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UNITED STATES ATOMIC ENERGY COMMISSION

THE WELDING OF TYPE 347 STEELS

The Results of Nitric Acid and Copper Sulfate-Sulfuric Acid Tests on Modified Type 347 Weld Deposits

By
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July 28, 1955

Arcos Corporation
Philadelphia, Pennsylvania

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The Welding of Type 347 Steels

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on Modified Type 347 Weld Deposits

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Work performed under Contract No. AT(30-1)-1233

ABSTRACT

The results of nitric acid and copper sulfate - sulfuric acid tests of a standard partially ferritic Type 347 weld deposit were compared with four modified Type 347 and one Type 308ELC weld compositions.

The highest corrosion rates of partially ferritic Type 347 weld deposits are observed when heat treated in the range of 1100°F to 1300°F. Acceptable rates are observed as-welded and after heat treatment at 1550°F or higher. Optimum rates are observed after heat treatment at 1700°F and higher. After sensitizing at 1250°F, the rates are acceptable; annealing at 1950°F prior to exposure to the sensitizing temperature reduces this corrosion rate by about half. No intergranular attack was observed in any of the partially ferritic welds. The substitution of tantalum for a portion of the columbium had no affect on corrosion resistance.

Fully austenitic Type 347 weld deposits show extremely high corrosion rates when heat treated at 1100°F or sensitized at 1250°F; they also show moderately high rates when heat treated at 1300°F. Acceptable rates are observed as-welded and after heat treatment at 1550°F or higher. Optimum results are obtained after heat treatment at 1700°F or higher. Annealing at 1950°F prior to sensitizing at 1250°F reduces the corrosion rate of the sensitized specimens to an acceptable level. Intergranular attack was noted after heat treating in the range of 1100°F to 1300°F. Very slight intergranular attack was also noted in the as-welded condition.

In general the Type 308ELC weld deposit shows the best corrosion resistance of all compositions tested, except when sensitized following an anneal at 1950°F.

The Welding of Type 347 Steels

The Results of Nitric Acid and Copper Sulfate - Sulfuric Acid Corrosion Tests on Modified Type 347 Weld Deposits

INTRODUCTION

In the course of a program sponsored by the Commission toward the development of a modified Type 347 electrode, five variations in composition, including a non-columbium bearing 308ELC type, were selected for extensive testing to determine their suitability for replacing the standard composition.

These five modified compositions have been compared with a standard composition as to weld crack sensitivity⁽¹⁾, suitability for use under standard fabrication conditions⁽²⁾, the effect of heat treatment on the .505" tensile properties⁽³⁾, and the effect of heat treatment on the notched bar impact properties⁽⁴⁾.

The purpose of this phase of the investigation was to determine the relative corrosion rates of these modified compositions, after various heat treatments designed to reveal the effect of stress relieving and of service temperatures on the respective corrosion rates.

PROCEDURE

The non-dilution weld compositions are listed in Table IA. They include a standard partially ferritic composition (A), a standard composition in which tantalum replaced part of the columbium (D), a standard composition modified to be fully austenitic (B), a high carbon fully austenitic composition (C), and a high manganese fully austenitic composition (H); in addition a standard Type 308ELC (extra-low-carbon) composition (F) was tested.

The all-weld-metal corrosion test coupons were approximately 3/16" x 3/8" x 2" long and were cut longitudinally from butt welds made in 1/2" thick stainless plate which was restrained to a 2-1/2" thick armor plate strong back. Welding was accomplished using DC reverse polarity at a current of 128-130 amps and 22-24 volts. Type 347 base plate was used for the welds deposited with the columbium-bearing electrodes and Type 304L plate was used for the Type 308ELC composition. The compositions of the base plates used are given in Table IB. All welds were made by a single experienced welder.

Samples of each composition for testing in boiling 65% nitric acid and in a 10% copper sulfate-10% sulfuric acid solution were heat treated at each of the following temperatures for the times indicated.

- (a) As-welded
- (b) 1100°F for 8 and 100 hours
- (c) 1300°F for 8 and 100 hours
- (d) 1550°F for 8 and 100 hours
- (e) 1700°F for 8 and 100 hours
- (f) 1950°F for 2 hours
- (g) 1250°F for 1 hour
- (h) 1950°F for 2 hours plus 1250°F for 1 hour

The samples were placed in a furnace already at the heat treating temperature and water quenched after holding the specified length of time, in order to eliminate any effect of heating or cooling rate.

