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EXPLORATION OF THE FEASIBILITY OF PRODUCTION ROLLING AN OPTIMUM--ETC(U)

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Exploration of the Feasibility of Production Rolling an Optimum Aluminum Alloy System Which Has an As-Welded Yield Strength of 30 KSI Minimum

FINAL REPORT

R.W. Rogers, Jr.
W.D. Vernam
M.B. Shumaker
Aluminum Company of America
Alcoa Laboratories

ALCOA

Contract N00024–74–C–5241
issued by Naval Sea Systems Command
Project Serial Number SF541-702 Task 17350-21

September 22, 1976

EXPLORATION OF THE FEASIBILITY OF PRODUCTION ROLLING AN OPTIMUM ALUMINUM ALLOY SYSTEM WHICH HAS AN AS-WELDED YIELD STRENGTH OF 30 KSI MINIMUM

by

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R. W. Rogers, Jr.
Project Engineer

H. Y. Hunsicker
Project Supervisor

September 22, 1976

ALUMINUM COMPANY OF AMERICA
ALCOA LABORATORIES
PHYSICAL METALLURGY DIVISION
ALCOA TECHNICAL CENTER

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FOREWORD

This report covers work done by the Aluminum Company of America at its Davenport Works and Alcoa Technical Center under Contract N00024-74-C-5241 issued by Naval Sea Systems Command. The Technical Supervisor for NAVSEA was Mr. T. C. West.

Plate fabrication at Davenport Works was supervised by Mr. R. W. Westerlund. Tensile and fracture toughness testing was directed by Mr. F. G. Nelson, Jr.; welding by Mr. G. P. Yanok; and metallographic studies were made by Mr. D. C. Sargent.

The cooperation and assistance of International Nickel Company's Francis L. LaQue Corrosion Laboratory at Wrightsville Beach, North Carolina, in conducting the sea water corrosion tests is greatly appreciated.

SYNOPSIS

A high-strength weldable aluminum-magnesium alloy, CS19, developed previously on an exploratory basis for ship structure applications was fabricated into plate from large ingots on production rolling mills to evaluate the feasibility of production rolling this alloy. Plate in 6.3 mm (.250") and 25.4 mm (1.0") thicknesses was produced from two commercial sizes of ingot with no difference in product characteristics observed between plates fabricated from either size or from smaller laboratory-cast ingots.

Tensile, notch-tensile, and corrosion tests of 25.4 mm CS19 plate and weldments confirmed the results of tests on laboratory-rolled plate of the same thickness to the effect that CS19 had an as-welded minimum tensile yield strength of 207 MPa (30 ksi) and corrosion and fracture toughness properties equivalent to or better than the current 5456-H116 or H117 alloys. As in the earlier work, CS19 was indicated to have a more rapid rate of stress-corrosion crack growth than 5456 under certain conditions but equal resistance to SCC initiation.

The thinner 6.3 mm CS19 plate and weldments had higher strengths than 25.4 mm plate and weldments but lower toughness; the latter, however, was judged to be equivalent to that of 5456-H117 of the same thickness. Corrosion resistance of the 6.3 mm plate and weldments was also good, except for SCC resistance of weldments after thermal treatments simulating the effects of long periods of service. Here the conditions of greater strain in the thinner plate produced a heat-affected zone structure which was susceptible to SCC but only after thermal treatment.

INTRODUCTION

In recognition of the need for a higher strength aluminum structural alloy for high-speed marine vessels, the Navy Ship Systems Command in 1972 issued a contract (N00024-72-C-5571) to Alcoa for test and exploratory development of a work-hardenable aluminum alloy plate material which was to have an as-welded minimum tensile yield strength of 207 MPa (30 ksi) and corrosion and fracture toughness properties equivalent to or better than those of present 5456-H116 or H117 alloys.

The result of this work[1] was an alloy designated CS19 whose composition was tentatively established as:

Mg	Mn	Cr	Fe	Si	Others
7.75-8.75	.30-.50	.05-.20	.12*	.10*	.05*

*maximum

CS19 plate was shown to produce weldments of 10% higher yield strength than 5456 and which readily met the 207 MPa minimum as-welded yield strength criterion; fracture toughness of CS19 plate and weldments was at least equivalent to that of 5456. Resistance to general and exfoliation corrosion of CS19 plate and weldments was also judged equivalent or superior to 5456. The resistance to stress-corrosion cracking of plate and weldments was considered equivalent to that of 5456 with the exception of more rapid crack growth in as-fabricated CS19 plate stressed in the short transverse direction using precracked specimens loaded to very high stress intensity (tension pop-in). For most of this work including all of the weldment evaluations, 25.4 mm (1.0") plate from laboratory-cast ingots was employed.

To explore the feasibility of production rolling the alloy selected from the test and exploratory development contract, Navy Ship Systems Command on January 22, 1974, issued Contract N00024-74-C-5241 to Alcoa to undertake a production plate evaluation. For this phase, Alcoa had proposed to do the following:(2)

(1) Cast production size CS19 ingots in two sizes: 300 mm x 960 mm x 3050 mm and 460 mm x 1520 mm x 3800 mm (12" x 38" x 120" and 18" x 60" x 150").

(2) Roll on production rolling mills each size of ingot into the following thicknesses and tempers of plate:

   (A) 25.4 mm (1.0") H3E19
   (B) 25.4 mm (1.0") H1E48
   (C) 6.3 mm (.250") H3E19
   (D) 6.3 mm (.250") H1E48
   (E) 6.3 mm (.250") H2E38

(3) Evaluate all ten items for transverse tensile properties and exfoliation resistance of plate and tensile properties of full section weldment specimens.

(4) Complete testing of items in each thickness which met the requirements of the initial

evaluation program for the following:

(A) tensile properties

(i) as-fabricated
(ii) after elevated temperature storage (66°C, 80°C, 100°C)
(iii) annealed

(B) notch-tensile properties

(C) corrosion resistance

(i) as-fabricated

(a) exfoliation
(b) SCC
(c) general

(ii) after elevated temperature storage

(a) exfoliation
(b) SCC
(c) general

(iii) annealed temper

(a) general

(5) Produce GMA (MIG) weldments of one item in each thickness and perform the following tests:

(A) tensile properties

(i) as-welded - reduced section
(ii) after elevated temperature storage

(B) notch-tensile properties

(C) bend tests

(D) corrosion resistance

(i) as-welded

(a) exfoliation
(b) SCC
(c) general

(ii) after elevated temperature storage

(a) exfoliation
(b) SCC
(c) general

FABRICATION OF CS19 PLATE

Ingots

The 300 mm x 960 mm x 3050 mm (12" x 38" x 120" ingots were cast at Alcoa Technical Center and the 460 mm x 1520 mm x 3800 mm (18" x 60" x 150") ingots at Davenport Works. No problems were encountered in casting these ingots; results of spectrographic analyses of cast sample specimens are listed in Table 1.

Examination of macroetched sections sawed from the head ends of one ingot of each size showed average grain diameter to be 0.8 mm (1/32") for the 300 mm x 960 mm ingot and 3.2 mm (1/8") for the 460 mm x 1520 mm. The finer grain size of the former can be attributed to faster chilling rate in casting and to grain refining effect of Ti.

Before homogenizing, the ingots were machined (scalped) to 267 mm (10.5") and 419 mm (16.5"), respectively, to remove approximately 19 mm (3/4") per rolling face. All ingots were ultrasonically inspected and found to be sound and suitable for rolling.

The homogenizing treatment produced a thermal soak of eight hours minimum at 496°C metal temperature prior to cooling to 425°C rolling temperature.

Hot Rolling - 25.4 mm (1.0") Plate

The H3E19 rolling practice calls for no particular temperature control during hot rolling, but requires a subsequent stretching operation to achieve desired strength levels.

TABLE 1

CHEMICAL COMPOSITION OF CS19 PRODUCTION INGOTS
FOR CONTRACT N00024-74-C-5241

Identification	Size	Produced at	Number	Mg	Mn	Cr	Fe	Si	Zn	Ti	Be
S-422050A	300 mm x 960 mm x 3050 mm (12" x 38" x 120")	ATC	1	8.60	0.39	0.11	0.06	0.05	0.05	0.02	0.001
S-422050B	300 mm x 960 mm x 3050 mm	ATC	1	8.40	0.40	0.11	0.06	0.05	0.01	0.03	0.001
S-422050C	300 mm x 960 mm x 3050 mm	ATC	1	8.22	0.42	0.11	0.06	0.05	0.01	0.02	0.001
S-422050D	300 mm x 960 mm x 3050 mm	ATC	1	8.51	0.39	0.10	0.06	0.05	0.00	0.02	0.001
H951-01	460 mm x 1520 mm x 3800 mm (18" x 60" x 151")	Davenport	3	8.42	0.33	0.10	0.07	0.08	--	--	0.001

Values listed are spectrographic analyses of cast sample plates.

The H1E48 temper, on the other hand, requires plate to have its final hot rolling passes at 280°C in order to finish at 260-275°C with subsequent rapid cooling by mill coolant solution to below 200°C; a lesser degree of stretching is required. The H3E19 practice is a more desirable practice from the standpoint of hot mill productivity.

The ingots were initially cross-rolled on a 4 m (160") hot mill to widths of 1460 mm (57.5") and 2220 mm (87.5") for 300 mm x 960 mm and 460 mm x 1520 mm ingots, respectively, prior to lengthwise rolling to 25.4 mm (1.0"). No end preparation of the ingots was required prior to rolling and a moderate degree of alligatoring was encountered. Edge quality (maintained by edge rolling) and surface quality were excellent.

Hot Rolling - 6.3 mm (.250") Plate

Starting stock was part of the 25.4 mm plate rolled previously which was reheated to 425°C prior to the additional rolling to thinner plate thicknesses. Both H3E19 and H1E48 tempers were produced in 6.3 mm (.250") thickness with the same temperature restrictions employed for the thicker plates. No problems with edge cracking were encountered.

Cold Rolling - 6.3 mm (.250") Plate

The H2E38 temper was produced by cold rolling a 9.8 mm (.385") plate to 6.3 mm (.250") followed by an eight-hour soak at 246°C stabilizing thermal treatment. The 9.8 mm plate was also produced by hot rolling pieces of 25.4 mm CS19 plate rolled previously. No edge cracking was encountered in cold rolling the 35% reduction, but many passes were required because of the high level of hardness developed in an alloy with such a high Mg content.

Finishing

No stretching problems were encountered in plate produced from the larger 460 mm x 1520 mm ingot, but plates from the 300 mm x 960 mm ingot broke before the complete stretch had been accomplished. A lower yield strength in H3E19 plate from this ingot size was attributed to this.

The fabricating practices employed are summarized in Table 2. The concensus of operating personnel following the plant trial was that production of CS19 plate was feasible but increased operating difficulties and more rolling passes, compared to 5456, could be anticipated.

TABLE 2

FABRICATING PRACTICES FOR CS19 PLATE ROLLED AT DAVENPORT WORKS OF ALCOA

Order:	TNS-C3534-AW					TNS-C3534-AX				
Item:	1	3	5	6	7	1	3	5	6	7
	25.4 mm (1.000")	25.4 mm (1.000")	6.3 mm (.250")	6.3 mm (.250")	6.3 mm (.250")	25.4 mm (1.000")	25.4 mm (1.000")	6.3 mm (.250")	6.3 mm (.250")	6.3 mm (.250")
	H3E19	H1E48	H3E19	H1E48	H2E38	H3E19	H1E48	H3E19	H1E48	H2E38
Lot Number:	403-931	404-121	210-621	210-622	210-623	210-611	404-061	210-612	210-613	210-614
Ingot Size:	300 mm x 960 mm x 3050 mm (12" x 38" x 120")					460 mm x 1520 mm x 3800 mm (18" x 60" x 150")				
Scalped to:	267 mm (10-1/2")					419 mm (16-1/2")				
Hot Roll - Width:	1460 mm (57-1/2")					2220 mm (86-3/4")				
Thickness:	25.4 mm	25.4 mm*	25.4 mm			25.4 mm	25.4 mm*	25.4 mm		
Hot Roll:	---	---	6.3 mm	6.3 mm**	9.8 mm	---	---	6.3 mm	6.3 mm**	9.8 mm
Cold Roll:	---	---	---	---	6.3 mm	---	---	---	---	6.3 mm
Stabilize:	---	---	---	---	8 hr/246°C	---	---	---	---	8 hr/246°C
Stretch:	4%	1.5%	1.5%	1.5%	1.5%	4%	1.5%	1.5%	1.5%	1.5%

*Rolled from 41 mm to 25.4 mm at 282°C.
**Rolled from 12 mm to 6.3 mm at 282°C.

INITIAL EVALUATION OF CS19 PLATE

In accordance with the contract proposal[2], all ten items of production-rolled plate were tested for transverse tensile properties and resistance to exfoliation; in addition, MIG weldments were prepared from each item and full section specimens tested for as-welded tensile properties. Results of these initial evaluations are reported below.

Tensile Properties of Plate

Results of transverse tensile tests for the ten items of plate fabricated from two sizes of production ingot at Davenport are listed in Table 3 together with similar data for laboratory-fabricated plate from the earlier exploratory development contract report.[1] These tests were made in accordance with ASTM Method E8. Results show that if the same fabricating procedures were employed for a given temper, the tensile properties were very similar regardless of ingot size employed and whether rolled on laboratory or production mills.

The strengths of the 25.4 mm thick plate were consistently lower than those of the 6.3 mm plate for similar tempers. This is a reflection of the higher equivalent cold work induced by hot rolling the thinner gauge plate. The low yield strength of S-438562 from 300 mm x 960 mm ingot was attributed to failure to achieve the full 4% stretch because of breakage in stretching.

TABLE 3

TRANSVERSE TEST RESULTS FOR CS19 PLATE FABRICATED BY LABORATORY AND PRODUCTION ROLLING PROCEDURES

					Average Transverse Tensile Properties				
			Amount of	Number of	Tensile Str.		Yield Str.		Elongation
Thickness	Temper	S. No.	Stretch	Tests	MPa	(ksi)	MPa	(ksi)	(% in 50.8 mm)
150 mm x 400 mm x 900 mm (6" x 16" x 36") Ingot(1)									
6.3 mm	H1E48	421896	1.5%	--	451	(65.4)	272	(39.4)	25.0
(.250")	H2E38	421894	1.5%	--	449	(65.1)	252	(36.6)	13.5
	H3E19	421895	1.5%	--	436	(63.2)	250	(36.3)	24.0
25.4 mm	H1E48	416448	1.5%	2	411	(59.6)	244	(35.4)	21.5
(1.0")	H1E48	419453	1.5%	2	423	(61.4)	261	(37.8)	22.9
	H3E19	419453	4.0%	2	421	(61.1)	251	(36.4)	22.0
300 mm x 960 mm x 3050 mm (12" x 38" x 120") Ingot									
6.3 mm	H1E48	438628	1.5%	3	441	(63.9)	274	(39.8)	22.7
	H2E38	438726	1.5%	3	416	(60.3)	258	(37.4)	9.0
	H3E19	438564	1.5%	3	452	(65.6)	286	(41.5)	22.7
25.4 mm	H1E48	438563	1.5%	3	420	(60.9)	254	(36.9)	22.0
	H3E19	438562	(4.0%)	3	405	(58.8)	230	(33.4)	21.3
460 mm x 1520 mm x 3800 mm (18" x 60" x 150") Ingot									
6.3 mm	H1E48	438568	1.5%	3	435	(63.1)	288	(41.8)	21.8
	H2E38	438629	1.5%	3	397	(57.6)	226	(32.8)	12.0
	H3E19	438567	1.5%	3	438	(63.5)	282	(40.9)	21.7
25.4 mm	H1E48	438566	1.5%	3	412	(59.7)	247	(35.8)	21.8
	H3E19	438565	4.0%	3	405	(58.7)	248	(36.0)	22.7

Note: (1) Data for this ingot size from Reference 1 for laboratory-rolled plate.

In the 6.3 mm plate items, lower strengths of the H2E38 temper, especially S-438629, resulted from the precipitation treatment of eight hours at 246°C. Strengths of the H3E19 and H1E48 tempers were quite similar.

Exfoliation Resistance of Plate

The resistance to exfoliation of all ten items of production-rolled CS19 alloy plate was evaluated with the ASSET immersion test as recommended by the Aluminum Association Task Group on Exfoliation to replace both of the corrosion tests previously specified under Federal Specification QQ-A-00250/20 for alloy 5456. The results of the exfoliation tests performed on the 25.4 mm and 6.3 mm thick CS19 plate from the two production-size ingots are listed in Table 4 together with results for the laboratory-rolled 25.4 mm plate in the earlier test and exploratory development contract.(1) They indicate excellent resistance to exfoliation for both thicknesses of plate regardless of the size ingot. The resistance to exfoliation of both laboratory and plant-fabricated CS19 alloy plate was comparable to 5456 alloy plate, which was one of the key objectives of the contract.

Tensile Properties of Weldments

The tensile properties of full section (Fig. I in Appendix) specimens of the two tempers of plate produced in 25.4 mm thick plate are listed in Table 5 along with comparable data for the laboratory-produced plate of contract N00024-C-5571.

TABLE 4

ACCELERATED EXFOLIATION TEST (ASSET) RESULTS FOR CS19 PLATE FABRICATED BY LABORATORY AND PRODUCTION ROLLING PROCEDURES

Thickness	S-No.	Temper	Exfoliation after ASSET Test[1] As-Fabricated	Exfoliation after ASSET Test[1] After One Week at 100C
	150 mm x 400 mm x 900 mm (6" x 16" x 36") Ingot[2]			
6.3 mm (.250")	421896[2]	H1E48	N	N
	421894[2]	H2E38	N	P-A
	421895[2]	H3E19	N	N
25.4 mm (1.0")	419453[2]	H1E48	N	N
	419453[2]	H3E19	N	N
	300 mm x 960 mm x 3050 mm (12" x 38" x 120") Ingot			
6.3 mm	438628	H1E48	N	N
	448726	H2E38	N	N
	438564	H3E19	N	N
25.4 mm	438563	H1E48	N	N
	438560	H3E19	N	N
	460 mm x 1520 mm x 3800 mm (18" x 60" x 150") Ingot			
6.3 mm	438568	H1E48	P-A	N
	438629	H2E38	N	N
	438567	H3E19	P-A	N
25.4 mm	438566	H1E48	N	N
	438565	H3E19	N	N

Notes: (1) 24 hours total immersion in solution of 1N NH_4Cl, 0.25 N NH_4NO_3, 0.01 M ammonium tartrate and 3 g/l hydrogen peroxide at 66°C; N is no appreciable attack; P-A is slight pitting attack.

(2) Data for this ingot size from Reference 1 for laboratory-rolled plate.

CS19 filler electrode was employed for the production plate. As shown, the as-welded yield strengths were quite consistent and were essentially the same for both tempers of production plate produced from two ingot sizes and for the laboratory-rolled plate despite somewhat different parent plate yield strengths. The increase in parent plate yield strength obtained by stretching the production plate (4% for H3E19 and 1.5% for H1E48) was apparently lost from the heat of welding as it was not reflected in any increase in weldment yield strength.

