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

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Department of the Interior
Minerals Management Service
Attention: Mr. Charles E. Smith (LMS-Mail Stop 647)
Reston, VA 22092

Re: Assessment Criteria for Environmental Cracking of High-Strength Tension Members

Gentlemen:

Enclosed is a Progress Report on Stress-Corrosion Cracking Test Results on Four High-Strength Steels in Natural Sea Water. If additional information is required, please contact Mr. T. W. Crooker, 202/767/2947.

Sincerely yours,

B. B. Rath

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Acting Superintendent, Material Science and Technology Division
By direction of the Commanding Officer

LETTER REPORT

STRESS-CORROSION CRACKING TEST RESULTS ON FOUR HIGH-STRENGTH STEELS IN NATURAL SEA WATER

J. A. Hauser II and T. W. Crooker
Material Science and Technology Division
Code 6384
Naval Research Laboratory
Washington, DC 20375

INTRODUCTION

The use of high-strength steels (σ_{ys} > 100 ksi) in tension members of 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 is known to occur slowly in many high-strength steels in sea water under the combined action of sustained tensile stress, which TLP legs will experience, and exposure to a corrosive environment, which TLP legs may suffer if corrosion protection systems break down in service. If allowed to progress unchecked, SCC can lead to catastrophic failure of a tension member.

Many conventional, low-to-moderate strength structural steels are considered to be immune to SCC in sea water, and thus the problem is ignored for most conventional offshore platforms. However, experience has shown that immunity, or sensitivity, to SCC in sea water is a function of yield strength level. Previous Navy research has indicated that many steels in the 100 to 130 ksi yield strength range, such as those under consideration for TLP leg construction, exhibit some degree of sensitivity to SCC [2]. Based upon this Navy experience, it was considered prudent to study the SCC sensitivity of high-stength steels which may be used in TLP legs. These materials will enter service without the benefits of prior experience gained in marine applications.

MATERIALS

For this initial phase of investigation on SCC in materials for TLP leg construction, four steels were chosen for study. Two steels were provided by Conoco Inc. and are representative of materials being used in the legs of the Hutton TLP, which is being deployed in the North Sea. Two additional steels, HY-100 and HY-130, were provided by the Navy and are representative of materials under consideration for naval construction. The Navy steels were included for purposes of comparison. Chemical compositions of the four steels are given in Table 1 and tensile properties are provided in Table 2. The two steels provided by Conoco Inc. are distinguished by the supplier which manufactured them and are designated "Conoco B" and "Conoco J", accordingly.

The data in Tables 1 and 2 show that the four steels are very similar in terms of chemical compositions and tensile properties, and that the two Navy steels essentially bracket the two Conoco steels.

Table 1 - Chemical Compositions

Material	C	Si	Mn	P	S	Ni	Cr	Mo	V	N	Sn	Cu
	Element (weight percent)											
Conoco B	0.29 max	0.05 max	0.39 max	0.008 max	0.004 max	3.54-3.61	1.46-1.52	0.48-0.54	0.13 max	0.004 max	0.007 max	-
Conoco J	0.27 max	0.06 max	0.24 max	0.006 max	0.002 max	3.66-3.84	1.79-1.85	0.39-0.42	0.13 max	0.004 max	0.006 max	-
HY-100	0.16	0.23	0.25	0.009	0.013	2.94	1.59	0.43	0.005	-	-	0.05
HY-130	0.13	0.24	0.82	-	0.002	5.20	0.44	0.52	0.05	-	-	0.05

Table 2 - Tensile Properties

Material	0.2% yield strength (ksi)	Ultimate tensile strength (ksi)	reduction in area (%)	elongation (%)
Conoco B	121	139	67	23
Conoco J	125	141	72	24
HY-100	108	124	-	21
HY-130	136	143	-	20

EXPERIMENTAL PROCEDURES

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

The test specimens used were 2-inch thick constant-displacement bolt-loaded wedge-opening-loaded (WOL) type, with overall dimensions conforming to the 2T configuration, Figure 1. Duplicate specimens of each material were tested. The duration of testing was 368 days (8,800 hours). A one-year duration is considered to be the minimum acceptable for this type of SCC investigtion.