After heat treatment all specimens were polished to a 120 grit finish in preparation for testing.

One set of specimens was sent to the Electro Metallurgical Company for the 65% boiling nitric acid tests. The results of these tests were submitted to Arcos in the form of a report by Mr. C. R. Bishop⁽⁵⁾. The other set of specimens was tested at Arcos in a boiling 10% copper sulfate - 10% sulfuric acid solution; the total exposure time was 500 hours. The solution was renewed after totals of 72, 150, and 250 hours. Specimens were 4 to a flask with 50 to 60 mls. of solution per square inch of surface.

NITRIC ACID TESTS

The nitric acid corrosion rates of the various samples heat treated according to the schedule above are given in Tables II to VII inclusive. For easy reference the averages of the five forty-eight hour boiling periods are plotted graphically as Figures 1, 2, and 3. After testing, all samples were examined at 7X magnification to determine whether the predominate type of corrosion was general or intergranular. The type of corrosion is also noted in the tables and on the graphs.

Results of Tests on 19/9Cb and 19/9CbTa Compositions With 6%-7% Ferrite (Compositions A and D)

The standard partially ferritic Type 347 electrode (Composition A) and the standard composition modified by replacing a portion of the tantalum with columbium (Composition D) showed similar corrosion rates. In the as-welded condition the corrosion rates were satisfactory. Those specimens which were heat treated for 8 and 100 hours at 1100°F and those which were sensitized for 1 hour at 1250°F showed moderate increases in corrosion rates and those samples heat treated for 8 and 100 hours at 1300°F showed only slightly higher corrosion rates than the as-welded samples. Heat treatments for 8 and 100 hours at 1550°F and 1700°F significantly improved the corrosion rates over the as-welded condition,

with the higher temperature showing the better results. The heat treatment of 2 hours at 1950°F yielded results which were comparable with the 1700°F heat treatments. A 2 hour heat treatment at 1950°F prior to sensitizing at 1250°F reduced the corrosion rate to one-half that shown by those samples which were sensitized in the as-welded condition.

Results of Tests on 19/13Cb (Compositions B & C) and
19/13MnCb (Composition H) Fully Austenitic Welds

The fully austenitic welds, Composition B with .087% carbon, Composition C with .115% carbon, and Composition H with .095% carbon and 5.00% manganese, showed comparable and acceptable corrosion rates in the as-welded condition. These rates, however, appeared to increase somewhat with increasing carbon content. Those samples which were heat treated for 8 and 100 hours at 1100°F showed extremely high rates, with intergranular attack, which increased considerably when held 100 hours at temperature. The samples sensitized at 1250°F for 1 hour also showed extremely high corrosion rates and intergranular attack. The samples heat treated at 1300°F for 8 hours showed rates only slightly higher than the partially ferritic compositions; the lowest rate of the austenitic group was almost equal to the highest rate for one of the partially ferritic compositions. When held for 100 hours at this 1300°F temperature the difference between the rates of the partially ferritic compositions and the fully austenitic compositions became even less. The samples which were heat treated for 8 and 100 hours at 1550°F and 1700°F, and for 2 hours at 1950°F, all showed corrosion rates which were lower than the as-welded samples. Samples heat treated at 1950°F prior to sensitizing at 1250°F for 1 hour showed corrosion rates equal to the partially ferritic compositions, except that the high carbon composition C showed a somewhat higher rate and intergranular attack.

Results of Tests on Type 308ELC (Composition F) Weld
Deposits Containing 4% Ferrite

The Type 308ELC weld deposit showed the lowest corrosion rate of all compositions tested in the as-welded condition. Some sensitization occurred on heat treating for 8 hours at 1100°F; when held for 100 hours at this temperature the corrosion rate decreased, apparently because of diffusion of chromium and/or stabilization of carbides. Heat treatments for 8 and 100 hours at 1300°F also increased the corrosion rate slightly over the as-welded condition. The corrosion rates after these heat treatments at 1100°F and 1300°F were considerably better, however, than any of the other compositions tested. After heat treatments of 8 and 100 hours at 1550°F and 1700°F and for 2 hours at 1950°F, the corrosion rates were good and were equivalent to the partially ferritic Type 347 compositions.