The tensile properties of full section (Fig. I in Appendix) specimens of the three tempers of plate produced from 6.3 mm thick plate are listed in Table 6. CS19 filler electrode was employed. It will be noted that the yield strengths of the 6.3 mm plate weldments are quite similar for H3E19 and H1E48 tempers; the higher yield strengths compared to those of 25.4 mm plate weldments reflect the higher strength of the thinner parent plate. The inconsistent and erratic weld tensile strengths and elongation values are a reflection of the type of abnormal failures encountered in the fractured specimens. Such failures can be encountered when developing welding parameters for new or experimental alloys. For the most part, such failures are isolated and can be controlled through experience. Although these inconsistencies developed in the 6.3 mm plate

TABLE 5

TENSILE TEST RESULTS FOR WELDMENTS OF 25.4 mm (1.0") CS19 PLATE FABRICATED BY LABORATORY AND PRODUCTION ROLLING PROCEDURES

Temper	S-No.	Parent Plate[1] Tensile Str. MPa	(ksi)	Yield Str. MPa	(ksi)	Elongation, % in 50.8 mm (2")	Weldment[2] Tensile Str. MPa	(ksi)	Yield Str. MPa	(ksi)	Elong. - % mm 50.8 mm (2")	254 mm (10")	Location of Fracture	Type of Fracture
150 mm x 400 mm x 900 mm (6" x 16" x 36") Ingot[3]														
H1E48	416448[4]	403	(58.5)	232	(33.6)	23.6	316	(45.9)	229	(33.2)	9.0	4.	Zone of fusion	--
							337	(48.9)	223	(32.3)	10.5	5.7	Zone of fusion	--
	419453[4]	410	(59.4)	234	(34.0)	24.0	341	(49.4)	230	(33.4)	9.0	4.3	Zone of fusion	--
							329	(47.7)	229	(33.2)	9.0	3.7	Zone of fusion	--
	426723[4]	398	(57.7)	223	(32.3)	24.0	312	(45.2)	224	(32.5)	8.4	4.2	Zone of fusion	--
300 mm x 960 mm x 3050 mm (12" x 38" x 120") Ingot														
H1E48	438563	421	(61.1)	256	(37.2)	21.5	350	(50.8)	228	(33.0)	10.0	4.5	Zone of fusion	Typical weld/parent interface fracture.
		420	(60.9)	254	(36.8)	22.0	366	(53.1)	228	(33.0)	8.5	4.9	Zone of fusion	Lack of fusion fracture through both weld bead and fusion zone.
		418	(60.6)	254	(36.8)	22.5	359	(52.1)	229	(33.1)	10.0	4.7	Zone of fusion	Typical weld/parent interface fracture.
	Avg.	420	(60.9)	254	(36.9)	22.0	359	(52.0)	228	(33.0)	9.5	4.7		
H3E19	438560	405	(58.8)	230	(33.4)	21.5	367	(53.3)	219	(31.8)	12.0	7.2	Zone of fusion	Fracture through both bead and fusion zone.
		410	(59.4)	231	(33.5)	22.0	352	(51.1)	218	(31.6)	11.0	6.3	Zone of fusion	Typical weld/parent interface fracture.
		402	(58.3)	229	(33.2)	20.5	347	(50.3)	219	(31.7)	10.5	5.8	Zone of fusion	Typical weld/parent interface fracture.
	Avg.	405	(58.8)	230	(33.4)	21.3	356	(51.6)	219	(31.7)	11.2	6.4		
460 mm x 1520 mm x 3800 mm (18" x 60" x 150") Ingot														
H1E48	438566	416	(60.4)	248	(36.0)	21.0	363	(52.6)	226	(32.8)	13.0	7.4	Zone of fusion	Typical weld/parent interface fracture.
		409	(59.3)	246	(35.7)	23.5	349	(50.6)	227	(32.9)	12.0	6.7	Zone of fusion	Typical weld/parent interface fracture.
		410	(59.4)	247	(35.8)	21.0	358	(51.9)	225	(32.7)	12.0	6.9	Zone of fusion	Typical weld/parent interface fracture.
	Avg.	412	(59.7)	247	(35.8)	21.8	356	(51.7)	226	(32.8)	12.3	7.0		
H3E19	438565	402	(58.3)	251	(36.4)	22.5	366	(53.1)	219	(31.7)	13.5	8.4	Zone of fusion	Typical weld/parent interface fracture.
		402	(58.3)	241	(35.0)	23.0	356	(51.7)	218	(31.6)	13.5	7.4	Zone of fusion	Typical weld/parent interface fracture.
		410	(59.4)	252	(36.5)	22.5	341	(49.5)	220	(31.9)	12.5	6.3	Zone of fusion	Typical weld/parent interface fracture.
	Avg.	405	(58.7)	248	(36.0)	22.7	354	(51.4)	219	(31.7)	13.2	7.4		

Notes:
(1) Transverse tests.
(2) Longitudinal welds; full section boiler-plate specimens. Electrode alloy was CS19 type.
(3) Data for this ingot size from Reference 1 for laboratory-rolled plate.
(4) Not stretched.

TABLE 6

TENSILE TEST RESULTS FOR WELDMENTS OF 6.3 mm (.250") CS19 PLATE FABRICATED BY LABORATORY AND PRODUCTION ROLLING PROCEDURES

		Parent Plate[1]					Weldment[2]							
		Tensile Str.		Yield Str.		Elongation, % in 50.8 mm	Tensile Str.		Yield Str.		Elong. - % 50.8 mm	254 mm	Location of	
Temper	S-No.	MPa	(ksi)	MPa	(ksi)	(2")	MPa	(ksi)	MPa	(ksi)	(2")	(10")	Fracture	Type of Fracture
300 mm x 960 mm x 3050 mm (12" x 38" x 120") Ingot														
H1E48	438628	439	(63.6)	275	(39.9)	23.0	298	(43.2)	270	(39.1)	5.0	1.2	Zone of fusion	Lack of weld fusion.
		447	(64.8)	273	(39.7)	22.5	260	(37.7)	261	(37.9)	2.5	0.8	Zone of fusion	Lack of weld fusion.
		437	(63.4)	273	(39.7)	22.5	343	(49.8)	268	(38.8)	6.0	2.2	Zone of fusion	Lack of weld fusion.
	Avg.	441	(63.9)	274	(39.8)	22.7	301	(43.6)	266	(38.6)	4.5	1.2		
H2E38	448726	427	(62.0)	257	(37.3)	10.5	403	(58.5)	251	(36.4)	10.0	6.3	Parent metal	--
		398	(57.7)	256	(37.2)	9.0	315	(45.7)	250	(36.2)	5.5	2.3	Zone of fusion	Lack of weld fusion.
		422	(61.2)	259	(37.6)	6.0	311	(45.1)	247	(35.8)	5.0	2.1	Zone of fusion	Lack of weld fusion.
	Avg.	416	(60.3)	258	(37.4)	9.0	343	(49.8)	249	(36.1)	6.8	3.6		
H3E19	438564	453	(65.7)	285	(41.3)	23.0	379	(55.0)	267	(38.7)	10.0	5.1	Zone of fusion	Typical weld/parent interface fracture.
		453	(65.7)	287	(41.6)	23.5	305	(44.3)	266	(38.6)	5.0	1.5	Zone of fusion	Lack of weld fusion.
		451	(65.5)	286	(41.5)	21.5	359	(52.1)	264	(38.3)	8.5	4.4	Zone of fusion	Typical weld/parent interface fracture.
	Avg.	452	(65.6)	286	(41.5)	22.7	348	(50.5)	265	(38.5)	7.8	3.7		
460 mm x 1520 mm x 3800 mm (18" x 60" x 150") Ingot														
H1E48	438568	433	(62.8)	288	(41.8)	21.0	321	(41.6)	255	(37.0)	6.5	2.4	Zone of fusion	Typical weld/parent interface fracture.
		435	(63.1)	286	(41.5)	22.0	319	(46.2)	257	(37.3)	6.5	2.2	Zone of fusion	Typical weld/parent interface fracture.
		438	(63.5)	290	(42.0)	22.0	321	(46.6)	256	(37.2)	6.0	2.2	Zone of fusion	Typical weld/parent interface fracture.
	Avg.	435	(63.1)	288	(41.8)	21.8	320	(46.5)	256	(37.2)	6.3	2.3		
H2E38	438629	396	(57.5)	228	(33.0)	10.5	340	(49.3)	228	(33.0)	7.5	3.5	Zone of fusion	Small inclusion in weld bead.
		393	(57.0)	226	(32.8)	9.5	315	(45.7)	226	(32.8)	5.5	2.7	Zone of fusion	Lack of fusion and porosity.
		402	(58.3)	225	(32.7)	16.0	295	(42.8)	228	(33.0)	5.5	2.2	Zone of fusion	Small inclusion at toe of weld.
	Avg.	397	(57.6)	226	(32.8)	12.0	316	(45.9)	227	(32.9)	6.2	2.8		
H3E19	438567	438	(63.5)	279	(40.5)	21.5	337	(48.9)	260	(37.7)	8.5	3.6	Zone of fusion	Lack of weld fusion.
		431	(62.5)	276	(40.1)	22.0	396	(57.4)	263	(38.1)	13.5	8.0	Zone of fusion	Typical weld/parent interface structure.
		444	(64.4)	290	(42.1)	21.5	397	(57.5)	265	(38.4)	12.0	7.7	Zone of fusion	Typical weld/parent interface structure.
	Avg.	438	(63.5)	282	(40.9)	21.7	376	(54.6)	263	(38.1)	11.3	6.5		

Notes: (1) Transverse tests.
(2) Longitudinal welds; full section boiler-plate type specimens. Electrode alloy was CS19 type.

weldments, all tempers exceeded the contract objective of 207 MPa (30 ksi) minimum as-welded yield strength.

Summary of Initial Evaluation

Results of this initial evaluation program indicated first of all that CS19 plate fabricated on production-rolling equipment from large-size ingots was very similar in strength to CS19 plate fabricated by similar practices but in the laboratory previously from smaller ingots. The same was true for the strength of weldments and for resistance to exfoliation.

As will be discussed subsequently, other evaluations including stress-corrosion testing confirmed the equivalency of H1E48 and H3E19 tempers from the standpoint of corrosion resistance. Since the H3E19 temper fabricating practices were advantageous productionwise, it was decided to gather complete data for the two items in this temper for each thickness in the remaining contract work.

CS19 PLATE PROPERTIES

Tensile Properties

Longitudinal and transverse tensile properties of CS19 plate were determined in accordance with ASTM Method E8.

CS19-H3E19 Plate

Results are listed in Table 7 for the plates from two different ingot sizes in each thickness, 6.3 mm (.250") and 25.4 mm (1.0"). The greater amount of equivalent cold work retained in the hot-rolled 6.3 mm plate is reflected in its considerably higher level of strength even though the 25.4 mm plate had 4% nominal subsequent stretching versus 1.5% for 6.3 mm plate.

The lower yield strength of the 25.4 mm plate produced from the 300 mm x 960 mm ingot (S-438560) is attributed to its failure to obtain the full 4% stretch because of breakage in the stretching operation.

CS19-H3E19 After Elevated Temperature Exposure

Results of tensile tests after three periods of elevated temperature storage (30 days at 66°C, 7 days at 80°C, or 7 days at 100°C) are tabulated in Table 8. The thermal treatments produced slight losses in yield strength but little, if any, change in tensile strength. The largest yield strength loss was in the 25.4 mm plate (S-438565) which had received the most (4%) stretch.

TABLE 7

TENSILE PROPERTIES OF CS19 PLATE

Thickness	S-No.	Ingot Size	Amount of Stretch	Longitudinal					Transverse				
				Tensile Strength		Yield Strength		Elong.	Tensile Strength		Yield Strength		Elong.
			(%)	MPa	(ksi)	MPa	(ksi)	(% in 50.8 mm)	MPa	(ksi)	MPa	(ksi)	(% in 50.8 mm)
				H3E19 Temper									
6.3 mm	438564	300 mm x 960 mm	1.5	478	(69.3)	340	(49.3)	16.0	452	(65.6)	286	(41.5)	22.7
(.250")	438567	460 mm x 1520 mm	1.5	452	(65.6)	314	(45.6)	15.2	438	(63.5)	282	(40.9)	21.7
25.4 mm	438560	300 mm x 960 mm	4.0	424	(61.5)	263	(38.2)	22.0	405	(58.8)	230	(33.4)	21.3
(1.0")	438565	460 mm x 1520 mm	4.0	419	(60.8)	269	(39.0)	22.0	405	(58.7)	248	(36.0)	22.7
				O Temper									
6.3 mm	438564	300 mm x 960 mm	--	395	(57.3)	187	(27.1)	28.2	392	(56.9)	186	(27.0)	28.5
	438567	460 mm x 1520 mm	--	374	(54.3)	181	(26.2)	29.2	381	(55.2)	183	(26.5)	27.5
25.4 mm	438560	300 mm x 960 mm	--	407	(59.0)	196	(28.4)	27.5	405	(58.7)	193	(28.0)	27.8
	438565	460 mm x 1520 mm	--	401	(58.2)	198	(28.7)	25.3	390	(56.5)	192	(27.8)	26.7
5456-O[3]	--	--	--	310	(45.0)	159	(23.0)	24.0	--	--	--	--	--

Notes: (1) All results are averages of three tests except longitudinal H3E19 which were single tests.

(2) Annealing treatment was one hour at 427°C (800°F).

(3) Typical values for 5456-O from "Aluminum Standards and Data, 1976", The Aluminum Association. Thickness, test direction, and annealing temperature not specified.

TABLE 8

TENSILE PROPERTIES OF CS19-H3E19 PLATE AFTER EXTENDED PERIODS AT ELEVATED TEMPERATURES

Thickness	S-No.	Ingot Size	Condition	Tensile Strength MPa	Tensile Strength (ksi)	Yield Strength MPa	Yield Strength (ksi)	Elongation (% in 50.8 mm)
6.3 mm (.250")	438564	300 mm x 960 mm	As-fabricated	452	(65.6)	286	(41.5)	22.7
			After 30 days at 66°C	449	(65.1)	282	(40.9)	21.5
			After 7 days at 80°C	452	(65.5)	281	(40.7)	21.5
			After 7 days at 100°C	451	(65.4)	280	(40.6)	20.8
	438567	460 mm x 1520 mm	As-fabricated	438	(63.5)	282	(40.9)	21.7
			After 30 days at 66°C	432	(62.7)	273	(39.6)	23.2
			After 7 days at 80°C	431	(62.5)	272	(39.4)	23.3
			After 7 days at 100°C	436	(63.3)	266	(38.6)	23.5
25.4 mm (1.0")	438560	300 mm x 960 mm	As-fabricated	405	(58.8)	230	(33.4)	21.3
			After 30 days at 66°C	414	(60.1)	222	(32.2)	24.0
			After 7 days at 80°C	416	(60.3)	220	(31.9)	24.3
			After 7 days at 100°C	413	(59.9)	212	(30.7)	24.8
	438565	460 mm x 1520 mm	As-fabricated	405	(58.7)	248	(36.0)	22.7
			After 30 days at 66°C	401	(58.2)	230	(33.3)	24.7
			After 7 days at 80°C	400	(58.1)	224	(32.5)	24.8
			After 7 days at 100°C	400	(58.1)	217	(31.5)	25.2

Note: All results are averages of three tests for specimens cut in the long transverse direction.

In the laboratory-rolled 25.4 mm plate in the previous contract, no loss in yield strength after thermal treatments was reported. That plate, however, was not stretched and was in the equivalent of H1E48 temper (finish hot rolled at about 275°C). Considering all of these data, it would appear that the yield strength increase imparted by stretching as in the current material is reduced to some extent in extended thermal treatments designed to simulate the effects of metallurgical changes taking place over long periods of service.

CS19-O Plate

Two thicknesses of plate in the H3E19 temper were annealed by a treatment of one hour at 427°C. The tensile properties are also listed in Table 7. Annealed temper strengths are about 10% higher than those of typical 5456-O but are below the 207 MPa (30 ksi) level which was the minimum for welded plate. While annealed plate yield strength above 207 MPa would be desirable to assure weldment yield strength greater than 207 MPa, the latter property is not entirely dependent upon the former. As shown subsequently, the target value of 207 MPa can be met by welding material having higher strengths than annealed material even though the annealed yield strength is below 207 MPa.

The greater degree of retained cold work in the 6.3 mm hot rolled plate is apparent here as lower strengths after annealing which resulted from the higher degree of recrystallization achieved than was the case for 25.4 mm plate.

Fracture Toughness

CS19-H3E19 Plate

Notch-tensile tests were made in accordance with an ASTM draft method. Specimens with 60° edge notches were employed; specimens for the 6.3 mm plate were 12.7 mm wide, and for 25.4 mm plate, were 12.7 mm - diameter rounds.

Results are listed in Table 9 for the two CS19-H3E19 plates from two different ingot sizes in each thickness, 6.3 mm and 25.4 mm, as well as for one 25.4 mm stretched CS19-H1E48 plate from the earlier laboratory work. Also listed for comparison are notch-tensile test data for 6.3 mm 5456-H321 plate.[3]

From the current work it is indicated that the fracture toughness of this 25.4 mm production-rolled plate is comparable to that of the previous laboratory-rolled product of the same thickness. In the report on the latter[1], it was concluded that CS19 fracture toughness was at least equivalent to that of 5456. This view is supported by the comparisons here of NTS/YS results for 6.3 mm CS19-H3E19 with those for 6.3 mm 5456-H321.

The lower toughness of the 6.3 mm compared to 25.4 mm thickness is again attributed to the greater amount of equivalent cold work retained in the thinner hot-rolled plate.

TABLE 9

NOTCH TOUGHNESS OF CS19-H3E19 PLATE[1]

Thickness	S-No.	Test Direction	Tensile Strength MPa	Tensile Strength (ksi)	Yield Strength MPa	Yield Strength (ksi)	Elongation (% in 50.8 mm)	Notch Tensile Strength[1] MPa	Notch Tensile Strength[1] (ksi)	NTS/YS
150 mm x 400 mm x 900 mm (6" x 16" x 36") Ingot										
25.4 mm (1.0")	416448	Longitudinal	430	(62.3)	291	(42.2)	16.2	480	(69.6)	1.65
		Transverse	411	(59.6)	244	(35.4)	21.5	439	(63.7)	1.79
300 mm x 960 mm x 3050 mm (12" x 38" x 120") Ingot										
6.3 mm (.250")	438564	Longitudinal	478	(69.3)	340	(49.3)	16.0	390	(56.5)	1.15
		Transverse	452	(65.6)	286	(41.5)	22.7	359	(52.0)	1.25
25.4 mm	438560	Longitudinal	424	(61.5)	263	(38.2)	22.0	421	(61.1)	1.60
		Transverse	405	(58.8)	230	(33.4)	21.3	412	(59.7)	1.79
460 mm x 1520 mm x 3800 mm (18" x 60" x 150") Ingot										
6.3 mm	438567	Longitudinal	452	(65.6)	314	(45.6)	15.2	390	(56.5)	1.24
		Transverse	438	(63.5)	282	(40.9)	21.7	362	(52.5)	1.28
25.4 mm	438565	Longitudinal	419	(60.8)	269	(39.0)	22.0	464	(67.3)	1.73
		Transverse	405	(58.7)	248	(36.0)	22.7	452	(65.6)	1.82
Plant Production Ingot										
6.3 mm	5456-H321[2]	Transverse	370	(53.7)	256	(37.2)	19.5	303	(44.0)	1.18

Notes: (1) Averages of three tests.
(2) Results for three-inch wide edge-notched specimens per Reference 3.

