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EVALUATION OF THE STRESS CORROSION CRACKING RESISTANCE OF SEVERAL HIGH STRENGTH LOW ALLOY STEELS

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16. ABSTRACT

A comprehensive investigation of the stress corrosion cracking resistance of high strength alloy steels 4130, 4340, and H-11 at selected strength levels and D6AC and HY140 at a single strength is presented. Round tensile and C-ring type specimens were stressed up to 100 percent of their yield strengths and exposed to alternate immersion in salt water, salt spray, the atmosphere at Marshall Space Flight Center, and the seacoast at Kennedy Space Center. Under the test conditions, 4130 and 4340 steels heat treated to a tensile strength of 1240 MPa (180 ksi), H-11 and D6AC heat treated to a tensile strength of 1450 MPa (210 ksi), and HY140 (1020 MPa, 148 ksi) are resistant to stress corrosion cracking because failures were not encountered at stress levels up to 75 percent of their yield strengths. A maximum exposure period of one month for alternate immersion in salt water or salt spray and three months for seacoast is indicated for alloy steel to avoid false indications of stress corrosion cracking because of failure resulting from severe pitting.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

TECHNICAL MEMORANDUM

EVALUATION OF THE STRESS CORROSION CRACKING RESISTANCE OF SEVERAL HIGH STRENGTH LOW ALLOY STEELS

INTRODUCTION

The requirement for continuing increases in the weight of space payloads makes it imperative that extreme measures be taken to reduce non-payload weight. This dictates that many structural components of space vehicles be fabricated from high strength steels to obtain high strength-to-density ratios. The advent of the Space Shuttle has increased the problem of material selection for aerospace structural designers. Not only have payloads increased significantly, but also the Shuttle is a multi-mission vehicle as opposed to a single mission for previous vehicles. This extension of service life certainly increases the need for material reliability in structural applications. The contribution of stress corrosion cracking (SCC) to service failure of vehicle structures and components is therefore of extreme interest.

This investigation was designed to evaluate the SCC of high strength low alloy steels used or contemplated for use in space vehicles. Some of the high strength low alloy steels that are of interest to the aerospace designers are 4130, 4340, H-11, HY140, and D6AC, and these are the materials evaluated. The testing was accomplished by exposing stressed specimens of the materials to corrosive environments that are representative of, or more severe than, those encountered during the manufacturing, testing, and servicing of space vehicles.

EXPERIMENTAL PROCEDURE

Although not as pronounced as in aluminum alloys, the SCC resistance of alloy steels is affected by the grain orientation. For this reason, tests were conducted in at least two grain directions for all test conditions. Two laboratory exposure media, alternate immersion in 3.5 percent sodium chloride (hereafter called AI) and 5 percent salt spray, were employed in addition to two natural environments, outside exposure at Marshall Space Flight Center (MSFC) and seacoast exposure at Kennedy Space Center (KSC). Round tensile specimens stressed in uniaxial tension and C-rings stressed by constant deflection were used exclusively for test specimens. The C-ring specimen was used only to test the transverse direction of a 1 in. diameter bar of H-11 steel.

All specimens were fabricated and then heat treated according to MIL-H-6875 except for alloys H-11 and D6AC which were supplied in the heat treat condition tested. The specimens were strained or deflected to the desired stresses (40 to 100 percent of the directional 0.2 percent offset yield strengths) which were calculated from measured mechanical properties. The stressing jigs that were exposed to salt water and salt spray were coated with a strippable coating (Mascoat No. 2, Western Coating Company) to protect them from corrosion and to prevent galvanic action between the aluminum jigs and steel specimens. Mascoat No. 2 is not suitable for outside exposure because it cracks and flakes off. For outside exposure, several coats of neoprene rubber cement (MSFC X-94) were applied to the area where the specimen contacts the end caps to combat galvanic corrosion. The specimens were wiped with alcohol and exposed to the selected test media. A detailed description of the test specimens, formulas for calculating deflection and strain, and methods of loading and testing are given in Reference 1.

RESULTS AND DISCUSSION

The compositions of the test alloys are listed in Table 1, and the mechanical properties of the materials in all heat treatments and grain directions tested are given in Table 2. The SCC results in all test media are shown in Tables 3 through 7. These results indicate that the SCC resistance of these alloy steels was affected by the grain direction in which the stress was applied. The short and long transverse directions were the most susceptible and thus these directions should always be tested when evaluating alloy steels.

During the testing phase of this investigation, it was noted that specimens of all test materials suffered severe pitting in all media except MSFC atmosphere. The effect of the pitting is shown in Table 8 where the losses in load carrying ability of the corroded specimens were calculated from the differences in their breaking strengths (breaking loads divided by cross-sectional areas before exposure) and the tensile strengths of the parent materials. There are several ways in which pitting or non-uniform corrosion can interfere with the interpretation of SCC test results. Pitting of tension specimens with relatively small cross sections can significantly reduce the effective cross-sectional areas and produce a net section stress greater than the nominal gross section stress. This can result in SCC of specimens at an actual stress higher than the intended nominal test stress or fracture by mechanical overload of materials that are not susceptible to SCC. This is illustrated in Table 9 and Figures 1 through 6 in which the effect of pitting and exposure time on the type of failure is shown. One method of combatting the problem associated with pitting is to shorten the exposure period as much as possible and still maintain an adequate period for SCC evaluation of materials. This is illustrated in Table 10 in which failures of all test alloys after one month exposure in AI and salt spray and three months to the seacoast are compared with those obtained after longer exposure periods. The results from all three test media are in better agreement for the shorter exposure periods than those obtained with longer exposures. In addition, as discussed previously, the effect of pitting on specimen failure is greatly reduced. A shorter exposure may be beneficial but participation by a group of investigators such as those involved in the Joint Aluminum Association – ASTM G1.06.91 Task Group on Stress Corrosion Testing of Aluminum Alloys [2] will be required to ascertain the optimum exposure time for each test medium and to select a preferred laboratory medium.

4130 and 4340 Steel

Both 4130 and 4340 steels were found to possess high resistance to SCC when heat treated to obtain an ultimate tensile strength below 1240 MPa (180 ksi). This was obtained by tempering the 4130 alloy at 727 to 742 K (850° to 875°F) and the 4340 alloy at 755 to 780 K (900° to 925°F). Materials of both alloys tempered at lower temperatures were susceptible to SCC and, as with most alloys, the susceptibility to SCC increased as the tensile strength increased. This is readily seen by comparing the SCC results of these alloys at various tensile strengths in Tables 3, 4, and 10. Numerous failures were encountered after extended exposure in all three test media, but metallurgical examination revealed that the failures that occurred after extended exposure probably resulted from tensile overload because of the severe pitting. The specimens that failed from SCC are illustrated in Table 9 and Figures 1, 2, and 3. Those that suffered failure primarily from overload are illustrated in Table 9 and Figures 4, 5, and 6. Basing the results on one month instead of three months exposure to AI and salt spray and three months instead of six months exposure to the seacoast eliminates most of the failures that resulted primarily from pitting and gives good comparative results among the three test media.

