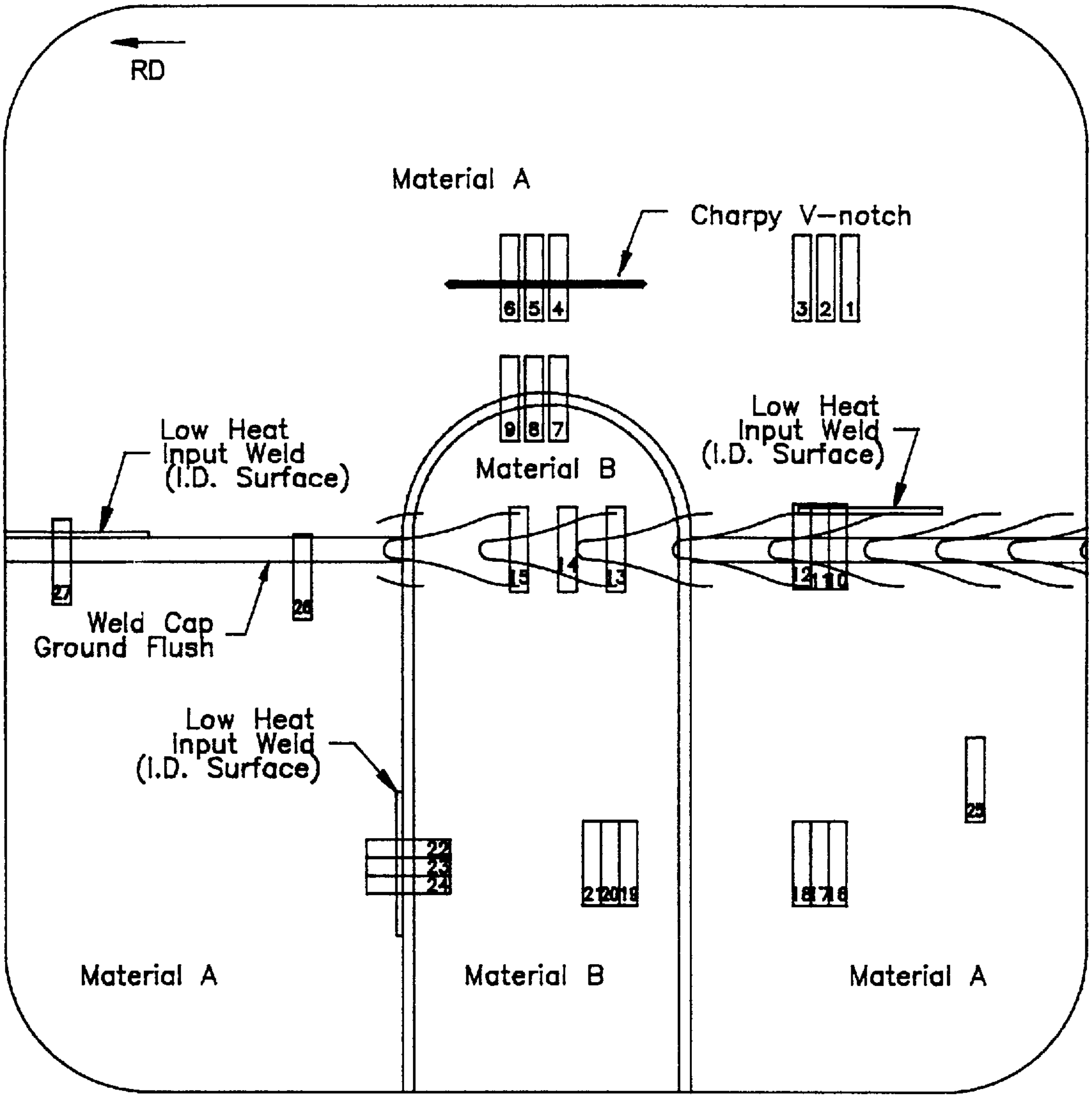
Material A:	A516 Grade 70
CLI Number:	2278
Chemistry:	C=0.22, P=0.020, S=0.017
Material Condition:	As Rolled
Mechanical Properties:	Yield=48.2ksi, UTS=78.9ksi, % elongation=25.0

Material B:	A516 Grade 70
CLI Number:	3201
Chemistry:	C=0.21, P=0.005, S=0.001
Material Condition:	Normalized
Mechanical Properties:	Yield=49.6ksi, UTS=76.2ksi, % elongation=27.0

O.D. View

Date: 9/2/93	Project #: L902103KT
Disk #: L500–1	File #: 2209
Scale:	Drawn By: K. Koenig

APPENDIX III - FIGURE 2



Material A: A516 Grade 70
CLI Number: 2278
Chemistry: C=0.22, P=0.020, S=0.017
Material Condition: As Rolled
Mechanical Properties: Yield=48.2ksi, UTS=78.9ksi, % elongation=25.0

Material B: A516 Grade 70
CLI Number: 3201
Chemistry: C=0.21, P=0.005, S=0.001
Material Condition: Normalized
Mechanical Properties: Yield=49.6ksi, UTS=76.2ksi, % elongation=27.0

O.D. View

Date: 9/2/93	Project #: L902103KT
Disk #: L500-1	File #: 2209
Scale:	Drawn By: K. Koenig

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284−87

Sponsor : API / MPC
Material : A516 Grade 60
Window # : 3
Condition : Colled Rolled, Welded

Solution : TM0177−90
Exposure : One−sided
pH (INIT) : 2.7
pH (FINL) : 3.4

Project # : L922209KT
CLI : 2278
Section : 1,2,3
File # : 3W123.WK1
Date : 9/23/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
1	Top 1/3	0.1594	0.0669	2.411	0.500	BS/BT/BS	3.19	31.19	58.82
		0.0866	0.0394			BS			
		0.0496	0.0244			BS			
		0.0181	0.0016			BT			
		0.1358	0.0571			BS/BT/BS			
		0.2165	0.0630			BT/BS			
		0.0512	0.0276			BS			
	Mid 1/3	0.0264	0.0138			BM			
		0.0083	0.0004			BM			
	Bot. 1/3	0.0000	0.0000						
2	Top 1/3	0.1693	0.0965	2.406	0.498	BS/BT	5.75	49.22	59.29
		0.0354	0.0079			BS			
		0.0094	0.0016			BT			
		0.0402	0.0157			BT			
		0.2992	0.0768			BS/BT/BS			
		0.0327	0.0031			BT			
		0.0110	0.0035			BT			
		0.0591	0.0047			BT			
		0.0083	0.0012			BT			
		0.4843	0.0571			BS/BT/BS/BT			
		0.0213	0.0260			BS			
	Mid 1/3	0.0142	0.0012			BM			
	Bot. 1/3	0.0000	0.0000						

Page 1 of 2

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API / MPC
Material : A516 Grade 60
Window # : 3
Condition : Colled Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.4

Project # : L922209KT
CLI : 2278
Section : 1,2,3
File # : 3W123.WK1
Date : 9/23/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
3	Top 1/3	0.0197	0.0256	2.398	0.500	BS	5.28	53.85	71.65
		0.0472	0.0126			BS			
		0.1240	0.0551			BS/BT			
		0.0512	0.0047			BT			
		0.1693	0.0630			BS/BT/BS			
		0.0236	0.0031			BT			
		0.0386	0.0173			BT/BS			
		0.0197	0.0114			BS			
		0.0248	0.0122			BS			
		0.0846	0.0413			BT			
		0.1496	0.0394			BT			
	Mid 1/3	0.4882	0.0689			BT/BM/BT			
		0.0094	0.0008			BM			
		0.0413	0.0028			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	4.74	Std. Dev. =	0.68
Avg. CLR =	44.75	Std. Dev. =	4.84
Avg. CTR =	63.25	Std. Dev. =	5.34

2/3 Thickness Averages of All Three Sections

Avg. CSR =	4.74	Std. Dev. =	0.70
Avg. CLR =	44.75	Std. Dev. =	4.92
Avg. CTR =	63.25	Std. Dev. =	5.35

1/3 Thickness Averages of All Three Sections

Avg. CSR =	3.79	Std. Dev. =	0.60
Avg. CLR =	36.59	Std. Dev. =	4.27
Avg. CTR =	57.40	Std. Dev. =	5.29

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Base metal LT section
- 28 day test

Page 2 of 2

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API / MPC
Material : A516 Grade 60
Window # : 3
Condition : Colled Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.4

Project # : L922209KT
CLI : 2278
Section : 4,5,6
File # : 3W456.WK1
Date : 9/23/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
4	Top 1/3	0.0925	0.0335	2.410	0.498	BS	7.91	36.76	66.72
		0.0102	0.0016			BT			
		0.4272	0.1732			BS/BT			
		0.0449	0.0236			BT			
		0.2106	0.0610			BS/BT/BS			
		0.1004	0.0394			BS			
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
5	Top 1/3	0.1161	0.0453	2.280	0.498	BS/BT/BS	1.98	31.41	38.82
		0.0283	0.0087			BS			
		0.0638	0.0197			BS			
		0.1240	0.0295			BS			
		0.1535	0.0650			BS/BT/BT			
	Mid 1/3	0.1358	0.0039			BM			
		0.0197	0.0008			BM			
		0.0748	0.0205			BM			
	Bot. 1/3	0.0000	0.0000						
6	Top 1/3	0.1280	0.0630	2.415	0.498	BS/BT/BS	9.87	87.17	96.45
		0.0748	0.0295			BS			
		0.1811	0.0591			BS/BT/BS			
		0.0567	0.0173			BT			
		0.3307	0.0413			BT			
		0.0551	0.0197			BS			
		0.0807	0.0335			BT			
		0.0886	0.0335			BT			
		0.0492	0.0079			BT			
	Mid 1/3	0.5906	0.0709			BT/BM/BT/BM/BT			
		0.3937	0.0846			BM			
		0.0394	0.0181			BM			
		0.0366	0.0020			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	6.59	Std. Dev. =	1.27
Avg. CLR =	51.78	Std. Dev. =	5.66
Avg. CTR =	67.33	Std. Dev. =	7.02

2/3 Thickness Averages of All Three Sections

Avg. CSR =	6.59	Std. Dev. =	1.32
Avg. CLR =	51.78	Std. Dev. =	5.71
Avg. CTR =	67.33	Std. Dev. =	7.04

1/3 Thickness Averages of All Three Sections

Avg. CSR =	4.42	Std. Dev. =	1.31
Avg. CLR =	33.78	Std. Dev. =	4.15
Avg. CTR =	53.89	Std. Dev. =	7.13

Crack Location Codes

B–Base Metal	WR–Weld Root
H1–Heat Affected Zone 1	S–Surface
H2–Heat Affected Zone 2	T–Tension
W–Weld	M–Middle
WC–Weld Cap	C–Compression

Comments

- Base metal LT section
- 28 day test
- Across Charpy V-notch

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API / MPC
Material : A516 Grade 60
Window # : 3
Condition : Colled Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.4

Project # : L922209KT
CLI : 2278, 3201
Section : 7,8,9
File # : 3W789.WK1
Date : 9/23/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
7	Top 1/3	0.0394	0.0315	2.306	0.500	BS	3.63	38.94	43.8
		0.0043	0.0004			BS			
		0.0335	0.0209			BS			
		0.0028	0.0173			BS			
		0.0354	0.0031			BT			
		0.0528	0.0079			BT			
		0.0378	0.0024			BT			
		0.0039	0.0008			H2S			
		0.0020	0.0047			H1S			
		0.0067	0.0067			H2S			
		0.0181	0.0024			H2T			
		0.0925	0.0138			BT			
	Mid 1/3	0.4173	0.0846			H1M/H2M/BM/BT			
		0.0236	0.0031			BM			
		0.1280	0.0197			BM			
	Bot. 1/3	0.0000	0.0000						
8	Top 1/3	0.0315	0.0039	2.325	0.500	BT	7.97	67.21	41.2
		0.0528	0.0213			BS			
		0.1575	0.0512			BS/BT/H2S			
		0.1004	0.0394			BS			
		0.0689	0.0197			BT			
	Mid 1/3	0.0197	0.0020			BM			
		1.1319	0.0689			H1M/H2M/BM/BT/BM			
	Bot. 1/3	0.0000	0.0000						
9	Top 1/3	0.0669	0.0063	2.298	0.500	BS	0.97	14.73	25.9
		0.1378	0.0512			BS/BT/BS			
		0.0591	0.0374			BS/BT			
		0.0457	0.0323			BS/BT			
	Mid 1/3	0.0146	0.0008			BM			
		0.0146	0.0016			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	4.19	Std. Dev. =	1.28
Avg. CLR =	40.30	Std. Dev. =	8.85
Avg. CTR =	37.01	Std. Dev. =	4.34

2/3 Thickness Averages of All Three Sections

Avg. CSR =	4.19	Std. Dev. =	1.33
Avg. CLR =	40.30	Std. Dev. =	9.21
Avg. CTR =	37.01	Std. Dev. =	4.39

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.86	Std. Dev. =	0.19
Avg. CLR =	15.14	Std. Dev. =	1.82
Avg. CTR =	24.96	Std. Dev. =	3.24

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

Comments

- Weld metal LT section
- 28 day test

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API / MPC
Material : A516 Grade 60
Window # : 3
Condition : Colled Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.4

Project # : L922209KT
CLI : 2278
Section : 10,11,12
File # : 3W101112.WK1
Date : 9/23/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
10	Top 1/3	0.0079	0.0295	3.133	0.493	BS/H2S/H1S	7.42	59.77	86.8
		0.0488	0.0433			H2T/H1T			
		0.0984	0.0413			BS			
		0.3012	0.0906			H1S/WS/H1S/H1T			
		0.1083	0.0217			BT			
		0.0591	0.0079			H1T			
	Mid 1/3	0.5610	0.0945			BT/BM			
		0.3445	0.0551			H1T/H1M/BM			
		0.0346	0.0071			BM			
		0.0315	0.0016			BM			
		0.0146	0.0067			H2M/H1M			
		0.2185	0.0256			H2M/BM			
		0.0224	0.0020			BM			
		0.0217	0.0012			BM			
	Bot. 1/3	0.0000	0.0000						
11	Top 1/3	0.2165	0.1240	3.132	0.495	BS/BT	15.13	70.43	86.0
		0.0496	0.0134			BS			
	Mid 1/3	0.7736	0.1909			BS/BT/BM			
		0.0921	0.0197			BM			
		0.0598	0.0189			BM			
		0.0280	0.0020			BM			
		0.9862	0.0571			H2M/BM			
	Bot. 1/3	0.0000	0.0000						

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Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API / MPC
Material : A516 Grade 60
Window # : 3
Condition : Colled Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.4

Project # : L922209KT
CLI : 2278
Section : 10,11,12
File # : 3W101112.WK1
Date : 9/23/92

12	Top 1/3	0.2264	0.0374	3.132	0.495	BS	6.78	60.69	69.0
		0.0197	0.0543			H1S/H2T/BT			
		0.0047	0.0228			H1S			
		0.0591	0.0217			BT			
		0.0846	0.0217			BT			
		0.1122	0.0276			BT			
	Mid 1/3	0.9154	0.0709			BM/BT/BM/BT/BM/BT			
		0.0528	0.0110			BM			
		0.0091	0.0008			BM			
		0.0173	0.0146			BM			
		0.3996	0.0591			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	9.78	Std. Dev. =	1.85
Avg. CLR =	63.63	Std. Dev. =	8.17
Avg. CTR =	80.63	Std. Dev. =	8.13

2/3 Thickness Averages of All Three Sections

Avg. CSR =	9.78	Std. Dev. =	1.91
Avg. CLR =	63.63	Std. Dev. =	8.36
Avg. CTR =	80.63	Std. Dev. =	8.21

1/3 Thickness Averages of All Three Sections

Avg. CSR =	1.72	Std. Dev. =	0.58
Avg. CLR =	14.86	Std. Dev. =	2.74
Avg. CTR =	37.58	Std. Dev. =	6.22

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Weld metal LT section
- 28 day test

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API / MPC
Material : A516 Grade 60
Window # : 3
Condition : Colled Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.4

Project # : L922209KT
CLI : 3201
Section : 13,14,15
File # : 3W131415.WK1
Date : 9/23/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
13	Top 1/3	0.0591	0.0276	3.077	0.515	BS	0.21	5.30	30.2
		0.0531	0.0059			BT			
		0.0118	0.0965			WS/WT			
		0.0098	0.0118			BS			
		0.0047	0.0098			BS			
	Mid 1/3	0.0138	0.0020			BM			
		0.0106	0.0024			BM			
	Bot. 1/3	0.0000	0.0000						
14	Top 1/3	0.0087	0.0008	3.071	0.515	BT	0.04	4.10	15.9
		0.0094	0.0004			BS			
		0.0122	0.0039			BS			
		0.0256	0.0063			BS			
		0.0031	0.0004			BT			
		0.0083	0.0319			WS			
		0.0031	0.0303			H1S/H2S			
	Mid 1/3	0.0098	0.0016			BM			
		0.0039	0.0008			BM			
		0.0236	0.0039			BM			
		0.0102	0.0008			BM			
		0.0079	0.0008			BM			
	Bot. 1/3	0.0000	0.0000						

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Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API / MPC
Material : A516 Grade 60
Window # : 3
Condition : Colled Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.4

Project # : L922209KT
CLI : 3201
Section : 13,14,15
File # : 3W131415.WK1
Date : 9/23/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
15	Top 1/3	0.0197	0.0067	3.075	0.515	BS	0.18	7.61	21.1
		0.0039	0.0031			BS			
		0.0480	0.0039			BT			
		0.0106	0.0051			BT			
		0.0051	0.0004			BS			
		0.0102	0.0402			H1S/H2S/H2T			
		0.0280	0.0173			BS			
		0.0567	0.0252			BS			
		0.0138	0.0020			BT			
	Mid 1/3	0.0047	0.0008			BM			
		0.0079	0.0012			BM			
		0.0047	0.0008			BM			
		0.0039	0.0012			BM			
		0.0165	0.0012			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	0.14	Std. Dev. =	0.02
Avg. CLR =	5.67	Std. Dev. =	0.51
Avg. CTR =	22.45	Std. Dev. =	3.50

2/3 Thickness Averages of All Three Sections

Avg. CSR =	0.14	Std. Dev. =	0.03
Avg. CLR =	5.67	Std. Dev. =	0.51
Avg. CTR =	22.45	Std. Dev. =	3.60

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.14	Std. Dev. =	0.03
Avg. CLR =	4.39	Std. Dev. =	0.59
Avg. CTR =	21.33	Std. Dev. =	4.20

Crack Location Codes

B–Base Metal
H1–Heat Affected Zone 1
H2–Heat Affected Zone 2
W–Weld
WC–Weld Cap
WR–Weld Root
S–Surface
T–Tension
M–Middle
C–Compression

Comments

– Weld metal LT section
– 28 day test

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Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API / MPC
Material : A516 Grade 60
Window # : 3
Condition : Colled Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.4