After final machining, the specimens were fatigue precracked in an ambient laboratory air environment at a maximum crack-tip stress-intensity factor of 40 ksi$\sqrt{in}$. The crack length-to-width (a/W) values after precracking for each specimen are given in Table 3.

The specimens were loaded at the Key West site while the crack-tip region of each specimen was exposed to the sea water environment. Internally strain-gaged bolts were used so that long-term changes in load values could be monitored. Initial stress-intensity factors (K_{Ii}) and corresponding bolt loads (P_i) for each specimen are also given in Table 3. However, the K_{Ii} values in Table 3 were determined from crack-mouth-opening-displacement (CMOD) values obtained from clip-gages applied to each specimen during loading. This is considered to be a more accurate method of measuring K_{Ii} values than using load values obtained from the strain-gaged bolts.

Table 3 - Initial Conditions

Specimen No.	$\frac{a}{W}$	K_{Ii} (ksi$\sqrt{in}$)	P_i (kips)
HY-130-1	0.47	110	47
HY-130-2	0.46	95	42
HY-100-1	0.53	109	40
HY-100-2	0.49	110	44
B-1	0.47	105	45
B-2	0.52	101	38
J-1	0.50	103	41
J-2	0.48	101	42

For long-term test purposes, the specimens were placed in polyethylene reservoirs through which the natural sea water flowed in a single-pass mode. In the reservoirs, two zinc anodes were connected to each specimen, one on each side of the crack. The zinc anodes simulated the effects of cathodic protection and provided polarization potentials of approximately -1.03 V versus a Ag/AgCl reference electrode. (By the termination of the tests, the potentials had dropped to approximately -0.990 V.) Zinc anodes, rather than a potentiostat, were chosen for long-term test purposes because the Key West site is subject to power outages which would disrupt an impressed current system. The temperature of the sea water was uncontrolled and varied from 72 to 84°F due to seasonal changes over the duration of the tests.

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 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. A representative photograph of one of the fracture surfaces is shown in Figure 2.

RESULTS

None of the eight specimens in this investigation showed evidence of SCC. Looking at the fracture surface photograph, Figure 2, several distinct areas can be seen: (1) machined notch, (2) fatigue precrack, and (3) post-test fracture. If SCC had occurred, there would be visible evidence of a distinctly different area of crack growth between the fatigue precrack and the post-test fracture areas. None was evident on any of the eight specimens.

The record of strain-gaged bolt readings also confirms an absence of SCC cracking. Only one of the bolts showed a significant decrease in load readings over the one-year duration of the tests. However, this is thought to be the result of strain gage failure in the form of debonding between the gage and the inner surface of the bolt.

DISCUSSION

The results of these tests are favorable for the use of Conoco's 3-1/2 Ni-Cr-Mo-V steels in TLP leg construction [5]. However, it would be worthwhile to put these results into prespective.

The absence of SCC crack initiation and growth in this investigation does not necessarily prove that any of these four steels are totally immune to SCC, since SCC in HY-130 and HY-100 baseplate materials coupled to zinc in salt water been observed by previous investigators [2]. Rather, the safest conclusion to draw from these results is that SCC may be possible in any of these steels, but that SCC crack initiation may require higher K_{Ii} levels and/or longer exposure times.

The K_{Ii} levels used in this investigation, approximately 110 ksi $\sqrt{in.}$, can be interpreted in terms of flaw sizes and stress levels for large tubular members as shown in Figure 3.

CONCLUSION

Each of the four steels studied in this investigation has a high resistance to stress-corrosion cracking (SCC) in natural sea water. No evidence of SCC was found in any of the eight specimens tested to durations of 8,800 hours. These results suggest that the steels studied in this investigation are not likely to be susceptible to environmental cracking under purely static loads.

