DEPARTMENT OF THE NAVY
NAVAL RESEARCH LABORATORY
WASHINGTON, D.C. 20375

IN REPLY REFER TO:

11 June 1985

Mr. Charles E. Smith
Minerals Management Service
647 National Center
Reston, VA 22091

Dear Charles:

Enclosed is a progress report on stress-corrosion cracking tests conducted on materials provided to NRL by Chevron. You can expect to receive a final report on this task by the end of FY-85.

Regarding additonal work underway at NRL under MMS sponsorship, Joe Hauser and I are continuing follow-up tests here in Washington on materials provided by Conoco which were originally tested at Key West and reported upon a year ago. However, a final report on these follow-up Conoco tests may be as much as a year away. Basically, with both the Conoco and Chevron materials, we want to be very sure of their long-term behavior before giving them a clean bill of health for offshore applications.

A preliminary paper on the ripple-loading studies has been accepted by the ASME for presentation at a symposium in Bal Horbor, Florida next December and also for publication in the ASME Journal of Engineering Materials and Technology. In addition, Joe has been invited to offer an overview presentation on marine stress-corrosion cracking in high-strength steels at the 1986 Offshore Mechanics and Arctic Engineering Conference in New Orleans next February.

For FY-86, I am hopeful of receiving new funding on the ripple-loading problem from both ONR and the Coast Guard. Conoco has provided a large sample of Hutton Platform steel for the ripple-loading studies. If your organization could continue to provide some support for this study, which was originated solely under MMS sponsorship, I am confident that we would be in a position to develop both a basic understanding of the problem and its full engineering significance.

I shall be in contact with you soon. If you have any questions, please contact me at any time.

Sincerely,

Tom

Thomas W. Crooker
Material Science and Technology Division
Code 6384

Letter Report

Stress-Corrosion Cracking Test Results on Nine Low-Alloy Steels in Natural Seawater

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Introduction

The use of high-strength steels in tendons for tension leg platforms (TLP's) raises questions concerning the possibility of stress-corrosion cracking (SCC) occurring in service over long periods of time [1]. SCC is a type of cracking which can develop slowly in many high-strength steels in seawater under the combined action of sustained tensile stress, which TLP tendons will experience, and exposure to a corrosive environment, which TLP tendons may suffer if corrosion protection systems deteriorate in service. If allowed to progress unchecked, SCC can lead to catastrophic failure of a tendon.

Many low-strength and intermediate-strength structural steels are considered to be virtually immune to SCC in seawater, and thus the problem is safely ignored for most conventional offshore structures. However, experience has shown that immunity, or sensitivity, to SCC in seawater is strongly dependent on material yield strength. Sensitivity to SCC increases with increasing yield strength. Previous studies have shown that SCC in seawater can occur in wrought steels at yield strength levels as low as 100 ksi and in weld metals at yield strength levels as low as 80 ksi [2]. Thus, based on past studies conducted for military applications, it was considered prudent to examine the SCC sensitivity of candidate steels for TLP tendon applications. TLP tendon materials will enter service without the benefit of prior experience in similar marine applications.

Materials

This report presents results from the second phase of a continuing investigation on the SCC characteristics of candidate materials for TLP tendon applications. In this phase of the work, nine samples of low-alloy steels provided by the Chevron Corporation were studied. The data presented in Tables I through III provide details on the materials.

In summary, the materials studied are representative of the types of steels that would be used in a welded three-piece TLP tendon comprised of a rolled-and-welded tubular member welded to forged-and-threaded ends. Each of the various types of rolled plate, forging and welds are represented in the nine materials studied.

Experimental Procedures

The SCC studies employed in this investigation consisted of fracture mechanics tests conducted using precracked specimens following established procedures [3,4]. All tests were performed in fresh flowing natural seawater at NRL's Marine Corrosion Research Laboratory located at Key West, Florida.

