WELDING RESEARCH

SUPPLEMENT TO THE *WELDING JOURNAL*, FEBRUARY 1993
Sponsored by the American Welding Society and the Welding Research Council

RESEARCH/DEVELOPMENT/RESEARCH/DEVELOPMENT/RESEARCH/DEVELOPMENT/RESEARCH/DEVELOPMENT

Corrosion Behavior of Stainless Steel and High-Alloy Weldments in Aggressive Oxidizing Environments

Nickel alloy filler metals compensate for the lower corrosion resistance of matching composition stainless steel welds in aggressive environments

BY A. H. TUTHILL AND R. E. AVERY

ABSTRACT. Stainless steel weldments closely approach the corrosion resistance of the base metal in most of the process environments in which they are used. However, in a few aggressive environments such as those found in the chlorine and chlorine dioxide stages of paper mill bleach plants, subtle changes in welding procedures, filler metals and postweld treatments can reduce the corrosion resistance of the weld as compared to the base metal.

Microsegregation or coring in weld metal dendrites, particularly in the molybdenum-containing welds, lowers pitting and crevice corrosion resistance in aggressive environments. Autogenous welds (welds with no filler metal addition) consistently exhibit lower corrosion resistance than the base metal unless the weld receives a full solution anneal. However, by using high-alloy filler metal, welds of comparable corrosion resistance can be achieved.

Macrosegregation can occur in the weld metal as a result of inadequate mixing before solidification. In some aggressive environments, macrosegregation may reduce corrosion resistance of welds even though high-alloy filler metal is used. This condition is particularly undesirable in the root pass of pipe welds. Options to eliminate macrosegregation in the pipe root pass include increased automation of the root pass welds, a wider root opening or use of consumable inserts.

Inadequate attention to postweld cleanup also leads to reduced corrosion resistance of stainless steel weldments. Heat tint oxides, embedded iron, surface defects and contaminants may initiate crevice or pitting corrosion well in advance of attack on clean surface areas.

A. H. TUTHILL, Tuthill Associates, Inc., and R. E. AVERY, Avery Consulting Associates, Inc., are consultants to the Nickel Development Institute, Toronto, Canada.

KEY WORDS

Corrosion Behavior
Stainless Steel
High-Alloy Steels
Ni-Alloy Filler Metal
Aggressive Environment
Bleach Plant Environment
Weld Metal Corrosion
Postweld Cleaning
Autogenous Welds
Corrosion Resistance

Introduction

In the 1980s, corrosion of welded austenitic, ferritic and duplex stainless steels in aggressive acid chloride environments was explored in a series of test programs undertaken by the Metals Subcommittee of the Corrosion and Engineering Materials Committee of the Engineering Division of the Technical Association of the Pulp and Paper Industry, TAPPI. While the findings have been published as individual papers in TAPPI literature, this summary has been prepared for the broader audience of engineers concerned with the corrosion resistance of alloy weldments. The findings are summarized and reviewed in this paper.

The Kraft process used in papermaking produces brown pulp, which is bleached to produce white paper. Bleaching normally starts with chlorination (C or C/D stage), followed by alkaline extraction (E stage) and by chlorine dioxide (D stage). These three stages are common to most bleach plants. Bleaching practices after D stage vary considerably, but often include a hypochlorite (H) stage. Coupon exposure tests were made in C or D/C, D and H stages. Chlorination is normally carried out at a pH 1.8 to 2.0, chlorine dioxide at 3.5 to 4.0 and hypochlorite at 9 to 10. Residual ox-