ACKOWLEDGMENTS

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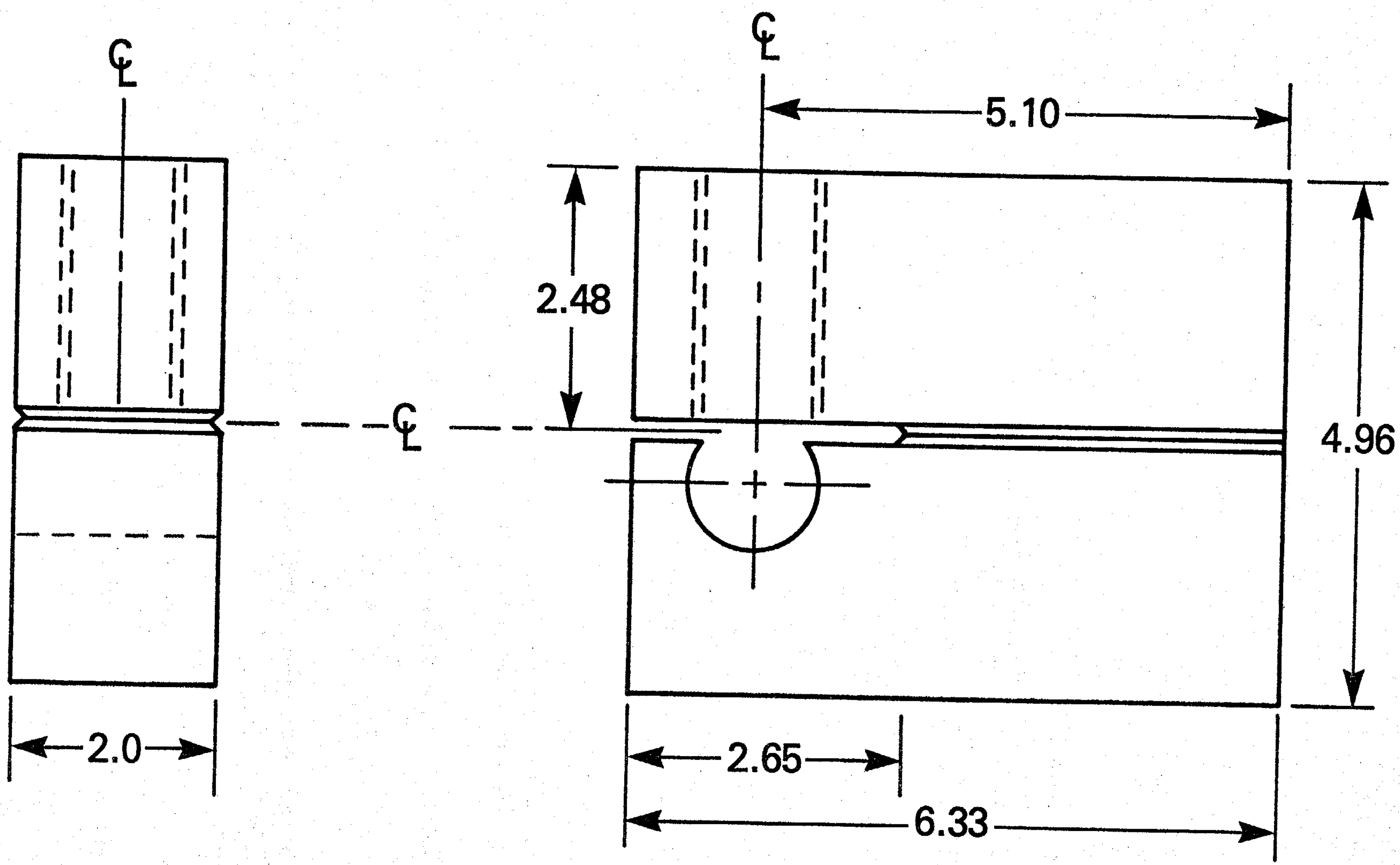

Figure 1 - Configuration and dimensions of the 2T bolt-loaded wedge-opening-loaded (WOL) fracture mechanics specimen used for stress-corrosion cracking tests. Dimensions are in inches.