The test specimens used were 1-inch thick constant-displacement bolt-loaded wedge-opening-loaded (WOL) type, with overall dimensions conforming to the 1T configuration, Figure 1. Duplicate specimens of each material were tested. This report covers the results of one specimen of each pair tested, the remaining specimen of each pair remains in test at Key West at this time. The duration of testing for the specimens reported here was 8,000 hours (333 days). An approximate one-year testing duration is considered to be desirable for SCC investigations on low-alloy steels of the yield strength range studied here.

Specimen blanks were received by NRL from Chevron. Machining and precracking was performed by NRL. After final machining, the specimens were fatigue precracked in an ambient laboratory air environment at a maximum crack-tip stress-intensity factor (K_I) of 40 ksi$\sqrt{\text{in}}$. The crack length-to-width (a/W) values after precracking were approximately 0.50.

The test specimens were bolt-loaded at the Key West field site while the crack-tip region of each specimen was exposed to the seawater environment. Internally strain-gaged bolts were used so that long-term changes in load values could be monitored remotely. Initial K_I values were approximately 100 ksi√in. for the specimens reported here. The remaining specimens still under test at Key West were loaded to initial K_I values of 110 ksi√in. These initial K_I values were determined from crack-mouth-opening-displacement data obtained from clip-gages applied to each specimen during loading. This is considered to be a more accurate method of measuring initial K_I values than using load values obtained from the strain-gaged bolts.

For long-term test purposes, the specimens were placed in polyethylene reservoirs through which the natural seawater flowed in a single-pass once-through mode. In the reservoirs, two zinc anodes were connected to each specimen, one on each side of the crack. The zinc anodes provided a cathodic protection potential of approximately -1.03 V versus the Ag/AgCl reference electrode. (By the termination of the test duration, the potential had dropped to approximately -0.99 V.) Zinc anodes, rather than an impressed current potentiostat, were chosen for long-term test purposes because the Key West field site is subject to power outages which would disrupt an impressed-current system. The temperature of the seawater was uncontrolled and varied from approximately 70 to 80 deg. F over the duration of the tests. The use of fresh flowing seawater assured that the test solution was fully oxygenated at all times.

Strain-gage readings from the loading bolts were taken daily to monitor any long-term load changes. Load reductions over time are indicative of either stress relaxation or SCC crack growth. Upon completion of exposure testing at Key West, the specimens were returned to NRL, unloaded and subsequently broken open to reveal the fracture surfaces for visual evidence of SCC crack growth.

Results

None of the nine test specimens in this investigation showed evidence of SCC. There was no visual evidence of SCC crack growth on the specimen surfaces revealed by breaking them open after exposure at Key West for more than 8,000 hours, and no evidence of load reduction over time which would be indicative of crack growth.

Additional verification of these results will be sought upon completion of ongoing tests on companion specimens. These remaining tests will be completed and reported upon by 30 September 1985.

Conclusion

Each of the low-alloy steels studied in this investigation showed no evidence of susceptibility to seawater stress-corrosion cracking (SCC) using conventional fracture mechanics test procedures and simulated cathodic protection involving zinc coupling. These results suggest that stress-corrosion cracking under purely static loading is not likely to be a significant factor in structural applications for these steels involving marine environments and cathodic protection.

Acknowledgments

Funding for this investigation was provided by the United States Coast Guard and the Minerals Management Service of the Department of the Interior. Test materials were provided by the Chevron Corporation.

References

[1] T. W. Crooker and J. A. Hauser II, "Assessment Criteria for Environmental Cracking of High-Strength Steels in Seawater," NRL Memorandum Report 5035, March 18, 1983.

[2] Clive S. Carter, "Stress-Corrosion Cracking and Corrosion Fatigue of Medium-Strength and High-Strength Steels," DARPA Handbook on Stress-Corrosion Cracking and Corrosion Fatigue.