H-11 and HY140 Steel

Alloy H-11 steel exhibited high resistance to SCC (Table 5) when heat treated to 1450 MPa (210 ksi) and low resistance to SCC when heat treated to a tensile strength of 1650 MPa (240 ksi). The results indicate that HY140 steel (1020 MPa, 148 ksi) is highly resistant to SCC because no failures were encountered in any of the test media even at high stress levels (Table 6).

D6AC Steel

Alloy D6AC exhibited high resistance to SCC when heat treated to 1450 MPa (210 ksi) as indicated in Table 7. Some failures occurred after extended exposure in AI, and metallurgical evaluation indicated that the failures probably resulted from overload because of the extensive pitting (Table 9). Basing the results on one month instead of three months exposure eliminates the failures, and the results are in agreement with those obtained after three years in MSFC atmosphere and two years at the seacoast (Table 10). The severe pitting suffered by D6AC when exposed to AI is illustrated in Table 8 by the high loss in load carrying ability of the specimens after one half to three months exposure.

CONCLUSIONS

The results obtained in this investigation revealed that:

1) The following alloy steels are highly resistant to SCC at the indicated tensile strengths:

a) 4130 and 4340, below 1240 MPa (180 ksi)

b) H-11, 1450 MPa (210 ksi)

c) D6AC, 1450 MPa (210 ksi)

d) HY140, 1020 MPa (148 ksi).

Except for D6AC and HY140 which were tested at the indicated strengths only, the alloys are susceptible to SCC above these tensile strengths, and the susceptibility increases with increasing tensile strength. The results confirm the ratings of the SCC resistance assigned to 4130 and 4340 alloy steels in MSFC-SPEC-522A [3]. Alloys D6AC and H-11 steel are highly resistant to SCC at tensile strengths up to 1450 MPa instead of the 1240 MPa indicated in the specification.

2) It is believed that a maximum exposure of one month for alternate immersion in salt water or salt spray and three months for seacoast should be used for alloy steels because longer exposure periods result in severe, non-uniform corrosion which interferes with the interpretation of SCC test results.

3) Either alternate immersion in salt water or salt spray is an acceptable medium for laboratory SCC testing of high strength low alloy steel.

4) The long and short transverse grain directions are more susceptible to SCC than the longitudinal direction and should be tested in the evaluation of alloy steels.

REFERENCES

1. Humphries, T. S.: Procedures for Externally Loading and Corrosion Testing Stress Corrosion Specimens. NASA TM X-53483, June 1966.

2. Sprowls, D. O., Summerson, T. J., Ugiansky, G. M., Epstein, S. G., and Craig, H. L., Jr.: Evaluation of a Proposed Standard Method of Testing for Susceptibility to Stress-Corrosion Cracking of High-Strength 7XXX Series Aluminum Alloy Products. Stress Corrosion-New Approaches, ASTM STP 610, American Society for Testing and Materials, 1976, pp. 3-31.

3. Marshall Space Flight Center: Design Criteria for Stress Corrosion Cracking. MSFC-SPEC-522A, November 18, 1977.

TABLE 1. CHEMICAL COMPOSITION OF THE TEST ALLOY STEELS

Alloy	Composition-Weight Percent C	Mn	Si	Ni	Cr	Mo	V	P	S
4130-1/4 in. plate	.33	.56	.30	.13	.97	.23	-	.004	.015
4130-4 in. plate	.32	.60	.27	.13	.89	.18	-	.003	.007
4340-2 in. plate	.41	.74	.27	1.95	.80	.25	-	.009	.003
4340-4 in. plate	.38	.72	.31	1.80	.80	.28	-	.008	.007
H-11	.44	.29	.87	-	4.80	1.20	.60	0	.01
D6AC*	.48	.76	.20	.58	1.07	1.00	.07	.008	.004
HY140*	.10	.75	.30	5.00	.55	.55	.06	.01	.01

*Mill analysis

TABLE 2. MECHANICAL PROPERTIES OF THE TEST ALLOY STEELS

Alloy	Form	Grain Direction	Tensile Strength MPa	Tensile Strength ksi	Yield Strength MPa	Yield Strength ksi	Percent Elongation
4130	10.2 cm plate	ST	1380	200	1310	190	6
		LT	1380	200	1300	188	9
		ST	1190	172	1120	162	7
		LT	1210	175	1160	168	9
4130	0.6 cm plate	LT	1430	208	1330	193	13
		LO	1360	197	1250	181	9
		LT	1350	195	1250	181	6
		LO	1240	180	1160	168	11
		LT	1210	175	1150	166	8
4340	10.2 cm plate	ST	1450	210	1380	200	3
		LT	1500	218	1380	200	10
		ST	1370	198	1310	190	8
		LT	1390	201	1310	190	13
		ST	1310	190	1280	185	15
		LT	[illegible]	190	1270	184	13
		LO	1330	193	1310	190	15
		ST	1230	179	1190	173	13
		LT	1240	180	1210	175	16
		LO	1230	179	1210	175	14
4340	5.1 cm plate	ST	1380	200	1310	190	14
		LT	1380	200	1310	190	[illegible]
		LO	1360	197	1290	187	14
		ST	1280	185	1230	179	17
		LT	1280	185	1250	181	[illegible]
		LO	1280	185	1230	179	15
H-11	2.5 cm dia. bar	LO	1650	240	1490	216	13
	0.6 cm plate	LT	1450	210	1230	179	14
D6AC	Motor Cases	LT	1450	210	1350	195	14
		LO	1450	210	1350	195	15
HY140	2.5 cm plate	LT	1020	148	970	140	22
		LO	1020	148	960	139	22

Specimens heat treated according to MIL-H-6875
All properties are an average of three specimens.