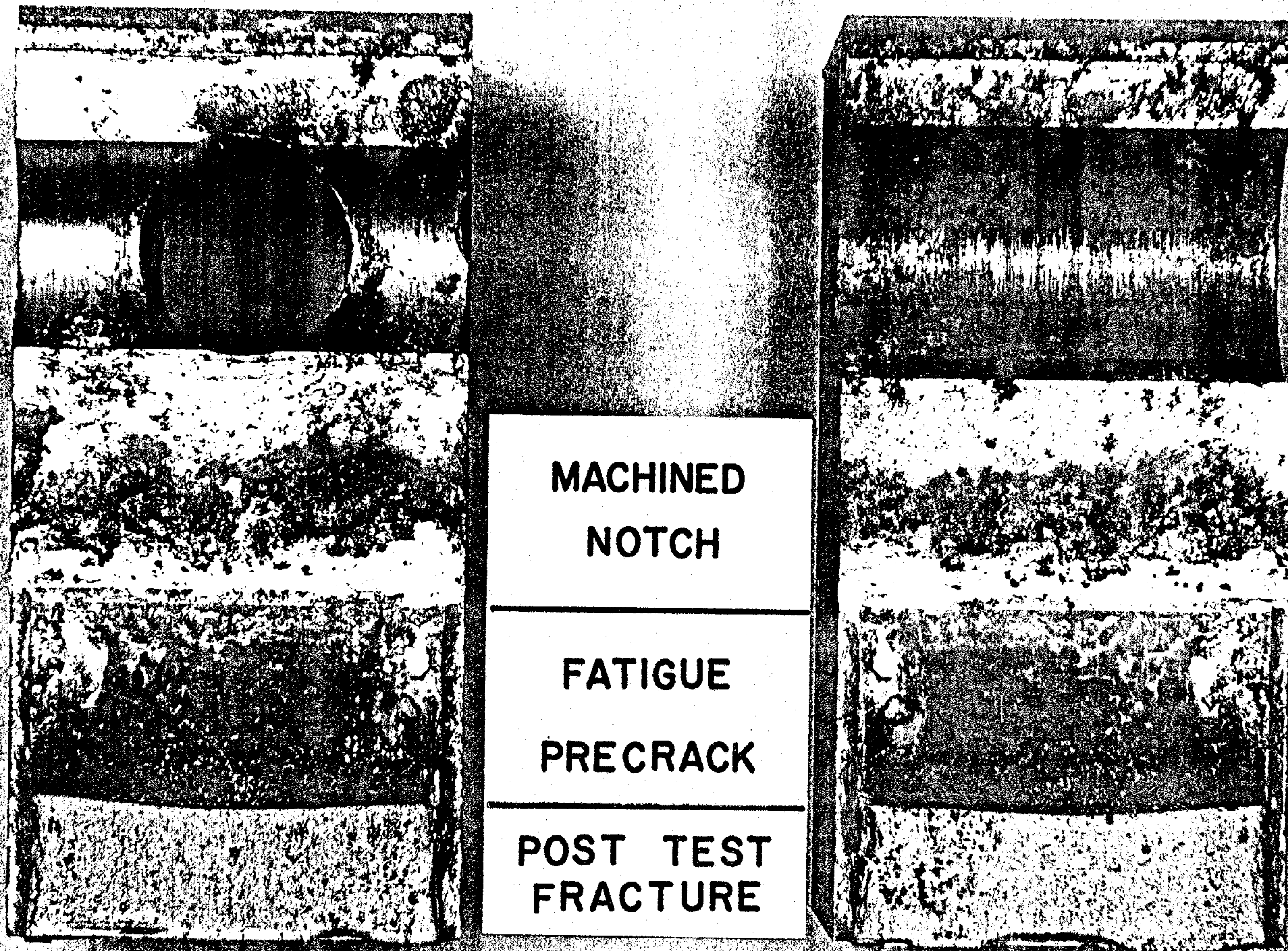

Figure 2 - Post-test fracture surface of a WOL specimen tested in this investigation. Note the absence of any region of stress-corrosion crack growth between the corroded fatigue precrack area and the overload fracture surface created by breaking the specimen open after testing in sea water.