The sample sensitized at 1250°F for 1 hour showed the lowest corrosion rate of all compositions tested in this condition of heat treatment. When heat treated at 1950°F prior to sensitization at 1250°F, however, the corrosion rate was almost the highest of all compositions tested. The reason for this is believed to be due to a difference in the distribution of the carbides. When sensitized in the as-welded condition the carbides are precipitated at the interfaces of the ferrite islands and the austenite matrix. The precipitated carbides would then be discontinuous with respect to the grain boundaries and the corrosion rate would be expected to be low. When heat treated at 1950°F most of the ferrite goes into solution in the austenite matrix, and as a result the carbides are precipitated intergranularly during sensitization at 1250°F; as a result the corrosion rate would be expected to be high. (See Figures 4, 5A, and 5B.)

COPPER SULFATE - SULFURIC ACID TESTS

Duplicate heat treated samples were boiled for a total of 500 hours in a 10% copper sulfate - 10% sulfuric acid solution and then were bent and examined under 10X magnification for evidence of intergranular attack. Doubtful specimens were cross sectioned and polished for microscopic examination and observed under 500X magnification in the unetched condition. The results of the examination of the bend specimens are presented in Table VIII.

It will be observed from the Table that neither of the partially ferritic Type 347 compositions (A and D) showed any evidence of intergranular attack in any of the heat treatment conditions.

The fully austenitic compositions all showed slight attack in the as-welded condition and severe attack after heat treatments for 8 and 100 hours at 1100°F. After heat treatment for 8 hours at 1300°F, fully austenitic compositions B & H showed slight intergranular attack and the high carbon fully austenitic composition C showed severe intergranular attack. After 100 hours at 1300°F the high carbon fully austenitic composition showed severe attack, the fully austenitic composition H showed slight attack, and any attack on fully austenitic composition B was questionable. No intergranular attack was apparent on any of the fully austenitic compositions for the times heat treated at temperatures between 1550°F and 1950°F. All fully austenitic compositions showed slight susceptibility when sensitized at 1250°F for one hour, whether preceded by a 1950°F heat treatment or not.

The low carbon Type 308ELC composition (F) showed no evidence of intergranular attack except for a slight amount after a heat treatment at 1100°F for 8 hours or when sensitized at 1250°F following a 2 hour 1950°F quench annealing heat treatment.

All specimens which were heat treated in the same manner as those which showed intergranular attack in the nitric acid tests, showed intergranular attack in the copper sulfate - sulfuric acid

tests. In addition the copper sulfate - sulfuric acid tests revealed two cases of severe and twelve cases of slight intergranular attack which were not detected by binocular examination of the nitric acid test specimens. These cases are indicated in Table VIII.

Because of the fact that there were fourteen instances where intergranular attack was observed in the copper sulfate - sulfuric acid tests and while no intergranular attack was observed by binocular examination of the corresponding nitric acid specimens, it was decided to bend the nitric acid test specimens in the same manner as the copper sulfate - sulfuric acid specimens. After bending of these nitric acid test specimens they were rated as to degree of intergranular attack in the same manner as that used for Table VIII. These nitric acid ratings were seen to be identical to the ratings shown in Table VIII with the following four exceptions: in the case of composition B heat treated for 100 hours at 1300°F slight attack was noted; in the case of composition C heat treated for 8 and 100 hours at 1300°F slight attack instead of severe attack was noted; also, in the case of composition C after a heat treatment for 1 hour at 1250°F severe attack was observed instead of slight attack.

DISCUSSION

Data in the literature on the corrosion rates of weld metals similar to the alloys tested are rather meager and are confined to the partially ferritic 347, 347 with Ta, and 308ELC types. The only direct comparison available is in the as-welded condition, because the times at temperature and the cooling rates of the other investigators differed from those used in this investigation. Those portions of the nitric acid corrosion data published by Thomas⁽⁶⁾ and by Ebling and Scheil⁽⁷⁾ which cover the temperatures used in this investigation are compared in the simplified table below. For details on holding times and cooling rates the references should be consulted.