Corrosion Resistance

Corrosion resistance of CS19-H3E19 plate was evaluated in regard to exfoliation susceptibility and stress-corrosion crack (SCC) susceptibility in laboratory-accelerated tests and to general corrosion susceptibility from quiescent and flowing sea water. Both plate in the as-fabricated condition and after elevated temperature exposures were tested.

CS19-H3E19 As-Fabricated Condition

Exfoliation Resistance

Evaluations of exfoliation susceptibility employing ASSET tests were carried out in the initial evaluation program and are reported in Table 4. These tests indicated excellent resistance to exfoliation for the CS19-H3E19 plate in both thicknesses as well as for all of the other CS19 plate tempers evaluated.

SCC Resistance

Long Transverse. Stress-corrosion resistance of the two thicknesses of CS19 alloy plate was evaluated in the long-transverse direction with 3.175 mm (.125") diameter tensile bars taken from the T/4 plane of the plate and full thickness beam assemblies. The results listed in Table 10 are for specimens stressed to 75% of their yield strength and exposed to the 3-1/2% NaCl alternate immersion test (ASTM G44-75, Federal Test Standard 151b, Method 823).

TABLE 10

RESISTANCE TO STRESS-CORROSION CRACKING OF CS19 PLATE
EXPOSED TO 3-1/2% NaCl SOLUTION BY ALTERNATE IMMERSION

			Beam Assemblies - Stressed 75% Y.S.				3.175 mm (1/8") Dia. Long Transverse Tensile Bars - Stressed 75% Y.S.			
			As-Fabricated		Heated 1 wk/100°C		As-Fabricated		Heated 1 wk/100°C	
Thickness	S-No.	Temper	F/N	Days to Fail	F/N	Days to Fail	F/N	Days to Fail	F/N	Days to Fail
300 mm x 960 mm x 3050 mm (12" x 38" x 120") Ingot										
6.3 mm (0.250")	446286	H3E19	0/2	OK-290	0/2	OK-290	0/3	OK-289	0/3	OK-289
	446287	H1E48	0/2	OK-290	0/2	OK-290	0/3	OK-289	0/3	OK-289
	446595	H2E38	0/2	OK-290	0/2	OK-290	0/3	OK-289	0/3	OK-289
25.4 mm (1.0")	438650	H3E19	--	--	--	--	0/3	OK-156	0/3	OK-156
460 mm x 1520 mm x 3800 mm (18" x 60" x 150") Ingot										
6.3 mm	446290	H3E19	0/2	OK-290	0/2	OK-290	0/3	OK-289	0/3	OK-289
	446291	H1E48	0/2	OK-290	0/2	OK-290	0/3	OK-289	0/3	OK-289
25.4 mm	446288	H3E19	0/2	OK-290	0/2	OK-290	0/3	OK-289	0/3	OK-289
	446289	H1E48	0/2	OK-290	0/2	OK-290	0/3	OK-289	0/3	OK-289

Note: (1) F/N denotes number of specimens failed over number of specimens exposed.

No evidence of SCC was observed after a significant exposure period of 290 days.

It will be noted that H1E48 plate was also evaluated for SCC resistance in both thicknesses with no susceptibility indicated for this temper either. This is consistent with the conclusion reached in the initial evaluation from exfoliation test results that H1E48 and H3E19 tempers were equivalent corrosionwise.

Short Transverse. The 25.4 mm (1.0") CS19-H3E19 plate was also tested in the short-transverse direction with 19.0 mm (.75") diameter C-ring specimens stressed to 75 and 50% of the long transverse yield strengths and exposed to the 3-1/2% NaCl alternate immersion test. The results (Table 11) show no evidence of SCC after a significant exposure period of 280 days. Previous test results for the test and exploratory development contract[1] indicated that both laboratory-fabricated CS19 and 5456 alloy plate showed no evidence of SCC after an exposure period of one year.

Fracture Mechanics-Type Specimens. Stress-corrosion tests were performed with the double cantilever beam specimens (Figure II in Appendix) using a beam height of 25.4 mm (1.0"). Duplicate short transverse specimens (S-L orientation) from 25.4 mm thick CS19-H3E19 temper plate were exposed to 3.5% NaCl solution (added dropwise to the precrack three times a day) for three

TABLE 11

RESISTANCE TO STRESS-CORROSION CRACKING OF CS19 PLATE
EXPOSED TO 3-1/2% NaCl SOLUTION BY ALTERNATE IMMERSION

Thickness	S-No.	Temper	Stressed %Y.S.	19 mm (0.75") Dia. Short Transverse C-Rings As-Fabricated F/N	As-Fabricated Days to Fail	Heated 1 wk/100°C F/N	Heated 1 wk/100°C Days to Fail
300 mm x 960 mm x 3050 mm (12" x 38" x 120") Ingot							
25.4 mm (1.0")	438560	H3E19	75	0/3	OK-160	0/3	OK-160
			50	0/3	OK-160	0/3	OK-160
460 mm x 1520 mm x 3800 mm (18" x 60" x 150") Ingot							
25.4 mm	446288	H3E19	75	0/3	OK-280	0/3	OK-280
			50	0/3	OK-280	0/3	OK-280
25.4 mm	446289	H1E48	75	0/3	OK-280	0/3	OK-280
			50	0/3	OK-280	0/3	OK-280

Note: (1) F/N denotes number of specimens failed over number of specimens exposed.

conditions: as-fabricated, heated one week at 100°C, and one week at 80°C. Pop-in was difficult to achieve because of the toughness of the CS19 alloy. Crack growth was monitored daily, and the results are graphically presented in Figures 1-3.

The extensive crack growth observed in the as-fabricated condition (Fig. 1) was not unexpected as extensive crack growth was previously observed for laboratory-fabricated CS19 plate.[(1)] The curve for the as-fabricated condition was similar to the curves for the heated material. Metallographic examination of crack tips revealed that the propagation was by typical intergranular SCC. Figures 4 (100X) and 5 (500X) are representative and show the cracking at the crack tip to be following grain boundaries which are outlined discontinuously with precipitate. The greater amount of grain boundary precipitate in CS19 accounts for the more rapid crack growth observed in the as-fabricated condition for CS19 compared to 5456. There was some concern that cracking was possibly associated with aligned constituents; however, this did not appear to be a factor.

Figures 6-8 contain fracture mechanics-type specimen results for a 25.4 mm H1E48 temper plate tested in the same three conditions. The similarity in crack growth to that of Figures 1-3 again illustrates the equivalent corrosion performance of the H3E19 and H1E48 tempers.

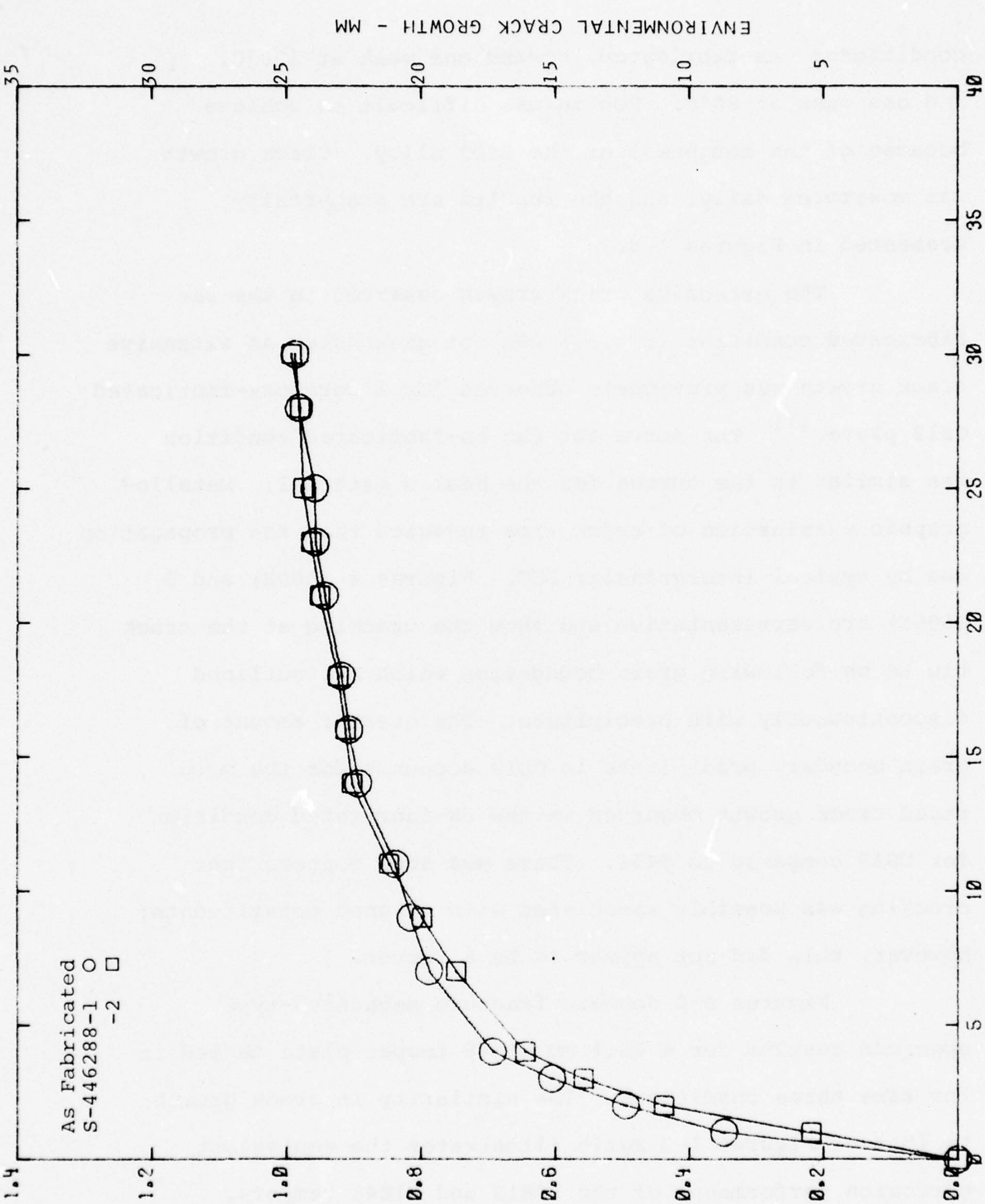

FIG.1 ENVIRONMENTAL CRACK GROWTHS OF SHORT TRANSVERSE CS19-H3E19 DCB SPECIMENS EXPOSED TO 3.5% NACL SOLUTION DROPWISE

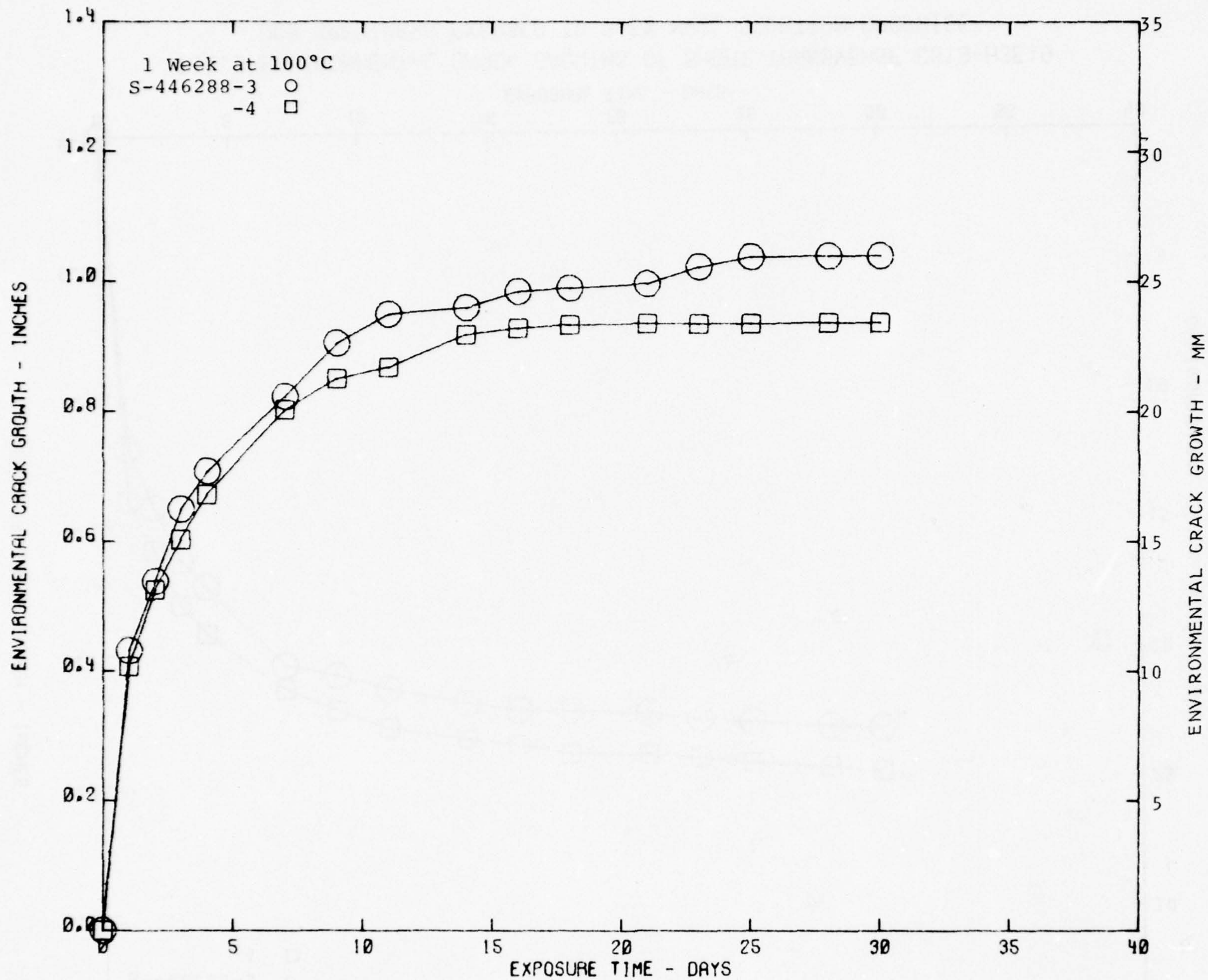

FIG.2 ENVIRONMENTAL CRACK GROWTHS OF SHORT TRANSVERSE CS19-H3E19 DCB SPECIMENS EXPOSED TO 3.5% NACL SOLUTION DROPWISE

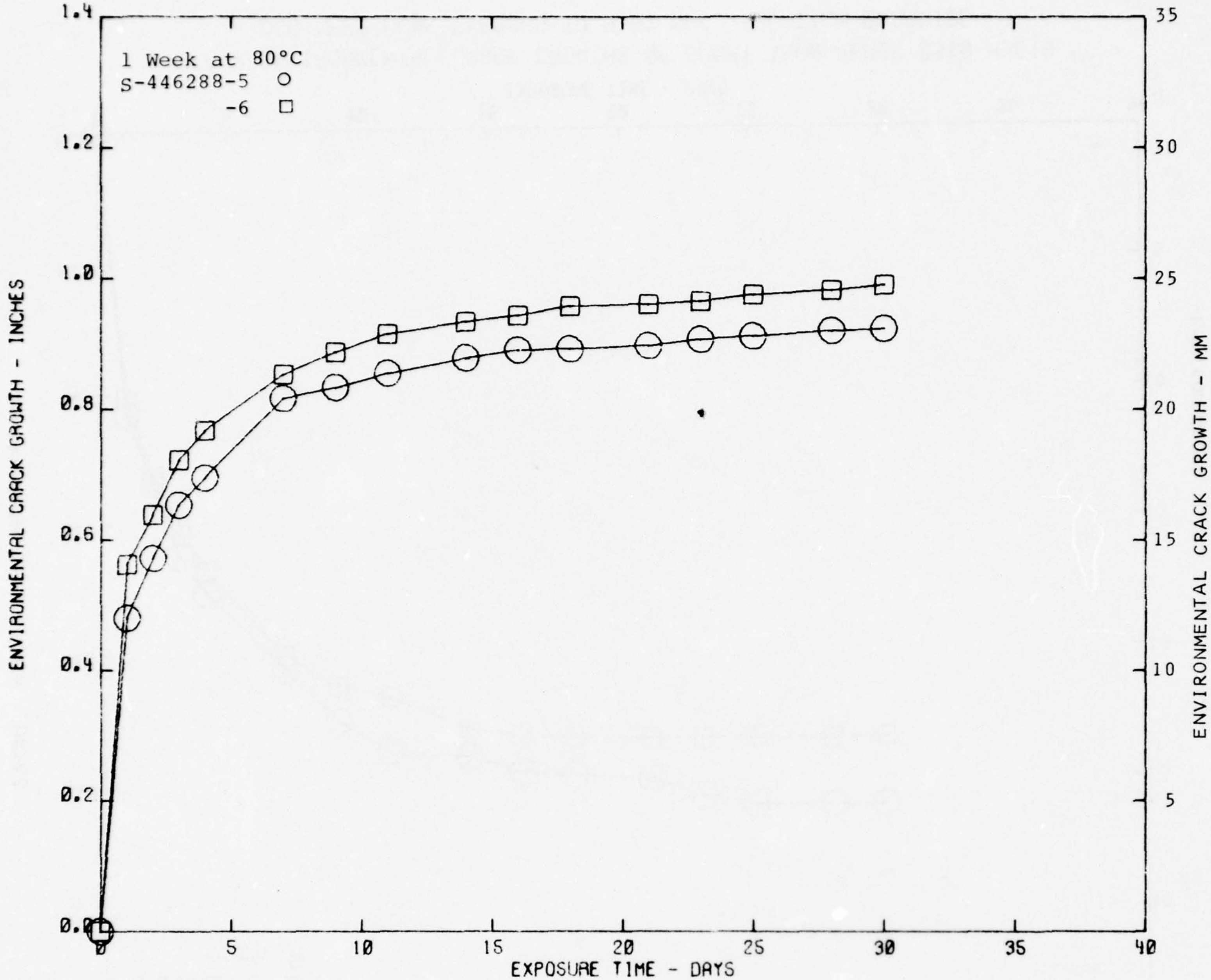

FIG.3 ENVIRONMENTAL CRACK GROWTHS OF SHORT TRANSVERSE CS19-H3E19 DCB SPECIMENS EXPOSED TO 3.5% NACL SOLUTION DROPWISE

Figure 4

S-446288-SL2 100X H_3PO_4 Etch

CS19-H3E19 DCB SPECIMEN IN AS-FABRICATED CONDITION

Illustrates cracking (far right) at the crack tip in T/2 plane.

Figure 5

ENLARGEMENT (500X) OF CRACKING AT THE CRACK TIP IN FIG. 4

Note outlining of grain boundaries with precipitate and intergranular path of cracking.