Project # : L922209KT
CLI : 2278
Section : 16,17,18
File # : 3W161718.WK1
Date : 9/23/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
16	Top 1/3	0.0098	0.0008	2.648	0.505	BT	18.45	118.96	76.64
		0.1969	0.0571			BT			
		0.1988	0.0492			BS/BT			
		0.0882	0.0220			BS			
		0.1280	0.0374			BT			
	Mid 1/3	0.0256	0.0079			BM			
		0.6004	0.0571			BM			
		0.0386	0.0035			BM			
		0.0228	0.0071			BM			
		0.1594	0.0315			BM			
		1.6240	0.1102			BM/BT/BM			
		0.0362	0.0020			BM			
		0.0213	0.0012			BM			
	Bot. 1/3	0.0000	0.0000						
17	Top 1/3	0.0728	0.0236	2.621	0.505	BS	7.81	90.20	90.90
		0.1575	0.0354			BS/BT			
		0.0268	0.0047			BT			
		0.0236	0.0189			BS			
		0.1181	0.0512			BT/BS			
		0.0323	0.0248			BS/BT			
		0.0276	0.0039			BS			
		0.0354	0.0138			BS			
		0.1516	0.0807			BS/BT/BS			
	Mid 1/3	0.0240	0.0075			BM			
		0.0091	0.0008			BM			
		0.0079	0.0004			BM			
		0.0189	0.0020			BM			
		0.1634	0.0256			BM			
		0.0299	0.0102			BM			
		0.0969	0.0244			BM			
		0.8524	0.0591			BM			
		0.2264	0.0098			BM			
		0.2657	0.0610			BM			
		0.0240	0.0012			BM			
	Bot. 1/3	0.0000	0.0000						

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Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API / MPC
Material : A516 Grade 60
Window # : 3
Condition : Colled Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.4

Project # : L922209KT
CLI : 2278
Section : 16,17,18
File # : 3W161718.WK1
Date : 9/23/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	Section CSR (%)	Section CLR (%)	Section CTR (%)
18	Top 1/3	0.2559	0.1417	2.606	0.507	BS/BT	31.85	94.97	99.47
	Mid 1/3	1.4016	0.2559			BS/BT/BM			
		0.0098	0.0008			BM			
		0.0197	0.0016			BM			
		0.0496	0.0031			BM			
		0.0421	0.0063			BM			
		0.0319	0.0020			BM			
		0.0307	0.0016			BM			
		0.0315	0.0043			BM			
		0.1280	0.0217			BM			
		0.3937	0.0551			BM			
		0.0094	0.0008			BM			
		0.0709	0.0094			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR :	19.37	Std. Dev. =	4.25
Avg. CLR :	101.37	Std. Dev. =	12.15
Avg. CTR :	89.00	Std. Dev. =	8.78

2/3 Thickness Averages of All Three Sections

Avg. CSR :	19.37	Std. Dev. =	4.37
Avg. CLR :	101.37	Std. Dev. =	12.43
Avg. CTR :	89.00	Std. Dev. =	8.95

1/3 Thickness Averages of All Three Sections

Avg. CSR :	2.30	Std. Dev. =	0.68
Avg. CLR :	19.31	Std. Dev. =	2.86
Avg. CTR :	37.28	Std. Dev. =	6.93

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Base metal LT section
- 28 day test

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Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API / MPC
Material : A516 Grade 60
Window # : 3
Condition : Colled Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.4

Project # : L922209KT
CLI : 3201
Section : 19,20,21
File # : 3W192021.WK1
Date : 9/23/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
19	Top 1/3	0.0087	0.0008	2.466	0.515	BS	0.51	16.25	27.0
		0.0472	0.0126			BS			
		0.0543	0.0165			BS			
		0.0031	0.0004			BT			
		0.0110	0.0012			BT			
		0.0535	0.0283			BS			
		0.0055	0.0012			BS			
		0.0087	0.0008			BT			
		0.0346	0.0205			BS			
		0.0173	0.0024			BT			
		0.0031	0.0008			BT			
		0.0161	0.0020			BT			
		0.0327	0.0177			BS			
		0.0669	0.0295			BS			
	Mid 1/3	0.0126	0.0012			BM			
		0.0173	0.0028			BM			
		0.0079	0.0008			BM			
	Bot. 1/3	0.0000	0.0000						
20	Top 1/3	0.0413	0.0024	2.446	0.515	BT	0.27	12.70	12.1
		0.0535	0.0094			BS			
		0.0945	0.0213			BT/BS			
		0.0177	0.0020			BS			
		0.0315	0.0075			BS			
		0.0130	0.0043			BS			
		0.0331	0.0142			BS			
	Mid 1/3	0.0260	0.0016			BM			
	Bot. 1/3	0.0000	0.0000						

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Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API / MPC
Material : A516 Grade 60
Window # : 3
Condition : Colled Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.4

Project # : L922209KT
CU : 3201
Section : 19,20,21
File # : 3W192021.WK1
Date : 9/23/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
21	Top 1/3	0.0323	0.0165	2.436	0.515	BS	0.45	13.71	23.8
		0.0323	0.0283			BT/BS			
		0.0063	0.0028			BT			
		0.0984	0.0217			BT			
		0.0480	0.0197			BS			
		0.0417	0.0181			BS			
		0.0157	0.0012			BT			
		0.0083	0.0024			BS			
		0.0331	0.0102			BS			
		0.0079	0.0012			BT			
	Mid 1/3	0.0098	0.0008			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	0.41	Std. Dev. =	0.05
Avg. CLR =	14.22	Std. Dev. =	0.98
Avg. CTR =	21.02	Std. Dev. =	1.81

2/3 Thickness Averages of All Three Sections

Avg. CSR =	0.41	Std. Dev. =	0.05
Avg. CLR =	14.22	Std. Dev. =	0.96
Avg. CTR =	21.02	Std. Dev. =	1.82

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.41	Std. Dev. =	0.05
Avg. CLR =	13.22	Std. Dev. =	1.00
Avg. CTR =	20.56	Std. Dev. =	1.85

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Base metal LT section
- 28 day test

Page 2 of 2

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API / MPC
Material : A516 Grade 60
Window # : 3
Condition : Colled Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.4

Project # : L922209KT
CLI : 3201/2278
Section : 22,23,24
File # : 3W222324.WK1
Date : 9/23/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
22	Top 1/3	0.0094	0.0008	2.356	0.510	BS	3.42	35.19	45.9
		0.0035	0.0157			BS			
		0.0012	0.0083			BS			
		0.1949	0.0551			BS/BT/BS			
		0.0118	0.0520			WS/H1S/H2S/H2T			
	Mid 1/3	0.3760	0.0413			BM			
		0.2323	0.0610			BM/H2M/H1M			
	Bot. 1/3	0.0000	0.0000						
23	Top 1/3	0.0437	0.0063	2.355	0.504	BT	9.16	83.67	61.8
		0.1142	0.0335			BS			
		0.0154	0.0020			BT			
		0.2441	0.0177			BT			
		0.0945	0.0150			BS			
		0.0047	0.0181			H1S/H2S			
		0.1693	0.0177			BT			
		0.0984	0.0197			BT			
		0.0394	0.0217			BT			
	Mid 1/3	0.0130	0.0008			BM			
		0.4783	0.0650			BT/BM/BT/BM			
		0.6555	0.0945			BM/BT/BM/H2M/H1M			
	Bot. 1/3	0.0000	0.0000						
24	Top 1/3	0.0524	0.0390	2.355	0.507	H1S/H2S/BS	6.12	64.08	63.2
		0.0051	0.0287			WS/H1S/H2S			
		0.1358	0.0315			BT			
	Mid 1/3	0.1791	0.0709			BM/BT			
		0.5413	0.0669			BM			
		0.2165	0.0295			BM			
		0.0323	0.0087			H2M			
		0.2815	0.0374			BM/H2M			
		0.0650	0.0079			H2M/H1M			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	6.24	Std. Dev. =	1.12
Avg. CLR =	60.98	Std. Dev. =	7.21
Avg. CTR =	57.00	Std. Dev. =	4.87

2/3 Thickness Averages of All Three Sections

Avg. CSR =	6.24	Std. Dev. =	1.16
Avg. CLR =	60.98	Std. Dev. =	7.31
Avg. CTR =	57.00	Std. Dev. =	4.76

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.94	Std. Dev. =	0.22
Avg. CLR =	17.52	Std. Dev. =	3.14
Avg. CTR =	25.17	Std. Dev. =	3.00

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

Comments

- Weld metal TL section
- 28 day test
- LHI weld

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API / MPC
Material : A516 Grade 60
Window # : 3
Condition : Colled Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.4

Project # : L922209KT
CLI : 2278
Section : 25
File # : 3W25.WK1
Date : 9/23/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
25	Top 1/3	0.0622	0.0520	3.300	0.500	WS/H1S/H1T	2.70	32.99	151.6
		0.0118	0.0307			H1T/H2T			
		0.0134	0.0669			WS/H1S/H2S/H2T			
		0.0039	0.0614			WS/H1S/H2S/H2T			
		0.0087	0.0701			WS/H1S/H2S/H2T/BT			
		0.1677	0.0669			WS/H1S/H2S/H2T/BT			
		0.0165	0.0638			WS/H1S/H2S/H2T/BT			
		0.0197	0.0591			WS/H1S/H2S/H2T/BT			
		0.0039	0.0441			WS/H1S/H2S/H2T/BT			
		0.0102	0.0394			WS/H1S/H2S			
		0.0024	0.0331			H1S/H2S			
		0.0039	0.0283			H1S/H2S			
		0.0354	0.0299			H1S/H2S			
		0.0039	0.0213			H1S/H2S			
	Mid 1/3	0.4331	0.0354			BM			
		0.0366	0.0091			BM			
		0.0169	0.0031			BM			
		0.0118	0.0012			BM			
		0.1969	0.0413			BM			
		0.0295	0.0012			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Average

Avg. CSR =	0.90	Std. Dev. =	0.25
Avg. CLR =	11.00	Std. Dev. =	3.01
Avg. CTR =	50.55	Std. Dev. =	4.63

2/3 Thickness Average

Avg. CSR =	0.90	Std. Dev. =	0.25
Avg. CLR =	11.00	Std. Dev. =	3.06
Avg. CTR =	50.55	Std. Dev. =	4.45

1/3 Thickness Average

Avg. CSR =	0.42	Std. Dev. =	0.17
Avg. CLR =	3.67	Std. Dev. =	1.28
Avg. CTR =	44.46	Std. Dev. =	3.30

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Base metal LT section
- 28 day test

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284−87

Sponsor : API / MPC
Material : A516 Grade 70
Window # : 3
Condition : Cold Rolled, Welded

Solution : TM0177−90
Exposure : One−sided
pH (INIT) : 2.7
pH (FINL) : 3.4

Project # : L922209KT
CLI : 2278
Section : 26,27
File # : 3W2627.WK1
Date : 9/23/92

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
26	Top 1/3	0.0110	0.0012	2.590	0.487	BT	12.34	76.98	43.01
		0.0094	0.0165			H2S			
		0.0575	0.0598			H1S/H2S/H2T/BT			
		0.0181	0.0020			H1T			
	Mid 1/3	1.3780	0.0984			BM			
		0.5197	0.0315			BM/H2M/H1M			
	Bot. 1/3	0.0000	0.0000						
27	Top 1/3	0.0146	0.0390	2.573	0.487	H2S/BS	7.15	57.00	46.65
		0.2559	0.0276			BT			
		0.0925	0.0335			BT			
	Mid 1/3	0.7933	0.0846			BM/NT/BM/BT			
		0.2815	0.0413			BM			
		0.0287	0.0012			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of Two Sections

Avg. CSR =	9.74	Std. Dev. =	3.22
Avg. CLR =	66.99	Std. Dev. =	16.14
Avg. CTR =	44.83	Std. Dev. =	6.58

2/3 Thickness Averages of Two Sections

Avg. CSR =	9.74	Std. Dev. =	3.11
Avg. CLR =	66.99	Std. Dev. =	15.62
Avg. CTR =	44.83	Std. Dev. =	6.20

1/3 Thickness Averages of Two Sections

Avg. CSR =	0.57	Std. Dev. =	0.20
Avg. CLR =	8.91	Std. Dev. =	3.22
Avg. CTR =	18.43	Std. Dev. =	4.00

Crack Location Codes

B−Base Metal	WR−Weld Root
H1−Heat Affected Zone 1	S−Surface
H2−Heat Affected Zone 2	T−Tension
W−Weld	M−Middle
WC−Weld Cap	C−Compression

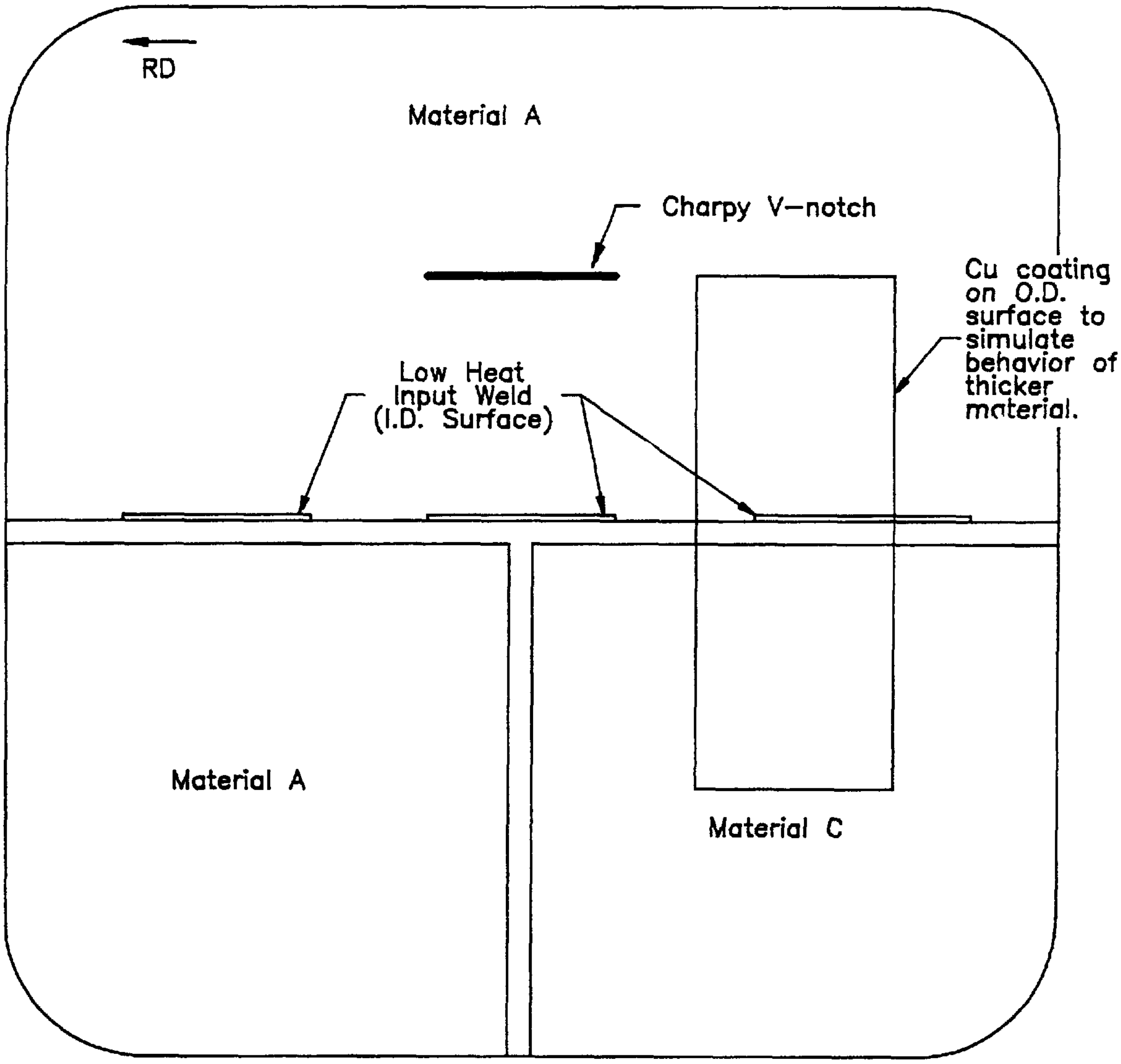
Comments

− Weld metal LT section
− 28 day test

APPENDIX IV

SIMULATION OF THICK PLATE BEHAVIOR

APPENDIX IV - FIGURE 1



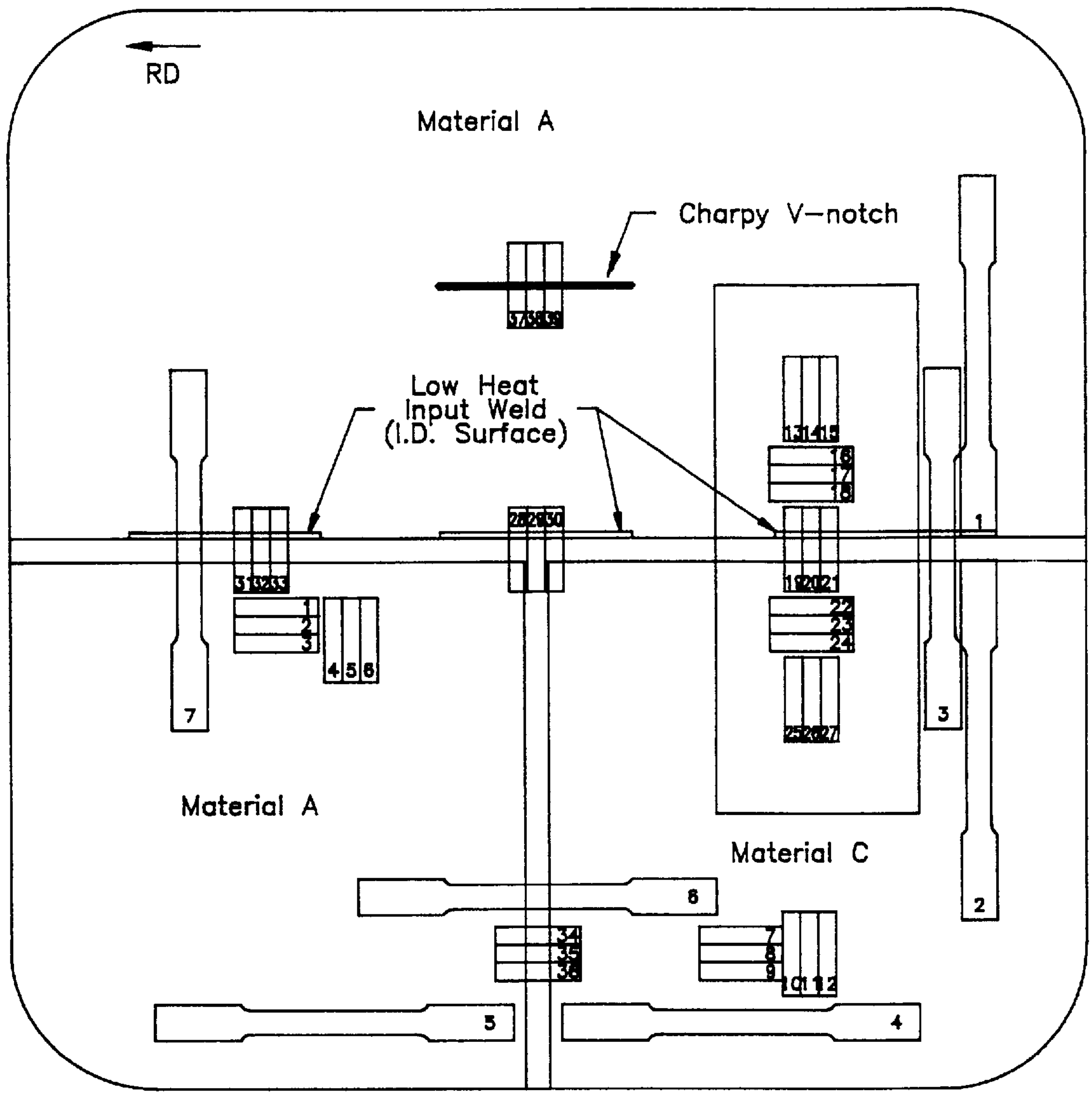
Material A: A516 Grade 70
CLI Number: 2278
Chemistry: C=0.22, P=0.020, S=0.017
Material Condition: As Rolled
Mechanical Properties: Yield=48.2ksi, UTS=78.9ksi, % elongation=25.0