Comparison of Results

<u>Type</u>	<u>Heat Treating Temperature</u>	<u>Average Nitric Acid Corrosion Rates (Mils/yr)</u>			
		<u>Present Study</u>	<u>Thomas</u>	<u>Ebling & Scheil Overall</u>	<u>Est. Weld*</u>
347(Cb)	As-welded	12	10	8	<10
347(Cb)	1100°F	30	-	20	26-50
347(Cb)	1550°F	8	10	-	-
347(Cb)	1950°F	6	5	8	<10
347Cb+Ta	As-welded	11	8	11	<10
347Cb+Ta	1100°F	24	-	23	26-50
347Cb+Ta	1550°F	8	8	-	-
347Cb+Ta	1950°F	6	5	-	-
308ELC	As-welded	7	7	7	<10
308ELC	1100°F	21	-	21	26-50
308ELC	1550°F	7	6	-	-
308ELC	1950°F	6	7	7	<10

* Specimens of Ebling & Scheil were composite coupons including weld, heat affected zone, and base metal.

The comparison of data given in the table above indicates good agreement between the results obtained in this investigation and those found in the literature.

The nitrogen content of all welds ranged from .037 to .044%. This range is too small to draw any conclusions as to the affect of nitrogen on the nitric acid corrosion rates.

An attempt was made to determine the reason why the fully austenitic compositions were susceptible to intergranular attack when heat treated at temperatures between 1100°F and 1300°F, while the partially ferritic compositions were not. The following explanation is postulated. If chromium carbides are formed in partially ferritic welds during heat treatment at these temperatures, they will be precipitated at the interfaces between the ferrite islands and the austenitic matrix. The precipitated carbides would then be arranged in a discontinuous manner. In the case of the fully austenitic weld deposits the chromium carbides will be formed in the grain boundaries. The presence of chromium carbides in composition C after heat treatment for 100 hours at 1300°F was confirmed by x-ray diffraction analysis(4). The different manner in which carbides were precipitated subsequent to solution heat treatment in the 308ELC weld deposit tends to substantiate this theory.

CONCLUSIONS

1. The substitution of tantalum for a portion of the columbium had no affect on the corrosion resistance of partially ferritic Type 347 steels.
2. The maximum corrosion rate for the partially ferritic Type 347 weld deposits was obtained after heat treatments for 8 and 100 hours at 1100°F and 1300°F, or for 1 hour at 1250°F. Solution annealing at 1950°F for 2 hours prior to sensitization reduced the corrosion rate considerably. No condition of heat treatment employed produced intergranular attack in these partially ferritic types.
3. The corrosion resistance of the fully austenitic Type 347 welds was appreciably lower than that of partially ferritic types and the attack was of an intergranular nature when heat treated for 8 or 100 hours at 1100°F and 1300°F, or for 1 hour at 1250°F. Solution annealing at 1950°F for 2 hours prior to sensitizing at 1250°F reduced the corrosion rate to a satisfactory level.
4. The high manganese fully austenitic composition H deposits showed very slightly higher corrosion rates than the other fully austenitic compositions when heat treated at temperatures of 1550°F or over. At heat treating temperatures of 1300°F or below, the corrosion rate seemed dependent on carbon content when compared with the other fully austenitic compositions. The difference was so slight, however, that more work would be necessary to determine if manganese has an effect on the corrosion resistance.

5. In general the Type 308ELC weld deposit showed the best corrosion resistance of all compositions tested. The one exception to this occurred when a sensitizing heat treatment at 1250°F was given following a solution anneal at 1950°F. Slight intergranular attack was observed after this heat treatment.
6. No conclusions could be drawn on the effect of nitrogen since all compositions were in the range of .037% to .044% nitrogen.

WORK IN PROGRESS

In view of the excellent impact and corrosion results obtained with the Type 308ELC weld deposit, additional tests have been initiated to determine the impact toughness of this alloy after heat treatment at 800°F and 900°F and to measure the nitric acid corrosion properties after heat treatment at 800°F, 900°F, 1000°F, 1050°F, and 1200°F.

Additional studies of the effect of the various elements on the crack sensitivity of fully austenitic welds are in process.