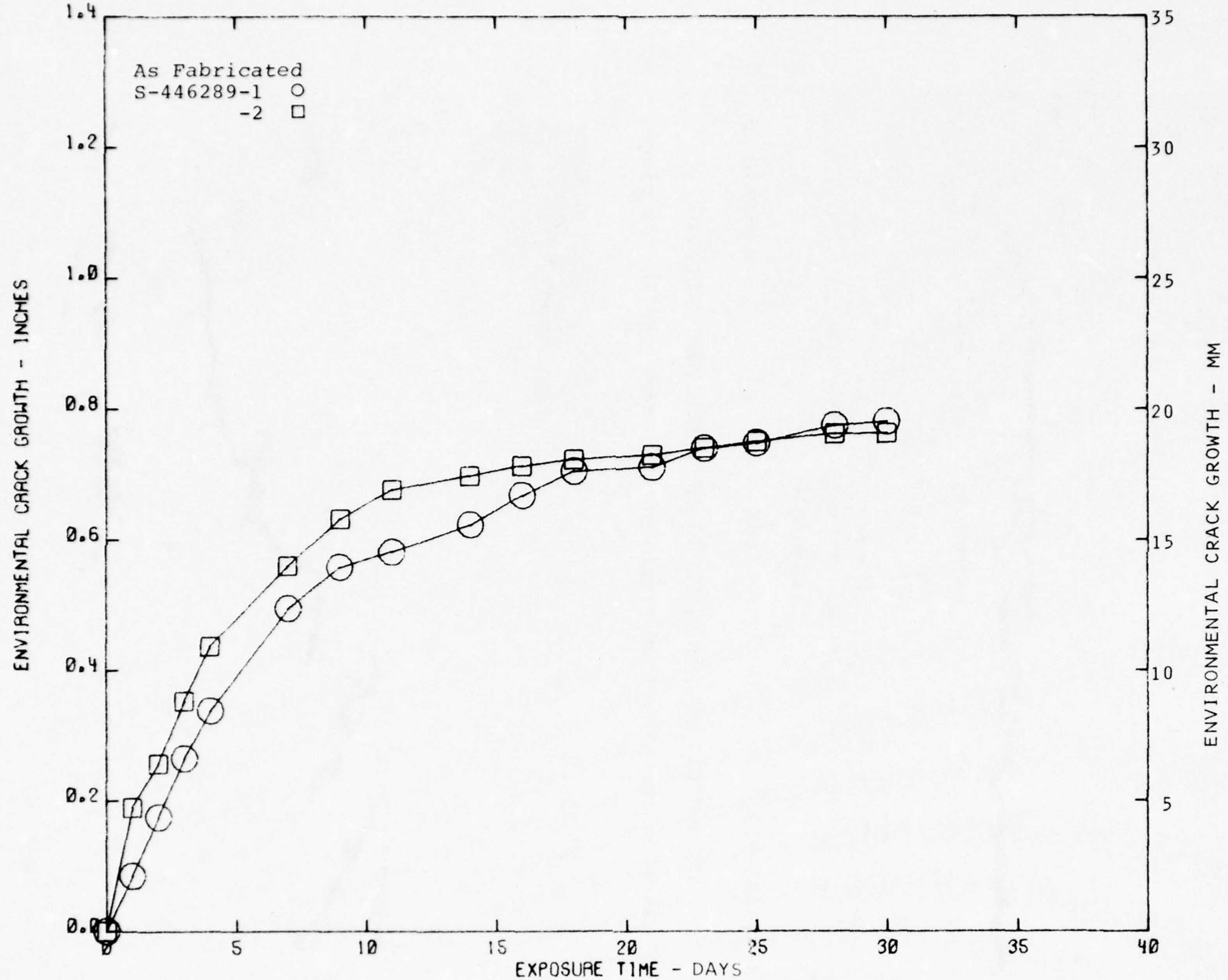

FIG. 6 ENVIRONMENTAL CRACK GROWTHS OF SHORT TRANSVERSE CS19-H1E48 DCB SPECIMENS EXPOSED TO 3.5% NACL SOLUTION DROPWISE

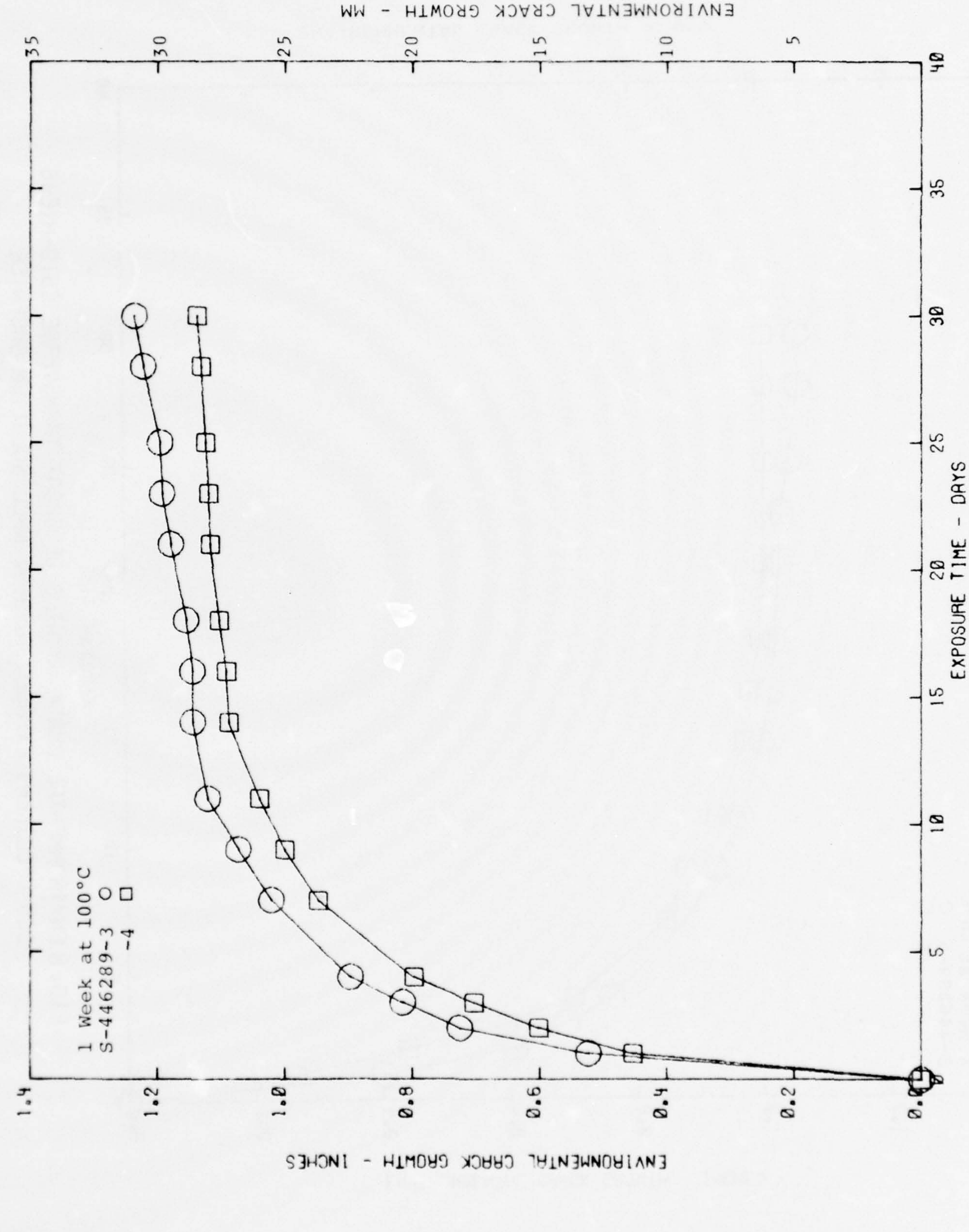

FIG. 7 ENVIRONMENTAL CRACK GROWTHS OF SHORT TRANSVERSE CS19-H1E48 DCB SPECIMENS EXPOSED TO 3.5% NACL SOLUTION DROPWISE

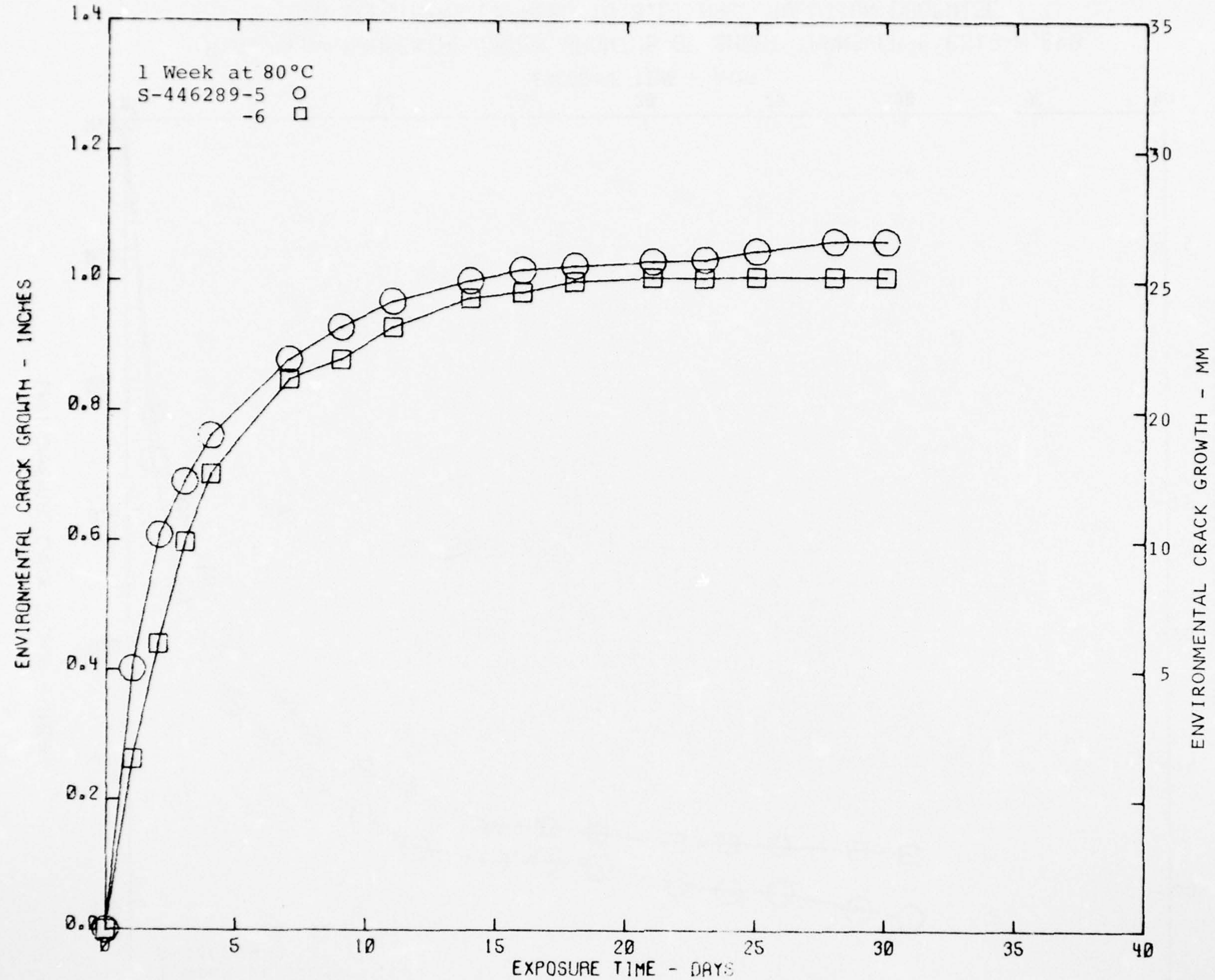

FIG. 8 ENVIRONMENTAL CRACK GROWTHS OF SHORT TRANSVERSE CS19-H1E48 DCB SPECIMENS EXPOSED TO 3.5% NACL SOLUTION DROPWISE

The stressed tensile bar and C-ring test results again indicated that the likelihood of SCC initiation in CS19-H3E19 plate was no greater than in 5456-H117 plate, but tests with fracture mechanics-type specimens showed the propagation of SCC in the S-L orientation under extreme stress intensity to be more rapid in CS19. If this is considered to be a serious limitation, successful service performance of CS19 would be dependent upon avoiding high short-transverse tensile stresses.

Resistance to General Corrosion in Sea Water

To determine the general corrosion resistance in sea water, 6.3 mm and 25.4 mm thick CS19 alloy plates were tested in quiescent sea water as 102 mm x 305 mm (4" x 12") panels and in flowing sea water (610 mm/sec or 2 ft/sec) as 102 mm x 152 mm (4" x 6") panels. Because Alcoa Laboratories does not have facilities to perform these tests, the sea water tests were performed in the standard facilities maintained at Wrightsville Beach, North Carolina, by the International Nickel Company's Francis L. LaQue Corrosion Laboratory.

For both quiescent and flowing sea water, tests were also made for some of the other tempers included in the initial evaluation program and not just for the H3E19 temper plates.

Quiescent Sea Water. Table 12 shows the results of visual examinations of panels of as-fabricated plate from both large and small size ingot after 180 days' exposure totally immersed in sea water. The panels showed excellent resistance to corrosion for both thicknesses of plate with no attack or only minute blisters or pits observed. The results were similar to those previously observed for 25.4 mm laboratory-fabricated CS19 plate and 5456-H117 alloy plate in the test and exploratory development contract.[1] In this work, no appreciable corrosion was observed after 406 days' exposure for panels of CS19-type alloy compositions in the original series of materials evaluated.

Flowing Sea Water. A similar group of panels (Table 13) was exposed to flowing sea water (610 mm/sec or 2 ft/sec) for a period of 180 days. Visual examinations revealed excellent resistance to corrosion in the as-fabricated condition with no significant attack of the surface or edges. The performance of the 25.4 mm thick CS19 plate was similar to that observed for the laboratory-fabricated CS19 and 5456-H117 alloy plate.[1]

As in the case of the quiescent sea water tests, the performance of CS19-H3E19 was at least comparable to that of 5456-H117 plate.

TABLE 12

RESISTANCE TO CORROSION OF CS19 PLATE AFTER 180 DAYS' EXPOSURE TO QUIESCENT SEA WATER

Thickness	Temper	S-No.	As-Fabricated	After 7 Days at 100°C	Annealed
		300 mm x 960 mm x 3050 mm (12" x 38" x 120") Ingot			
6.3 mm (.250")	H1E48	438628	***	**	--
	H2E38	448726	***	***	--
	H3E19	438564	N	N	N
25.4 mm (1.0")	H3E19	438560	***	***	N
		460 mm x 1520 mm x 3800 mm (18" x 60" x 160") Ingot			
6.3 mm	H1E48	438568	***	**	--
	H3E19	438567	N	--	N
25.4 mm	H1E48	438566	***	***	--
	H3E19	438565	*	*	N

Notes: (1) 102 mm x 305 mm (4" x 12") panels were used.
(2) Test made at Francis L. LaQue Corrosion Laboratory, Wrightsville Beach, N.C.
(3) Code for visual examination:
N = no appreciable attack
* = A very few scattered mild pits on rolled surfaces
** = A few scattered sites of minute blisters and pits on rolled surfaces
*** = Many scattered sites of minute pitting on rolled surfaces

TABLE 13

RESISTANCE TO CORROSION OF CS19 PLATE AFTER 180 DAYS' EXPOSURE TO FLOWING SEA WATER

Thickness	Temper	S-No.	As-Fabricated	After 7 Days at 100°C	Annealed
		300 mm x 960 mm x 3050 mm (12" x 38" x 120") Ingot			
6.3 mm (.250")	H1E48	438628	N	N	--
	H2E38	448726	N	N	--
	H3E19	438564	N	N	N
25.4 mm (1.0")	H3E19	438560	N	N	N
		460 mm x 1520 mm x 3800 mm (18" x 60" x 160") Ingot			
6.3 mm	H1E48	438568	N	N	--
	H3E19	438567	N	N	N
25.4 mm	H1E48	438566	N	N	--
	H3E19	438565	N	N	N

Notes:
(1) 102 mm x 152 mm (4" x 6") panels were used.
(2) Flow rate was 610 mm/sec (2 ft/sec).
(3) Tests made at Francis L. LaQue Corrosion Laboratory, Wrightsville Beach, N.C.
(4) Code for visual examination:
N = no appreciable attack

After Elevated Temperature Exposure

To simulate the metallurgical changes that will be produced by long time natural aging during service, three thermal treatments were employed: one week at 100°C, one week at 80°C, and 30 days at 66°C. The more drastic treatment of one week at 100°C was used in most instances as it produces the more extreme degree of precipitation and its general usage is more commonly recognized.

Exfoliation Resistance

The results listed in Table 4 indicated that heating one week at 100°C did not affect the excellent resistance to exfoliation observed in the as-fabricated condition.

SCC Resistance

Long Transverse. The results contained in Table 10 demonstrated that stressed tensile bars and beam assemblies of material heated one week at 100°C were not adversely affected as no evidence of SCC was observed after an exposure period of 289 or 290 days.

Short Transverse. Table 11 shows that short transverse C-rings stressed to 75 and 50% of the long transverse yield strengths also maintained the same high resistance to SCC after heating as in the as-fabricated condition.

While these results were similar to the laboratory-fabricated CS19 plate and one lot of CS19-type composition evaluated in the test and exploratory development contract[1], a second lot in that program showed SCC similar to that of 5456-H117. Because of the limited number of comparative lots of both alloys tested to date, it can only be concluded that CS19 is showing some susceptibility to SCC but is not highly susceptible and therefore, it is not less resistant to SCC than 5456-H117 alloy plate.

Fracture Mechanics-Type Specimens. Extensive crack growth was observed for the double cantilever beam CS19 specimens after being heated one week at 100°C and one week at 80°C as graphically presented in Figures 2, 3, 7 and 8. The grain boundaries were almost continuously outlined with precipitate (Figure 9 at 100X and 10 at 500X) which resulted in intergranular SCC and a more rapid crack growth rate. This condition was also observed with heated 5456-H117 plate.[1]

Resistance to General Corrosion in Sea Water

Quiescent Sea Water. Panels of the 25.4 mm plate (Table 12) showed excellent resistance to corrosion in sea water in both the as-fabricated and heated conditions. In the case of the thinner 6.3 mm plate, the H1E48 temper heated one week at 100°C showed randomly scattered small blisters on both top and bottom surfaces for both size ingots.

Figure 9

S-446283-SL4 100X H_3PO_4 Etch

CS19-H3E19 DCB SPECIMENS, HEATED 7 DAYS AT 100°C

Illustrates cracking (far right) at the crack tip in T/2 plane.