Material C: A516 Grade 70
CLI Number: 2279
Chemistry: C=0.22, P=0.014, S=0.019
Material Condition: Normalized
Mechanical Properties: Yield=57.3ksi, UTS=78.4ksi, % elongation=23.0

O.D. View

Date: 9/2/93	Project #: L902103KT
Disk #: L500-1	File #: 2209
Scale:	Drawn By: K. Koenig

APPENDIX IV - FIGURE 2



Material A: A516 Grade 70
CLI Number: 2278
Chemistry: C=0.22, P=0.020, S=0.017
Material Condition: As Rolled
Mechanical Properties: Yield=48.2ksi, UTS=78.9ksi, % elongation=25.0

Material C: A516 Grade 70
CLI Number: 2279
Chemistry: C=0.22, P=0.014, S=0.019
Material Condition: Normalized
Mechanical Properties: Yield=57.3ksi, UTS=78.4ksi, % elongation=23.0

O.D. View

Date: 9/2/93	Project #: L902103KT
Disk #: L500-1	File #: 2209
Scale:	Drawn By: K. Koenig

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516 Grade 70
Window # : 4
Condition : As Rolled, Cold Rolled, Welded

Solution : NACE TM0177
Exposure : One-sided
pH (INIT) : 2.8
pH (FINL) : 3.4

Project # : L922216TK
CLI : 2278
Section : 1,2,3
File # : 4W123.WK1
Date : 2/24/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W4-1	Top 1/3	0.0118	0.0020	2.419	0.510	BT	8.54	85.27	57.97
		0.0067	0.0008			BT			
		0.2421	0.0413			BT			
		0.0047	0.0035			BT			
		0.4783	0.1083			BT/BS			
		0.3268	0.0453			BT			
	Mid 1/3	0.1181	0.0217			BM			
		0.0886	0.0079			BM			
		0.3681	0.0335			BM			
		0.4173	0.0315			BM			
	Bot. 1/3	0.0000	0.0000						
W4-2	Top 1/3	0.0606	0.0276	2.428	0.510	BS	2.77	28.33	34.35
		0.4724	0.0591			BT			
		0.0512	0.0583			BS/BT			
		0.0382	0.0098			BS			
		0.0654	0.0205			BS			
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
W4-3	Top 1/3	0.1043	0.0335	2.437	0.510	BS	3.80	47.09	27.40
		0.4488	0.0709			BT			
	Mid 1/3	0.2362	0.0059			BM			
		0.3583	0.0295			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR :	5.04	Std. Dev. =	1.03
Avg. CLR :	53.56	Std. Dev. =	7.18
Avg. CTR :	39.91	Std. Dev. =	5.35

2/3 Thickness Averages of All Three Sections

Avg. CSR :	5.04	Std. Dev. =	1.07
Avg. CLR :	53.56	Std. Dev. =	7.13
Avg. CTR :	39.91	Std. Dev. =	5.32

1/3 Thickness Averages of All Three Sections

Avg. CSR :	3.94	Std. Dev. =	1.26
Avg. CLR :	31.76	Std. Dev. =	7.51
Avg. CTR :	31.42	Std. Dev. =	5.96

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Base metal TL section
- 28 day test

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516 Grade 70
Window # : 4
Condition : As Rolled, Cold Rolled, Welded

Solution : NACE TM0177
Exposure : One-sided
pH (INIT) : 2.8
pH (FINL) : 3.4

Project # : L922216TK
CLI : 2278
Section : 4,5,6
File # : 4W456.WK1
Date : 2/24/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W4-4	Top 1/3	0.3681	0.0866	2.475	0.509	BS/BT	6.81	56.20	56.70
		0.5433	0.0610			BT			
		0.0236	0.0102			BT			
		0.1890	0.0650			BS/BT/BS			
		0.1378	0.0531			BS/BT/BS			
	Mid 1/3	0.0787	0.0102			BM			
		0.0504	0.0024			BM			
	Bot. 1/3	0.0000	0.0000						
W4-5	Top 1/3	0.0827	0.0236	2.480	0.510	BT	9.11	62.39	89.47
		0.1555	0.0768			BT/BS			
		0.1260	0.0610			BT/BS			
		0.2618	0.0728			BT			
		0.1713	0.0354			BT			
	Mid 1/3	0.4882	0.1181			BT/BM			
		0.0071	0.0016			BM			
		0.0193	0.0189			BM			
		0.0150	0.0008			BM			
		0.2205	0.0472			BM			
	Bot. 1/3	0.0000	0.0000						
W4-6	Top 1/3	0.0228	0.0402	2.475	0.509	H2T	2.14	31.38	31.33
		0.0394	0.0189			BS			
		0.0354	0.0157			BS			
	Mid 1/3	0.1496	0.0138			BM			
		0.1654	0.0157			BM			
		0.3642	0.0551			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	6.02	Std. Dev. =	1.07
Avg. CLR =	49.99	Std. Dev. =	6.04
Avg. CTR =	59.16	Std. Dev. =	6.20

2/3 Thickness Averages of All Three Sections

Avg. CSR =	6.02	Std. Dev. =	1.11
Avg. CLR =	49.99	Std. Dev. =	6.03
Avg. CTR =	59.16	Std. Dev. =	6.05

1/3 Thickness Averages of All Three Sections

Avg. CSR =	3.54	Std. Dev. =	0.87
Avg. CLR =	29.02	Std. Dev. =	5.89
Avg. CTR =	40.60	Std. Dev. =	4.78

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

Comments

- Base metal LT section
- 28 day test

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516 Grade 70
Window # : 4
Condition : Normalized, Cold Rolled, Welded

Solution : NACE TM0177
Exposure : One-sided
pH (INIT) : 2.8
pH (FINL) : 3.4

Project # : L922216TK
CLI : 2279
Section : 7,8,9
File # : 4W789.WK1
Date : 2/24/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W4-7	Top 1/3	0.1437	0.0138	2.463	0.515	BT	0.38	7.67	14.91
		0.0453	0.0630			BS			
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
W4-8	Top 1/3	0.0472	0.0268	2.460	0.515	BT/BS	0.60	21.45	10.55
		0.2500	0.0020			BT			
	Mid 1/3	0.2303	0.0256			BM			
	Bot. 1/3	0.0000	0.0000						
W4-9	Top 1/3	0.1535	0.0433	2.460	0.515	BS/BT/BS	2.42	34.89	23.77
		0.1280	0.0413			BT/BS			
		0.0295	0.0008			BS			
		0.0197	0.0016			BS			
	Mid 1/3	0.5276	0.0354			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	1.14	Std. Dev. =	0.39
Avg. CLR =	21.34	Std. Dev. =	5.78
Avg. CTR =	16.41	Std. Dev. =	3.95

2/3 Thickness Averages of All Three Sections

Avg. CSR =	1.14	Std. Dev. =	0.41
Avg. CLR =	21.34	Std. Dev. =	5.94
Avg. CTR =	16.41	Std. Dev. =	3.94

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.49	Std. Dev. =	0.18
Avg. CLR =	11.07	Std. Dev. =	3.06
Avg. CTR =	12.46	Std. Dev. =	4.25

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

Comments

- Base metal TL section
- 28 day test

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516 Grade 70
Window # : 4
Condition : Normalized, Cold Rolled, Welded

Solution : NACE TM0177
Exposure : One-sided
pH (INIT) : 2.8
pH (FINL) : 3.4

Project # : L922216TK
CLI : 2279
Section : 10,11,12
File # : 4W101112.WK1
Date : 2/25/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W4-10	Top 1/3	0.1319	0.0315	2.547	0.515	BS/BT/BS	3.22	28.30	29.05
		0.4035	0.0827			BT			
	Mid 1/3	0.0118	0.0012			BM			
		0.0157	0.0016			BM			
		0.1476	0.0315			BM			
		0.0102	0.0012			BM			
	Bot. 1/3	0.0000	0.0000						
W4-11	Top 1/3	0.0984	0.0531	2.540	0.516	BS/BT/BS	7.41	63.74	47.31
		0.0146	0.0157			BT			
		0.1555	0.0669			BT			
		0.1555	0.0236			BT			
	Mid 1/3	1.0709	0.0709			BM/BT/BM			
		0.1240	0.0138			BM			
	Bot. 1/3	0.0000	0.0000						
W4-12	Top 1/3	0.1299	0.0531	2.530	0.515	BT	7.02	35.87	63.68
		0.0886	0.0217			BS/BT			
		0.1831	0.0925			BT			
		0.0059	0.0008			BT			
	Mid 1/3	0.4626	0.1417			BM/BT			
		0.0039	0.0130			BM			
		0.0047	0.0012			BM			
		0.0287	0.0039			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	5.88	Std. Dev. =	1.54
Avg. CLR =	42.64	Std. Dev. =	9.13
Avg. CTR =	46.68	Std. Dev. =	7.20

2/3 Thickness Averages of All Three Sections

Avg. CSR =	5.88	Std. Dev. =	1.63
Avg. CLR =	42.64	Std. Dev. =	9.52
Avg. CTR =	46.68	Std. Dev. =	7.29

1/3 Thickness Averages of All Three Sections

Avg. CSR =	2.11	Std. Dev. =	0.74
Avg. CLR =	17.94	Std. Dev. =	4.12
Avg. CTR =	28.57	Std. Dev. =	5.59

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

Comments

- Base metal LT section
- 28 day test

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC	Solution : NACE TM0177	Project # : L922216TK
Material : A516 Grade 70	Exposure : One-sided	CLI : 2278
Window # : 4	pH (INIT) : 2.8	Section : 13,14,15
Condition : As Rolled, Cold Rolled, Welded	pH (FINL) : 3.4	File # : 4W131415.WK1
		Date : 2/25/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W4-13	Top 1/3	0.0098	0.0008	2.518	0.515	BT	6.97	60.67	62.07
		0.3012	0.0630			BT			
		0.1240	0.0492			BS/BT/BS			
		0.1634	0.0591			BS/BT/BS			
		0.0866	0.0374			BS			
		0.0413	0.0472			BS/BT			
	Mid 1/3	0.8012	0.0630			BM			
	Bot. 1/3	0.0000	0.0000						
W4-14	Top 1/3	0.0650	0.0177	2.527	0.515	BS	4.82	38.48	160.92
		0.1378	0.0335			BS			
		0.1476	0.0571			BS/BT/BS			
		0.0650	0.0295			BS			
		0.0945	0.0256			BS			
	Mid 1/3	0.0551	0.6161			BM			
		0.0059	0.0130			BM			
		0.0157	0.0012			BM			
		0.3346	0.0295			BM			
		0.0512	0.0055			BM			
	Bot. 1/3	0.0000	0.0000						
W4-15	Top 1/3	0.0354	0.0079	2.531	0.515	BS	2.25	29.65	31.73
		0.2067	0.0945			BS/BT			
		0.0492	0.0197			BS			
		0.0728	0.0205			BS/BT/BS			
	Mid 1/3	0.0319	0.0012			BM			
		0.3543	0.0197			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	4.68	Std. Dev. =	0.90
Avg. CLR =	42.93	Std. Dev. =	6.66
Avg. CTR =	84.91	Std. Dev. =	22.48

2/3 Thickness Averages of All Three Sections

Avg. CSR =	4.68	Std. Dev. =	0.94
Avg. CLR =	42.93	Std. Dev. =	6.82
Avg. CTR =	84.91	Std. Dev. =	23.60

1/3 Thickness Averages of All Three Sections

Avg. CSR =	2.07	Std. Dev. =	0.47
Avg. CLR =	21.14	Std. Dev. =	2.92
Avg. CTR =	36.41	Std. Dev. =	4.60

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

Comments

- Base metal LT section
- 28 day test
- Under copper

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284–87

Sponsor : API/MPC
Material : A516 Grade 70
Window # : 4
Condition : As Rolled, Cold Rolled, Welded

Solution : NACE TM0177
Exposure : One–sided
pH (INIT) : 2.8
pH (FINL) : 3.4

Project # : L922216TK
CLI : 2278
Section : 16,17,18
File # : 4W161718.WK1
Date : 2/25/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W4–16	Top 1/3	0.0291	0.0063	2.538	0.515	BT	5.03	62.00	38.99
		0.1594	0.0256			BT			
		0.1280	0.0177			BS			
		0.3720	0.1004			BS/BT			
		0.0268	0.0075			BS			
	Mid 1/3	0.5276	0.0374			BM			
		0.3307	0.0059			BM			
	Bot. 1/3	0.0000	0.0000						
W4–17	Top 1/3	0.1319	0.0315	2.545	0.515	BS	11.10	76.19	60.01
		0.3937	0.1122			BS/BT/BS			
		0.5787	0.0906			BS/BT/BS			
	Mid 1/3	0.7283	0.0591			BM			
		0.1063	0.0157			BM			
	Bot. 1/3	0.0000	0.0000						
W4–18	Top 1/3	0.1575	0.0138	2.550	0.512	BT	4.26	47.40	54.60
		0.1378	0.0413			BS/BT/BS			
		0.3150	0.1122			BT/BS			
		0.0846	0.0433			BS			
		0.1594	0.0157			BT			
		0.0807	0.0433			BS			
	Mid 1/3	0.2736	0.0098			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

	6.79	Std. Dev. =	1.31
Avg. CLR :	61.86	Std. Dev. =	7.79
Avg. CTR :	51.20	Std. Dev. =	6.98

2/3 Thickness Averages of All Three Sections

Avg. CSR :	6.79	Std. Dev. =	1.35
Avg. CLR :	61.86	Std. Dev. =	7.56
Avg. CTR :	51.20	Std. Dev. =	6.90

1/3 Thickness Averages of All Three Sections

Avg. CSR :	5.04	Std. Dev. =	1.39
Avg. CLR :	36.08	Std. Dev. =	6.03
Avg. CTR :	42.91	Std. Dev. =	7.38

Crack Location Codes

B–Base Metal	WR–Weld Root
H1–Heat Affected Zone 1	S–Surface
H2–Heat Affected Zone 2	T–Tension
W–Weld	M–Middle
WC–Weld Cap	C–Compression

Comments

- Base metal TL section
- 28 day test
- Under copper

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284−87

Sponsor : API/MPC
Material : A516 Grade 70
Window # : 4
Condition : As Rolled, Cold Rolled, Welded
Normalized, Cold Rolled, Welded

Solution : NACE TM0177
Exposure : One−sided
pH (INIT) : 2.8
pH (FINL) : 3.4

Project # : L922216TK
CLI : 2278,2279
Section : 19,20,21
File # : 4W192021.WK1
Date : 2/25/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CLI No.	CSR (%)	Section CLR (%)	CTR (%)
W4−19	Top 1/3	0.0551	0.0965	2.288	0.514	H1S/H1T	2279	2.22	24.11	45.7
		0.0315	0.0457			BS/BT	2278			
		0.0220	0.0102			BT	2278			
		0.1713	0.0335			BT	2278			
	Mid 1/3	0.2717	0.0492			H1M/H2M/BM	2278			
	Bot. 1/3	0.0000	0.0000							
W4−20	Top 1/3	0.0362	0.0236	1.281	0.510	BS	2279	4.17	58.58	51.7
		0.0965	0.0472			BT	2279			
		0.0689	0.1024			H1S/H1T	2279			
		0.0063	0.0244			H1S	2278			
	Mid 1/3	0.0740	0.0189			BM	2279			
		0.1437	0.0118			BM	2278			
		0.3248	0.0354			BM	2278			
	Bot. 1/3	0.0000	0.0000							
W4−21	Top 1/3	0.0220	0.0354	2.278	0.515	BS	2279	2.60	39.08	66.7
		0.0528	0.0071			BT	2279			
		0.0236	0.0059			BS	2279			
		0.0394	0.1102			H1S/H1T/H2T	2279			
		0.0236	0.0453			H1S/H1T	2278			
		0.1634	0.0217			H1T/H2T/BT	2278			
		0.2618	0.0551			BS/BT/BS	2278			
		0.0591	0.0256			BS	2278			
		0.0551	0.0118			BT	2278			
	Mid 1/3	0.0110	0.0008			BM	2279			
		0.1516	0.0236			BM	2278			
		0.0268	0.0012			BM	2278			
	Bot. 1/3	0.0000	0.0000							

Full Thickness Averages of All Three Sections

Avg. CSR =	2.99	Std. Dev. =	0.45
Avg. CLR =	40.59	Std. Dev. =	5.46
Avg. CTR =	54.73	Std. Dev. =	5.90

2/3 Thickness Averages of All Three Sections

Avg. CSR =	2.99	Std. Dev. =	0.46
Avg. CLR =	40.59	Std. Dev. =	5.54
Avg. CTR =	54.73	Std. Dev. =	5.83

1/3 Thickness Averages of All Three Sections

Avg. CSR =	1.77	Std. Dev. =	0.36
Avg. CLR =	19.74	Std. Dev. =	3.07
Avg. CTR =	45.56	Std. Dev. =	6.23

Crack Location Codes

B−Base Metal	WR−Weld Root
H1−Heat Affected Zone 1	S−Surface
H2−Heat Affected Zone 2	T−Tension
W−Weld	M−Middle
WC−Weld Cap	C−Compression