[3] "Characterization of Environmentally Assisted Cracking for Design: State of the Art," National Materials Advisory Board, Publication NMAB-386, National Academy Press, Washington, D. C., 1982.

[4] J. A. Hauser II, R. W. Judy, Jr. and T. W. Crooker, "Draft Standard Method of Test for Plane-Strain Stress-Corrosion-Cracking Resistance of Metallic Materials in Marine Environments," NRL Memorandum Report 5295, March 22, 1984.

TABLE I

IDENTIFICATION OF SOCAL K_{ISCC} SPECIMENS

Sample I.D.	Material	Condition	No. of Samples
A	2¼Cr1Mo, JSW	Q & T	4
C	U-80 plate, Summitomo	Q & T	4
D	U-80 longseam weldmetal, Summitomo	Q & T	4
E	U-80 plate, NKK	Q & T	4
F	U-80 longseam weldmetal, NKK	Q & T	4
G	U-80 plate, Kawasaki	Q & T	4
H	U-80 longseam weldmetal, Kawasaki	Q & T	4
I	Weldmetal, NKK U-80 to JSW 2¼Cr1Mo	PWHT	3
J	Weldmetal, Kaw. U-80 to Kaw. 2¼Cr1Mo	PWHT	3

TABLE II

CHEMISTRY AND MECHANICAL PROPERTIES

	Chemistry									Heat Treatment		Mechanical Properties			
Sample	C	Mn	Si	P	S	Ni	Cr	Mo	Other	Austenitize	Temper	Yield (ksi)	UTS (ksi)	El (%)	CVN ft-lbs, -5°F
A	.13	0.53	0.06	.007	.013	0.17	2.42	0.99	--	1706°F 5 hr., WQ	1160°F 5 hr., AC	92.3	119.0	20	--
C	.12	1.24	0.31	.008	.001	0.86	0.29	0.20	--	1710°F ½ hr., WQ	1150°F 1 hr.	101	115	23	--
D										1710°F ½ hr., WQ	1150°F 1 hr.	--	99.9	--	--
E	.12	1.46	0.25	.018	.002	0.13	0.07	0.11	0.045V	1680°F WQ	1264°F 20 min.	89	99	26	230
F	.11	1.22	0.18	.017	.004	1.73	0.34	0.07	--	1680°F WQ	1264°F 20 min.	88	98	25	126
G	.10	0.83	0.26	.007	.001	1.18	0.50	0.45	--	(?) WQ	1256°F 1 hr.	87.8	101.3	27	215
H	.05	1.27	--	--	--	2.22	0.66	0.40	--	(?) WQ	1256°F 1 hr.	81	100	29	125
I	.12	--	--	--	--	0.6	0.8	0.6	--	None	1150°F 5 hr., AC	90.1	96.0	27	100
J	--	--	--	--	--	1.2	1.5	0.7	--	None	1200°F 1 hr.	88	102.5	27	90

TABLE III

WELDING PARAMETERS

Sample	Welding Process	Joint Design	Filler Metal		Preheat (min.)	Interpass (max.)	Heat Input
D	SAW	Double Bevel	?		?	?	?
F	DSAW	Double Bevel	Kobe USO52 (.9Mn-.3Ni-1.0Cr) Kobe US72 (1.5Mn-.5Mo-.03V)		?	?	60 KJ/in
H	SAW	Double Bevel	1.0Ni 0.5Cr 0.4Mo	3/16" Φ	250°F	350°F	45 KJ/in
I	SMAW-Root SAW-Fill	Double Bevel	E8018-Cl EF1	5/32" Φ 3/32" Φ	350°F 350°F	700°F 700°F	34 KJ/in 36 KJ/in
J	SAW	Double Bevel	2.0Ni 0.5Cr 0.4Mo	3/16" Φ	300°F	400°F	100 KJ/in