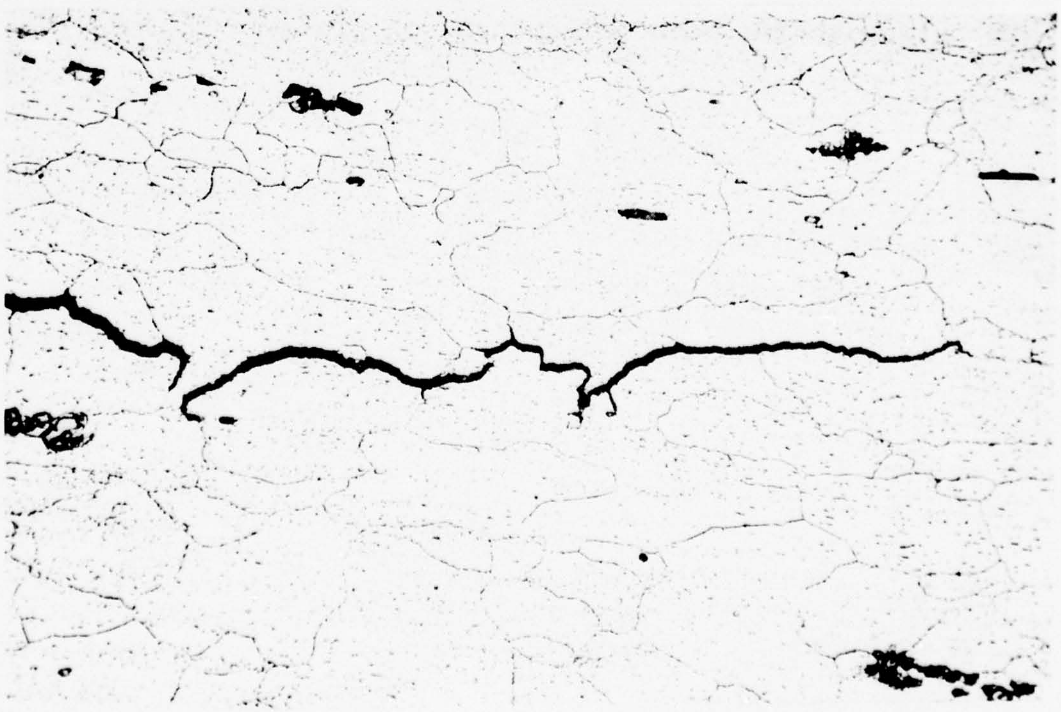

Figure 10

ENLARGEMENT (500X) OF CRACKING AT THE CRACK TIP IN FIG. 9

Note the nearly continuous outlining of grain boundaries with precipitate and resulting intergranular SCC.

This was not evident, however, in the as-fabricated condition nor with the thick plate. It should be noted that this material heated one week at 100°C when exposed to the accelerated exfoliation test (ASSET) showed no appreciable exfoliation attack (Table 4).

Flowing Sea Water. Heating one week at 100°C did not affect the excellent resistance to corrosion observed in the as-fabricated condition (Table 13).

CS19-O Plate

Resistance to General Corrosion in Sea Water

The results of visual examinations of panels of annealed plate exposed to quiescent and flowing sea water for 180 days (Tables 12 and 13) indicated excellent resistance to corrosion for both thicknesses of plate.

CS19-H3E19 PLATE WELDMENTS

Weld properties initially were determined on ten items of plate in various tempers produced from two sizes of production size ingots (Tables 5 and 6). These were GMA (MIG) welded using CS19-type filler electrode. Welding parameters, unless otherwise noted, were standard butt welds using a 60°V, 180-220 amps, 26-28 volts and shielding gas of 40% helium-60% argon at 1.7 m^3/hr (60 CFH).

An interpass cooling temperature of 120°C was employed initially in all tests to produce a desirable structure for minimizing susceptibility to SCC as had previously been demonstrated for 25.4 mm (1.0") CS19 plate.[1] Unsatisfactory SCC results on 6.3 mm (.250") plate led to a later investigation of other interpass cooling temperature and/or heating of 6.3 mm plate prior to welding in attempts to improve the weld/parent interface microstructure and SCC resistance.

The supply of CS19-type electrode was exhausted by the time the later investigations were started. Commercial 5556 electrode was used since the SCC failures were associated with the heat-affected zone in the parent plate as discussed subsequently. Previous work in the earlier contract had indicated strengths of weldments were equivalent for the two electrode alloys and this was also indicated in limited comparisons in the current work.

Tensile Properties

As-Welded Condition

The results of tensile tests of reduced section CS19-H3E19 weld specimens (Fig. III in Appendix) produced with 5556 and CS19 electrode are presented in Table 14 along with full section weldment test results from Tables 5 and 6. Reduced section test results for plate fabricated from the two sizes of ingot were somewhat inconsistent because of porosity but indicated about equivalent contributions to the strength of the weldment for the two electrodes.

After Elevated Temperature Exposure

Results of tensile testing of full section specimens after heating for 7-30 days at 66°C, 80°C, or 100°C are listed in Table 15. The weld strengths show slight decreases after heating in this temperature range. Although such thermal treatments induce precipitation of the Al_3Mg_2 phase, they do not have a large effect on strengths, although such precipitation can have adverse effects on SCC performance, particularly in recrystallized material.

The initial strengths of the 25.4 mm CS19-H3E19 plate weldments were slightly lower than reported in Table 5 for this product and the subsequent loss in yield strength upon elevated temperature storage brought yield strength values close to or slightly below the target 30 ksi minimum values.

TABLE 14

REDUCED SECTION TENSILE STRENGTHS FOR CS19-H3E19 WELDMENTS PRODUCED WITH CS19-TYPE AND 5556 ELECTRODE

				Full Section Specimens (Average)[1]						Reduced Section Specimens		
								Elongation in				
				Tensile Str.		Yield Str.		50.8 mm	254 mm	Tensile Str.		Location of
Thickness	S-No.	Ingot Size	Electrode	MPa	(ksi)	MPa	(ksi)	(2")	(10")	MPa	(ksi)	Fracture[2]
6.3 mm (.250")	438564	300 mm x 960 mm (12" x 38")	CS19	348	(50.5)	265	(38.5)	7.8	3.7	308	(44.7)	TW
										307	(44.6)	TW
										336	(48.8)	TW
									Avg.	317	(46.0)	
			5556	--	--	--	--	--	--	294	(42.7)	TW
										233	(33.8)[3]	TW
										325	(47.1)	TW
									Avg.	310	(44.9)	
	438567	460 mm x 1520 mm (18" x 60")	CS19	376	(54.6)	263	(38.1)	11.3	6.5	223	(32.3)[3]	TW
										232	(33.7)[3]	TW
										271	(39.3)	TW
									Avg.	271	(39.3)	
			5556	--	--	--	--	--	--	266	(38.6)	EW
										305	(44.3)	TW
										309	(44.8)	TW
									Avg.	294	(42.6)	
25.4 mm (1.0")	438560	300 mm x 960 mm	CS19	356	(51.6)	219	(31.7)	11.2	6.4	305	(44.2)	EW&TW
										336	(48.7)	EW&TW
										338	(49.0)	TW
									Avg.	326	(47.3)	
			5556	--	--	--	--	--	--	336	(48.7)	EW&TW
										330	(47.9)	EW
									Avg.	333	(48.3)	
	438565	460 mm x 1520 mm	CS19	354	(51.4)	219	(31.7)	13.2	7.4	283	(41.0)	EW&TW
										319	(46.3)	EW
										323	(46.9)	EW
									Avg.	308	(44.7)	
			5556	--	--	--	--	--	--	333	(48.3)	EW&TW
										333	(48.3)	TW
										335	(48.6)	TW
									Avg.	334	(48.4)	

Notes:
(1) Averages of three tests -- See Tables 5 and 6.
(2) TW is through centerline of weld; EW is edge of weld.
(3) Values disregarded in averages because of excessive porosity present.

TABLE 15

WELD STRENGTHS OF CS19-H3E19 PLATE WELDMENTS AFTER EXTENDED STORAGE AT ELEVATED TEMPERATURES

Thickness	S-No.	Ingot Size	Electrode Alloy	As-Welded Tensile Str. MPa	(ksi)	Yield Str. MPa	(ksi)	Elong. - % in 50.8 mm (2")	254 mm (10")	After 30 Days at 66°C Tensile Str. MPa	(ksi)	Yield Str. MPa	(ksi)	Elong. - % in 50.8 mm (2")	254 mm (10")
6.3 mm (.250")	438564	300 mm x 960 mm (12" x 38")	CS19	411	(59.6)	281	(40.8)	11.0	5.2	379	(54.9)	283	(41.1)	7.5	3.4
				407	(59.0)	286	(41.5)	11.5	5.0	417	(60.5)	283	(41.1)	11.0	9.7
				412	(59.8)	287	(41.6)	11.5	5.3	--	--	--	--	--	--
			Avg.	410	(59.5)	285	(41.3)	11.3	5.2	398	(57.7)	283	(41.1)	9.2	6.6
	438567	460 mm x 1520 mm (18" x 60")	CS19	319	(46.2)	269	(39.0)	6.5	2.1	414	(60.1)	265	(38.4)	14.5	9.5
				390	(56.5)	271	(39.4)	12.0	6.4	412	(59.7)	266	(38.6)	15.0	10.2
				406	(59.3)	272	(39.5)	14.5	8.8	350	(50.8)	265	(38.4)	7.5	3.6
			Avg.	372	(54.0)	271	(39.3)	11.0	5.8	392	(56.9)	266	(38.5)	12.3	7.8
25.4 mm (1.0")	438560	300 mm x 960 mm	CS19	316	(45.9)	211	(30.5)	9.5	4.5	328	(47.6)	204	(29.6)	11.0	5.6
				328	(47.6)	210	(30.4)	12.0	6.4	344	(49.9)	205	(29.7)	13.0	7.3
				349	(50.6)	210	(30.4)	13.0	6.8	302	(43.8)	204	(29.6)	9.5	4.4
			Avg.	331	(48.0)	210	(30.4)	11.5	5.9	325	(47.1)	204	(29.6)	11.2	5.8
	438565	460 mm x 1520 mm	CS19	356	(51.7)	214	(31.1)	15.3	8.6	346	(50.2)	212	(30.7)	13.0	7.2
				358	(51.9)	214	(31.1)	15.5	8.7	352	(51.0)	211	(30.6)	13.0	8.0
				354	(51.3)	214	(31.1)	15.0	8.7	361	(52.4)	211	(30.6)	13.5	8.3
			Avg.	356	(51.7)	214	(31.1)	15.3	8.6	353	(51.2)	211	(30.6)	13.2	7.8
				After 7 Days at 80°C						After 7 Days at 100°C					
6.3 mm (.250")	438564	300 mm x 960 mm	CS19	415	(60.2)	284	(41.2)	11.0	5.5	407	(59.4)	280	(40.7)	11.0	5.2
				423	(61.3)	288	(41.7)	12.0	6.3	423	(61.3)	281	(40.8)	12.0	5.2
				414	(60.0)	286	(41.5)	11.0	5.5	407	(59.4)	282	(40.9)	10.5	6.3
			Avg.	417	(60.5)	288	(41.8)	11.3	5.8	414	(60.0)	281	(40.8)	11.2	5.6
	438567	460 mm x 1520 mm	CS19	404	(58.6)	266	(38.6)	13.5	8.6	412	(59.8)	263	(38.1)	13.0	9.0
				418	(60.6)	268	(38.9)	15.5	10.6	417	(60.5)	262	(38.0)	14.5	9.5
				390	(58.0)	253	(36.7)	15.5	9.1	383	(55.5)	264	(38.2)	10.0	6.0
			Avg.	407	(59.1)	263	(38.1)	14.8	9.4	404	(58.6)	263	(38.1)	12.7	8.2
25.4 mm (1.0")	438560	300 mm x 960 mm	CS19	339	(49.1)	206	(29.8)	11.5	6.7	404	(50.6)	202	(29.3)	12.0	7.1
				330	(47.8)	205	(29.7)	11.5	6.2	331	(48.0)	201	(29.2)	11.0	6.1
				352	(51.1)	205	(29.7)	12.5	7.3	353	(51.1)	201	(29.2)	12.5	7.6
			Avg.	340	(49.3)	205	(29.7)	11.8	6.7	344	(49.9)	201	(29.2)	11.8	6.9
	438565	460 mm x 1520 mm	CS19	336	(48.7)	208	(30.2)	13.0	7.5	347	(50.3)	205	(29.7)	14.0	8.9
				344	(49.9)	208	(30.2)	13.0	7.5	403	(50.5)	207	(30.0)	15.5	9.2
				351	(50.9)	209	(30.3)	13.5	8.7	331	(48.0)	207	(30.0)	12.5	7.0
			Avg.	343	(49.8)	208	(30.2)	13.2	7.9	342	(49.6)	206	(29.9)	14.0	8.4

Note: MIG welds with 120°C interpass cooling temperature.

Fracture Toughness

In a manner similar to fracture toughness testing of the parent plate, CS19-H3E19 plate weldments were tested across the weld using specimens with the notch located in the weld bead. For 6.3 mm plate, double-notched sheet specimens (Fig. IV in Appendix) were employed while notched, round specimens were used for 25.4 mm plate.

Prior fracture toughness tests of 25.4 mm plate weldments in the test and development contract indicated CS19-H1E48 and 5456-H117 MIG weldments with Al-7Mg-0.1Ti electrode alloy had similar fracture toughness characteristics.[1] Current notch-tensile test results listed in Table 16 for 25.4 mm CS19-H3E19 plate MIG welded with CS19-type electrode show notch-tensile strength/yield strength (NTS/YS) values of about 1.7 compared to 1.8 for the H1E48 plate weldments in the earlier work. There is some implied advantage to weld toughness with the use of CS19 electrode.

The fracture toughness of the 6.3 mm plate weldments as measured by notch-tensile/yield strength ratios is considerably lower than that of 25.4 mm plate and is probably a reflection of the poor weld quality experienced with the 6.3 mm plate weldments as well as of the higher strength and lower ductility of the thinner parent plate.

TABLE 16

NOTCH-TENSILE TEST RESULTS FOR CS19-H3E19 PLATE WELDMENTS[1]

Thickness	Ingot Size	S-No.	Electrode	Notch-Tensile Str. MPa	(ksi)	Yield Str.[2] MPa	(ksi)	NTS/YS
6.4 mm (.250")	300 mm x 960 mm (12" x 38")	438564	CS19	261	(37.8)	267	(38.7)	.98
				259	(37.5)	266	(38.6)	.97
				261	(37.9)	264	(38.3)	.99
			Avg.	260	(37.7)	265	(38.5)	.98
			5556	239	(34.6)			
				239	(34.6)			
				247	(35.8)			
			Avg.	241	(35.0)			
	460 mm x 1520 mm (18" x 60")	438567	CS19	257	(37.3)	260	(37.7)	.99
				255	(37.0)	263	(38.1)	.97
				256	(37.2)	265	(38.4)	.97
			Avg.	256	(37.2)	263	(38.1)	.98
			5556	240	(35.8)			
				232	(33.6)			
				248	(36.0)			
			Avg.	242	(35.1)			
25.4 mm (1.0")	300 mm x 960 mm	438560	CS19	361	(52.3)	220	(31.8)	1.64
				362	(52.5)	219	(31.7)	1.66
				366	(53.1)	218	(31.6)	1.65
			Avg.	363	(52.6)	219	(31.7)	1.66
			5556	361	(52.3)			
				358	(51.9)			
				358	(51.9)			
			Avg.	359	(52.0)			
	460 mm x 1520 mm	438565	CS19	365	(52.9)	219	(31.7)	1.65
				385	(55.9)	218	(31.6)	1.75
				379	(54.8)	220	(31.9)	1.70
			Avg.	376	(54.5)	219	(31.7)	1.70
			5556	346	(50.2)			
				353	(51.2)			
				348	(50.5)			
			Avg.	349	(50.6)			

Notes: (1) MIG weld with 120°C interpass cooling temperature.
(2) Full section weldment yield strength from Tables 5 and 6.

Weld Ductility

Weld ductility as measured by free-bend specimens (Fig. V and VI in the Appendix) are presented in Table 17. Guided face, guided root, or free bend specimens are an added measure of determining weld soundness by determining their ability to bend satisfactorily over a bend radius without fracture or developing cracks or other open defects during bending without such defects exceeding a specified size after bending. The results show that 25.4 mm CS19-H3E19 plate weldments are quite ductile, are identical for both 5556 and CS19 electrodes, and are similar to those of 5456-H117 commercial plate weldments.

For 6.3 mm CS19-H3E19 plate weldments, weld ductility results were somewhat erratic which is attributed to the inconsistency in weld quality. Where 180° bends were obtained, the weld ductility was comparable to that of weldments of 1.0" CS19-H3E19 plate and to 5456-H117 commercial plate weldments.

Corrosion Resistance of CS19 Weldments

The weldments of CS19-H3E19 plate were subjected to the same types of corrosion evaluation as the parent plate, i.e., exfoliation and stress-corrosion susceptibility in accelerated tests and general corrosion in quiescent and flowing sea water. Evaluations were made of the as-welded plate and after exposure to elevated temperatures.

TABLE 17

GUIDED BEND TESTS OF CS19-H3E19 PLATE WELDMENTS

				Guided Root Bend			Guided Face Bend		
Thickness	Ingot Size	S-No.	Electrode	Radius	Angle, Degrees	Remarks	Radius	Angle, Degrees	Remarks
6.3 mm (.250")	300 mm x 960 mm (12" x 38")	438564	CS19	4T	180	OK	4T	180	F-EW
				4T	180	OK	4T	180	OK
				4T	180	OK	4T	180	OK
			5556	4T	180	OK	4T	100	F-EW
				4T	180	OK	4T	180	F-EW
				4T	95	F-TW	4T	100	F-EW
	460 mm x 1520 mm (18" x 60")	438567	CS19	4T	180	OK	4T	180	OK
				4T	180	OK	4T	180	OK
				4T	95	F-EW	4T	180	OK
			5556	4T	180	OK	4T	180	OK
				4T	180	OK	4T	180	OK
				4T	140	F-EW	4T	180	OK
25.4 mm (1.0")	300 mm x 960 mm	438560	CS19	3-1/2T	180	OK	3-1/2T	180	OK
				3-1/2T	180	OK	3-1/2T	180	OK
			5556	3-1/2T	180	OK	3-1/2T	180	OK
				3-1/2T	180	OK	3-1/2T	180	OK
				3-1/2T	180	OK	3-1/2T	180	OK
	460 mm x 1520 mm	438565	CS19	3-1/2T	180	OK	3-1/2T	180	OK
				3-1/2T	180	OK	3-1/2T	180	OK
				3-1/2T	180	OK	3-1/2T	180	OK
			5556	3-1/2T	180	OK	3-1/2T	180	OK
				3-1/2T	180	OK	3-1/2T	180	OK
				3-1/2T	180	OK	3-1/2T	180	OK

Notes: (1) MIG as-welded, 120°C interpass cooling.
(2) EW - Edge of weld failures.
(3) TW - Through the weld failures.

As-Welded Condition

Exfoliation Resistance

Butt-welded strip specimens, 38 mm x 203 mm (1-1/2" x 8") from two lots each of 6.3 mm and 25.4 mm thick CS19-H3E19 plate welded with CS19 filler wire were exposed to ASSET to determine their resistance to exfoliation. The results presented in Table 18 for as-welded and heated specimens showed no evidence of exfoliation for the as-welded specimens.

SCC Resistance

For stress-corrosion testing, full thickness beam specimens 25.4 mm wide x 508 mm long (1" x 20") with machined edges and weld beads intact were stressed to 75% of the weldment yield strength and exposed to the 3-1/2% NaCl alternate immersion test. A stressed beam assembly and the stressing formula are shown in Figure VII of the Appendix. In the loading procedure it was assumed that the beams had a uniform thickness and were straight, thus neglecting any effect of bow in the joint or of stress concentrations in the fillets at the edges of the weld beads.