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Table IA

Composition and Designations of Experimental Electrodes*

<u>Composition</u>	<u>Type</u>	<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb+Ta</u>	<u>N₂</u>	<u>Ferrite % Calc.+</u>
A**	19/9Cb	.080	1.55	.017	.012	.44	9.31	19.22	.71	.044	7%
B	19/13Cb	.087	1.49	.017	.013	.33	13.02	19.09	.74	.039	None
C	19/13Cb	.115	1.32	.019	.013	.45	13.06	19.09	.70	.044	None
D	19/9CbTa	.080	1.55	.017	.010	.42	9.27	19.22	.78	.039	7%
F	19/10LC	.036	.73	.04	.018	.26	10.53	18.92	--	.044	4%
H	19/13MnCb	.095	5.04	.024	.012	.37	12.99	18.50	.91	.037	None

* Chemical analysis from non-dilution weld pads made in accordance with AWS-ASTM specifications.

+ Calculated from chemical analysis according to the Schaeffler diagram.

** Standard Type 347 composition, recently reclassified by the American Iron and Steel Institute as Type 348.

Table IB

Composition of Base Metals*

<u>Type</u>	<u>Thickness</u>	<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb+Ta</u>
347	1/2"	.06	1.39	.026	.010	.66	10.51	19.40	.77
304L	1/2"	.024	1.55	.026	.016	.38	9.50	17.76	--

* Mill analysis reports.

NYO-3499

Table II

Results of Boiling 65% Nitric Acid Tests

Composition A

<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb</u>	<u>N₂</u>	<u>% Ferrite Calc.</u>
.080	1.55	.017	.012	.44	9.31	19.22	.71	.044	7

Corrosion Rate - Inches Penetration Per Month

<u>Heat-Treatment</u>	<u>Code</u>	<u>1st 48-Hr. Period</u>	<u>2nd 48-Hr. Period</u>	<u>3rd 48-Hr. Period</u>	<u>4th 48-Hr. Period</u>	<u>5th 48-Hr. Period</u>	<u>Average</u>	<u>Predominant Type of Corrosion</u>
As-welded	AW	0.00072	0.00072	0.00094	0.00115	0.00132	0.00097	General
8 hr. 1100°F.WQ	18	0.00094	0.00165	0.00275	0.00340	0.00390	0.00253	General
100 hr. 1100°F.WQ	10	0.00099	0.00192	0.00260	0.00288	0.00302	0.00228	General
8 hr. 1300°F.WQ	38	0.00095	0.00134	0.00170	0.00187	0.00195	0.00156	General
100 hr. 1300°F.WQ	30	0.00101	0.00113	0.00147	0.00160	0.00177	0.00140	General
8 hr. 1550°F.WQ	58	0.00068	0.00056	0.00067	0.00074	0.00085	0.00070	General
100 hr. 1550°F.WQ	50	0.00074	0.00051	0.00054	0.00055	0.00064	0.00055	General
8 hr. 1700°F.WQ	78	0.00058	0.00042	0.00048	0.00045	0.00053	0.00049	General
100 hr. 1700°F.WQ	70	0.00062	0.00043	0.00042	0.00041	0.00045	0.00047	General
2 hr. 1950°F.WQ	92	0.00070	0.00046	0.00049	0.00048	0.00059	0.00054	General
2 hr. 1950°F.WQ)	92S	0.00071	0.00069	0.00097	0.00114	0.00135	0.00097	General
+1 hr. 1250°F.WQ)								
1 hr. 1250°F.WQ	S	0.00091	0.00159	0.00250	0.00298	0.00322	0.00224	General

NYO-3499

Table III

13

Results of Boiling 65% Nitric Acid Tests

Composition B

<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb</u>	<u>N₂</u>	<u>% Ferrite Calc.</u>
.087	1.49	.017	.013	.33	13.02	19.09	.74	.039	None