Comments

− Weld metal LT section
− 28 day test
− LHI weld
− Under copper

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC	Solution : NACE TM0177	Project # : L922216TK
Material : A516 Grade 70	Exposure : One-sided	CLI : 2279
Window # : 4	pH (INIT) : 2.8	Section : 22,23,24
Condition : Normalized, Cold Rolled, Welded	pH (FINL) : 3.4	File # : 4W222324.WK1
		Date : 2/25/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W4-22	Top 1/3	0.1024	0.0236	2.546	0.520	BS	4.17	51.15	29.60
		0.0299	0.0063			BS			
		0.0213	0.0083			BS			
		0.0787	0.0252			BS			
		0.0130	0.0020			BT			
		0.1614	0.0394			BT			
	Mid 1/3	0.8957	0.0492			BM			
	Bot. 1/3	0.0000	0.0000						
W4-23	Top 1/3	0.1043	0.0354	2.550	0.522	BS/BT	2.73	36.59	32.05
		0.1220	0.0197			BS			
		0.0984	0.0354			BS			
		0.4390	0.0512			BT			
	Mid 1/3	0.1693	0.0256			BM			
	Bot. 1/3	0.0000	0.0000						
W4-24	Top 1/3	0.4646	0.0472	2.555	0.522	BT	2.28	38.71	19.76
		0.1280	0.0236			BT			
		0.0382	0.0008			BT			
	Mid 1/3	0.1693	0.0256			BM			
		0.1890	0.0059			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	3.06	Std. Dev. =	0.81
Avg. CLR =	42.15	Std. Dev. =	8.24
Avg. CTR =	27.14	Std. Dev. =	3.30

2/3 Thickness Averages of All Three Sections

Avg. CSR =	3.06	Std. Dev. =	0.85
Avg. CLR =	42.15	Std. Dev. =	8.46
Avg. CTR =	27.14	Std. Dev. =	3.06

1/3 Thickness Averages of All Three Sections

Avg. CSR =	1.71	Std. Dev. =	0.56
Avg. CLR =	23.54	Std. Dev. =	5.50
Avg. CTR =	20.34	Std. Dev. =	3.09

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

Comments

- Base metal TL section
- 28 day test
- Under copper

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284–87

Sponsor : API/MPC
Material : A516 Grade 70
Window # : 4
Condition : Normalized, Cold Rolled, Welded

Solution : NACE TM0177
Exposure : One–sided
pH (INIT) : 2.8
pH (FINL) : 3.4

Project # : L922216TK
CLI : 2279
Section : 25,26,27
File # : 4W252627.WK1
Date : 2/25/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W4–25	Top 1/3	0.1870	0.0217	2.381	0.525	BT	4.13	50.04	36.82
		0.0295	0.0138			BT			
	Mid 1/3	0.3484	0.0669			BM/BT			
		0.0378	0.0024			BM			
		0.2106	0.0295			BM			
		0.3150	0.0551			BM/BT/BM			
		0.0551	0.0031			BM			
		0.0079	0.0008			BM			
	Bot. 1/3	0.0000	0.0000						
W4–26	Top 1/3	0.0000	0.0000	2.385	0.524		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
W4–27	Top 1/3	0.1319	0.0610	2.391	0.523	BS/BT	1.47	10.62	27.85
		0.1220	0.0846			BS/BT/BS			
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR :	1.87	Std. Dev. =	0.55
Avg. CLR :	20.22	Std. Dev. =	4.78
Avg. CTR :	21.56	Std. Dev. =	5.39

2/3 Thickness Averages of All Three Sections

Avg. CSR :	1.87	Std. Dev. =	0.58
Avg. CLR :	20.22	Std. Dev. =	4.90
Avg. CTR :	21.56	Std. Dev. =	5.58

1/3 Thickness Averages of All Three Sections

Avg. CSR :	0.61	Std. Dev. =	0.33
Avg. CLR :	6.57	Std. Dev. =	2.90
Avg. CTR :	11.53	Std. Dev. =	6.04

Crack Location Codes

B–Base Metal	WR–Weld Root
H1–Heat Affected Zone 1	S–Surface
H2–Heat Affected Zone 2	T–Tension
W–Weld	M–Middle
WC–Weld Cap	C–Compression

Comments

– Base metal LT section
– 28 day test
– Under copper

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284−87

Sponsor : API/MPC
Material : A516 Grade 70
Window # : 4
Condition : As Rolled, Cold Rolled, Welded
Normalized, Cold Roll, Welded

Solution : NACE TM0177
Exposure : One−sided
pH (INIT) : 2.8
pH (FINL) : 3.4

Project # : L922216TK
CLI : 2278,2279
Section : 28,29,30
File # : 4W282930.WK1
Date : 2/25/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CLI No.	CSR (%)	Section CLR (%)	CTR (%)
W4−28	Top 1/3	0.0728	0.1398	2.540	0.503	WS/H1T/H2T/BT	2278	4.62	29.90	154.9
		0.0531	0.0669			H1S/H1T/H2T	2278			
		0.1417	0.1319			WS/H1T/H2T	2278			
		0.0142	0.0315			WS	2278			
		0.0335	0.1142			WS/WT	2278			
		0.0236	0.0039			BM	2278			
		0.0315	0.1161			WS/WT/H1T	2278			
		0.0051	0.0335			H1S/H2S	2278			
		0.1673	0.0512			BS/BT/BS	2278			
		0.1024	0.0394			BS/BT/BS	2278			
		0.1142	0.0512			BS/BT/BS	2278			
	Mid 1/3	0.0000	0.0000							
	Bot. 1/3	0.0000	0.0000							
W4−29	Top 1/3	0.0610	0.0984	2.546	0.506	WS/H1S/H1T/H2T	2279	3.10	22.33	129.0
		0.0965	0.1083			WS/H1T/H2T	2279			
		0.0157	0.0630			WS/WT	2279			
		0.0335	0.0945			WS/WT	2279			
		0.0087	0.0559			WS/WT	2279			
		0.0020	0.0189			WS	2279			
		0.0492	0.0394			WS	2278			
		0.1398	0.0827			WS/H1S/H1T/H2T/BT/H2T	2278			
		0.0945	0.0492			BS/BT	2278			
		0.0118	0.0323			BS/BT	2278			
		0.0244	0.0039			BT	2278			
		0.0315	0.0063			BT	2278			
	Mid 1/3	0.0000	0.0000							
	Bot. 1/3	0.0000	0.0000							

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Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516 Grade 70
Window # : 4
Condition : As Rolled, Cold Rolled, Welded
Normalized, Cold Roll, Welded

Solution : NACE TM0177
Exposure : One-sided
pH (INIT) : 2.8
pH (FINL) : 3.4

Project # : L922216TK
CLI : 2278,2279
Section : 28,29,30
File # : 4W282930.WK1
Date : 2/25/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CLI No.	CSR (%)	Section CLR (%)	CTR (%)
W4-30	Top 1/3	0.0197	0.0531	2.565	0.504	WS/H1T/H2T	2279	1.48	20.84	49.9
		0.0157	0.0709			H1S/H1T/H2T/BT	2278			
		0.1181	0.0945			BS/BT	2278			
		0.0335	0.0118			BT	2278			
	Mid 1/3	0.0583	0.0039			BM	2279			
		0.2894	0.0177			BM	2278			
	Bot. 1/3	0.0000	0.0000							

Full Thickness Averages of All Three Sections

Avg. CSR =	3.07	Std. Dev. =	0.35
Avg. CLR =	24.36	Std. Dev. =	2.43
Avg. CTR =	111.32	Std. Dev. =	8.36

2/3 Thickness Averages of All Three Sections

Avg. CSR =	3.07	Std. Dev. =	0.35
Avg. CLR =	24.36	Std. Dev. =	2.44
Avg. CTR =	111.32	Std. Dev. =	8.15

1/3 Thickness Averages of All Three Sections

Avg. CSR =	2.93	Std. Dev. =	0.36
Avg. CLR =	19.84	Std. Dev. =	1.86
Avg. CTR =	109.89	Std. Dev. =	7.74

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Weld metal LT section
- 28 day test
- LHI weld

Page 2 of 2

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284–87

Sponsor :	API/MPC	Solution :	NACE TM0177	Project # :	L922216TK
Material :	A516 Grade 70	Exposure :	One–sided	CLI :	2278
Window # :	4	pH (INIT) :	2.8	Section :	31,32,33
Condition :	As Rolled, Cold Rolled, Welded Normalized, Cold Roll, Welded	pH (FINL) :	3.4	File # :	4W313233.WK1
				Date :	2/25/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W4–31	Top 1/3	0.1535	0.0354	2.527	0.504	BT	5.26	43.03	80.22
		0.3051	0.1378			BS/BT			
		0.1969	0.0531			BS/BT			
		0.0039	0.0354			WS			
		0.0047	0.0362			H1S/H2S			
		0.1083	0.0256			BS			
		0.0591	0.0630			BS/BT			
	Mid 1/3	0.1122	0.0079			BM			
		0.1437	0.0098			BM			
	Bot. 1/3	0.0000	0.0000						
W4–32	Top 1/3	0.0335	0.0114	2.541	0.505	BS	2.17	28.48	53.40
		0.0098	0.0551			H1S/H2S/BT			
		0.2520	0.0551			BT/H2T/H1T			
		0.0650	0.0807			H1S/H2T/BT			
		0.1319	0.0354			BS			
		0.0063	0.0008			BT			
	Mid 1/3	0.0449	0.0063			BM			
		0.1339	0.0197			BM/H2M/H1M			
		0.0465	0.0051			BM			
	Bot. 1/3	0.0000	0.0000						
W4–33	Top 1/3	0.0906	0.0413	2.525	0.505	BS/BT	1.27	18.40	54.34
		0.0906	0.0512			BT/H2T/H1T			
		0.0138	0.0472			WS/H1S/H2T			
		0.0079	0.0748			H1S/H1T/H2T/BT			
		0.0315	0.0087			BS			
		0.1280	0.0433			BS			
	Mid 1/3	0.1024	0.0079			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	2.90	Std. Dev. =	0.63
Avg. CLR =	29.97	Std. Dev. =	3.10
Avg. CTR =	62.66	Std. Dev. =	6.14

2/3 Thickness Averages of All Three Sections

Avg. CSR =	2.90	Std. Dev. =	0.66
Avg. CLR =	29.97	Std. Dev. =	3.06
Avg. CTR =	62.66	Std. Dev. =	6.02

1/3 Thickness Averages of All Three Sections

Avg. CSR =	2.74	Std. Dev. =	0.73
Avg. CLR =	22.29	Std. Dev. =	3.40
Avg. CTR =	58.91	Std. Dev. =	5.84

Crack Location Codes

B–Base Metal	WR–Weld Root
H1–Heat Affected Zone 1	S–Surface
H2–Heat Affected Zone 2	T–Tension
W–Weld	M–Middle
WC–Weld Cap	C–Compression

Comments

– Weld metal LT section
– 28 day test
– LHI weld

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516 Grade 70
Window # : 4
Condition : As Rolled, Cold Rolled, Welded
Normalized, Cold Rolled, Welded

Solution : NACE TM0177
Exposure : One-sided
pH (INIT) : 2.8
pH (FINL) : 3.4

Project # : L922216TK
CLI : 2278,2279
Section : 34,35,36
File # : 4W343536.WK1
Date : 2/25/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CLI No.	CSR (%)	Section CLR (%)	CTR (%)
W4-34	Top 1/3	0.0197	0.0669	2.377	0.510	WS/H1T/H2T	2279	0.77	15.49	26.6
		0.0197	0.0472			H1S/H2T/BT	2278			
	Mid 1/3	0.3287	0.0217			BM	2278			
	Bot. 1/3	0.0000	0.0000							
W4-35	Top 1/3	0.0827	0.0315	2.374	0.510	BS	2279	1.18	12.39	48.0
		0.0157	0.0768			H1S/H2T	2279			
		0.0866	0.0945			H1S/H2T/BT/H2T	2278			
		0.0492	0.0236			BS	2278			
		0.0598	0.0189			BS/BT/BS	2278			
	Mid 1/3	0.0000	0.0000							
	Bot. 1/3	0.0000	0.0000							
W4-36	Top 1/3	0.0236	0.1280	2.373	0.511	H1S/H2T/BT	2279	0.59	15.20	35.5
		0.0181	0.0339			H1S/H2S/BS	2278			
	Mid 1/3	0.1063	0.0059			BM	2279			
		0.2126	0.0138			BM	2278			
	Bot. 1/3	0.0000	0.0000							

Full Thickness Averages of All Three Sections

Avg. CSR =	0.85	Std. Dev. =	0.20
Avg. CLR =	14.36	Std. Dev. =	3.67
Avg. CTR =	36.75	Std. Dev. =	7.24

2/3 Thickness Averages of All Three Sections

Avg. CSR =	0.85	Std. Dev. =	0.20
Avg. CLR =	14.36	Std. Dev. =	3.81
Avg. CTR =	36.75	Std. Dev. =	7.15

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.56	Std. Dev. =	0.18
Avg. CLR =	5.27	Std. Dev. =	1.14
Avg. CTR =	34.05	Std. Dev. =	6.77

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Weld metal TL section
- 28 day test

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516 Grade 70
Window # : 4
Condition : As Rolled, Cold Rolled, Welded

Solution : NACE TM0177
Exposure : One-sided
pH (INIT) : 2.8
pH (FINL) : 3.4

Project # : L922216TK
CLI : 2278
Section : 37,38,39
File # : 4W373839.WK1
Date : 2/25/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W4-37	Top 1/3	0.0217	0.0276	2.565	0.509	BS	0.98	20.80	30.01
		0.1083	0.0433			BS/BT/BS			
		0.1102	0.0492			BS/BT/BS			
		0.0197	0.0047			BT			
		0.0110	0.0008			BT			
		0.0118	0.0024			BT			
		0.0886	0.0098			BT			
	Mid 1/3	0.0106	0.0012			BM			
		0.0748	0.0059			BM			
		0.0768	0.0079			BM			
	Bot. 1/3	0.0000	0.0000						
W4-38	Top 1/3	0.0728	0.0197	2.545	0.509	BS	1.14	26.10	31.64
		0.0728	0.0217			BS			
		0.0551	0.0315			BS/BT			
		0.0614	0.0213			BT			
		0.1713	0.0276			BT			
	Mid 1/3	0.0146	0.0020			BM			
		0.0291	0.0039			BM			
		0.0512	0.0031			BM			
		0.0098	0.0008			BM			
		0.1260	0.0295			BM			
	Bot. 1/3	0.0000	0.0000						

Page 1 of 2

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516 Grade 70
Window # : 4
Condition : As Rolled, Cold Rolled, Welded

Solution : NACE TM0177
Exposure : One-sided
pH (INIT) : 2.8
pH (FINL) : 3.4

Project # : L922216TK
CLI : 2278
Section : 37,38,39
File # : 4W373839.WK1
Date : 2/25/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W4-39	Top 1/3	0.0256	0.0394	2.523	0.510	BS/BT	1.51	32.78	46.32
		0.0650	0.0197			BT			
		0.0154	0.0035			BT			
		0.0165	0.0039			BT			
		0.1398	0.0315			BT			
		0.0339	0.0142			BS			
		0.0787	0.0252			BS			
		0.1378	0.0453			BS/BT			
	Mid 1/3	0.0409	0.0047			BM			
		0.0591	0.0118			BM			
		0.1181	0.0118			BM			
		0.0217	0.0055			BM			
		0.0748	0.0197			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR :	1.21	Std. Dev. =	0.13
Avg. CLR :	26.56	Std. Dev. =	1.78
Avg. CTR :	35.99	Std. Dev. =	2.81

2/3 Thickness Averages of All Three Sections

Avg. CSR :	1.21	Std. Dev. =	0.14
Avg. CLR :	26.56	Std. Dev. =	1.72
Avg. CTR :	35.99	Std. Dev. =	2.78

1/3 Thickness Averages of All Three Sections

Avg. CSR :	0.98	Std. Dev. =	0.15
Avg. CLR :	17.27	Std. Dev. =	1.85
Avg. CTR :	28.93	Std. Dev. =	2.88

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

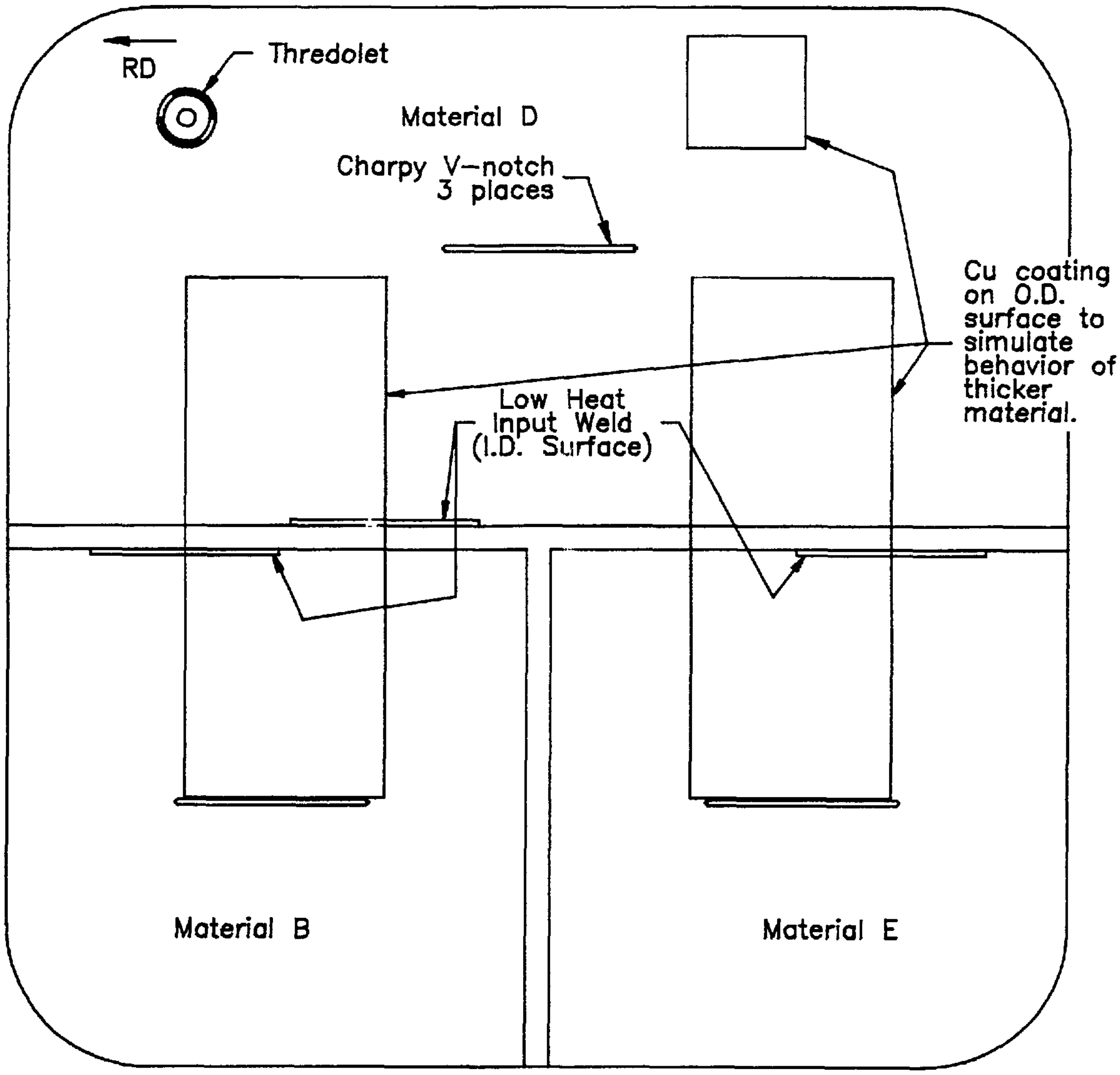
Comments

- Base metal LT section
- 28 day test
- Across Charpy V-notch

APPENDIX V

ENVIRONMENTAL STAGING/EFFECT OF CLEANING

APPENDIX V - FIGURE 1



Material B: A516 Grade 70
CLI Number: 3201
Chemistry: C=0.21, P=0.005, S=0.001
Material Condition: Normalized
Mechanical Properties: Yield=49.6ksi, UTS=76.2ksi, % elongation=27.0