Beam assemblies of plant-fabricated 6.3 mm and 25.4 mm thick CS19-H3E19 plate showed no evidence of SCC in the as-welded condition after an exposure of 188 days (Table 19) which is again indicative of the good resistance to SCC reported for the 25.4 mm thick laboratory-fabricated

TABLE 18

RESISTANCE TO EXFOLIATION OF CS19 WELDMENTS AFTER EXPOSURE TO ASSET[1] TEST

Thickness	Temper	S-No.	Filler Alloy	-1 As-Welded	-2 Heated 7 Days/100°C	-3 Heated 7 Days/80°C	-4 Heated 30 Days/66°C
300 mm x 960 mm x 3050 mm (12" x 38" x 120") Ingot							
6.3 mm (.250")	H3E19	438564	CS19	N	N	N	N
25.4 mm (1.000")	H3E19	438560	CS19	N	N	N	N
460 mm x 1520 mm x 3800 mm (18" x 60" x 150") Ingot							
6.3 mm	H3E19	438567	CS19	N	E-B	N	N
25.4 mm	H3E19	438565	CS19	N	N	N	N

Note: (1) 24 hours total immersion in solution of 1N NH_4Cl, 0.25 N NH_4NO_3, 0.01M ammonium tartrate and 3 g/l hydrogen peroxide at 66°C; N is no appreciable attack; E is exfoliation attack with degree of severity from A to D.

TABLE 19

RESISTANCE TO STRESS-CORROSION CRACKING OF CS19 WELDMENTS EXPOSED AS STRESSED BEAM ASSEMBLIES TO 3-1/2% NaCl SOLUTION BY ALTERNATE IMMERSION

				Beam Assemblies - Stressed 75% Weldment Y.S.							
			Filler	As-Welded		Heated 7 Days/100°C		Heated 7 Days/80°C		Heated 30 Days/66°C	
Thickness	Temper	S-No.	Alloy	F/N[1]	Days to Fail	F/N	Days to Fail	F/N	Days to Fail	F/N	Days to Fail
300 mm x 960 mm x 3050 mm (12" x 38" x 120") Ingot											
6.3 mm (.250")	H3E19	438564	CS19	0/2	OK-188	2/2	4,4	0/2	OK-188	2/2	4,9
25.4 mm (1.000")	H3E19	438560	CS19	0/2	OK-188	0/2	OK-188	0/2	OK-188	0/2	OK-188
460 mm x 1520 mm x 3800 mm (18" x 60" x 150") Ingot											
6.3 mm	H3E19	438567	CS19	0/2	OK-188	2/2	7,7	0/2	OK-188	1/2	7, OK-188
25.4 mm	H3E19	438565	CS19	0/2	OK-188	0/2	OK-188	0/2	OK-188	0/2	OK-188

Note: (1) F/N designates number of specimens failed over number of specimens exposed.

CS19 plate in the test and exploratory contract.[1] In the latter, no SCC failures in the as-welded beam assemblies of CS19-H1E48 plate occurred in exposures up to 365 days.

Resistance to General Corrosion in Sea Water

Quiescent Sea Water. Table 20 lists results of examinations of weldments of CS19-H3E19 alloy after 180 days' immersion in quiescent sea water. The panels showed excellent resistance to corrosion with no indication of any special attack of the weld zone or in the edges of the plate. The performance was similar to that observed for laboratory-fabricated 5456 and CS19 plate in the test and exploratory contract work.

Flowing Sea Water. A similar group of panels (Table 21) was exposed to flowing sea water for a period of six months. Visual examinations revealed excellent resistance to corrosion. As in the case of the quiescent sea water tests, the performance of plant-fabricated CS19-H3E19 plate was comparable to that of laboratory-fabricated 5456 and CS19 plate in the earlier work.

After Elevated Temperature Exposure

As in the case of parent plate, butt-welded strip specimens were heated at the various times and temperatures--one week/100°C, one week/80°C, and 30 days/66°C--to simulate the various metallurgical changes that might be expected to occur in service.

TABLE 20

RESISTANCE TO CORROSION OF CS19-H3E19 WELDMENTS[1] AFTER 180 DAYS' EXPOSURE TO QUIESCENT SEA WATER

Thickness	S-No.	-1 As-Welded	-2 7 Days/100°C	-3 7 Days/80°C	-4 30 Days/66°C
300 mm x 960 mm x 3050 mm (12" x 38" x 120") Ingot					
6.3 mm (.250")	438564	N	*	N	N
25.4 mm (1.0")	438560	N	N	N	N
460 mm x 1520 mm x 3800 mm (18" x 60" x 150") Ingot					
6.3 mm	438567	N	*	N	N
25.4 mm	438565	N	N	N	N

Notes: (1) Flow rate was 610 mm/sec (2 ft/sec). CS19 alloy filler wire

(2) Code for visual examination:
N = No appreciable attack
* = A few scattered sites of minute blisters and pits on rolled surfaces.

TABLE 21

RESISTANCE TO CORROSION OF CS19-H3E19 WELDMENTS[1] AFTER 180 DAYS' EXPOSURE TO FLOWING SEA WATER

Thickness	S-No.	-1 As-Welded	-2 7 Days/100°C	-3 7 Days/80°C	-4 30 Days/66°C
	300 mm x 960 mm x 3050 mm (12" x 38" x 120") Ingot				
6.3 mm (.250")	438564	N	N	N	N
25.4 mm (1.0")	438560	N	N	N	N
	460 mm x 1520 mm x 3800 mm (18" x 60" x 150") Ingot				
6.3 mm	438567	N	N	N	N
25.4 mm	438565	N	N	N	N

Notes: (1) Flow rate was 610 mm/sec (2 ft/sec).
CS19 alloy filler wire

(2) Code for visual examination:
N = No appreciable attack

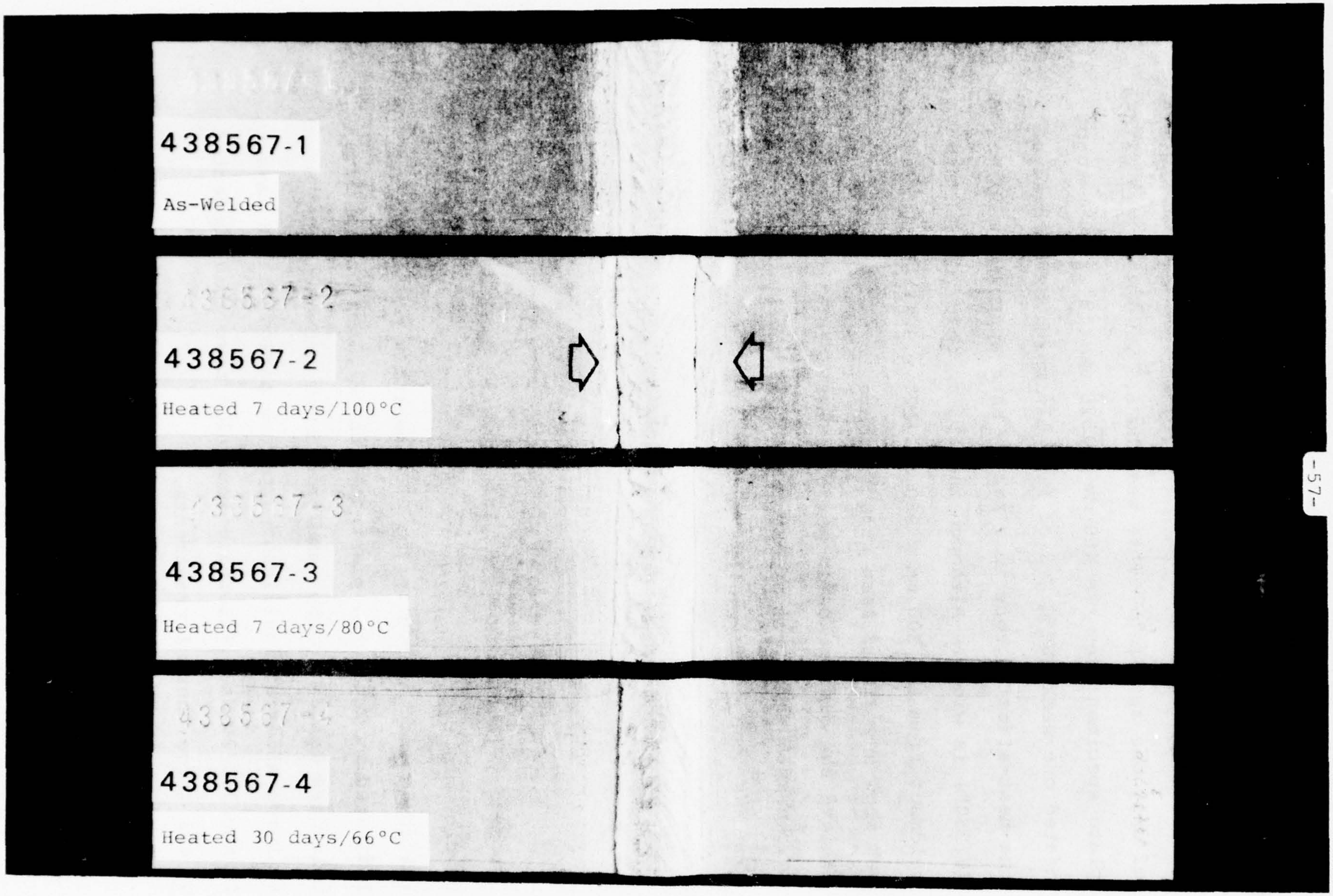

Figure 11

6.3 mm (.250") Thick CS19-H3E19 Plate Welded with CS19 Filler Exposed to ASSET for 24 Hours
Note 3 mm to 6 mm wide band of exfoliation on each side of -2 specimen (see arrows).

Exfoliation Resistance

The results listed in Table 18 showed exfoliation of only one specimen. This was the 6.3 mm CS19-H3E19 welded plate specimen from the 460 mm x 1520 mm (18" x 60") ingot heated one week/100°C (-2 of Fig. 11) which exfoliated at the heat-affected zone in a narrow band approximately 6.3 mm (0.250") in width. Although the 6.3 mm thick CS19-H3E19 weldment from the 300 mm x 960 mm (12" x 38") ingot did not show any significant attack, there is no reason to believe the difference in performance is related to ingot thickness. This form of exfoliation at the heat-affected zone has been occasionally observed with thin 5456-H117 butt welds so that the performance of 6.3 mm thick CS19 alloy weldments is not completely unexpected.

SCC Resistance

Improved welding procedures were developed with the laboratory-fabricated CS19 plate for the test and exploratory development contract to overcome susceptibility to SCC initially encountered in the 25.4 mm thick plate.[1] As indicated in Table 19, plant-fabricated plate of the same thickness welded by the same procedures showed no SCC failures after a significant exposure period of 188 days in the 3-1/2% NaCl alternate immersion test when subjected to all three thermal treatments.

These welding procedures, however, were not effective with the 6.3 mm thick plate as SCC failures occurred in relatively short periods of time, four to nine days, for weldment specimens heated one week at 100°C and 30 days at 66°C. No failures, however, were observed with specimens heated for one week at 80°C.

Several of the failures were examined metallographically to determine the cause of failure. Figures 12 through 15 are photomicrographs of the 6.3 mm thick CS19-H3E19 weld specimen, S-438564-7, heated one week at 100°C, which failed after four days' exposure to the 3-1/2% NaCl solution by alternate immersion and is representative of the failures that occurred. Figure 12 shows the crack initiating at the toe of the weld and proceeding through the heat-affected zone in close proximity to the weld interface. Figure 13 is an enlargement (500X) of the initiation of the crack at the toe of the weld (Figure 12), and Figure 14 is an enlargement of the tip of the crack beyond that shown in Figure 12. Both figures indicate that the structure in the heat-affected zone is recrystallized and that the grain boundaries are continuously outlined with precipitate, thus providing the intergranular path for the SCC failures. These structures can be compared with the microstructures shown in Figure 15 which is parent plate away from the heat-affected zone. The grain structure is more elongated for the parent plate and shows less continuity of precipitate.

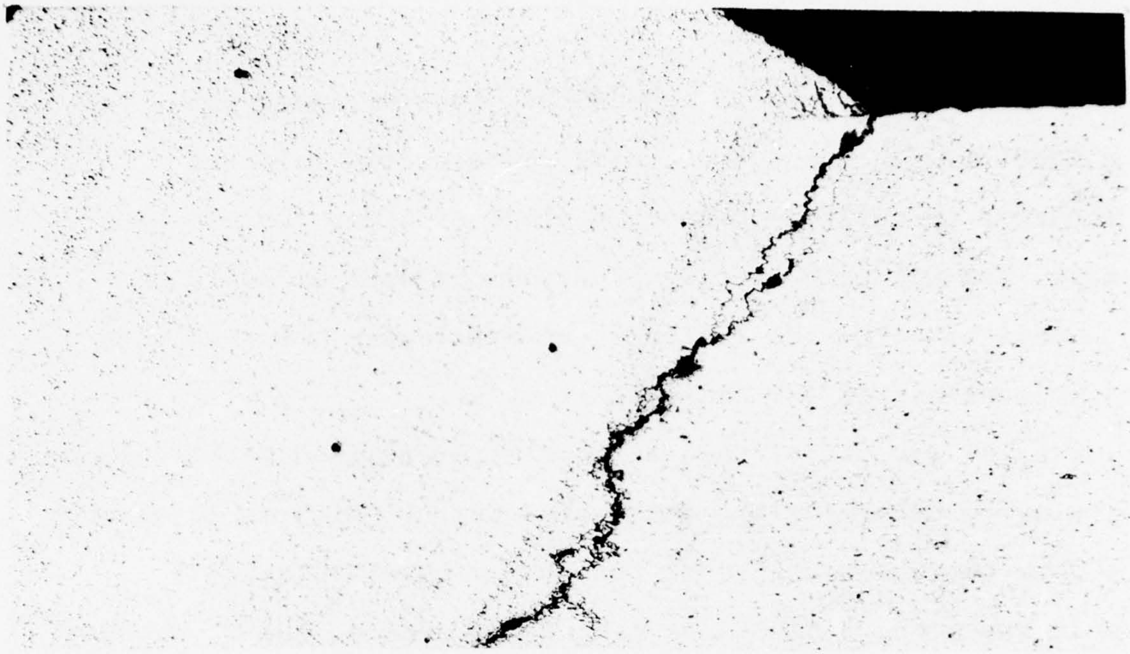

Figure 12

S-438564-7 50X H_3PO_4 Etch

6.3 mm (.250") CS19-H3E19 welded with CS19, 120°C interpass cooling; heated 7 days/100°C. Illustrates SCC cracking at heat-affected zone (HAZ).

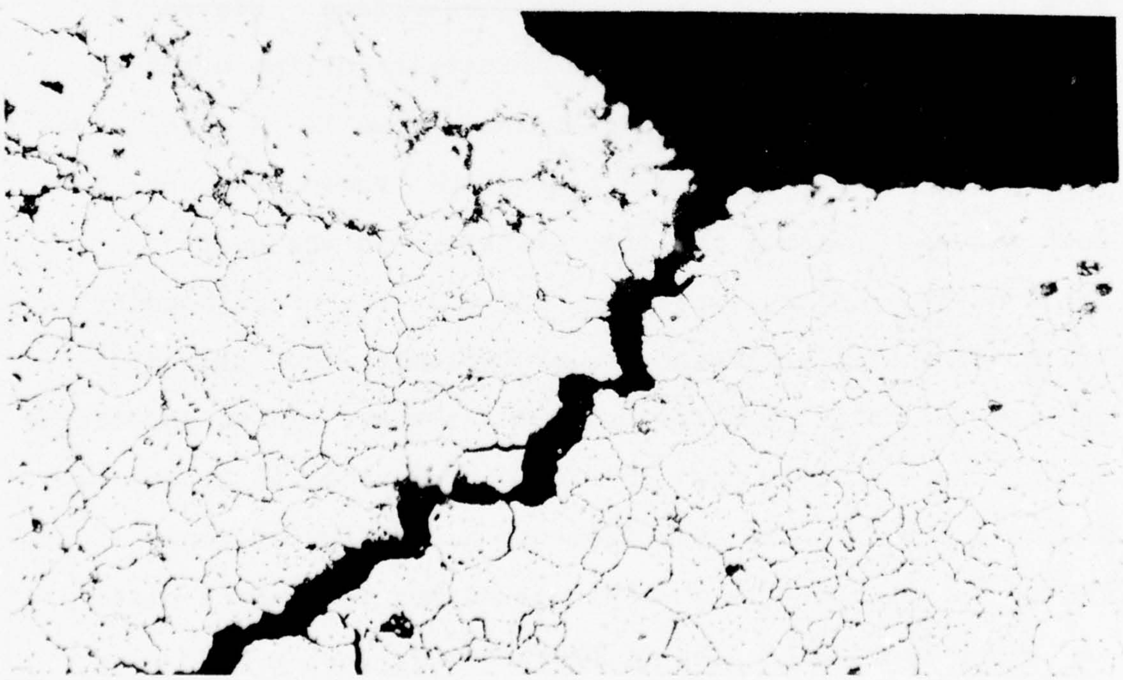

Figure 13

S-438564-7 500X H_3PO_4 Etch

Enlargement of Fig. 12 at toe of weld, shows initiation of cracking in recrystallized grain structure of HAZ.

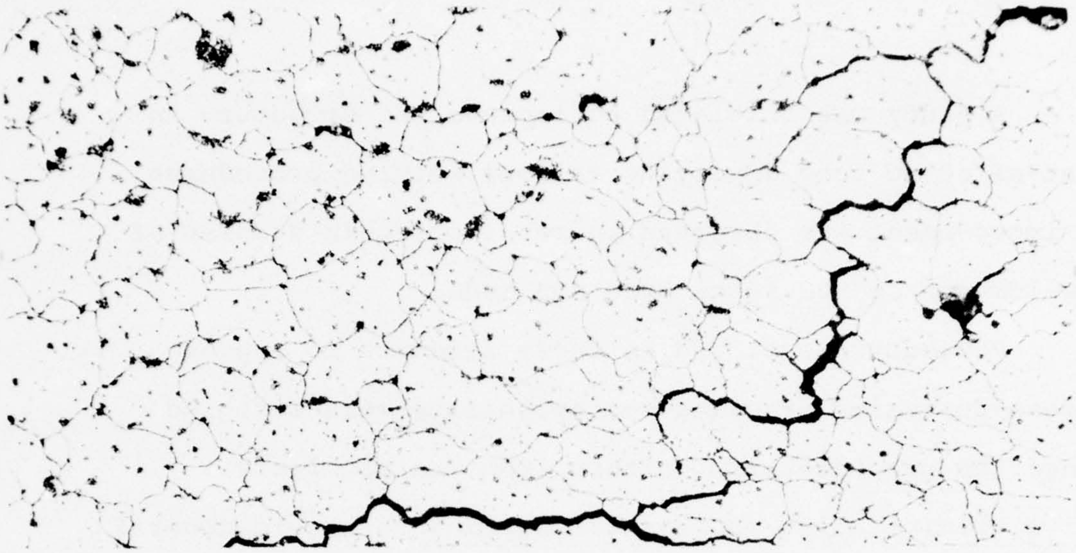

Figure 14

S-438564-7 500X H_3PO_4 Etch

Enlargement of specimen of Fig. 12 at tip of crack showing intergranular path of SCC failures. Grain boundaries of recrystallized structure continuously outlined with Al_3Mg_2 precipitate.