Corrosion Rate - Inches Penetration Per Month

<u>Heat-Treatment</u>	<u>Code</u>	<u>1st 48-Hr. Period</u>	<u>2nd 48-Hr. Period</u>	<u>3rd 48-Hr. Period</u>	<u>4th 48-Hr. Period</u>	<u>5th 48-Hr. Period</u>	<u>Average</u>	<u>Predominant Type of Corrosion</u>
As-welded	AW	0.00060	0.00057	0.00074	0.00091	0.00108	0.00078*	General
8 hr. 1100°F.WQ	18	0.00224	0.0124	0.0171	0.0266	0.0244	0.0166	Intergranular
100 hr. 1100°F.WQ	10	0.00495	0.0280	0.0460	0.0560	0.0590	0.0388	Intergranular
8 hr. 1300°F.WQ	38	0.00086	0.00130	0.00197	0.00236	0.00266	0.00183	General
100 hr. 1300°F.WQ	30	0.00076	0.00098	0.00150	0.00185	0.00210	0.00144	General
8 hr. 1550°F.WQ	58	0.00058	0.00051	0.00068	0.00085	0.00103	0.00073	General
100 hr. 1550°F.WQ	50	0.00062	0.00050	0.00064	0.00074	0.00090	0.00068	General
8 hr. 1700°F.WQ	78	0.00055	0.00043	0.00049	0.00052	0.00061	0.00052	General
100 hr. 1700°F.WQ	70	0.00050	0.00041	0.00044	0.00042	0.00049	0.00045	General
2 hr. 1950°F.WQ	92	0.00064	0.00046	0.00051	0.00055	0.00068	0.00057	General
2 hr. 1950°F.WQ)	92S	0.00069	0.00060	0.00072	0.00101	0.00119	0.00084	General
+1 hr. 1250°F.WQ)								
1 hr. 1250°F.WQ	S	0.00133	0.00324	0.00940	0.0166	0.0194	0.00999	Intergranular

* Small section of plate metal present along edge of weld.

NYO-3499

Table IV

Results of Boiling 65% Nitric Acid Tests

Composition C

<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb</u>	<u>N₂</u>	<u>% Ferrite Calc.</u>
.115	1.32	.019	.013	.45	13.06	19.09	.70	.044	None

Corrosion Rate - Inches Penetration Per Month

<u>Heat Treatment</u>	<u>Code</u>	<u>1st 48-Hr. Period</u>	<u>2nd 48-Hr. Period</u>	<u>3rd 48-Hr. Period</u>	<u>4th 48-Hr. Period</u>	<u>5th 48-Hr. Period</u>	<u>Average</u>	<u>Predominant Type of Corrosion</u>
As-welded	AW	0.00085	0.00079	0.00112	0.00143	0.00175	0.00119	General
8 hr. 1100°F.WQ	18	0.00550	0.0252	0.0410	0.0620	0.0530	0.0373	Intergranular
100 hr. 1100°F.WQ	10	0.0105	0.0435	0.0610	0.0760	0.0670	0.0526 *	Intergranular
8 hr. 1300°F.WQ	33	0.00084	0.00150	0.00223	0.00233	0.00342	0.00213	General
100 hr. 1300°F.WQ	30	0.00095	0.00120	0.00180	0.00224	0.00264	0.00177	General
8 hr. 1550°F.WQ	53	0.00064	0.00065	0.00033	0.00099	0.00130	0.00088	General
100 hr. 1550°F.WQ	50	0.00069	0.00060	0.00071	0.00033	0.00114	0.00079	General
8 hr. 1700°F.WQ	73	0.00057	0.00047	0.00056	0.00063	0.00089	0.00062	General
100 hr. 1700°F.WQ	70	0.00059	0.00047	0.00052	0.00052	0.00063	0.00056	General
2 hr. 1950°F.WQ	92	0.00062	0.00051	0.00061	0.00065	0.00099	0.00068	General
2 hr. 1950°F.WQ)	92S	0.00071	0.00110	0.00133	0.00139	0.00139	0.00148	General + Intergranular
+1 hr. 1250°F.WQ)								
1 hr. 1250°F.WQ	S	0.00231	0.0145	0.0307	0.0272	0.0312	0.0212	Intergranular

* Small section of plate metal present along edge of weld.