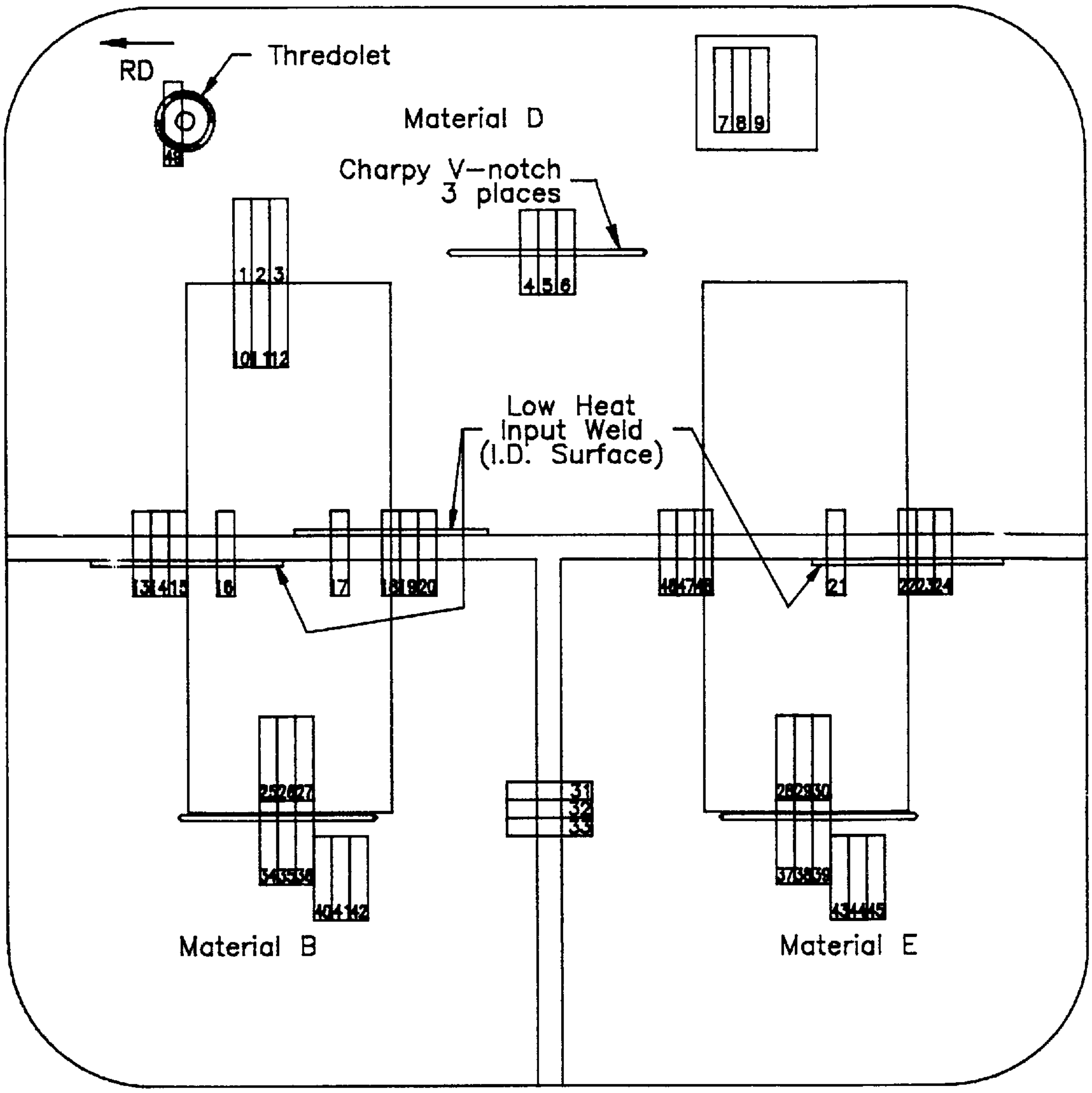
Material D: A516 Grade 70
CLI Number: 2098
Chemistry: C=0.21, P=0.013, S=0.007
Material Condition: Normalized
Mechanical Properties: Yield=47.6ksi, UTS=78.8ksi, % elongation=45.0

Material E: A841
CLI Number: 3249
Chemistry: C=0.12, P=0.005, S=0.001
Material Condition: TMCP
Mechanical Properties: Yield=61.4ksi, UTS=74.2ksi, % elongation=26.0

O.D. View

Date: 9/2/93	Project #: L922228KT
Disk #: L500-1	File #: 2209
Scale:	Drawn By: K. Koenig

APPENDIX V - FIGURE 2



Material B: A516 Grade 70
CLI Number: 3201
Chemistry: C=0.21, P=0.005, S=0.001
Material Condition: Normalized
Mechanical Properties: Yield=49.6ksi, UTS=76.2ksi, % elongation=27.0

Material D: A516 Grade 70
CLI Number: 2098
Chemistry: C=0.21, P=0.013, S=0.007
Material Condition: Normalized
Mechanical Properties: Yield=47.6ksi, UTS=78.8ksi, % elongation=45.0

Material E: A841
CLI Number: 3249
Chemistry: C=0.12, P=0.005, S=0.001
Material Condition: TMCP
Mechanical Properties: Yield=61.4ksi, UTS=74.2ksi, % elongation=26.0

O.D. View

Date: 9/2/93	Project #: L922226KT
Disk #: L500-1	File #: 2209
Scale:	Drawn By: K. Koenig

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516-70
Window # : 5
Condition : Hot Rolled

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 4.1 (Staged Experiment)
pH (FINL) : 3.0 (Staged Experiment)

Project # : L922226KT
CLI : 2098
Section : 1,2,3
File # : 5W123.WK1
Date : 4/15/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W5-1	Top 1/3	0.1437	0.0787	2.501	0.492	BS/BT/BS	1.04	8.20	29.1
		0.0071	0.0008			BT			
		0.0165	0.0016			BT			
	Mid 1/3	0.0142	0.0012			BM			
		0.0236	0.0610			BM			
	Bot. 1/3	0.0000	0.0000						
W5-2	Top 1/3	0.0827	0.0610	2.512	0.494	BT/BS	2.84	23.85	55.3
		0.2303	0.0650			BS/BT			
		0.1260	0.0531			BS/BT/BS			
		0.1102	0.0728			BS/BT/BS			
		0.0283	0.0157			BS			
		0.0102	0.0008			BT			
		0.0055	0.0004			BT			
	Mid 1/3	0.0059	0.0047			BM			
	Bot. 1/3	0.0000	0.0000						
W5-3	Top 1/3	0.0197	0.0067	2.504	0.492	BT	1.02	8.99	23.8
		0.0091	0.0008			BT			
		0.1437	0.0728			BS/BT/BS			
		0.0528	0.0370			BS/BT			
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	1.63	Std. Dev. =	0.32
Avg. CLR =	13.68	Std. Dev. =	2.27
Avg. CTR =	36.12	Std. Dev. =	5.62

2/3 Thickness Averages of All Three Sections

Avg. CSR =	1.63	Std. Dev. =	0.33
Avg. CLR =	13.68	Std. Dev. =	2.34
Avg. CTR =	36.12	Std. Dev. =	5.79

1/3 Thickness Averages of All Three Sections

Avg. CSR =	1.59	Std. Dev. =	0.36
Avg. CLR =	13.10	Std. Dev. =	2.54
Avg. CTR =	31.59	Std. Dev. =	5.88

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

Comments

- Base metal LT section
- No pre-exposure
- 33 day test

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516-70
Window # : 5
Condition : Hot Rolled

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 4.1 (Staged Experiment)
pH (FINL) : 3.0 (Staged Experiment)

Project # : L922226TK
CLI : 2098
Section : 4,5,6
File # : 5W456.WK1
Date : 4/15/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W5-4	Top 1/3	0.1181	0.0630	2.481	0.491	BS/BT/BS	2.85	24.69	57.09
		0.0984	0.0370			BS/BT			
		0.0787	0.0492			BS/BT/BS			
		0.0378	0.0091			BS			
		0.0787	0.0413			BS/BT/BS			
		0.2008	0.0807			BS/BT/BS			
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
W5-5	Top 1/3	0.1063	0.0492	2.479	0.491	BS/BT/BS	1.46	14.83	43.70
		0.0126	0.0276			BT			
		0.0846	0.0689			BS/BT/BS			
		0.0020	0.0008			BT			
		0.0043	0.0016			BT			
		0.1024	0.0610			BS/BT/BS			
		0.0161	0.0016			BT			
		0.0102	0.0012			BT			
		0.0150	0.0012			BT			
	Mid 1/3	0.0063	0.0004			BM			
		0.0028	0.0004			BM			
		0.0051	0.0008			BM			
	Bot. 1/3	0.0000	0.0000						

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Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516-70
Window # : 5
Condition : Hot Rolled

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 4.1 (Staged Experiment)
pH (FINL) : 3.0 (Staged Experiment)

Project # : L922226TK
CLI : 2098
Section : 4,5,6
File # : 5W456.WK1
Date : 4/15/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W5-6	Top 1/3	0.1043	0.0413	2.492	0.495	BS/BT/BS	1.96	18.94	45.41
		0.0343	0.0067			BT			
		0.0220	0.0441			BT			
		0.0406	0.0083			BT			
		0.1831	0.0807			BS/BT/BS			
		0.0827	0.0433			BT/BS			
		0.0051	0.0004			BS			
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	2.09	Std. Dev. =	0.31
Avg. CLR =	19.49	Std. Dev. =	2.10
Avg. CTR =	48.74	Std. Dev. =	5.27

2/3 Thickness Averages of All Three Sections

Avg. CSR =	2.09	Std. Dev. =	0.31
Avg. CLR =	19.49	Std. Dev. =	2.15
Avg. CTR =	48.74	Std. Dev. =	5.37

1/3 Thickness Averages of All Three Sections

Avg. CSR =	2.09	Std. Dev. =	0.34
Avg. CLR =	19.30	Std. Dev. =	2.24
Avg. CTR =	48.63	Std. Dev. =	5.54

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

Comments

- Base metal LT section
- No pre-exposure
- 33 day test
- Charpy V-notch
- External charging

Page 2 of 2

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516-70
Window # : 5
Condition : Hot Rolled

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 4.1 (Staged Experiment)
pH (FINL) : 3.0 (Staged Experiment)

Project # : L922226TK
CLI : 2098
Section : 7,8,9
File # : 5W789.WK1
Date : 4/15/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	Section CSR (%)	Section CLR (%)	Section CTR (%)
W5-7	Top 1/3	0.0886	0.0472	2.429	0.481	BS/BT/BS	1.45	15.61	38.88
		0.1024	0.0472			BS/BT/BS			
		0.0244	0.0043			BT			
		0.0614	0.0291			BT			
		0.1024	0.0591			BS/BT/BS			
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
W5-8	Top 1/3	0.0433	0.0236	2.459	0.490	BT	1.48	13.22	26.03
		0.0543	0.0228			BT			
		0.0197	0.0016			BT			
		0.0047	0.0004			BT			
		0.1969	0.0787			BS/BT/BS			
	Mid 1/3	0.0063	0.0004						
	Bot. 1/3	0.0000	0.0000						
W5-9	Top 1/3	0.1476	0.0669	2.471	0.484	BS/BT/BS	0.87	6.90	18.14
		0.0228	0.0209			BT			
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR :	1.26	Std. Dev. =	0.29
Avg. CLR =	11.91	Std. Dev. =	2.07
Avg. CTR :	27.68	Std. Dev. =	4.81

2/3 Thickness Averages of All Three Sections

Avg. CSR :	1.26	Std. Dev. =	0.31
Avg. CLR =	11.91	Std. Dev. =	2.14
Avg. CTR :	27.68	Std. Dev. =	4.97

1/3 Thickness Averages of All Three Sections

Avg. CSR :	1.26	Std. Dev. =	0.33
Avg. CLR =	11.83	Std. Dev. =	2.26
Avg. CTR :	27.66	Std. Dev. =	5.14

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

Comments

- Base metal LT section
- No pre-exposure
- 33 day test
- Under patch probe

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516-70
Window # : 5
Condition : Hot Rolled

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 4.1 (Staged Experiment)
pH (FINL) : 3.0 (Staged Experiment)

Project # : L922226TK
CLI : 2098
Section : 10,11,12
File # : 5W101112.WK1
Date : 4/15/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W5-10	Top 1/3	0.1319	0.0551	2.534	0.495	BT/BS/BT/BS	1.40	15.06	35.0
		0.0063	0.0008			BT			
		0.0409	0.0071			BT			
		0.1024	0.0492			BS/BT/BS			
		0.0067	0.0012			BT			
		0.0846	0.0591			BS/BT			
		0.0087	0.0012			BT			
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
W5-11	Top 1/3	0.1063	0.0630	2.530	0.496	BS/BT/BS	2.20	28.24	52.4
		0.0114	0.0016			BS			
		0.0945	0.0472			BS/BT/BS			
		0.0173	0.0024			BT			
		0.0677	0.0181			BT			
		0.1634	0.0394			BS/BT/BS			
		0.0114	0.0150			BT			
		0.1319	0.0591			BS/BT/BS			
		0.0126	0.0012			BT			
		0.0028	0.0008			BS			
		0.0630	0.0094			BT			
		0.0323	0.0031			BT			
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						

Page 1 of 2

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516-70
Window # : 5
Condition : Hot Rolled

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 4.1 (Staged Experiment)
pH (FINL) : 3.0 (Staged Experiment)

Project # : L922226TK
CLI : 2098
Section : 10,11,12
File # : 5W101112.WK1
Date : 4/15/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W5-12	Top 1/3	0.1732	0.0748	2.540	0.495	BS/BT/BS	3.20	31.02	56.9
		0.1693	0.0157			BT			
		0.0925	0.0433			BS/BT/BS			
		0.0378	0.0157			BT			
		0.0079	0.0024			BS			
		0.1614	0.0709			BS/BT/BS/BT			
		0.1457	0.0591			BS/BT/BS			
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	2.27	Std. Dev. =	0.27
Avg. CLR =	24.77	Std. Dev. =	2.30
Avg. CTR =	48.16	Std. Dev. =	4.94

2/3 Thickness Averages of All Three Sections

Avg. CSR =	2.27	Std. Dev. =	0.28
Avg. CLR =	24.77	Std. Dev. =	2.33
Avg. CTR =	48.16	Std. Dev. =	5.03

1/3 Thickness Averages of All Three Sections

Avg. CSR =	2.27	Std. Dev. =	0.29
Avg. CLR =	24.77	Std. Dev. =	2.37
Avg. CTR =	48.16	Std. Dev. =	5.12

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Base metal LT section
- No pre-exposure
- 33 day test
- Under copper

Page 2 of 2

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516-70
Window # : 5
Condition : Hot Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 4.1 (Staged Experiment)
pH (FINL) : 3.0 (Staged Experiment)

Project # : L922226TK
CLI : 2098, 3201
Section : 13, 14, 15
File # : 5W131415.WK1
Date : 4/15/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CLI No.	CSR (%)	Section CLR (%)	CTR (%)
W5-13	Top 1/3	0.0217	0.0008	2.543	0.512	BT	3201	1.44	13.98	58.13
		0.1043	0.0531			BS/BT/BS	3201			
		0.0472	0.0457			H1S/H1T	3201#			
		0.0354	0.1535			WS/H1T	3201#			
		0.1280	0.0433			BS/BT/BS	2098			
	Mid 1/3	0.0098	0.0004			BM	3201			
		0.0039	0.0004			BM	3201			
		0.0051	0.0004			BM	3201			
	Bot. 1/3	0.0000	0.0000							
W5-14	Top 1/3	0.0787	0.0492	2.528	0.508	BS/BT/BS	3201	2.17	17.97	59.83
		0.1575	0.0787			BS/BT/BS	3201			
		0.0295	0.1004			WS/H1T/H2T/BT	3201#			
		0.0079	0.0083			H1S	2098			
		0.1339	0.0630			BS/BT/BS	2098			
	Mid 1/3	0.0343	0.0031			BM	3201			
		0.0126	0.0012			BM	3201			
	Bot. 1/3	0.0000	0.0000							
W5-15	Top 1/3	0.0071	0.0008	2.548	0.501	BT	3201	0.76	14.79	56.97
		0.0102	0.0012			BS	3201			
		0.0205	0.0016			BT	3201			
		0.0118	0.0012			BT	3201			
		0.0055	0.0004			BT	3201			
		0.0059	0.0004			BS	3201			
		0.0197	0.0512			H1S/H2S/BT	3201#			
		0.0024	0.0394			H1S	3201#			
		0.0181	0.0457			H1T/H2T	3201#			
		0.0118	0.0866			WS/H1T/H2T	3201#			
		0.1122	0.0492			BS/BT/BS	2098			
	Mid 1/3	0.1516	0.0079			BM	2098			
	Bot. 1/3	0.0000	0.0000							

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Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284−87

Sponsor : API/MPC	Solution : TM0177−90	Project # : L922226TK
Material : A516−70	Exposure : One−sided	CLI : 2098, 3201
Window # : 5	pH (INIT) : 4.1 (Staged Experiment)	Section : 13, 14, 15
Condition : Hot Rolled, Welded	pH (FINL) : 3.0 (Staged Experiment)	File # : 5W131415.WK1
		Date : 4/15/93

Full Thickness Averages of All Three Sections

Avg. CSR :	1.46	Std. Dev. =	0.21
Avg. CLR =	15.58	Std. Dev. =	1.81
Avg. CTR =	58.31	Std. Dev. =	6.93

2/3 Thickness Averages of All Three Sections

Avg. CSR :	1.46	Std. Dev. =	0.22
Avg. CLR =	15.58	Std. Dev. =	1.85
Avg. CTR =	58.31	Std. Dev. =	7.09