Figure 15

S-438564-7 500X H_3PO_4 Etch

6.3 mm (.250") CS19-H3E19 heated 7 days/100°C. Represents microstructure of parent plate remote from weld.

A study was initiated to improve the structure in the heat-affected zone employing various welding procedures, but no improvement was observed in metallographic studies of these weldments so SCC tests were not made.

Procedures employed in these attempts to improve the stress-corrosion cracking susceptibility were designed to change the precipitation pattern from one of highly selective precipitation on grain boundaries to a more general type and thus to reduce the readily available paths on which SCC might progress.

Changes in welding parameters were designed to slow down the cooling rate from the welding passes in order to permit a greater amount of precipitation to occur throughout the grain matrix. The changed welding parameters were the absence of cooling back-up plates, the placement of heat-sinks in the form of thick steel plates in areas adjacent to the weld bead during welding, and welds made with one pass (rather than three) to increase the heat of welding. None of the above procedures decreased the cooling rate sufficiently to improve the precipitation pattern from that obtained by the normal welding procedures.

The second program aimed at obtaining a more satisfactory microstructure in weldments of 6.3 mm plate involved both *H3E19* and *H2E38* temper plate given precipitation treatments of four hours at 232°C or one hour at 316°C to obtain a dense Al_3Mg_2 precipitate structure throughout the grains at the expense of slight decreases in strength. The weldments were also made with and without controlled interpass cooling at 120°C. The results of the SCC tests were not favorable (Table 22). Failures occurred in a relatively short period of time of four to eighteen days for all of the assemblies heated one week at 100°C. Table 23 contains the tensile test results for the thermally-treated plate illustrating the loss in strength with these treatments.

Resistance to General Corrosion in Sea Water

Quiescent Sea Water. The majority of the heated weldments (Table 20) showed no appreciable attack after six months' exposure to quiescent sea water. Two of the weldments in the H3E19 temper of the 6.3 mm thick plate developed a few scattered sites of minute blisters and pits on the rolled surfaces. Overall, the heated weldments showed excellent resistance to corrosion in sea water.

Flowing Sea Water. All of the heated weldments (Table 21) showed no appreciable attack after six months' exposure to the flowing sea water.

TABLE 22

RESISTANCE TO SCC OF 6.3 mm (0.250") CS19 WELDMENTS HEATED 7 DAYS AT 100°C AND EXPOSED AS STRESSED BEAM ASSEMBLIES TO 3-1/2% NaCl SOLUTION BY ALTERNATE IMMERSION

S-No.	Temper	Ingot Thickness	Precipitation Treatment	Interpass Cooling Temperature	Beam Assemblies - Stressed 75% of Y.S. F/N	Days to Fail
448726-2	H2E38	300 mm (12")	4 hr/232°C	--	2/2	6,6
438564-3	H3E19	300 mm (12")	4 hr/232°C	--	2/2	5,6
438567-1	H3E19	460 mm (18")	4 hr/232°C	--	2/2	4,5
448726-5	H2E38	300 mm	1 hr/316°C	--	2/2	4,4
438564-6	H3E19	300 mm	1 hr/316°C	--	2/2	6,6
438567-4	H3E19	460 mm	1 hr/316°C	--	2/2	5,6
448726-B	H2E38	300 mm	4 hr/232°C	120°C	2/2	6,11
438564-C	H3E19	300 mm	4 hr/232°C	120°C	2/2	4,6
438567-A	H3E19	460 mm	4 hr/232°C	120°C	2/2	6,13
448726-E	H2E38	300 mm	1 hr/316°C	120°C	2/2	4,5
438564-F	H3E19	300 mm	1 hr/316°C	120°C	2/2	17,18
438567-D	H3E19	460 mm	1 hr/316°C	120°C	2/2	13,22

Note: (1) 5556 alloy filler wire employed for all welds.

TABLE 23

TENSILE TEST RESULTS FOR WELDMENTS OF 6.3 mm (.250") CS19 PLATE GIVEN PRECIPITATION TREATMENTS AT 232°C AND 316°C

					As-Welded Tensile Properties					Tensile Properties After 7 Days/100°C				
					Tensile Str.		Yield Str.		Elongation,	Tensile Str.		Yield Str.		Elongation,
Plate Treatment	Interpass Cool	Temper	S-No.	Ingot Thickness	MPa	(ksi)	MPa	(ksi)	% in 50.8 mm	MPa	(ksi)	MPa	(ksi)	% in 50.8 mm
4 hr/232°C	--	H2E38	448726	300 mm (12")	319	(46.2)	230	(33.3)	6.5	335	(48.6)	227	(32.9)	8.0
		H3E19	438564	300 mm	343	(49.8)	243	(35.2)	8.0	321	(46.6)	243	(35.2)	6.0
			448567	460 mm (18")	288	(41.8)	225	(32.7)	6.5	400	(58.0)	229	(33.2)	13.0
1 hr/316°C	--	H2E38	448726	300 mm	327	(47.4)	228	(33.0)	8.0	352	(51.1)	223	(32.3)	9.5
		H3E19	438564	300 mm	299	(43.4)	236	(34.3)	7.5	248	(35.9)	230	(33.4)	4.0
			448567	460 mm	373	(54.1)	213	(31.0)	15.5	360	(52.2)	212	(30.7)	13.5
4 hr/232°C	120°C	H2E38	448726	300 mm	272	(39.5)	214	(32.8)	5.0	372	(54.0)	228	(33.0)	9.5
		H3E19	438564	300 mm	354	(51.4)	243	(35.2)	8.0	371	(53.9)	241	(34.9)	8.0
			448567	460 mm	350	(50.7)	226	(32.8)	10.5	315	(45.7)	228	(33.1)	6.0
1 hr/316°C	120°C	H2E38	448726	300 mm	321	(46.6)	225	(32.7)	7.5	357	(51.8)	225	(32.7)	5.7
		H3E19	438564	300 mm	290	(42.0)	232	(33.7)	6.5	310	(45.0)	229	(33.2)	6.0
			448567	460 mm	284	(41.2)	212	(30.8)	8.0	336	(48.7)	212	(30.8)	10.0

Note: (1) Tensile properties determined on full-thickness specimens.

SUMMARY

The primary objective of this contract was to determine the feasibility of rolling production size CS19 ingots on plant production rolling mills. Successful rolling of CS19 plate at Davenport Works without undue difficulty indicated that this alloy can be rolled commercially.

It was further indicated that CS19 plate produced by similar practices on laboratory equipment or on production mills had similar properties despite differences in the starting size of the ingots used.

Based on the initial screening evaluation which indicated the H1E48 and H3E19 tempers had the same strength and corrosion characteristics, it was decided to concentrate the complete testing program on the H3E19 temper which was the more advantageous temper from a production standpoint. The results of the more extensive tests, however, indicated some disadvantages to this temper compared to H1E48 temper; these were, first, a small loss in yield strength of H3E19 plate and possibly weldments after extended exposure to elevated temperatures and, secondly, a slightly lower as-welded yield strength in 25.4 mm (1.0") plate weldments by about 7-15 MPa (1-2 ksi). It should be noted that these observations are based on limited data but can be related to differences in the fabricating procedures employed for these

tempers. The 25.4 mm H3E19 plate obtained a higher proportion of its strength from cold working by a 4% stretch so a greater loss in strength could be anticipated by recovery in subsequent low temperature thermal treatments or from the heat of welding. No differences in corrosion characteristics were seen between H3E19 and H1E48 plate or weldments.

The production-rolled 25.4 mm plate demonstrated the same good corrosion characteristics of the 25.4 mm laboratory-rolled CS19-H1E48 plate and weldments in the previous test and exploratory development program.

Resistance to SCC for 6.3 mm (.250") plate weldments was good in the as-welded condition, but exposure to elevated temperatures simulating the effects of long time service made the weldments susceptible in accelerated SCC tests. In the previous test and exploratory development contract, weldments of 6.3 mm laboratory-rolled plate were not evaluated so that this situation had not been encountered previously.

The greater susceptibility to SCC of weldments of the thinner plate was attributed to its greater level of strain which was manifested in strength and toughness evaluations also. The heat of welding as a consequence produced a band of fine recrystallized grains adjacent to the fusion line, and these provided a path for SCC after precipitation of Al_3Mg_2 at grain boundaries during the elevated temperature treatments. Attempts to overcome this susceptibility were limited by the expiration of the time and funds for the contract and were not successful.

CONCLUSIONS

The major conclusion to be drawn from work done for this contract was that the rolling of CS19 plate on production rolling mills from production-size ingots is feasible. No effect of ingot size on the properties or characteristics of the plate products was observed.

The conclusions of the previous test and exploratory contract were to the effect that CS19 plate met its requirements, i.e., a work-hardenable aluminum alloy plate material which has an as-welded minimum tensile yield strength of 207 MPa (30 ksi) and corrosion and fracture toughness properties equivalent to or better than those of the present 5456-H116 or H117 alloys, except for mechanically-precracked specimens in the as-fabricated condition where CS19 showed more rapid SCC growth. Current work with production-rolled plate generally supports those conclusions except for one problem area which is the susceptibility to SCC of weldments of thin 6.3 mm CS19-H3E19 plate after exposure for extended periods to elevated temperatures to simulate the effects of long service times.

Further development work is needed in the following areas for the advancement of CS19 plate as a ship structure material: (1) development of fabricating and/or welding practices to overcome the susceptibility to SCC of thin 6.3 mm (.250") CS19 plate weldments after extended exposure to elevated temperatures; and (2) development of production mill fabricating practices over the complete range of thicknesses and widths for ship structure applications to produce transverse hot-rolled yield strengths of at least 228 MPa (33 ksi) with a minimum of stretching. This will assure meeting the 207 MPa minimum as-welded yield strength both initially and after extended exposure to elevated temperatures simulating the effects of long time service. Complete characterization of all structural and corrosion properties to provide design allowables for CS19 would be a corollary of this work.

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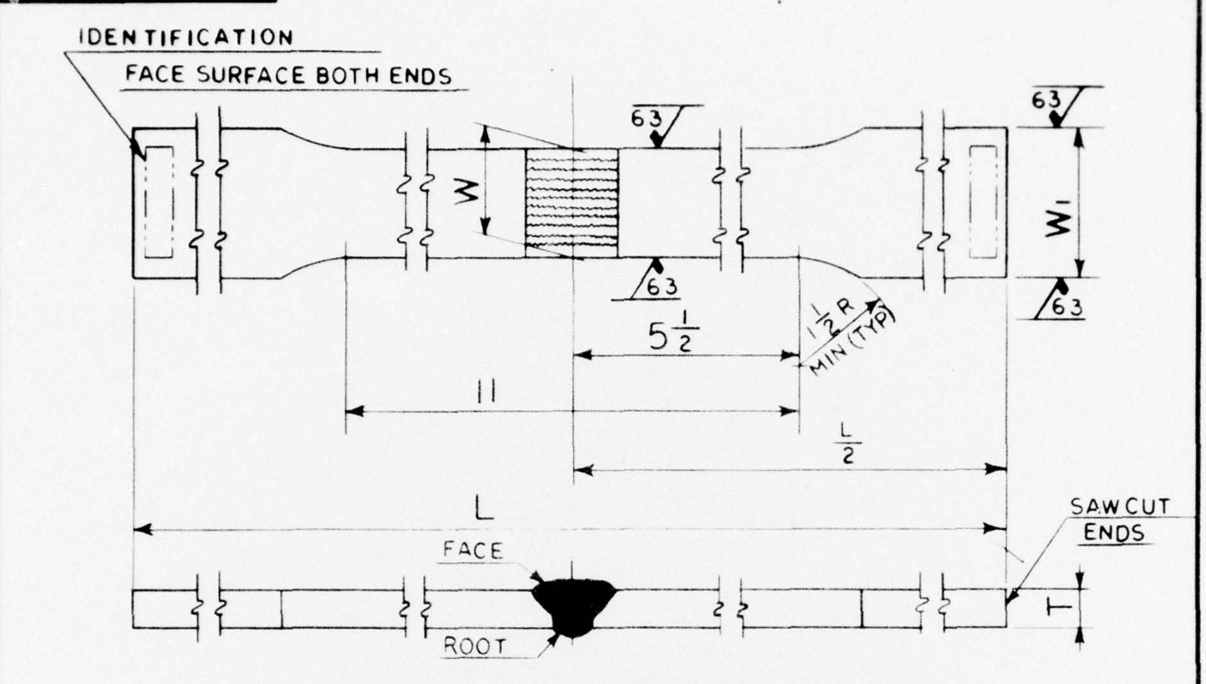
2. "Proposal to Explore the Feasibility of Production Rolling an Optimum Alloy System Which Has an As-Welded Yield Strength of 30 ksi Minimum," Aluminum Company of America, April 27, 1973.

3. Kaufman, J. G. and Holt, M.; "Fracture Characteristics of Aluminum Alloys," Alcoa Research Laboratories Technical Paper No. 18, 1965.

APPENDIX

L-7235-RK



~ TENSILE SPECIMEN — ▭ REQD ~

NOTES :

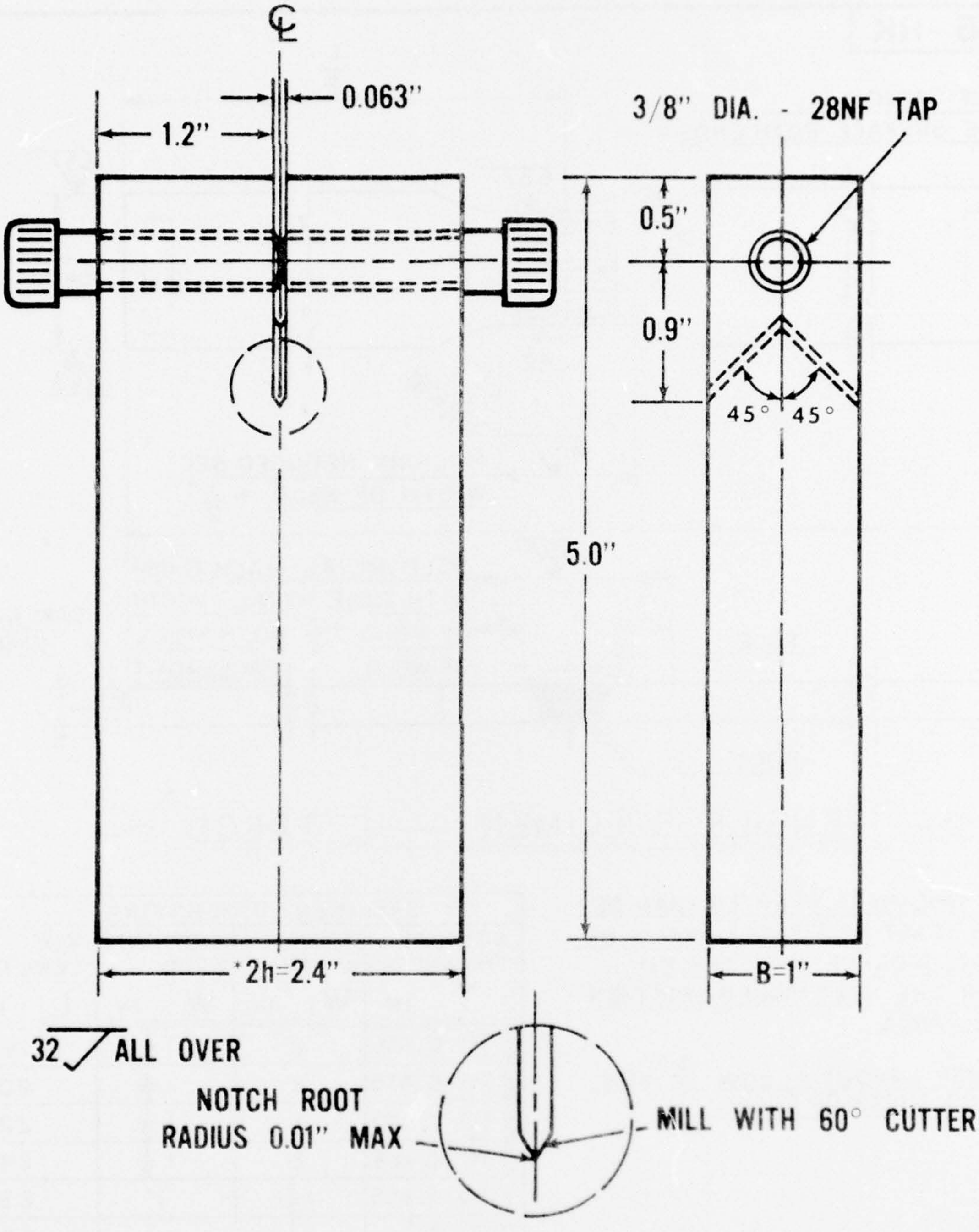
1. SPECIMEN THICKNESS GREATER THAN DECIMEL DIM (LAST N° 1ST COL) SHALL BE MACH IN ACCORDANCE WITH THE DIM SHOWN FOR THE NEXT HIGHER SPECIMEN THICKNESS RANGE

2. FOR SPECIMEN LAYOUT ALLOW 3/16" FOR SAWCUT AND FINISH OF EDGES

~ SPECIMEN DIMENSIONS ~

NOMINAL THICKNESS T IN	TOTAL WIDTH W1 IN	WIDTH AT WELD W IN	MIN LENGTH L IN
1/4 TO 0.356	2	1 1/2	20
3/8 TO 0.475	2	1 1/2	22
1/2 TO 0.720	2	1 1/2	24
3/4 TO 0.965	2	1 1/2	26
1" TO 1.455	1 1/2	1"	30
OVER 1 1/2	1 1/2	1"	32

Figure I - Full section weldment tensile specimen - 6.3 mm.



*NOTE: IF STOCK THICKNESS IS INSUFFICIENT FOR 2.4" BEAM HEIGHT, THIS DIMENSION MAY BE REDUCED

Figure II - Typical configuration of double cantilever beam specimen for stress-corrosion testing in short transverse direction (S-L orientation).