TABLE 3. SCC TEST RESULTS OF 4130 STEEL

Stress Direction	Tensile Strength MPa	Tensile Strength ksi	Stress % Y.S.	Environment: AI F/N	AI Days	Salt Spray F/N	Salt Spray Days	Seacoast F/N	Seacoast Days
				10.2 cm THICK PLATE					
ST	1380	200	50	3/3	28,29,45	3/3	26,32,42	5/5	13(3),76,86
			75	3/3	6,7,13	3/3	15,41,53	5/5	5,13,13,49,84
LT	1380	200	50	3/3	36,83,90	3/3	26,35,56	4/5	104,104,112,179
			75	3/3	28,29,41	3/3	41,47,67	5/5	86,86,93,111,147
ST	1190	172	50	2/3	75,83	3/3	46,48,67	1/5	147
			75	3/3	45,83,83	3/3	20,55,67	0/5	
LT	1210	175	50	0/3		1/3	67	0/5	
			75	2/3	69,83	2/3	53,67	0/5	
				0.6 cm THICK PLATE					
LT	1430	208	100	3/3	3,3,3	3/3	9,9,14		
LO	1360	197	75	1/3	90			0/5*	
			100	3/3	37,38,42	3/3	33,33,36	1/5	414*
LT	1350	195	25			1/3	67	0/4	
			50	3/3	13,29,41	3/3	35,46,49	4/4	82,99,103,117
			75	3/3	8,9,29	3/3	26,26,35	4/4	57,57,82,84
			100	3/3	6,7,8				
LO	1240	180	75	0/3				0/5*	
			100	1/3	81	3/3	23,33,44	0/5*	
LT	1210	175	25					0/4	
			50	3/3	64,78,83	3/3	35,43,81	2/4	91,163
			75	3/3	28,36,55	3/3	25,26,36	3/4	92,126,132
			100	3/3	28,29,29	3/3	20,22,26		

F/N Ratio of failures to number of specimens tested.
Total exposure was 3 months for AI and salt spray and 6 months for seacoast except where an asterisk appears in which case the exposure was 14 months.

TABLE 4. SCC TEST RESULTS OF 4340 STEEL

Stress Direction	Tensile Strength MPa	Tensile Strength ksi	Stress % Y.S.	Environment: AI F/N	AI Days	Salt Spray F/N	Salt Spray Days	Seacoast F/N	Seacoast Days
				10.2 cm THICK PLATE					
ST	1450	210	75	2/2	4,5				
			100	2/3	5,7				
LT	1500	218	75	3/3	25,26,40				
			100	3/3	3,5,7	3/3	19,25,59		
ST	1370	198	75	2/3	11,17				
LT	1390	201	100	2/3	25,73	3/3	45,45,52		
ST	1310	190	50	0/3				0/5	
			75	3/5	10,45,57			4/10	5,20,21,273
			100	2/2	4,4			4/5	5,5,36,197
LT	1310	190	75	0/3					
			100	4/6	53-63	2/3	55,62	0/5	
LO	1330	193	100	0/3				0/5	
ST	1230	179	50	0/3				0/5	
			75	0/3				1/10	40
			100					4/5	20,33,36,97
LT	1240	180	100	0/3					
LO	1230	179	100	0/3					
				5.1 cm THICK PLATE					
ST	1380	200	50	0/3				0/5	
			75	0/3				0/4	
LT	1380	200	100	1/3	75			0/5	
LO	1360	197	100	0/3				0/4	
ST	1280	185	50	0/3				0/5	
			75	0/3				0/5	
LT	1280	185	100	0/3				0/5	
LO	1280	185	100	0/3				0/5	

F/N Ratio of failures to number of specimens tested.
Total exposure time was 3 months for AI and salt spray and 14 months for seacoast.

TABLE 5. SCC TEST RESULTS OF H-11 STEEL

Stress Direction	Tensile Strength MPa	Tensile Strength ksi	Stress % Y.S.	Environment: AI F/N	AI Days	MSFC Atm F/N	MSFC Atm Days	Seacoast F/N	Seacoast Days
2.5 cm DIAMETER BAR									
TR	1650	240	25	0/2		0/2			
(C-Ring)			50	2/2	27,29	0/2			
			90	3/3	2,2,2	1/3	167		
LO	1650	240	50	5/5	20-35	0/4			
			90	5/5	7-13	0/4			
0.6 cm THICK PLATE									
LT	1450	210	50					0/5	
			75					1/5	117

F/N Ratio of failures to number of specimens tested.
Total exposure time was 3 months for AI, 6 months for MSFC atmosphere, and 2 years for seacoast.

TABLE 6. SCC TEST RESULTS OF HY140 STEEL

Stress Direction	Tensile Strength MPa	Tensile Strength ksi	Stress % Y.S.	Environment: AI F/N	AI Days	MSFC Atm F/N	MSFC Atm Days	Seacoast F/N	Seacoast Days
LT	1020	148	75	0/3		0/3		0/3	
			100	0/3		0/3		0/3	
LO	1020	148	75	0/3		0/3			
			100	0/3		0/3			

F/N Ratio of failures to number of specimens tested.
Total exposure time was 2 months for AI, 5 years for MSFC atmosphere, and 2 years for seacoast.

TABLE 7. SCC TEST RESULTS OF D6AC STEEL

Stress Direction	Tensile Strength MPa	Tensile Strength ksi	Stress % Y.S.	AI F/N	AI Days	MSFC Atm F/N	MSFC Atm Days	Seacoast F/N	Seacoast Days
			D6AC STEEL - 0.9 cm AND 2.5 cm THICK SECTIONS OF MOTOR CASE						
LT	1450	210	40	0/5					
			45	0/5					
			50	1/8	50	0/3		0/10	
			55	1/5	77				
			60	1/5	86				
			65	3/5	63,67,68				
			75	8/8	41-90	0/3		0/10	
			90			0/3			
LO	1450	210	45	0/5					
			50	0/3		0/3			
			55	1/5	77				
			65	2/5	74,77				
			75	3/3	58,71,86	0/3			

F/N - Ratio of failures to number of specimens tested.
Total exposure time was 3 months for AI, 3 years for MSFC atmosphere, and 2 years for seacoast.

TABLE 8. LOSS IN LOAD CARRYING ABILITY OF ALLOY STEELS

Stress Direction	Tensile Strength MPa	ksi	Stress % Y.S.	AI No. of Spec.	AI Percent Loss	AI Time (Mo)	Seacoast No. of Spec.	Seacoast Percent Loss	Seacoast Time (Mo)
			4130 STEEL - 10.2 cm THICK PLATE						
ST	1190	172	0				3	17	3
			0				3	30	6
			50	1	49	3			
			50,75				4ea	25,33	6
LT	1210	175	0				3	22	3
			0				3	36	6
			50	3	46	3			
			50,75				5ea	38,38	6
			4130 STEEL - 0.6 cm THICK PLATE						
LT	1350	195	25	4	33	3	4	30	6
			75,100				5ea	24,20	14
LT	1210	175	25,50				3ea	34,30	6
LO	1360	197	0				3	17	14
			75	2	41	3			
LO	1240	180	0				3	17	14
			75,100	3ea	38,35	3	5ea	24,23	14
			4340 STEEL - 10.2 cm THICK PLATE						
LT	1390	201	100	1	30	3			
ST	1310	190	0				3	13	14
			50,75	3ea	22,17	3	5ea	21,19	14
			75,100				1ea	15,15	14
LT	1310	190	75	3	30	3			
			100	2	25(20,30)	3	5	18	14
LO	1330	193	100	3	25	3	5	22	14
ST	1230	179	0				2	8	14
			50,75	3ea	21,24	3	5ea	25,24	14
			75,100				4ea	6,10	14
LT	1240	180	100	3	12	3	5	23	14
LO	1230	179	100	3	17(10-20)	3	5	22	14