1/3 Thickness Averages of All Three Sections

Avg. CSR :	1.42	Std. Dev. =	0.24
Avg. CLR =	12.73	Std. Dev. =	1.84
Avg. CTR =	57.43	Std. Dev. =	7.46

Crack Location Codes

B−Base Metal	WR−Weld Root
H1−Heat Affected Zone 1	S−Surface
H2−Heat Affected Zone 2	T−Tension
W−Weld	M−Middle
WC−Weld Cap	C−Compression

− Weld metal LT section
− No pre−exposure
− 33 day test
− Contain Low Heat Input Weld
− # Crack through Low Heat Input Weld

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Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test NACE Per TM0284-87

Sponsor : API/MPC
Material : A516-70
Window # : 5
Condition : Hot Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 4.1 (Staged Experiment)
pH (FINL) : 3.0 (Staged Experiment)

Project # : L922226TK
CLI : 2098, 3201
Section : 16, 17
File # : 5W1617.WK1
Date : 4/15/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location		Section CSR (%)	Section CLR (%)	Section CTR (%)
W5-16	Top 1/3	0.0748	0.0472	2.544	0.501	BT/BS	3201	0.86	11.59	49.04
		0.0197	0.0083			BT	3201			
		0.0764	0.0047			BT	3201			
		0.0150	0.0008			BT	3201			
		0.0087	0.0008			BT	3201			
		0.0173	0.0260			H1S/H2S	3201#			
		0.0252	0.0449			H1S	3201#			
		0.0472	0.1122			WS/H1T/H2T	3201#			
		0.0059	0.0004			BT	2098			
	Mid 1/3	0.0047	0.0004			BM	3201			
	Bot. 1/3	0.0000	0.0000							
W5-17	Top 1/3	0.1378	0.0236	2.497	0.495	BT	3201	0.66	0.33	1.65
		0.0197	0.0276			BS	3201			
		0.0276	0.0457			BS	3201			
		0.0051	0.0008			BT	3201			
		0.0228	0.0614			H1S/H2T	3201			
		0.0177	0.0925			WS/H1S/H2T/BT	2098#			
		0.0217	0.0020			BS	2098			
	Mid 1/3	0.0000	0.0000							
	Bot. 1/3	0.0000	0.0000							

Full Thickness Averages of All Three Sections

Avg. CSR =	0.51	Std. Dev. =	0.10
Avg. CLR =	3.97	Std. Dev. =	1.23
Avg. CTR =	16.89	Std. Dev. =	6.00

2/3 Thickness Averages of All Three Sections

Avg. CSR =	0.51	Std. Dev. =	0.11
Avg. CLR =	7.23	Std. Dev. =	1.25
Avg. CTR =	33.42	Std. Dev. =	6.14

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.51	Std. Dev. =	0.11
Avg. CLR =	7.17	Std. Dev. =	1.28
Avg. CTR =	33.39	Std. Dev. =	6.28

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

- Weld metal LT section
- No pre-exposure
- 33 day test
- # Contains low heat input weld
- Under copper

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516-70
Window # : 5
Condition : Hot Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 4.1 (Staged Experiment)
pH (FINL) : 3.0 (Staged Experiment)

Project # :L922226TK
CLI : 2098, 3201
Section : 18, 19, 20
File # : 5W181920.WK1
Date : 4/15/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location		CSR (%)	Section CLR (%)	CTR (%)
W5-18	Top 1/3	0.0260	0.0150	2.532	0.493	BS	3201	1.25	15.19	76.26
		0.0071	0.0016			BT	3201			
		0.0197	0.0039			BS	3201			
		0.0087	0.0008			BT	3201			
		0.0827	0.0295			BS	3201			
		0.0051	0.0004			BT	3201			
		0.0063	0.0008			BS	3201			
		0.0157	0.0008			BT	3201			
		0.0028	0.0004			BT	3201			
		0.0268	0.0315			H2S/H1S	3201			
		0.0571	0.1181			WS/H1S/H2T	3201			
		0.0157	0.0906			WS/WT	Weld			
		0.0394	0.0591			WS/H1S/H2T	2098#			
		0.0102	0.0016			BT	2098			
		0.0614	0.0220			BT	2098			
	Mid 1/3	0.0000	0.0000							
	Bot. 1/3	0.0000	0.0000							
W5-19	Top 1/3	0.0846	0.0394	2.531	0.494	BS	3201	1.08	12.37	58.82
		0.0339	0.0024			BT	3201			
		0.0142	0.0378			H1S/H2S	3201			
		0.0394	0.1476			WS/H1T/H2T/BM	2098*#			
		0.0217	0.0016			BT	2098			
	Mid 1/3	0.0650	0.0551			WS/H1T/H2T/BM	2098*#			
		0.0130	0.0016			BM	3201			
		0.0059	0.0004			BM	3201			
		0.0354	0.0047			H1M/H2M	2098			
	Bot. 1/3	0.0000	0.0000							

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Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516-70
Window # : 5
Condition : Hot Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 4.1 (Staged Experiment)
pH (FINL) : 3.0 (Staged Experiment)

Project # :L922226TK
CLI : 2098, 3201
Section : 18, 19, 20
File # : 5W181920.WK1
Date : 4/15/93

W5-20	Top 1/3	0.0020	0.0012	2.525	0.498	BT	3201	1.70	14.72	85.30
		0.0984	0.0453			BS/BT/BS	3201			
		0.0114	0.0016			BS	3201			
		0.0106	0.0012			BT	3201			
		0.0374	0.0787			H1S/H2T	3201			
		0.0252	0.0535			H1S/H2T	3201			
		0.0689	0.1220			H1S/H2T/BT	2098#			
		0.0551	0.0157			BT	2098			
		0.0146	0.0114			BS	2098			
		0.0031	0.0008			BS	2098			
		0.0335	0.0925			BS/BT	2098			
	Mid 1/3	0.0114	0.0008			BM	3201			
	Bot. 1/3	0.0000	0.0000							

Full Thickness Averages of All Three Sections

Avg. CSR =	1.35	Std. Dev. =	0.15
Avg. CLR =	14.09	Std. Dev. =	1.01
Avg. CTR =	73.46	Std. Dev. =	7.40

2/3 Thickness Averages of All Three Sections

Avg. CSR =	1.35	Std. Dev. =	0.15
Avg. CLR =	14.09	Std. Dev. =	1.02
Avg. CTR =	73.46	Std. Dev. =	7.55

1/3 Thickness Averages of All Three Sections

Avg. CSR =	1.24	Std. Dev. =	0.16
Avg. CLR =	12.37	Std. Dev. =	1.04
Avg. CTR =	69.24	Std. Dev. =	7.86

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Weld metal LT section
- No pre-exposure
- 33 day test
- Contain low heat input weld
- * Same Crack
- # Crack through Low Heat Input Weld

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Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516-70, A841
Window#: 5
Condition :Hot Rolled, Welded

Solution : TM0177-90
Exposure :One-sided
pH (INIT) : 4.1 (Staged Experiment)
pH (FINL): 3.0 (Staged Experiment)

Project # : L922226TK
CLI : 2098, 3249
Section : 21
File # : 5W21.WK1
Date : 4/15/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location		CSR (%)	Section CLR (%)	CTR (%)
W5-21	Top 1/3	0.0197	0.1083	2.496	0.487	WS/H1S/H2T/BT	3249#	0.52	4.09	71.79
		0.0256	0.1181			H1S/WS/WT	3249#			
		0.0063	0.0157			BS	2098			
		0.0063	0.0197			BS	2098			
		0.0142	0.0433			BS	2098+			
		0.0071	0.0276			BS	2098			
		0.0055	0.0126			BS	2098			
	Mid 1/3	0.0083	0.0016			BM	3249			
		0.0091	0.0028			BM	2098			
	Bot. 1/3	0.0000	0.0000							

Full Thickness Averages of All Three Sections

Avg. CSR =	0.52	Std. Dev. =	0.07
Avg. CLR =	4.09	Std. Dev. =	0.30
Avg. CTR =	71.79	Std. Dev. =	7.83

2/3 Thickness Averages of All Three Sections

Avg. CSR =	0.52	Std. Dev. =	0.08
Avg. CLR =	4.09	Std. Dev. =	0.31
Avg. CTR =	71.79	Std. Dev. =	8.00

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.51	Std. Dev. =	0.08
Avg. CLR =	3.39	Std. Dev. =	0.33
Avg. CTR =	70.90	Std. Dev. =	8.37

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

Comments

- Weld metal LT section
- No pre-exposure
- 33 day test
- # Contains low heat input weld
- + Strong back weld

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516-70, A841
Window#: 5
Condition :Hot Rolled, Welded

Solution: TM0177-90
Exposure: One-sided
pH (INIT): 4.1 (Staged Experiment)
pH (FINL): 3.0 (Staged Experiment)

Project # :L922226TK
CLI : 2098, 3249
Section : 22, 23, 24
File # : 5W222324.WK1
Date : 4/15/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location		CSR (%)	Section CLR (%)	CTR (%)
W5-22	Top 1/3	0.0118	0.0610	2.488	0.491	H1S/H2T	3249	1.86	12.39	86.60
		0.0157	0.1417			WS/WT/WM	3249*			
		0.0591	0.0709			BS/H2T	2098			
		0.0051	0.0004			BT	2098			
		0.0079	0.0016			BT	2098			
		0.1654	0.0748			BS/BT/BS	2098			
	Mid 1/3	0.0433	0.0748			WS/WT/WM	3249*			
	Bot. 1/3	0.0000	0.0000							
W5-23	Top 1/3	0.0098	0.0315	2.483	0.486	H1S	3249	0.77	6.47	78.34
		0.0118	0.0689			WS/H1S/H2T	3249			
		0.0276	0.1378			WS/WM	3249*			
		0.0150	0.0205			WS	2098			
		0.0728	0.0236			H1T/H2T	2098			
	Mid 1/3	0.0236	0.0984			WS/WM	3249*			
	Bot. 1/3	0.0000	0.0000							
W5-24	Top 1/3	0.0276	0.1476	2.487	0.485	WS/H1T/H2T/H1T/H2T/BM	3249*	1.03	5.78	57.23
		0.0945	0.0768			H2S/BT/BS	2098			
	Mid 1/3	0.0217	0.0531			WS/H1T/H2T/H1T/H2T/BM	3249*			
	Bot. 1/3	0.0000	0.0000							

Full Thickness Averages of All Three Sections

Avg. CSR =	1.22	Std. Dev. =	0.22
Avg. CLR =	8.21	Std. Dev. =	1.45
Avg. CTR =	74.05	Std. Dev. =	9.75

2/3 Thickness Averages of All Three Sections

Avg. CSR =	1.22	Std. Dev. =	0.23
Avg. CLR =	8.21	Std. Dev. =	1.50
Avg. CTR =	74.05	Std. Dev. =	9.92

1/3 Thickness Averages of All Three Sections

Avg. CSR =	1.04	Std. Dev. =	0.25
Avg. CLR =	7.02	Std. Dev. =	1.63
Avg. CTR =	58.57	Std. Dev. =	10.11

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Weld metal LT section
- No pre-exposure
- 33 day test
- Contain low heat input weld
- * Same Crack

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284−87

Sponsor : API/MPC
Material : A516−70
Window # : 5
Condition : Hot Rolled

Solution : TM0177−90
Exposure : One−sided
pH (INIT) : 4.1 (Staged Experiment)
pH (FINL) : 3.0 (Staged Experiment)

Project # : L922226TK
CLI : 3201
Section : 25, 26, 27
File # : 5W252627.WK1
Date : 4/15/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W5−25	Top 1/3	0.0457	0.0236	2.585	0.515	BS	0.31	14.68	17.58
		0.0685	0.0126			BT			
		0.0370	0.0181			BS			
		0.0728	0.0138			BS			
		0.0146	0.0039			BS			
		0.0409	0.0039			BT			
	Mid 1/3	0.0228	0.0020			BM			
		0.0106	0.0020			BM			
		0.0094	0.0055			BM			
		0.0268	0.0028			BM			
		0.0303	0.0024			BM			
	Bot. 1/3	0.0000	0.0000						
W5−26	Top 1/3	0.0535	0.0268	2.559	0.515	BS/BT	0.82	14.78	23.55
		0.1260	0.0610			BS/BT/BS			
		0.0031	0.0004			BT			
		0.0189	0.0024			BT			
	Mid 1/3	0.0213	0.0016			BM			
		0.0598	0.0213			BM			
		0.0114	0.0012			BM			
		0.0051	0.0008			BM			
		0.0059	0.0012			BM			
		0.0732	0.0047			BM			
	Bot. 1/3	0.0000	0.0000						

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Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284–87

Sponsor : API/MPC
Material : A516–70
Window # : 5
Condition : Hot Rolled

Solution : TM0177–90
Exposure : One–sided
pH (INIT) : 4.1 (Staged Experiment)
pH (FINL) : 3.0 (Staged Experiment)

Project # : L922226TK
CLI : 3201
Section : 25, 26, 27
File # : 5W252627.WK1
Date : 4/15/93

W5–27	Top 1/3	0.0051	0.0004	2.546	0.512	BT	0.50	16.62	22.22
		0.0583	0.0228			BS			
		0.0409	0.0150			BT			
		0.0276	0.0110			BS			
		0.0457	0.0252			BS			
		0.1122	0.0197			BT			
		0.0299	0.0024			BT			
		0.0535	0.0134			BT			
	Mid 1/3	0.0331	0.0031			BM			
		0.0098	0.0004			BM			
		0.0071	0.0004			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	0.54	Std. Dev. =	0.09
Avg. CLR =	15.36	Std. Dev. =	1.18
Avg. CTR =	21.12	Std. Dev. =	2.24

2/3 Thickness Averages of All Three Sections

Avg. CSR =	0.54	Std. Dev. =	0.09
Avg. CLR =	15.36	Std. Dev. =	1.19
Avg. CTR =	21.12	Std. Dev. =	2.29

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.49	Std. Dev. =	0.11
Avg. CLR =	11.12	Std. Dev. =	1.34
Avg. CTR =	17.93	Std. Dev. =	2.61

Crack Location Codes

B–Base Metal	WR–Weld Root
H1–Heat Affected Zone 1	S–Surface
H2–Heat Affected Zone 2	T–Tension
W–Weld	M–Middle
WC–Weld Cap	C–Compression

Comments

- Base metal LT section
- No pre–exposure
- 33 day test
- Under copper

Page 2 of 2

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A841
Window # : 5
Condition : Hot Rolled

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 4.1 (Staged Experiment)
pH (FINL) : 3.0 (Staged Experiment)

Project # : L922226TK
CLI : 3249
Section : 28, 29, 30
File # : 5W282930.WK1
Date : 4/15/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W5-28	Top 1/3	0.0000	0.0000	2.513	0.494		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
W5-29	Top 1/3	0.0000	0.0000	2.501	0.498		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
W5-30	Top 1/3	0.0000	0.0000	2.477	0.500		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

2/3 Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

Comments

- Base metal LT section
- No pre-exposure
- 33 day test
- Under copper

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516-70, A841
Window#: 5
Condition :Hot Rolled, Welded

Solution : TM0177-90
Exposure :One-sided
pH (INIT) : 4.1 (Staged Experiment)
pH (FINL): 3.0 (Staged Experiment)

Project # : L922226TK
CLI : 3201, 3249
Section : 31, 32, 33
File # : 5W313233.WK1
Date : 4/15/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location		CSR (%)	Section CLR (%)	CTR (%)
W5-31	Top 1/3	0.0413	0.0965	2.486	0.503	BS/BT	3201	0.37	8.05	22.15
		0.0110	0.0098			H1S	3201			
	Mid 1/3	0.1260	0.0039			BM	3201			
		0.0217	0.0012			BM	3201			
	Bot. 1/3	0.0000	0.0000							
W5-32	Top 1/3	0.0567	0.0016	2.487	0.505	BS	3201	0.25	16.43	19.57
		0.0748	0.0071			BS	3201			
		0.0157	0.0433			H1S/H2T	3201			
		0.0094	0.0409			H2S/BT	3249			
	Mid 1/3	0.2520	0.0059			BM	3201			
	Bot. 1/3	0.0000	0.0000							
W5-33	Top 1/3	0.0394	0.0457	2.491	0.482	H1S/H2T	3201	0.15	1.58	9.47
	Mid 1/3	0.0000	0.0000							
	Bot. 1/3	0.0000	0.0000							

Full Thickness Averages of All Three Sections

Avg. CSR =	0.26	Std. Dev. =	0.07
Avg. CLR =	8.69	Std. Dev. =	2.25
Avg. CTR =	17.06	Std. Dev. =	4.54

2/3 Thickness Averages of All Three Sections

Avg. CSR =	0.26	Std. Dev. =	0.07
Avg. CLR =	8.69	Std. Dev. =	2.36
Avg. CTR =	17.06	Std. Dev. =	4.78

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.20	Std. Dev. =	0.08
Avg. CLR =	3.33	Std. Dev. =	0.95
Avg. CTR =	16.34	Std. Dev. =	5.21

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Weld metal TL section
- No pre-exposure
- 33 day test

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516-70
Window # : 5
Condition : Hot Rolled

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 4.1 (Staged Experiment)
pH (FINL) : 3.0 (Staged Experiment)

Project # :L922226TK
CLI : 3201
Section : 34, 35, 36
File # : 5W343536.WK1
Date : 4/15/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W5-34	Top 1/3	0.0071	0.0173	2.469	0.515	BS	0.04	5.33	8.26
		0.0071	0.0157			BS			
	Mid 1/3	0.0142	0.0028			BM			
		0.0394	0.0028			BM			
		0.0126	0.0008			BM			
		0.0512	0.0031			BM			
	Bot. 1/3	0.0000	0.0000						
W5-35	Top 1/3	0.0039	0.0008	2.475	0.514	BT	0.01	2.43	1.38
		0.0094	0.0008			BT			
	Mid 1/3	0.0067	0.0008			BM			
		0.0031	0.0008			BM			
		0.0154	0.0016			BM			
		0.0031	0.0008			BM			
		0.0185	0.0016			BM			
	Bot. 1/3	0.0000	0.0000						

Page 1 of 2

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284–87

Sponsor : API/MPC	Solution : TM0177–90	Project # :L922226TK
Material : A516–70	Exposure : One–sided	CLI : 3201
Window # : 5	pH (INIT) : 4.1 (Staged Experiment)	Section : 34, 35, 36
Condition : Hot Rolled	pH (FINL) : 3.0 (Staged Experiment)	File # : 5W343536.WK1
		Date : 4/15/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	Section CSR (%)	Section CLR (%)	Section CTR (%)
W5–36	Top 1/3	0.0350	0.0020	2.469	0.514	BT	0.35	9.11	10.57
		0.1142	0.0374			BS/BT/BS			
	Mid 1/3	0.0063	0.0004			BM			
		0.0024	0.0004			BM			
		0.0098	0.0008			BM			
		0.0126	0.0008			BM			
		0.0031	0.0008			BM			
		0.0098	0.0091			BM			
		0.0142	0.0012			BM			
		0.0173	0.0016			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	0.13	Std. Dev. =	0.06
Avg. CLR =	5.62	Std. Dev. =	0.85
Avg. CTR =	6.74	Std. Dev. =	1.36