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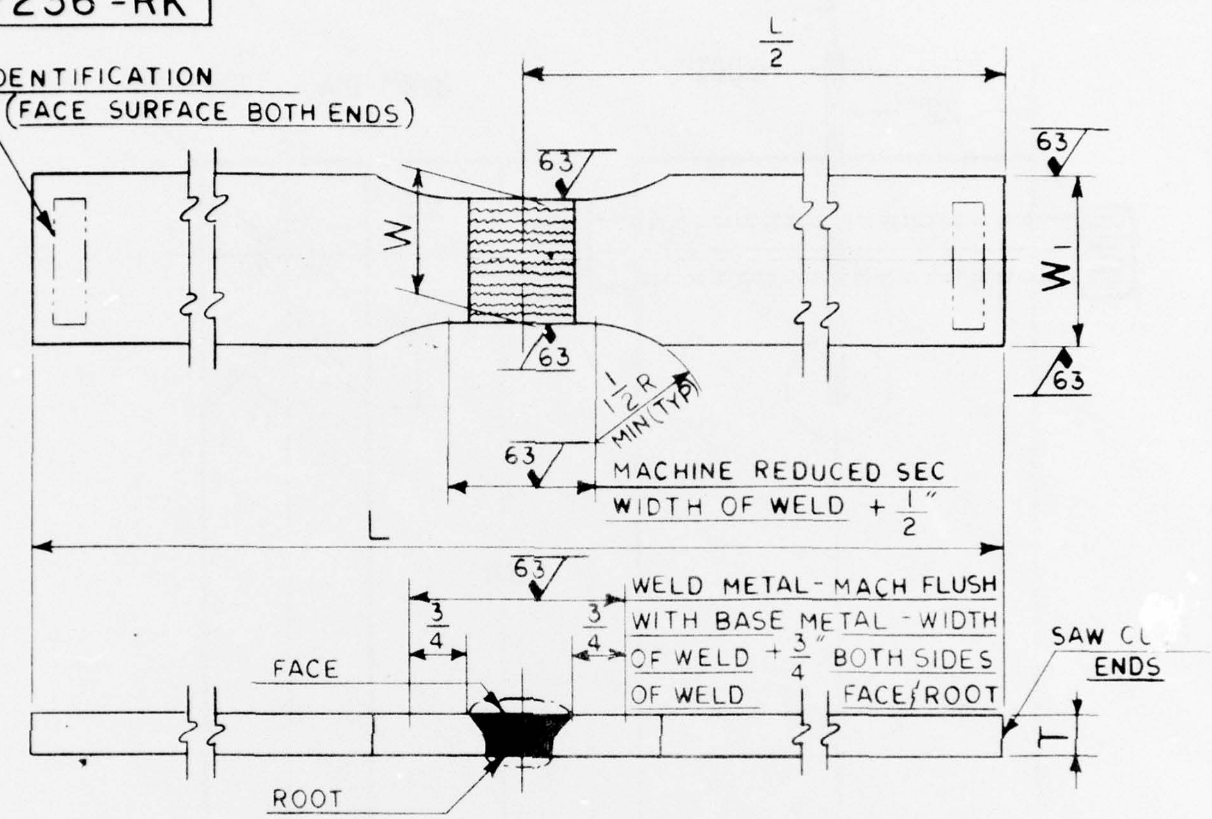

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NOMINAL THICKNESS T IN	TOTAL WIDTH W_1 IN	WIDTH AT WELD W IN	MIN LENGTH L IN
1/4 TO 0.356	2	1 1/2	18
3/8 TO 0.475	2	1 1/2	20
1/2 TO 0.720	2	1 1/2	22
3/4 TO 0.965	2	1 1/2	24
1" TO 1.455	1 1/2	1"	28
OVER 1 1/2	1 1/2	1"	30

Figure III - Reduced section beam specimen for stress-corrosion cracking (flat).

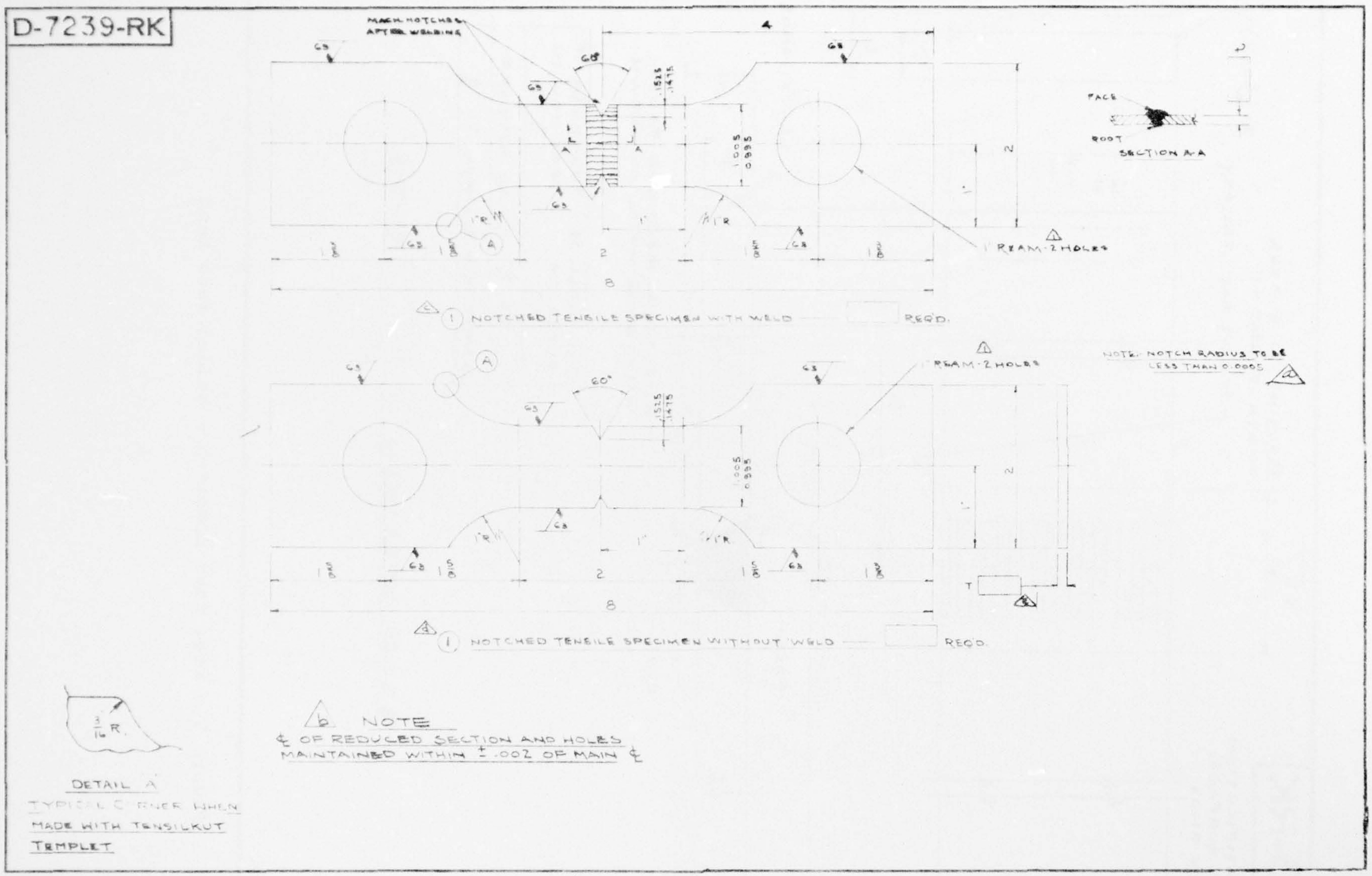
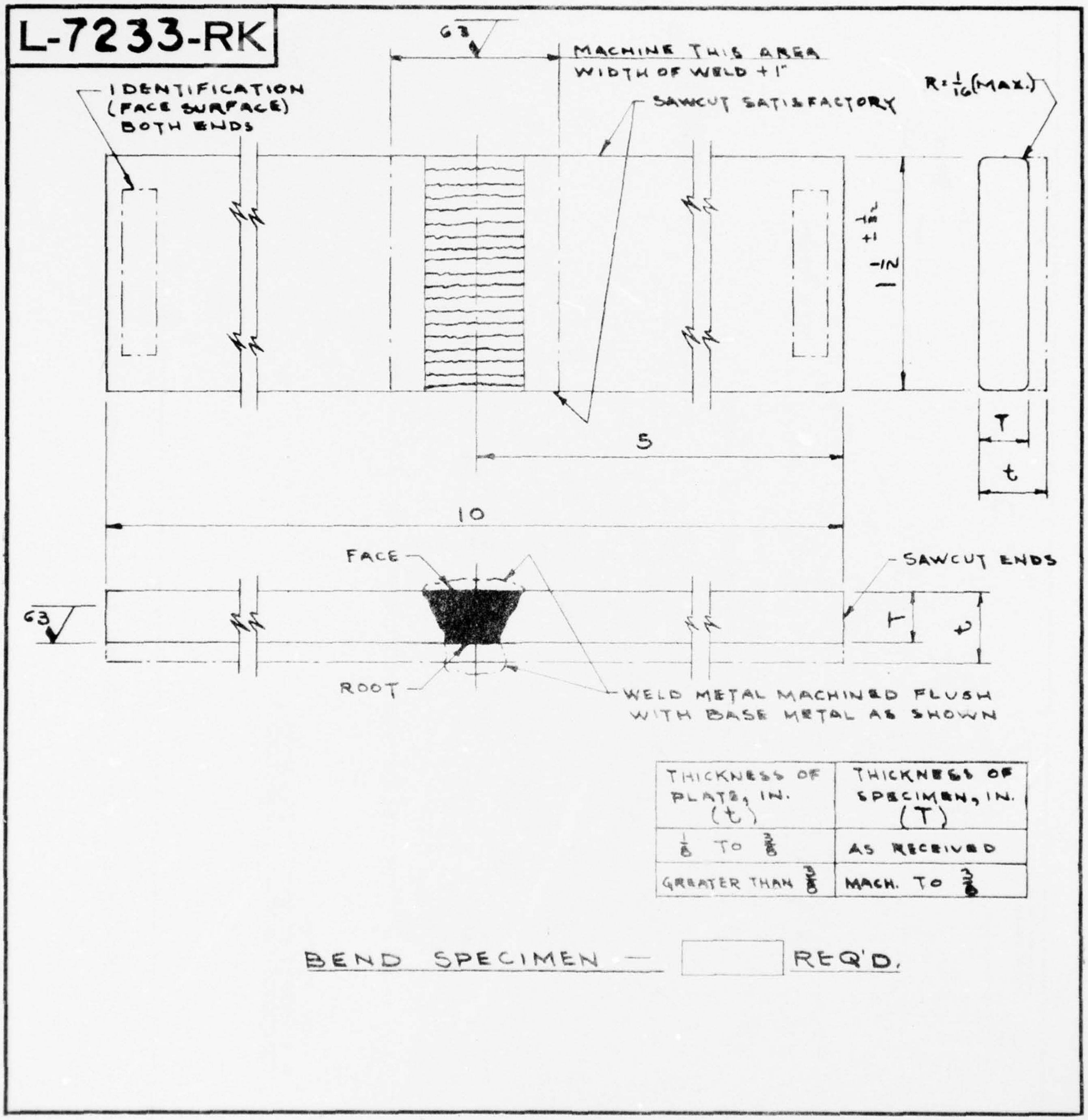


Figure IV - Double-notched beam specimen for stress-corrosion cracking - 6.3 mm.



THICKNESS OF PLATE, IN. (t)	THICKNESS OF SPECIMEN, IN. (T)
1/8 TO 3/8	AS RECEIVED
GREATER THAN 3/8	MACH. TO 3/8

Figure V - Free bend specimen - guided face bend.

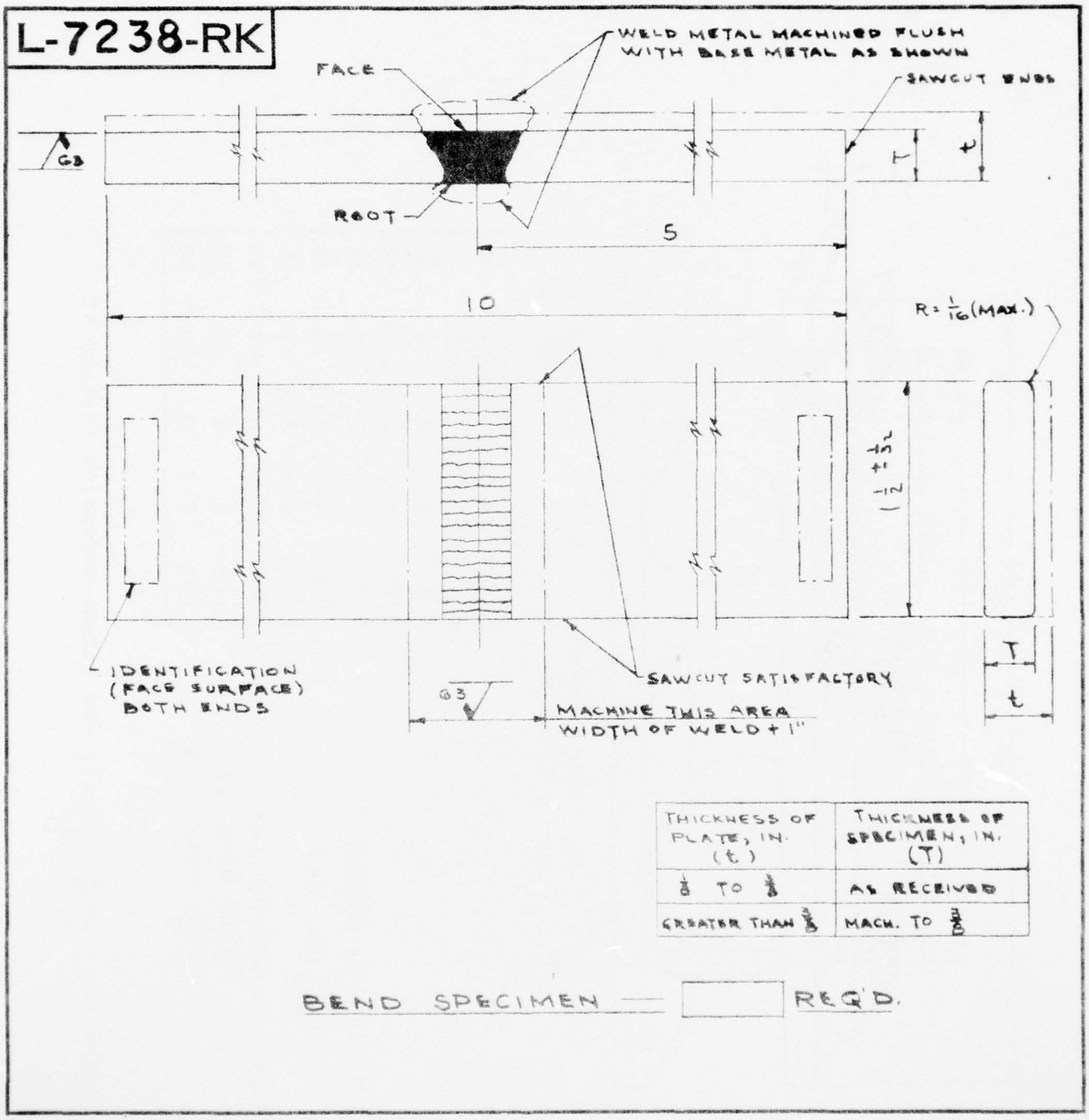
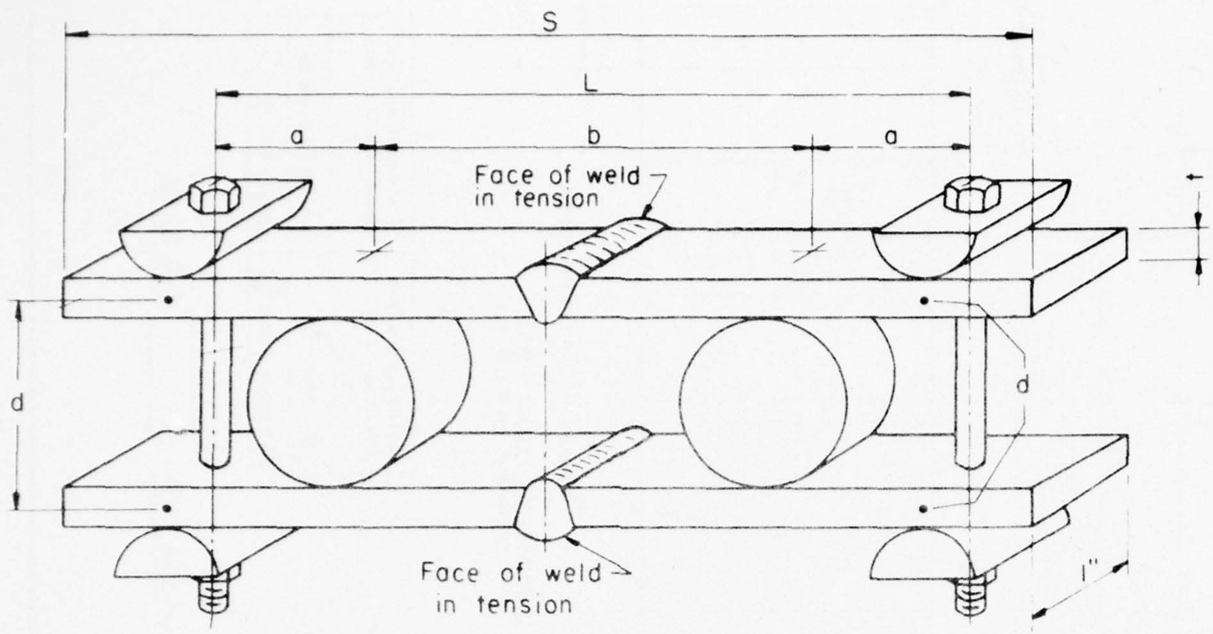


Figure VI - Free bend specimen - guided root bend.



Formula for stressing

$$\Delta d = \frac{2fa}{3Et}(3L - 4a)$$

Where Δd = deflection, inch

f = nominal stress, psi

E = Young's modulus, psi

Specimen dimensions for various plate thicknesses, inches

t	a	b	L	S
1/8	4	2	10	12
1/4	4	2	10	12
3/8	4 3/4	3 1/2	13	15
1/2	4 3/4	3 1/2	13	15
3/4	5 1/2	6	17	19
1	6	8	20	22
1 1/2	6 1/2	12	25	27

Figure VII - Beam assembly for stress-corrosion testing of weldments.

Security Classification

DOCUMENT CONTROL DATA - R&D

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Vernam, William D.
Shumaker, M. Byron

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
(.250-in.) 1.0-in.)	Naval Sea Systems Command Department of the Navy Washington, D.C. 20360

13. ABSTRACT

A high-strength weldable Al-Mg alloy, CS19, was fabricated into plate from large ingots on production rolling mills to evaluate feasibility. Plate in 6.3 mm (.250") and 25.4 mm (1.0") thicknesses was produced from two commercial sizes of ingot with no difference in product characteristics observed between plates fabricated from either size ingot. Tests on 25.4 mm thick CS19 plate and weldments showed it to have as-welded minimum yield strength of 207 MPa (30 ksi) and corrosion and fracture toughness equivalent to or better than 5456-H116 or H117 alloys. CS19 plate was shown to have more rapid rate of stress-corrosion crack growth than 5456 under some conditions but equal resistance to SCC initiation. The thinner plate and weldments had higher strength but lower toughness which was equivalent to that of 5456 of the same thickness. SCC resistance of the thinner plate and weldments was also good except for SCC resistance of weldments after thermal treatments simulating long service times. Greater strain in thinner plate produced an HAZ structure susceptible to SCC after thermal treatment.

DD FORM 1 JAN 64 1473

Security Classification

017460

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Aluminum-magnesium alloy (CS19, Experimental)						
High-strength, weldable aluminum alloy						
Aluminum alloy for ship structure						

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