TABLE 8. (Continued)

	Tensile		Stress	Loss In Load Carrying Ability					
				AI			Seacoast		
Stress Direction	Strength MPa	ksi	% Y.S.	No. of Spec.	Percent Loss*	Time (Mo)	No. of Spec.	Percent Loss*	Time (Mo)
				4340 STEEL - 5.1 cm THICK PLATE					
ST	1380	200	50,75	3ea	25,26	3	5	23,23	14
LT	1380	200	100	2	19	3	5	17(11-25)	14
LO	1360	197	100	3	21	3	5	16	14
ST	1280	185	50,75	3ea	20,20	3	5ea	24,21	14
LT	1280	185	.00	3	18(10-24)	3	5	22	14
LO	1280	185	100	3	16(8-22)	3	5	18	14
				H-11 STEEL - 2.5 cm DIAMETER BAR					
LO	1725	250	0	1	11	1			
				H-11 STEEL - 0.6 cm THICK PLATE					
LT	1450	210	0				3	10	14
			50				4	18	24
			75				4	18	24
				D6AC STEEL - 0.9 cm AND 2.5 cm THICK SECTION OF MOTOR CASE					
LT	1450	210	0	3	10	0.5	3	21	12
			0	5	15	1	2	23	15
			0	5	24	2	2	18(13,23)	24
			0	2	42	3			
			0	2	55 (50,60)	3.5			
			40	5	43 (24-51)	3			
			45	5	40	3			
			50	5	43 (38-51)	3			
			55	5	44	3			
			60	4	36(26-46)	3			
			65	2	30(24,35)	3			
LO	1450	210	0	3	8	0.5			
			0	3	12	1			
			0	3	16	2			
			0	2	44 (36,51)	3.5			
			45	5	44	3			
			50	3	43(37-49)	3.5			
			55	4	31	3			
			65	3	45	3			

TABLE 8. (Concluded)

				Loss In Load Carrying Ability					
	Tensile		Stress	AI			Seacoast		
Stress Direction	Strength MPa	ksi	% Y.S.	No. of Spec.	Percent Loss*	Time (Mo)	No. of Spec.	Percent Loss*	Time (Mo)
				HY140 STEEL - 2.5 cm THICK PLATE					
LT	1020	148	0	3	19	2	3	12	15
			75,90	3ea	16,17	2	3ea	12,10	24
LO	1020	148	0	3	19	2			
			75,90	3ea	18,16	2			

*Where there is a significant difference in the percent loss (10 or greater), the range is shown in parentheses.

TABLE 9. EFFECT OF PITTING AND EXPOSURE TIME ON TYPE OF FAILURE

Sample No.	Tensile Strength MPa	Tensile Strength ksi	Stress Direction	Exposure Media	Days to Failure	Type of Failure	Figure No.
			4130 STEEL - 10.2 cm THICK PLATE				
1	1380	200	ST	AI	6	SCC	2
2	1380	200	ST	AI	7	SCC	-
3	1380	200	ST	KSC	11	SCC	-
4	1190	172	ST	KSC	147	Overload	5
			4130 STEEL - 0.6 cm THICK PLATE				
5	1350	195	LT	AI	13	SCC	3
6	1210	175	LT	AI	28	SCC	-
7	1210	175	LT	SS	25	Overload	6
8	1210	175	LT	KSC	163	Mixed	-
9	1210	175	LT	KSC	91	Overload	4
			4340 STEEL - 10.2 cm THICK PLATE				
10	1500	218	LT	AI	3	SCC	-
11	1500	218	LT	AI	5	SCC	-
12	1310	190	ST	KSC	5	SCC	1
13	1310	190	ST	KSC	20	SCC	-
14	1310	190	ST	KSC	36	Mixed	-
			D6AC STEEL - 2.5 cm THICK SECTION OF MOTOR CASE				
15	1450	210	LT	AI	86	Overload	-

TABLE 10. COMPARISON OF SCC TEST RESULTS OF ALLOY STEELS BASED ON TWO EXPOSURE PERIODS

Stress Direction	Tensile Strength MPa	Tensile Strength ksi	Stress % Y.S.	Ratio of No. of Specimens Failed to No. Exposed: AI 1 Mo	AI 3 Mo	Salt Spray 1 Mo	Salt Spray 3 Mo	Seacoast 3 Mo	Seacoast 14 Mo[1]
4130 STEEL - 10.2 cm THICK PLATE									
ST	1380	200	50	2/3	3/3	1/3	3/3	3/5	5/5[a]
			75	3/3	3/3	1/3	3/3	5/5	5/5[a]
LT	1380	200	50	0/3	3/3	1/3	3/3	0/5	5/5[a]
			75	2/3	3/3	0/3	3/3	2/5	5/5[a]
ST	1190	172	50	0/3	2/3	0/3	3/3	0/5	1/5[a]
			75	0/3	3/3	1/3	3/3	0/5	0/5[a]
LT	1210	175	50	0/3	0/3	0/3	1/3	0/5	0/5[a]
			75	0/3	2/3	0/3	2/3	0/5	0/5[a]
4130 STEEL - 0.6 cm THICK PLATE									
LT	1430	208	100	3/3	3/3	3/3	3/3		
LO	1360	197	75	0/3	1/3			0/5	0/5
			100	0/3	3/3	0/3	3/3	0/5	1/5
LT	1350	195	25			0/3	1/3	0/4	0/4[a]
			50	2/3	3/3	0/3	3/3	1/4	4/4[a]
			75	3/3	3/3	2/3	3/3	4/4	4/4[a]
			100	3/3	3/3				
LO	1240	180	75	0/3	0/3			0/5	0/5
			100	0/3	1/3	0/3	3/3	0/5	0/5
LT	1210	175	25					0/4	0/4[a]
			50	0/3	3/3	0/3	3/3	0/4	2/4[a]
			75	1/3	3/3	2/3	3/3	0/4	3/4[a]
			100	3/3	3/3	3/3	3/3		
4340 STEEL - 10.2 cm THICK PLATE									
ST	1450	210	75	2/2	2/2				
			100	2/3	2/3				
LT	1500	218	75	2/3	3/3				
			100	3/3	3/3	2/3	3/3		
ST	1370	198	75	2/3	2/3				
LT	1390	201	100	1/3	2/3	0/3	3/3		