2/3 Thickness Averages of All Three Sections

Avg. CSR =	0.13	Std. Dev. =	0.06
Avg. CLR =	5.62	Std. Dev. =	0.87
Avg. CTR =	6.74	Std. Dev. =	1.41

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.12	Std. Dev. =	0.09
Avg. CLR =	2.39	Std. Dev. =	1.20
Avg. CTR =	4.80	Std. Dev. =	1.95

Crack Location Codes

B–Base Metal	WR–Weld Root
H1–Heat Affected Zone 1	S–Surface
H2–Heat Affected Zone 2	T–Tension
W–Weld	M–Middle
WC–Weld Cap	C–Compression

Comments

– Base metal LT section
– No pre–exposure
– 33 day test
– 1/2 under copper
– Charpy V–notch

Page 2 of 2

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A841
Window # : 5
Condition : Hot Rolled

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 4.1 (Staged Experiment)
pH (FINL) : 3.0 (Staged Experiment)

Project # : L922226TK
CLI : 3249
Section : 37, 38, 39
File # : 5W373839.WK1
Date : 4/16/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	Section CSR (%)	Section CLR (%)	Section CTR (%)
W5-37	Top 1/3	0.0000	0.0000	2.388	0.497		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
W5-38	Top 1/3	0.0000	0.0000	2.425	0.501		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
W5-39	Top 1/3	0.0000	0.0000	2.448	0.494		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

2/3 Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

Comments

- Base metal LT section
- No pre-exposure
- 33 day test
- 1/2 under copper
- Charpy V-notch

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516-70
Window # : 5
Condition : Hot Rolled

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 4.1 (Staged Experiment)
pH (FINL) : 3.0 (Staged Experiment)

Project # : L922226TK
CLI : 3201
Section : 40, 41, 42
File # : 5W404142.WK1
Date : 4/16/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W5-40	Top 1/3	0.0236	0.0433	2.550	0.515	BS/BT	0.13	9.82	12.61
		0.0472	0.0055			BS			
		0.0130	0.0008			BT			
		0.0425	0.0008			BT			
	Mid 1/3	0.0244	0.0031			BM			
		0.0433	0.0039			BM			
		0.0039	0.0008			BM			
		0.0260	0.0031			BM			
		0.0181	0.0024			BM			
		0.0083	0.0012			BM			
	Bot. 1/3	0.0000	0.0000						
W5-41	Top 1/3	0.0091	0.0004	2.546	0.518	BT	0.05	9.17	5.02
		0.0146	0.0016			BT			
		0.0236	0.0004			BT			
	Mid 1/3	0.0283	0.0039			BM			
		0.0433	0.0047			BM			
		0.0142	0.0020			BM			
		0.0035	0.0008			BM			
		0.0079	0.0012			BM			
		0.0283	0.0031			BM			
		0.0059	0.0012			BM			
		0.0130	0.0028			BM			
		0.0252	0.0024			BM			
		0.0165	0.0016			BM			
	Bot. 1/3	0.0000	0.0000						

Page 1 of 2

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516-70
Window # : 5
Condition : Hot Rolled

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 4.1 (Staged Experiment)
pH (FINL) : 3.0 (Staged Experiment)

Project # : L922226TK
CLI : 3201
Section : 40, 41, 42
File # : 5W404142.WK1
Date : 4/16/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W5-42	Top 1/3	0.0339	0.0173	2.551	0.514	BS	0.83	17.61	25.58
		0.0866	0.0433			BS/BT/BS			
		0.0504	0.0055			BT			
		0.1201	0.0472			BS/BT/BS			
		0.0122	0.0016			BT			
	Mid 1/3	0.0402	0.0039			BM			
		0.0299	0.0047			BM			
		0.0331	0.0031			BM			
		0.0339	0.0039			BM			
		0.0091	0.0008			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR :	0.33	Std. Dev. =	0.07
Avg. CLR :	12.20	Std. Dev. =	0.93
Avg. CTR :	14.40	Std. Dev. =	2.12

2/3 Thickness Averages of All Three Sections

Avg. CSR :	0.33	Std. Dev. =	0.08
Avg. CLR :	12.20	Std. Dev. =	0.93
Avg. CTR :	14.40	Std. Dev. =	2.17

1/3 Thickness Averages of All Three Sections

Avg. CSR :	0.30	Std. Dev. =	0.11
Avg. CLR :	6.23	Std. Dev. =	1.24
Avg. CTR :	10.87	Std. Dev. =	2.95

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

Comments

- Base metal LT section
- No pre-exposure
- 33 day test

Page 2 of 2

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A841
Window # : 5
Condition : Hot Rolled

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 4.1 (Staged Experiment)
pH (FINL) : 3.0 (Staged Experiment)

Project # : L922226TK
CLI : 3249
Section : 43, 44, 45
File # : 5W434445.WK1
Date : 4/16/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	Section CSR (%)	Section CLR (%)	Section CTR (%)
W5-40	Top 1/3	0.0000	0.0000	2.550	0.515		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
W5-41	Top 1/3	0.0000	0.0000	2.546	0.518		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
W5-42	Top 1/3	0.0000	0.0000	2.551	0.514		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

2/3 Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Base metal LT section
- No pre-exposure
- 33 day test

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516-70, A841
Window # : 5
Condition : Hot Rolled, Welded

Solution : TM0177-90
Exposure : One-sided
pH (INIT) : 4.1 (Staged Experiment)
pH (FINL) : 3.0 (Staged Experiment)

Project # : L922226TK
CLI : 2098, 3249
Section : 46, 47, 48
File # : 5W464748.WK1
Date : 4/16/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location		CSR (%)	Section CLR (%)	CTR (%)
W5-46	Top 1/3	0.0299	0.0087	2.403	0.487	BS	3249	2.15	19.74	51.25
		0.0213	0.0638			H1S/H2S/BT	3249			
		0.0827	0.0512			WT/H1T/H2S	2098			
		0.0512	0.0079			BT	2098			
		0.0689	0.0472			BS/BT	2098			
		0.2205	0.0709			BS/BT/BS/BT	2098			
	Mid 1/3	0.0000	0.0000							
	Bot. 1/3	0.0000	0.0000							
W5-47	Top 1/3	0.0071	0.0012	2.408	0.493	BT	3249	0.56	4.37	31.22
		0.0126	0.0177			BS	3249			
		0.0650	0.0925			H1S/H2S/BT	3249			
		0.0067	0.0012			H2T	2098			
		0.0035	0.0012			BT	2098			
		0.0102	0.0402			BS/BT	2098			
	Mid 1/3	0.0000	0.0000							
	Bot. 1/3	0.0000	0.0000							
W5-48	Top 1/3	0.0567	0.0276	2.415	0.490	BS	3249	0.25	4.97	27.56
		0.0102	0.0012			BT	3249			
		0.0079	0.0012			BT	3249			
		0.0138	0.0807			H1S/H2T/BT	2098			
		0.0110	0.0024			BT	2098			
		0.0098	0.0012			BT	2098			
		0.0106	0.0209			BT	2098			
	Mid 1/3	0.0000	0.0000							
	Bot. 1/3	0.0000	0.0000							

Full Thickness Averages of All Three Sections

Avg. CSR =	0.99	Std. Dev. =	0.24
Avg. CLR =	9.69	Std. Dev. =	1.70
Avg. CTR =	36.68	Std. Dev. =	5.35

2/3 Thickness Averages of All Three Sections

Avg. CSR =	0.99	Std. Dev. =	0.25
Avg. CLR =	9.69	Std. Dev. =	1.76
Avg. CTR =	36.68	Std. Dev. =	5.50

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.99	Std. Dev. =	0.27
Avg. CLR =	9.69	Std. Dev. =	1.87
Avg. CTR =	36.68	Std. Dev. =	5.66

Crack Location Codes

B-Base Metal	WR-Weld Root
H1-Heat Affected Zone 1	S-Surface
H2-Heat Affected Zone 2	T-Tension
W-Weld	M-Middle
WC-Weld Cap	C-Compression

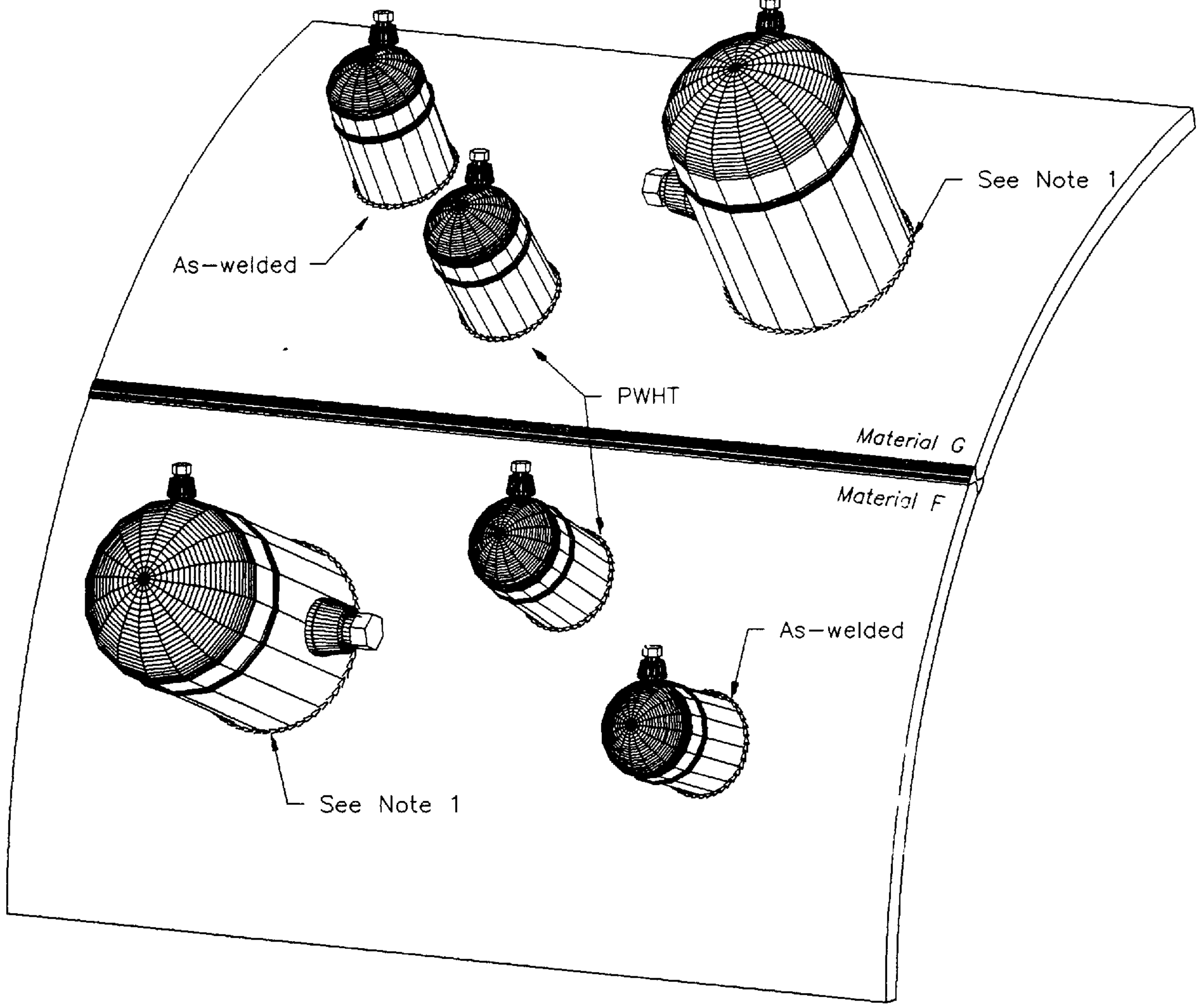
Comments

- Weld metal LT section
- No pre-exposure
- 33 day test
- Specimen 48 1/2 under copper

APPENDIX VI

SERVICEABILITY OF NOZZLE ATTACHMENTS AND PWHT

APPENDIX VI - FIGURE 1



Notes:

1 — Welds in 9 to 3 O'clock position (clockwise) were PWHT. Welds in 3 to 9 O'clock postion (clockwise) were left as—welded.

2 — PWHT was conducted at 1150°F for 1 hour at temperature.

3 — All threadolets are as—welded.

4 — Nozzle material is A53, Schedule 40 ERW pipe.

5 — Weldcap material is A234 standard wall.

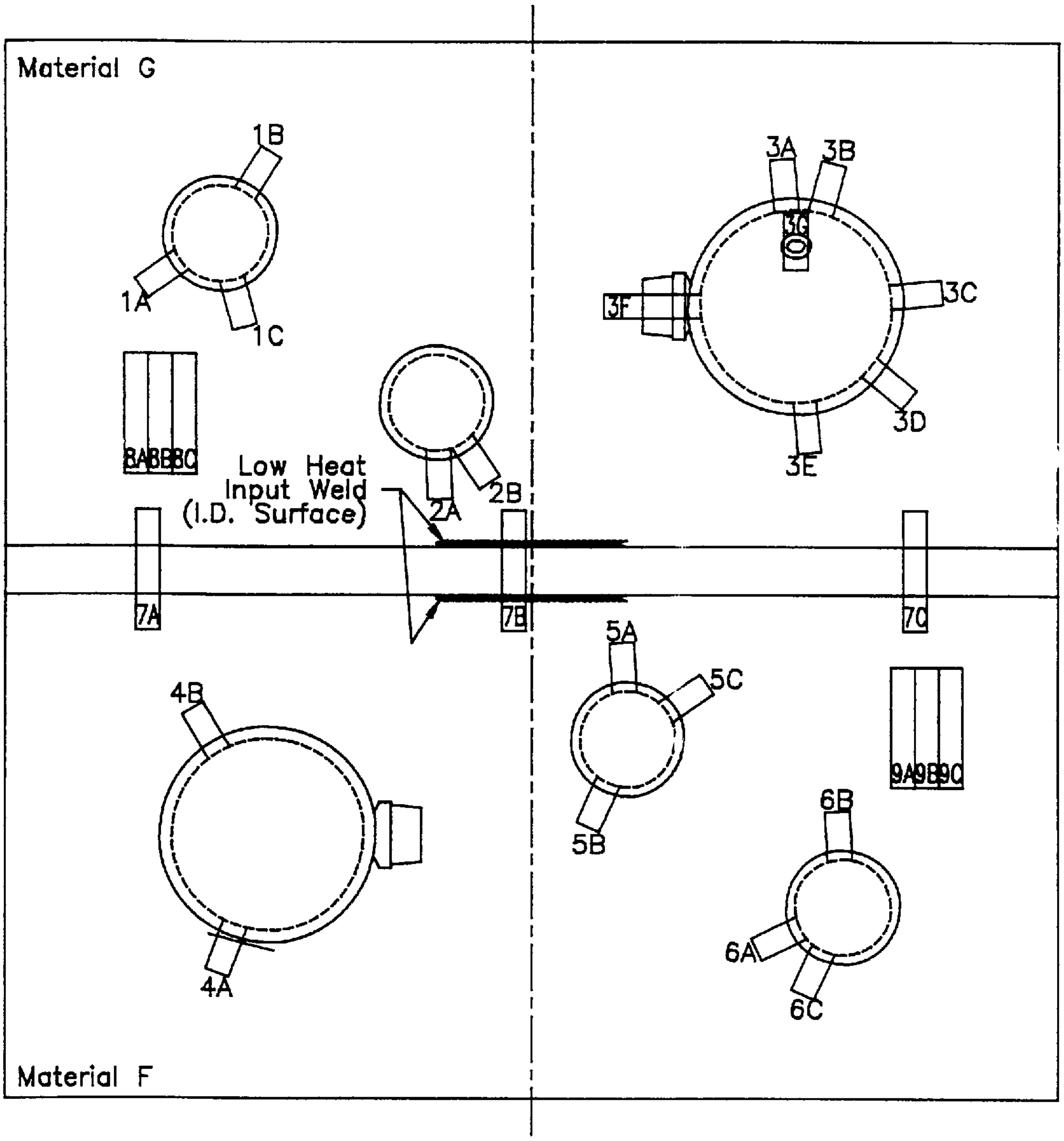
Material F: A841
CLI Number: 3250
Chemistry: C=0.09, P=0.003, S=0.001
Material Condition: TMCP
Mechanical Properties: Yield=67.0ksi, UTS=79.0ksi, % elongation=25.0

Material G: A516 Grade 70
CLI Number: 2280
Chemistry: C=0.22, P=0.027, S=0.020
Material Condition: Normalized
Mechanical Properties: Yield=52.0ksi, UTS=76.9ksi, % elongation=42.0

O.D. View

Date: 5/4/93	Project #: L922238TK
Disk #: L200-2	File #: 2238_1
Scale	Drawn By: K Koenig

APPENDIX VI - FIGURE 2



Material F: A841
CLI Number: 3250
Chemistry: C=0.09, P=0.003, S=0.001
Material Condition: TMCP
Mechanical Properties: Yield=67.0ksi, UTS=79.0ksi, % elongation=25.0

Material G: A516 Grade 70
CLI Number: 2280
Chemistry: C=0.22, P=0.027, S=0.020
Material Condition: Normalized
Mechanical Properties: Yield=52.0ksi, UTS=76.9ksi, % elongation=42.0

O.D. View

Date: 9/2/93	Project #: L922238TK
Disk #: L500-1	File #: 2238
Scale:	Drawn By: K. Koenig

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516 Grade 70, A53 ERW
Window # : 6
Condition : Normalized, As Welded

Solution : NACE TM0177
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.7

Project # : L922238TK
CLI : 2280
Section : 1A, 1B, 1C
File # : 6W1ABC.WK1
Date : 9/1/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W6-1A	Top 1/3	0.0000	0.0000	1.200	0.490		2.06	39.53	5.22
	Mid 1/3	0.4744	0.0256			BM			
	Bot. 1/3	0.0000	0.0000						
W6-1B	Top 1/3	0.0000	0.0000	1.100	0.490		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
W6-1C	Top 1/3	0.0000	0.0000	1.350	0.490		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	0.69	Std. Dev. =	0.65
Avg. CLR =	13.18	Std. Dev. =	12.42
Avg. CTR =	1.74	Std. Dev. =	1.64

2/3 Thickness Averages of All Three Sections

Avg. CSR =	0.69	Std. Dev. =	0.77
Avg. CLR =	13.18	Std. Dev. =	14.73
Avg. CTR =	1.74	Std. Dev. =	1.95

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Weld metal nozzle section
- 24 day test
- No pre-exposure

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516 Grade 70, A53 ERW
Window # : 6
Condition : Normalized, PWHT