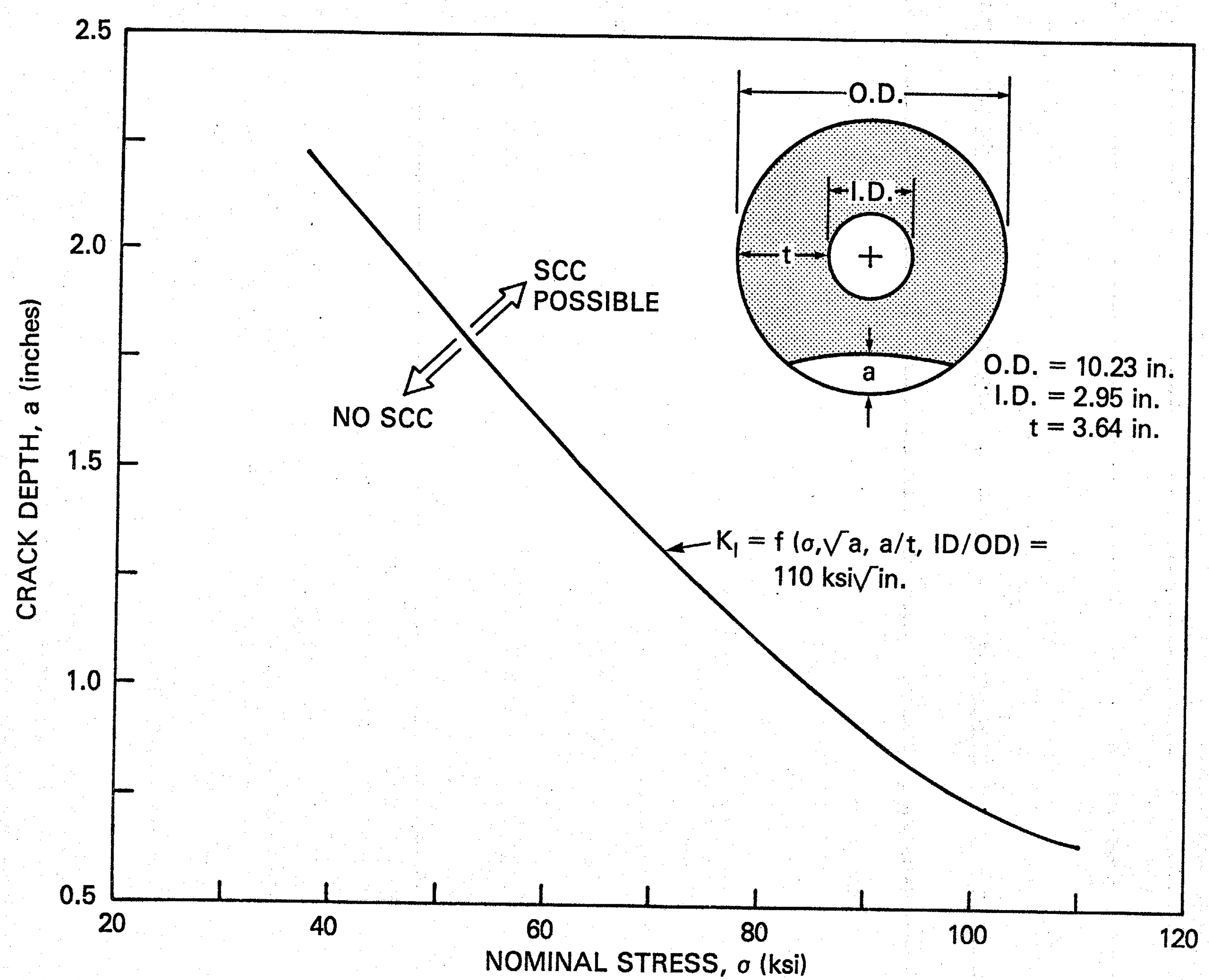

Figure 3 - Crack depth versus stress level relationship for possible stress-corrosion cracking threshold conditions in thick-walled tension member.