TABLE 10. (Concluded)

Stress Direction	Tensile Strength MPa	Tensile Strength ksi	Stress % Y.S.	Ratio of No. of Specimens Failed to No. Exposed: AI 1 Mo	AI 3 Mo	Salt Spray 1 Mo	Salt Spray 3 Mo	Seacoast(1) 3 Mo	Seacoast(1) 14 Mo
				4340 STEEL - 10.2 cm THICK PLATE					
ST	1310	190	50	0/3	0/3			0/5	0/5
			75	1/5	3/5			3/10	4/10
			100	2/2	2/2			3/5	4/5
LT	1310	190	75	0/3	0/3				
			100	0/6	4/6	0/3	2/3	0/5	0/5
LO	1330	193	100	0/3	0/3			0/5	0/5
ST	1230	179	50	0/3	0/3			0/5	0/5
			75	0/3	0/3			1/10	1/10
			100					3/5	4/5
LT	1240	180	100	0/3	0/3				
LO	1230	179	100	0/3	0/3				
				4340 STEEL - 5.1 cm THICK PLATE					
ST	1380	200	50	0/3	0/3			0/5	0/5
			75	0/3	0/3			0/4	0/4
LT	1380	200	100	0/3	1/3			0/5	0/5
LO	1360	197	100	0/3	0/3			0/4	0/4
ST	1280	185	50	0/3	0/3			0/5	0/5
			75	0/3	0/3			0/5	0/5
LT	1280	185	100	0/3	0/3			0/5	0/5
LO	1280	185	100	0/3	0/3			0/5	0/5
				D6AC STEEL SECTIONS OF MOTOR CASE					
			50	0/8	1/8			0/10	0/10(b)
			55	0/5	1/5				
			60	0/5	1/5				
			65	0/5	3/5				
			75	0/8	8/8			0/10	0/10(b)
LO	1450	210	45	0/5	0/5				
			50	0/3	0/3				
			55	0/5	1/5				
			65	0/5	2/5				
			75	0/3	3/3				

NOTE: (1) Total exposure at the seacoast was 14 months except as noted: (a) 6 months (b) 24 months

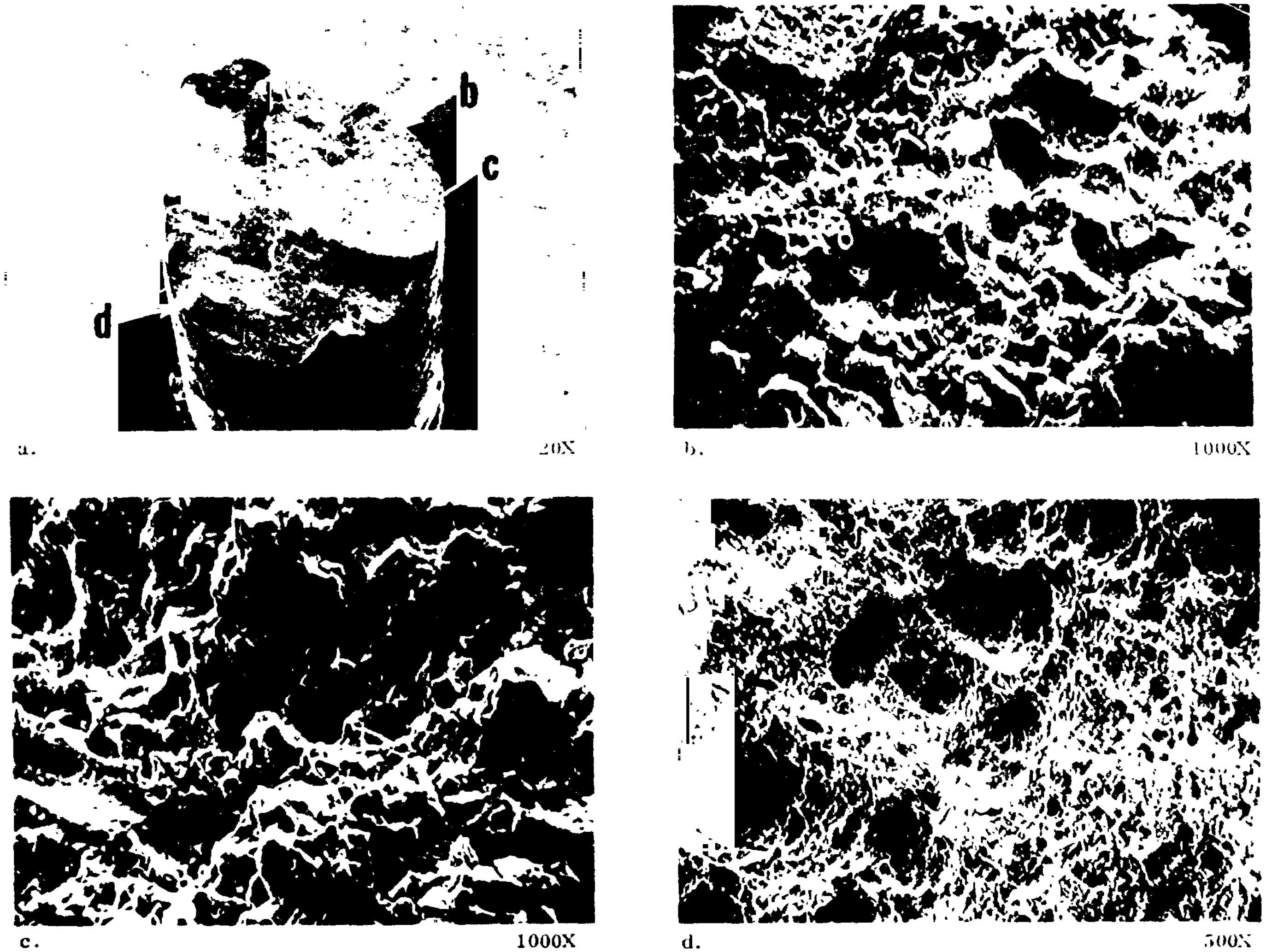

Figure 1. SEM fractographs showing blocky type intergranular initiation and propagation (a,b,c) and a ductile area of rapid failure (a,d) of a 4340 steel specimen after 5 days at KSC. (Ref. Table 9, Sample 12.)