Solution : NACE TM0177
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.7

Project # : L922238TK
CLI : 2280
Section : 2A, 2B
File # : 6W2AB.WK1
Date : 9/1/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W6-2A	Top 1/3	0.0000	0.0000	1.200	0.490		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
6W-2B	Top 1/3	0.1398	0.0492	1.260	0.490	BT	1.77	46.87	12.45
	Mid 1/3	0.0453	0.0020			BM			
		0.4055	0.0098			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	0.89	Std. Dev. =	0.42
Avg. CLR =	23.43	Std. Dev. =	11.07
Avg. CTR =	6.23	Std. Dev. =	3.44

2/3 Thickness Averages of All Three Sections

Avg. CSR =	0.89	Std. Dev. =	0.45
Avg. CLR =	23.43	Std. Dev. =	12.10
Avg. CTR =	6.23	Std. Dev. =	3.85

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.56	Std. Dev. =	0.56
Avg. CLR =	5.55	Std. Dev. =	5.55
Avg. CTR =	5.02	Std. Dev. =	5.02

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Weld metal nozzle section
- 24 day test
- No pre-exposure

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516 Grade 70, A53 ERW
Window # : 6
Condition : Normalized, PWHT, As welded

Solution : NACE TM0177
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.7

Project # : L922238TK
CLI : 2280
Section : 3A, 3B, 3C
File # : 6W3ABC.WK1
Date : 9/1/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
6W-3A	Top 1/3	0.0000	0.0000	1.210	0.490		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
6W-3B	Top 1/3	0.1594	0.0886	1.100	0.490	BS/BT/BS	2.74	22.19	19.69
	Mid 1/3	0.0846	0.0079			BM			
	Bot. 1/3	0.0000	0.0000						
6W-3C	Top 1/3	0.0000	0.0000	1.600	0.490		2.92	55.98	5.22
	Mid 1/3	0.8957	0.0256			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	1.89	Std. Dev. =	1.15
Avg. CLR =	26.06	Std. Dev. =	17.40
Avg. CTR =	8.30	Std. Dev. =	5.65

2/3 Thickness Averages of All Three Sections

Avg. CSR =	1.89	Std. Dev. =	1.30
Avg. CLR =	26.06	Std. Dev. =	19.94
Avg. CTR =	8.30	Std. Dev. =	6.50

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.87	Std. Dev. =	1.24
Avg. CLR =	4.83	Std. Dev. =	6.83
Avg. CTR =	6.03	Std. Dev. =	8.52

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Weld metal nozzle section
- 24 day test
- No pre-exposure

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284–87

Sponsor : API/MPC
Material : A516 Grade 70, A53 ERW
Window # : 6
Condition : Normalized, PWHT

Solution : NACE TM0177
Exposure : One–sided
pH (INIT) : 2.7
pH (FINL) : 3.7

Project # : L922238TK
CLI : 2280
Section : 3D, 3E
File # : 6W3DE.WK1
Date : 9/1/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
6W–3D	Top 1/3	0.0000	0.0000	1.060	0.490		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
6W–3E	Top 1/3	0.0079	0.0020	1.100	0.490	BT	0.21	14.24	6.43
	Mid 1/3	0.0413	0.0236			BM			
		0.0276	0.0059			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	0.11	Std. Dev. =	0.06
Avg. CLR =	7.12	Std. Dev. =	1.41
Avg. CTR =	3.21	Std. Dev. =	1.65

2/3 Thickness Averages of All Three Sections

Avg. CSR =	0.11	Std. Dev. =	0.07
Avg. CLR =	3.49	Std. Dev. =	1.49
Avg. CTR =	3.21	Std. Dev. =	1.82

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.36	Std. Dev. =	0.36
Avg. CTR =	0.20	Std. Dev. =	0.20

Crack Location Codes

B–Base Metal
H1–Heat Affected Zone 1
H2–Heat Affected Zone 2
W–Weld
WC–Weld Cap
WR–Weld Root
S–Surface
T–Tension
M–Middle
C–Compression

Comments

– Weld metal nozzle section
– 24 day test
– No pre–exposure

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A53 ERW, Thredolet
Window # : 6
Condition : As Welded

Solution : NACE TM0177
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.7

Project # : L922238TK
CLI :
Section : 3F, 3G
File # : 6W3FG.WK1
Date : 9/1/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
6W-3F	Top 1/3	0.0000	0.0000	2.590	0.225		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
6W-3G	Top 1/3	0.0531	0.0177	1.630	0.225	BT	3.63	123.45	26.25
	Mid 1/3	0.3228	0.0374			BM			
		0.0768	0.0039			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	1.82	Std. Dev. =	1.14
Avg. CLR =	61.73	Std. Dev. =	6.71
Avg. CTR =	13.12	Std. Dev. =	5.89

2/3 Thickness Averages of All Three Sections

Avg. CSR =	1.82	Std. Dev. =	1.29
Avg. CLR =	13.89	Std. Dev. =	7.36
Avg. CTR =	13.12	Std. Dev. =	6.38

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.13	Std. Dev. =	0.13
Avg. CLR =	1.63	Std. Dev. =	1.63
Avg. CTR =	3.94	Std. Dev. =	3.94

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- 6W-3F - Nozzle / Thredolet section
- 6W-3G - End cap / Thredolet section
- 24 day test
- No pre-exposure

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284–87

Sponsor : API/MPC
Material : A516 Grade 70, A53 ERW
Window # : 6
Condition : Normalized, As Welded, PWHT

Solution : NACE TM0177
Exposure : One–sided
pH (INIT) : 2.7
pH (FINL) : 3.7

Project # : L922238TK
CLI : 3250
Section : 4A, 4B
File # : 6W4AB.WK1
Date : 9/1/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	Section CSR (%)	Section CLR (%)	Section CTR (%)
6W–4A	Top 1/3	0.0000	0.0000	1.270	0.480		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
6W–4B	Top 1/3	0.0000	0.0000	1.680	0.480		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

2/3 Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

Crack Location Codes

B–Base Metal
H1–Heat Affected Zone 1
H2–Heat Affected Zone 2
W–Weld
WC–Weld Cap
WR–Weld Root
S–Surface
T–Tension
M–Middle
C–Compression

Comments

– Weld metal nozzle section
– 24 day test
– No pre–exposure

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A841, A53 ERW
Window # : 6
Condition : Normalized, PWHT

Solution : NACE TM0177
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.7

Project # : L922238TK
CLI : 3250
Section : 5A, 5B, 5C
File # : 6W5ABC.WK1
Date : 9/1/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W6-5A	Top 1/3	0.0000	0.0000	1.190	0.480		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
W6-5B	Top 1/3	0.0000	0.0000	1.230	0.480		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
W6-5C	Top 1/3	0.0000	0.0000	1.460	0.480		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

2/3 Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Weld metal nozzle section
- 24 day test
- No pre-exposure

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284−87

Sponsor : API/MPC
Material : A841, A53 ERW
Window # : 6
Condition : Normalized, As welded

Solution : NACE TM0177
Exposure : One−sided
pH (INIT) : 2.7
pH (FINL) : 3.7

Project # : L922238TK
CLI : 3250
Section : 6A, 6B, 6C
File # : 6W6ABC.WK1
Date : 9/1/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W6−6A	Top 1/3	0.0000	0.0000	1.490	0.480		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
W6−6B	Top 1/3	0.0000	0.0000	1.230	0.480		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
W6−6C	Top 1/3	0.0000	0.0000	1.230	0.480		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

2/3 Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

Crack Location Codes

B−Base Metal
H1−Heat Affected Zone 1
H2−Heat Affected Zone 2
W−Weld
WC−Weld Cap
WR−Weld Root
S−Surface
T−Tension
M−Middle
C−Compression

Comments

− Weld metal nozzle section
− 24 day test
− No pre−exposure

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516 Grade 70, A841
Window # : 6
Condition : Normalized

Solution : NACE TM0177
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.7

Project # : L922238TK
CLI : 2280, 3250
Section : 7A, 7B, 7C
File # : 6W7ABC.WK1
Date : 9/1/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CLI No.	CSR (%)	Section CLR (%)	CTR (%)
W6-7A	Top 1/3	0.0138	0.0315	2.570	0.490	H2T	2280	0.25	10.19	12.05
		0.0807	0.0217			H2T/H1T	2280			
	Mid 1/3	0.1673	0.0059			BM	2280			
	Bot. 1/3	0.0000	0.0000							
W6-7B	Top 1/3	0.1319	0.0728	2.530	0.490	BS/BT	2280	0.77	5.21	14.86
	Mid 1/3	0.0000	0.0000							
	Bot. 1/3	0.0000	0.0000							
W6-7C	Top 1/3	0.0217	0.0276	2.470	0.490	BS/BT	2280	1.84	19.37	21.29
		0.3287	0.0591			BT	2280			
	Mid 1/3	0.1280	0.0177			BM	2280			
	Bot. 1/3	0.0000	0.0000							

Full Thickness Averages of All Three Sections

Avg. CSR ·	0.96	Std. Dev. =	0.48
Avg CLR =	11.59	Std. Dev. =	3.98
Avg. CTR =	16.07	Std. Dev. =	4.88

2/3 Thickness Averages of All Three Sections

Avg CSR :	0.96	Std. Dev. =	0.53
Avg. CLR =	11.59	Std. Dev. =	4.08
Avg. CTR :	16.07	Std. Dev. =	4.78

1/3 Thickness Averages of All Three Sections

Avg. CSR ·	0.87	Std Dev. =	0.61
Avg. CLR =	7.69	Std. Dev. =	4.66
Avg. CTR :	14.46	Std Dev. =	4.05

Crack Location Codes

B - Base Metal
H1 - Heat Affected Zone 1
H2 - Heat Affected Zone 2
W - Weld
WC - Weld Cap
WR - Weld Root
S - Surface
T - Tension
M - Middle
C - Compression

Comments

- Weld metal LT section
- 24 day test
- No pre-exposure
- 6W-7B contains LHI welds

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284-87

Sponsor : API/MPC
Material : A516 Grade 70
Window # : 6
Condition : Normalized

Solution : NACE TM0177
Exposure : One-sided
pH (INIT) : 2.7
pH (FINL) : 3.7

Project # : L922238TK
CLI : 2280
Section : 8A, 8B, 8C
File # : 6W8ABC.WK1
Date : 9/1/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	CSR (%)	Section CLR (%)	CTR (%)
W6-8A	Top 1/3	0.0413	0.0354	2.500	0.490	BS/BT	0.72	10.63	28.92
		0.0256	0.0177			BS/BT			
		0.0689	0.0394			BS/BT			
		0.0295	0.0098			BS/BT			
		0.1004	0.0394			BS/BT			
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
W6-8B	Top 1/3	0.0374	0.0118	2.500	0.490	BS/BT/BS	4.72	40.87	29.33
		0.0669	0.0197			BS/BT/BS			
	Mid 1/3	0.1535	0.0354			BM			
		0.7126	0.0709			BM			
		0.0138	0.0020			BM			
		0.0374	0.0039			BM			
	Bot. 1/3	0.0000	0.0000						
W6-8C	Top 1/3	0.3740	0.1240	2.500	0.490	BS/BT	4.02	28.11	38.16
		0.0492	0.0197			BS/BT/BS			
	Mid 1/3	0.0315	0.0020			BM			
		0.0374	0.0197			BM			
		0.0118	0.0020			BM			
		0.0236	0.0039			BM			
		0.1516	0.0059			BM			
		0.0157	0.0079			BM			
		0.0079	0.0020			BM			
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	3.16	Std. Dev. =	1.08
Avg. CLR =	26.54	Std. Dev. =	6.11
Avg. CTR =	32.14	Std. Dev. =	5.68

2/3 Thickness Averages of All Three Sections

Avg. CSR =	3.16	Std. Dev. =	1.14
Avg. CLR =	26.54	Std. Dev. =	6.40
Avg. CTR =	32.14	Std. Dev. =	5.85

1/3 Thickness Averages of All Three Sections

Avg. CSR =	1.58	Std. Dev. =	1.16
Avg. CLR =	10.58	Std. Dev. =	4.14
Avg. CTR =	21.56	Std. Dev. =	6.77

Crack Location Codes

B-Base Metal
H1-Heat Affected Zone 1
H2-Heat Affected Zone 2
W-Weld
WC-Weld Cap
WR-Weld Root
S-Surface
T-Tension
M-Middle
C-Compression

Comments

- Base metal LT section
- 24 day test
- No pre-exposure

Data Analysis For API / MPC Full Scale Hydrogen Induced Cracking Test Per NACE TM0284–87

Sponsor : API/MPC
Material : A841
Window # : 6
Condition : Normalized

Solution : NACE TM0177
Exposure : One–sided
pH (INIT) : 2.7
pH (FINL) : 3.7

Project # : L922238TK
CLI : 3250
Section : 9A, 9B, 9C
File # : 6W9ABC.WK1
Date : 9/1/93

Section	Top 1/3, Mid 1/3, or Bot. 1/3	Crack Length A (in)	Crack Thickness B (in)	Specimen Width W (in)	Specimen Thickness T (in)	Crack Location	Section CSR (%)	Section CLR (%)	Section CTR (%)
W6–9A	Top 1/3	0.0000	0.0000	2.500	0.480		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
W6–9B	Top 1/3	0.0000	0.0000	2.500	0.480		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						
W6–9C	Top 1/3	0.0000	0.0000	2.500	0.480		0.00	0.00	0.00
	Mid 1/3	0.0000	0.0000						
	Bot. 1/3	0.0000	0.0000						

Full Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

2/3 Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

1/3 Thickness Averages of All Three Sections

Avg. CSR =	0.00	Std. Dev. =	0.00
Avg. CLR =	0.00	Std. Dev. =	0.00
Avg. CTR =	0.00	Std. Dev. =	0.00

Crack Location Codes

B–Base Metal
H1–Heat Affected Zone 1
H2–Heat Affected Zone 2
W–Weld
WC–Weld Cap
WR–Weld Root
S–Surface
T–Tension
M–Middle
C–Compression

Comments

– Base metal LT section
– 24 day test
– No pre–exposure

MANUAL ULTRASONIC EXAMINATION RECORD

UT DATA SHEET # 01-02
REF UT CAL SHEET # B04
TEST DATE 5/27/93

TEST ITEM	Bullet Nozzle Plate scan 4		
THICKNESS NEAR .520	FAR .520	WELD ID	Ni-W6 A_1-A_2
UT MACHINE Epoch 2002	S/N	COUPLANT	Ultragel II
PROBE MFGR KBA	MODEL QC	CABLE	RG 174 @ 6'
FREQUENCY 5 MHz	SIZE .25" S/N A65098	TEMPERATURE	Ambient
PROBE ANGLE, NOMINAL/ACTUAL	45° / 45°	MATERIAL CS	VEL. .1280
PROCEDURE	REV	SURFACE PREP.	Wire brushed
CAL BLOCK DNV.75	S/N S2001791	PROCEDURE DATE	
REF BLOCK N/A	S/N N/A	REFERENCE dB	45.7
CALIBRATION REFLECTOR	1/16" Nom. SDH		
REFERENCE POINT	12 o'clock position on all nozzles		
CODE/STANDARD	ASME V		

IND #	ECHO MAX dB	MPD (in)	SURFACE (in)	DEPTH (in)	Y-DIST (in)	X-MAX (in)	X-STRT (in)	LENGTH (in)	COMMENT
N-1 1	+3.4	0.89	0.69	0.35	0.75	0.5	0.25	0.75	Midwall (Not PWHT)
2	+6.9	1.06	0.75	0.29	0.7	3.375	3	0.6	Midwall (Not PWHT)
3	+4.8	0.55	0.39	0.39	0.4	4	3.9	0.25	Midwall (Not PWHT)
4	+8.6	1.11	0.78	0.26	0.6	4.5	4.4	0.45	Midwall (Not PWHT)
5	+10	0.72	0.51	0.51	0.5	5.4	5.2	0.5	ID connected (Not PWHT) TWD .05
6	+10	0.73	0.51	0.51	0.65	7	6.8	0.7	Intermittent (Not PWHT)
N-2 1	+10	0.71	0.5	0.5	0.55	0.5	0.2	0.4	ID connected (PWHT)
2	+5.9	0.75	0.53	0.51	0.55	3.4	3.2	0.8	ID connected (PWHT) TWD .07 (restrict crown weld)
3	+10	1	0.7	0.34	0.55	5.7	5.6	0.8	Midwall (PWHT)
4	+8	0.82	0.61	0.43	0.45	5.9	5.95	0.6	Multiple ind. intermittent (PWHT)
5	+6	0.75	0.53	0.51	0.7	7	6.9	0.8	ID connected (PWHT)

N-3	1	+12	0.74	0.53	0.51	0.6	1.1	0.95	0.65	Intermittent (PWHT)
	2	+10	0.69	0.49	0.49	0.55	3.25	3.25	0.5	ID connected (PWHT)
	3	+8	0.79	0.56	0.48	0.6	6.6	6.45	0.6	ID connected (Not PWHT)
	4	+8	0.76	0.54	0.50	0.55	7.2	7	0.75	Int. two Ind. ID connected (Not PWHT)
N-4	1	+4	1.15	0.81	0.23	0.7	0	0	0.4	Midwall (PWHT)
	2	+7.2	1.16	0.82	0.22	0.8	1.5	1.5	0.2	Midwall (PWHT)
	3	+10	0.75	0.53	0.51	0.55	4.1	4	0.35	ID connected (PWHT)
	4	+9.6	0.7	0.49	0.49	0.45	5.5	5.5	0.65	ID connected (Not PWHT)
	5	+7	0.73	0.51	0.51	0.55	7.35	7.35	0.45	ID connected (Not PWHT)
	6								1.7	Intermittent
	7	+6	0.89	0.63	0.41	0.45	10.5	10.4	0.35	Midwall (PWHT)
	8	+3	1.16	0.82	0.22	0.75	13.2	12.9	0.5	Midwall - multiple (PWHT)
N-5	1	+7	0.73	0.51	0.51	0.55	1	0.8	0.4	ID connected (PWHT)
	2	+3	0.71	0.5	0.5	0.55	2.5	2.4	0.6	Intermittent ID connected (PWHT)
	3	0	0.75	0.53	0.51	0.7	3.5	3.4	4.75	Int multiple ranges from ID to midwall (PWHT)
	4	+13.5	0.79	0.56	0.48	0.55	7.5	7.1	0.5	ID connected (PWHT) TWD .05
N-6	1	+9	0.79	0.55	0.49	0.55	3.7	3.65	0.2	ID connected (Not PWHT)
	2	+9	1.09	0.77	0.27	0.6	4.25	4.25	0.25	Midwall (Not PWHT)
	3	+6	0.73	0.51	0.51	0.75	5.7	5.45	0.25	ID connected (Not PWHT) TWD .05
	4	+11	0.65	0.46	0.46	0.75	0	7.45	0.5	ID connected (Not PWHT) TWD .05

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