NYO-3499

Table V

15

Results of Boiling 65% Nitric Acid Tests

Composition D

<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb+Ta</u>	<u>N₂</u>	<u>% Ferrite Calc.</u>
.080	1.55	.017	.010	.42	9.27	19.22	.78	.039	7

Corrosion Rate - Inches Penetration Per Month

<u>Heat-Treatment</u>	<u>Code</u>	<u>1st 48-Hr. Period</u>	<u>2nd 48-Hr. Period</u>	<u>3rd 48-Hr. Period</u>	<u>4th 48-Hr. Period</u>	<u>5th 48-Hr. Period</u>	<u>Average</u>	<u>Predominant Type of Corrosion</u>
As-welded	AW	0.00070	0.00067	0.00088	0.00097	0.00109	0.00086*	General
8 hr. 1100°F.WQ	18	0.00092	0.00134	0.00220	0.00262	0.00293	0.00200	General
100 hr. 1100°F.WQ	10	0.00102	0.00199	0.00274	0.00283	0.00307	0.00234*	General
8 hr. 1300°F.WQ	38	0.00087	0.00099	0.00130	0.00140	0.00146	0.00120*	General
100 hr. 1300°F.WQ	30	0.00086	0.00097	0.00113	0.00117	0.00114	0.00105	General
8 hr. 1550°F.WQ	58	0.00068	0.00058	0.00066	0.00069	0.00082	0.00069	General
100 hr. 1550°F.WQ	50	0.00077	0.00050	0.00052	0.00048	0.00059	0.00057	General
8 hr. 1700°F.WQ	78	0.00064	0.00043	0.00042	0.00042	0.00051	0.00048*	General
100 hr. 1700°F.WQ	70	0.00067	0.00045	0.00045	0.00042	0.00046	0.00049	General
2 hr. 1950°F.WQ	92	0.00075	0.00051	0.00048	0.00046	0.00058	0.00056	General
2 hr. 1950°F.WQ)	92S	0.00070	0.00069	0.00090	0.00102	0.00132	0.00093	General
+1 hr. 1250°F.WQ)								
1 hr. 1250°F.WQ	S	0.00088	0.00124	0.00135	0.00217	0.00243	0.00172*	General

* Small section of plate metal present along edge of weld.

NYO-3499

15

Table VI

Results of Boiling 65% Nitric Acid Tests

Composition H

<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb</u>	<u>N₂</u>	<u>% Ferrite Calc.</u>
.095	5.04	.024	.012	.37	12.99	18.50	.91	.037	None

Corrosion Rate - Inches Penetration Per Month

<u>Heat-Treatment</u>	<u>Code</u>	<u>1st 48-Hr. Period</u>	<u>2nd 48-Hr. Period</u>	<u>3rd 48-Hr. Period</u>	<u>4th 48-Hr. Period</u>	<u>5th 48-Hr. Period</u>	<u>Average</u>	<u>Predominant Type of Corrosion</u>
As-welded	AW	0.00073	0.00072	0.00101	0.00120	0.00147	0.00103	General
8 hr. 1100°F.WQ	18	0.00205	0.0141	0.0282	0.0272	0.0375	0.0213	Intergranular
100 hr. 1100°F.WQ	10	0.00570	0.0435	0.0795	0.0750	0.0670	0.0551	Intergranular
8 hr. 1300°F.WQ	38	0.00032	0.00121	0.00175	0.00202	0.00232	0.00162	General
100 hr. 1300°F.WQ	30	0.00094	0.00118	0.00167	0.00195	0.00220	0.00159	General
8 hr. 1550°F.WQ	58	0.00065	0.00075	0.00096	0.00115	0.00136	0.00097	General
100 hr. 1550°F.WQ	50	0.00069	0.00057	0.00070	0.00088	0.00125	0.00082	General
8 hr. 1700°F.WQ	78	0.00071	0.00069	0.00080	0.00090	0.00106	0.00083	General
100 hr. 1700°F.WQ	70	0.00064	0.00050	0.00053	0.00062	0.00080	0.00063 *	General
2 hr. 1950°F.WQ	92	0.00074	0.00072	0.00097	0.00117	0.00138	0.00100	General
2 hr. 1950°F.WQ)	92S	0.00075	0.00088	0.00105	0.00125	0.00144	0.00107	General
+1 hr. 1250°F.WQ)								
1 hr. 1250°F.WQ	S	0.00101	0.00201	0.00270	0.00650	0.01040	0.00452	Intergranular

* Small section of plate metal present along edge of weld.