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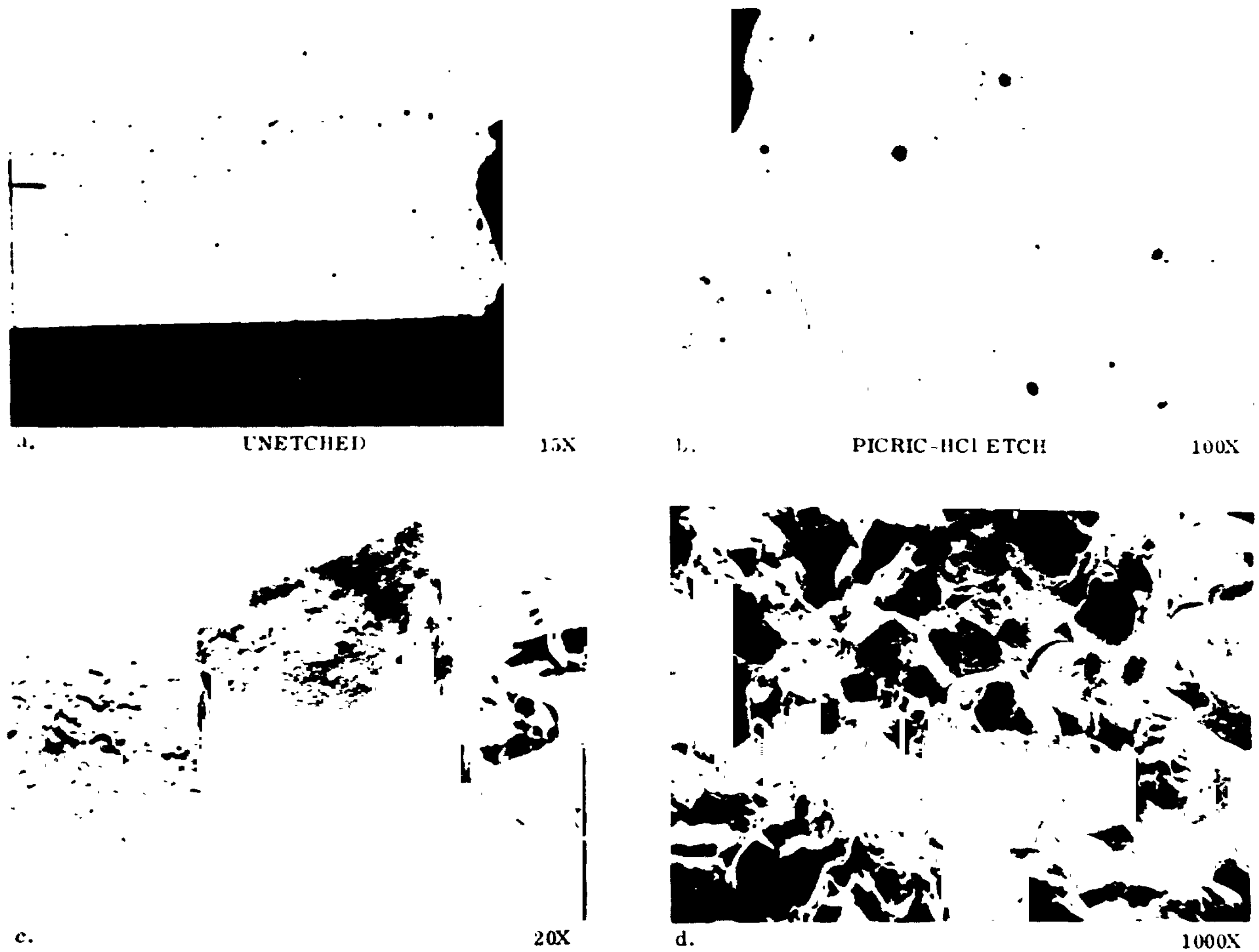

Figure 2. Photomicrographs and SEM fractographs showing the fracture and microstructure (a,b) and the blocky intergranular attack (c,d) that indicates failure by SCC of a 4130 steel specimen after 7 days in alternate immersion (Ref. Table 9, Sample i).