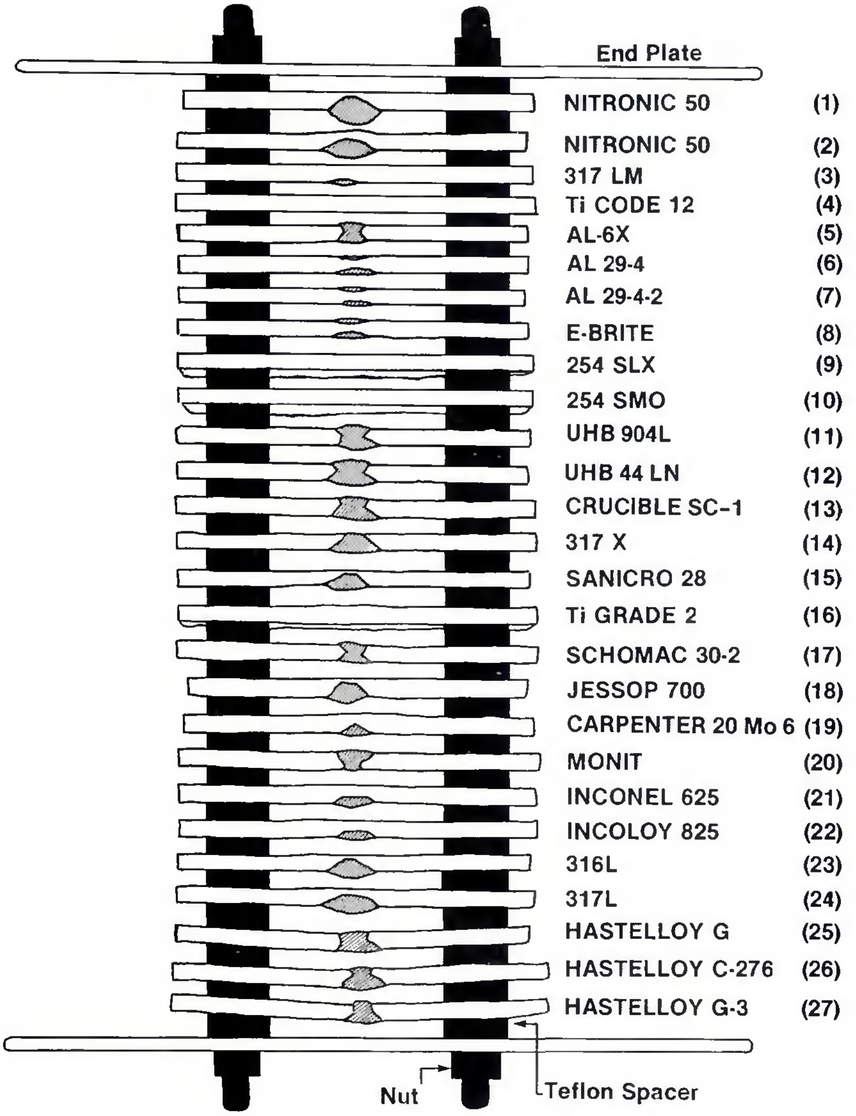

Fig. 1 — TAPPI phase II test rack.

idizers, expressed as chlorine or chlorine equivalent, temperature and chloride ion concentration are the normal environmental descriptors. Although each mill uses the same general practice, actual mill-to-mill environments vary widely.

The standard material of construction at the time the coupon exposure programs started was Type 317L, although some mills were still using 316L. Both alloys were suffering localized corrosion with reduction in the 20-year-plus earlier service life. General corrosion was not a factor, hence it was necessary to make comparisons and rank alloys by depth of localized corrosion, rather than by presence or absence of localized corrosion as is normally done. All findings and conclusions in this paper are based on the degree or extent of localized corrosion.

Procedures and Environment for Welded Coupon Tests

This program was undertaken to determine how welds made in accordance with producer recommendations would behave in bleach plant environments. Welded coupons of 24 stainless steels and nickel-based alloys plus two titanium alloys were exposed in 19 different bleach plant environments, 8 C or C/D stages, 8 D stage and 3 H stages. The coupons were 2 X 3 in. (50 X 75 mm) with the weld across the 2 in. dimension (Ref. 1). The test rack arrangement is shown in Fig. 1, base metal compositions in Table 1, and filler metal compositions in Table 2. Corrosivity, as estimated from total weight loss of all specimens exposed, varied by two orders of magnitude from the least to the most corrosive environment. Except for the most resistant alloys, this wide variation in corrosivity resulted in exposures to environments where the base metal, weld metal (WM) and heat-affected zone (HAZ) were resistant; more aggressive environments where the base metal was resistant but WM or HAZ or both pitted; and such aggressive environments where base metal, WM, and HAZ all were pitted. Titanium, and Alloys C-276 and 625 were so resistant that there were no environments were WM and HAZ were pitted. While it is not possible to identify the way in which 26 alloys performed in 19 different environments in a single table, there were multiple examples of each alloy within each of the three classes of environments as illustrated in Table 3.

The range of temperature, pH, chlorides and residual oxidizers such as chlorine in the C and D/C stage, ClO_2 in D stage and hypochlorite in H stage for the three environments are shown in Table 4.