NYO-3499

17

Table VII

Results of Boiling 65% Nitric Acid Tests

Composition F

<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb</u>	<u>N₂</u>	<u>% Ferrite Calc.</u>
.036	.73	.021	.018	.26	10.53	13.92	--	.044	4

Corrosion Rate - Inches Penetration Per Month

<u>Heat-Treatment</u>	<u>Code</u>	<u>1st 48-Hr. Period</u>	<u>2nd 48-Hr. Period</u>	<u>3rd 48-Hr. Period</u>	<u>4th 48-Hr. Period</u>	<u>5th 48-Hr. Period</u>	<u>Average</u>	<u>Predominant Type of Corrosion</u>
As-welded	AW	0.00068	0.00056	0.00057	0.00053	0.00057	0.00058	General
8 hr. 1100°F.WQ	18	0.00081	0.00104	0.00161	0.00220	0.00319	0.00177 *	General - {Intergranular on plate
100 hr. 1100°F.WQ	10	0.00065	0.00072	0.00093	0.00119	0.00142	0.00099	General
8 hr. 1300°F.WQ	38	0.00072	0.00064	0.00080	0.00088	0.00102	0.00081	General
100 hr. 1300°F.WQ	30	0.00070	0.00063	0.00077	0.00079	0.00088	0.00075	General
8 hr. 1550°F.WQ	58	0.00080	0.00062	0.00063	0.00064	0.00060	0.00066 *	General
100 hr. 1550°F.WQ	50	0.00072	0.00055	0.00052	0.00053	0.00054	0.00057	General
8 hr. 1700°F.WQ	78	0.00064	0.00044	0.00043	0.00040	0.00043	0.00047	General
100 hr. 1700°F.WQ	70	0.00064	0.00046	0.00047	0.00043	0.00046	0.00049	General
2 hr. 1950°F.WQ	92	0.00080	0.00047	0.00046	0.00044	0.00045	0.00052	General
2 hr. 1950°F.WQ)	92S	0.00070	0.00091	0.00123	0.00153	0.00256	0.00139	Intergranular
+1 hr. 1250°F.WQ)								
1 hr. 1250°F.WQ	S	0.00071	0.00093	0.00117	0.00150	0.00175	0.00121	General

* Small section of plate metal present along edge of weld.

NYO-3499

17

Table VIII

Evidence of Intergranular Attack Revealed by Bending Corrosion
Samples After Boiling 500 Hours in 10% Copper Sulfate - 10% Sulfuric Acid
Solution

<u>Heat-Treatment</u>	<u>Composition</u>					
	<u>Partially Ferritic</u>		<u>Fully Austenitic</u>			<u>Low Carbon</u>
	<u>A</u>	<u>D</u>	<u>B</u>	<u>C</u>	<u>H</u>	<u>F</u>
As-welded	no	no	slight**	slight+	slight+	no
8 hr. 1100°F.WQ	no	no	severe	severe	severe	slight**
100 hr. 1100°F.WQ	no	no	severe	severe	severe	no***
8 hr. 1300°F.WQ	no	no	slight**	severe+	slight**	no
100 hr. 1300°F.WQ	no	no	no**	severe+	slight**	no
8 hr. 1550°F.WQ	no	no	no	no	no	no
100 hr. 1550°F.WQ	no	no	no	no	no	no
8 hr. 1700°F. WQ	no	no	no	no	no	no
100 hr. 1700°F.WQ	no	no	no	no	no	no
2 hr. 1950°F.WQ	no	no	no	no	no	no
2 hr. 1950°F.WQ)	no	no	slight+	slight	slight**	slight*
+1 hr. 1250°F.WQ)						
1 hr. 1250°F.WQ	no	no	slight+	slight+	slight+	no***

* Metallographic examination showed intergranular penetrations of less than one grain in depth.

** Showed one slight intergranular penetration in metallographic examination.

*** Metallographic examination showed no intergranular penetrations.

+ Intergranular attack was not observed when examining the corresponding nitric acid test specimens under a binocular microscope.

NO-3499

Figure 2

Figure 3

P3985 Chromic Acid Electrolytic 1500X

Figure 4 - Microstructure of composition F weld deposit sensitized 1 hour at 1250°F. Carbides are precipitated around the ferrite islands in an austenitic matrix.

P3987 Chromic Acid Electrolytic 1500X

Figure 5A

P3986 Chromic Acid Electrolytic 1500X

Figure 5B

Figures 5A and 5B - Microstructures of composition F weld deposit after heat treating 2 hours at 1950°F followed by sensitizing at 1250°F for 1 hour. The carbides are precipitated intergranularly.

0-23