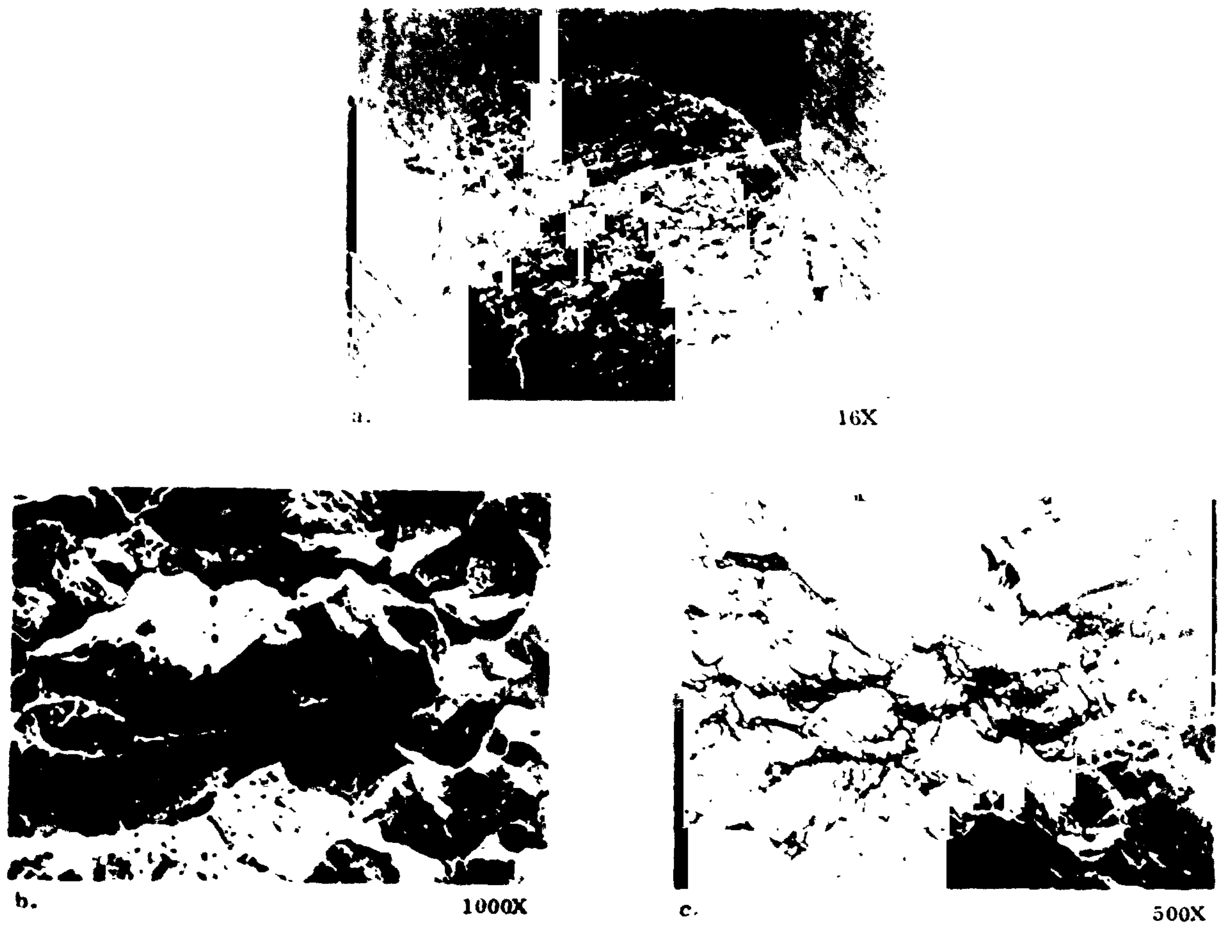

Figure 3. SEM fractographs showing blocky intergranular corrosion indicative of SCC of a 4130 steel specimen after 13 days in AI. (Ref. Table 9, Sample 5).

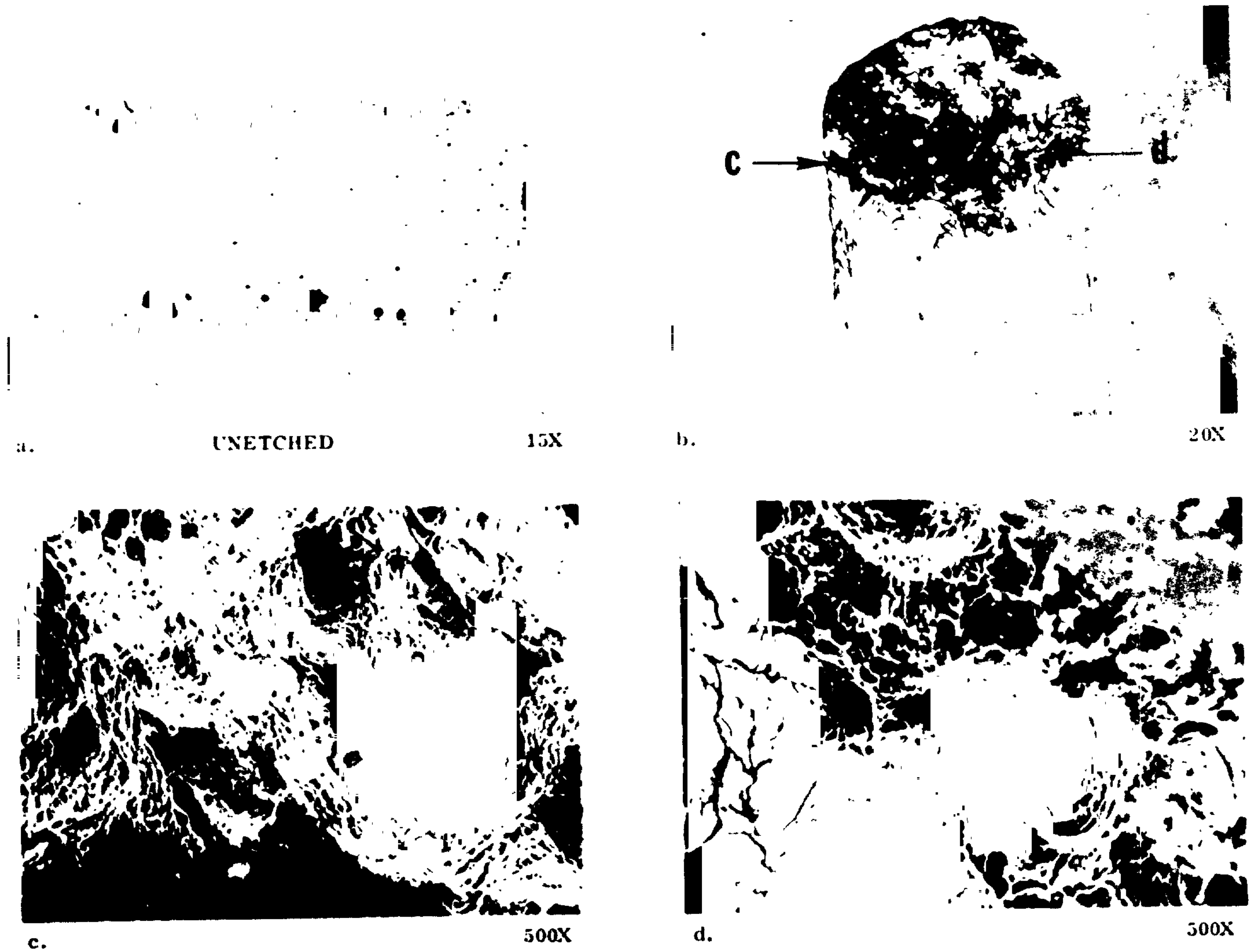

Figure 4. Photomicrograph and SEM fractographs showing the severe pitting (a) and ductile type failure (b,c,d) of a 4130 steel specimen after 91 days at KSC. (Ref. Table 9, Sample 9.)