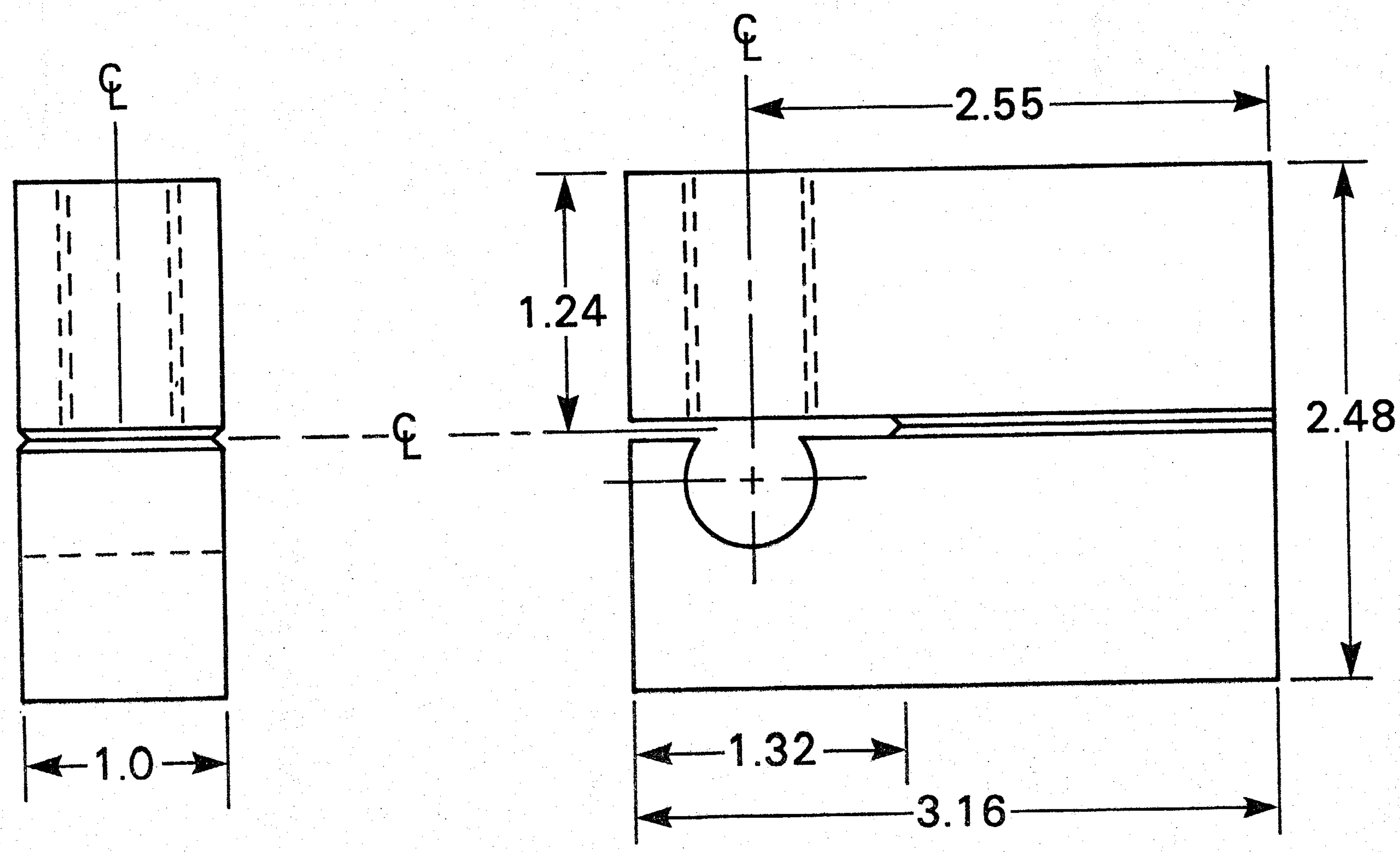

Figure 1 - Configuration of the 1T WOL fracture mechanics test specimen.