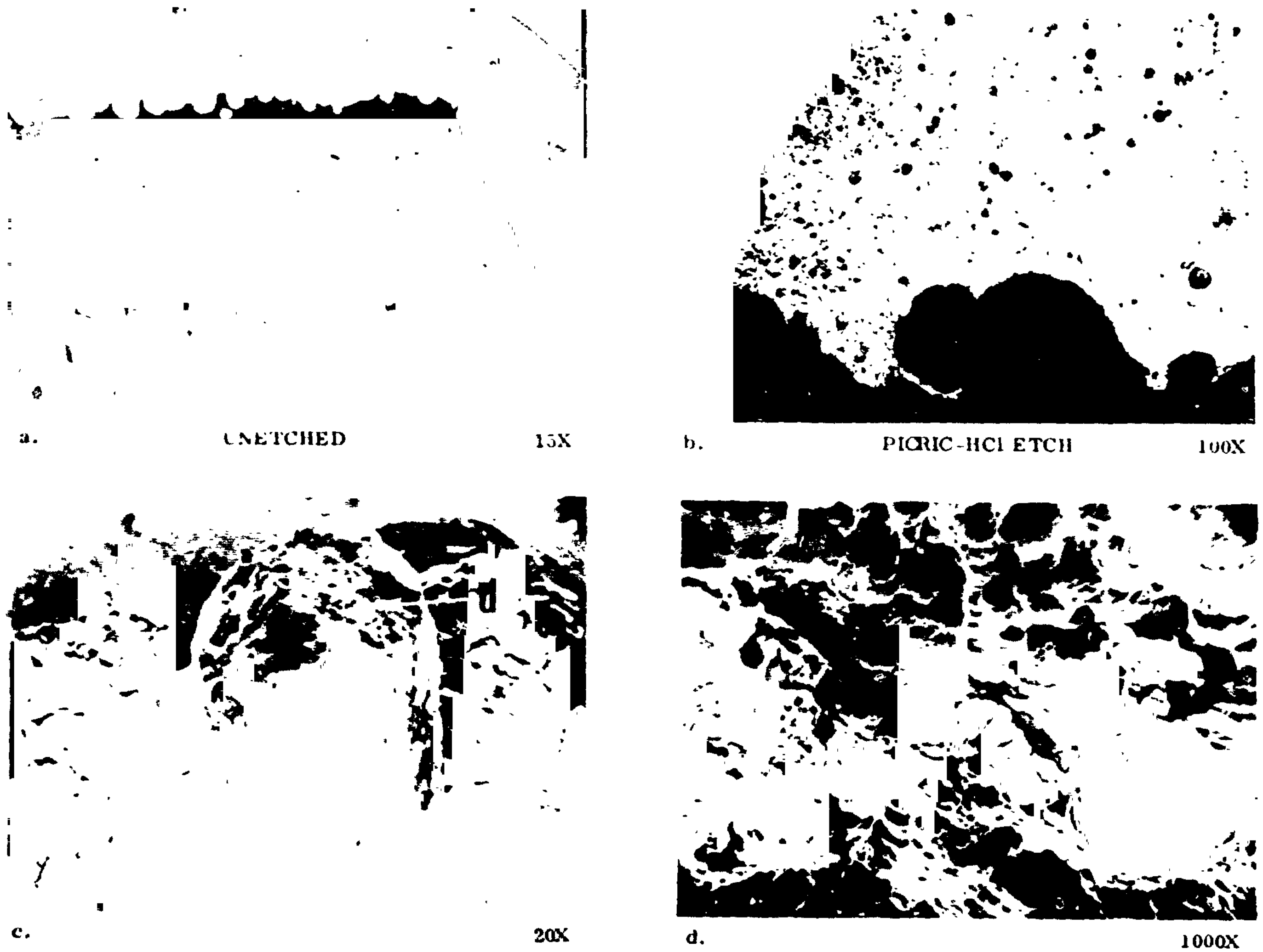

Figure 5. Photomicrographs and SEM fractographs showing microstructure and severe pitting (a,b) and the ductile dimples (c,d) of a 4130 steel specimen after 147 days at KSC. (Ref. Table 9, Sample 4.)

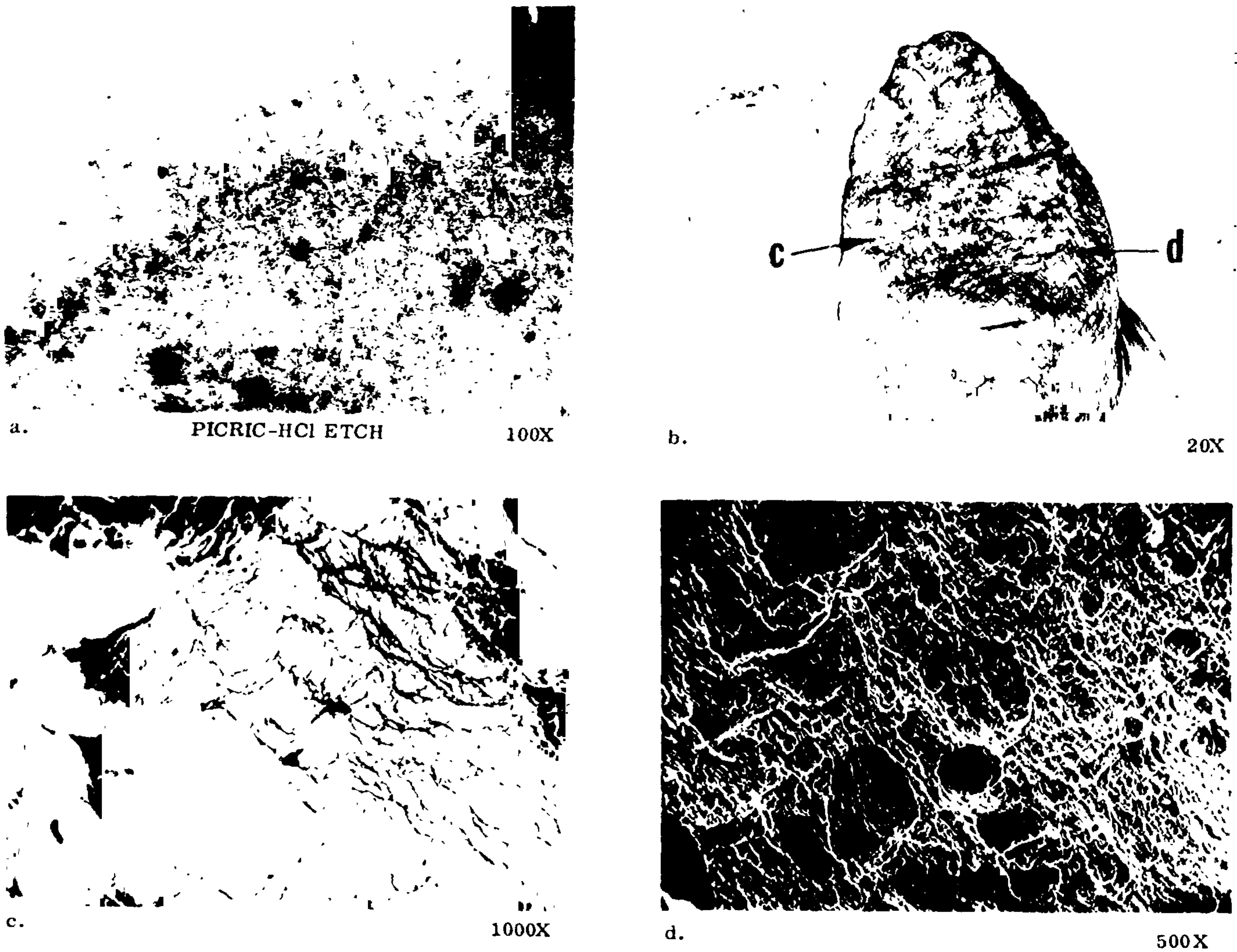

Figure 6. Photomicrograph and SEM fractographs showing the microstructure (a) and ductile failure (b,c,d) of a 4130 steel specimen after 25 days in salt spray. (Ref. Table 9, Sample 7.)

APPROVAL

EVALUATION OF THE STRESS CORROSION CRACKING HIGH STRENGTH LOW ALLOY STEELS

By

T. S. Humphries and E. E. Nelson

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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