The welds were made by each producer following standard procedures and using producer selected filler metal. Nickel-based Alloys 625, C-276, G-3 and G-30, the ferritic alloys and the two titanium alloys were welded with matching composition filler metal. The austenitic stainless steels were welded with either a matching composition filler metal or Alloy 625 as the producer supplying the test specimens elected. The one duplex alloy, Uddeholm 44LN, was welded with a 2.6% higher Ni and 1.3% higher Mo content filler metal as compared to the base metal.

Weld Metal Corrosion

The general nature of pitting attack that occurred in the matching composition weld metal is shown in Fig. 2. Corrosion of the weld metal, when it occurred, was by pitting. Figure 3 shows the depth of weld metal pitting on 317X welded with a matching composition filler metal in an exposure where there was no corrosion of the base metal.

Table 5 shows two lists. The alloys in the left column were welded with Alloy 625. The O indicates that there were no instances where the base metal was resistant and the weld metal corroded. In fact, there were multiple instances where the Alloy 625 weld metal was resistant but the base metal corroded. The alloys in the right column were welded with matching composition filler metal. A number of these welds were attacked, while the base metal remained resistant.

Table 1 — Base Metal Chemical Compositions (wt-%)

Alloy	C	Cr	Ni	Mo	Cu	Co	Mn	Si	S	P	Fe	Ti	Cb	W	N	Other
T-316L S/S	0.016	16.89	11.15	2.09	—	—	1.51	0.36	0.003	0.031	Bal	—	—	—	—	—
T-317L S/S	0.012	18.6	14.8	3.59	—	—	1.46	0.45	0.005	0.022	Bal	—	—	—	—	—
T-317LM S/S	0.019	18.01	14.91	4.15	0.13	0.30	1.00	0.52	0.021	0.018	Bal	—	—	—	0.046	—
Crucible T-317X	0.02	19.0	15.0	5.5	3.5	—	1.75	0.5	0.005	—	Bal	—	0.35	—	0.18	—
NITRONIC 50	0.035	20.69	12.40	2.14	—	—	4.78	0.40	0.012	0.023	Bal	—	0.13	—	0.23	Y-0.15
Jessop 700	0.018	20.60	25.30	4.42	0.16	0.10	1.72	0.47	0.015	0.021	Bal	—	0.22	—	0.037	Sn-0.020
Uddeholm 904L	0.024	20.2	24.8	4.4	1.43	0.22	1.59	0.40	0.010	0.025	Bal	—	—	—	0.057	—
Avesta 254 SLX	0.010	19.80	24.60	4.39	1.44	—	1.60	0.63	0.001	0.019	Bal	—	—	—	0.043	—
Avesta 254 SMO	0.011	20.0	18.2	6.13	0.70	—	0.42	0.42	0.003	0.024	Bal	—	—	—	0.19	—
AL-6X	0.028	20.42	24.82	6.08	—	—	1.50	0.29	0.001	—	Bal	—	—	—	0.055	—
Sanicro 28	0.013	26.9	31.1	3.43	1.07	—	1.75	0.11	0.003	0.013	Bal	—	—	—	—	—
Carpenter 20Mo-6	0.025	24.22	33.06	5.65	3.28	—	0.40	0.26	0.004	0.026	Bal	—	0.21	—	—	—
INCOLOY 825	0.03	21.98	41.05	3.24	1.77	—	0.30	0.17	0.003	—	30.27	1.11	—	—	—	Al-0.08
HASTELLOY G	0.009	22.19	40.38	6.43	1.88	2.40	1.47	0.25	—	—	19.37	—	2.18	0.81	—	Ta <0.05
HASTELLOY G-3	0.008	22.76	43.59	7.01	1.85	3.49	0.82	0.37	—	—	18.15	—	0.19	0.94	—	Ta <0.06
INCONEL 625	0.04	22.38	60.88	8.81	—	—	0.39	0.45	0.001	0.009	3.15	0.28	—	—	—	Cb+Ta 3.51
HASTELLOY G-30	0.01	29.60	45.7	4.90	1.70	1.20	0.70	0.45	0.002	0.010	15.00	—	—	—	—	Cb+Ta 0.71
HASTELLOY C-276	0.004	15.18	55.15	15.82	0.09	2.07	0.49	0.03	—	—	5.79	—	—	3.76	—	—
E-Brite 26-1	0.002	26.20	0.12	1.00	—	—	0.02	0.29	0.009	—	Bal	—	0.10	—	0.015	—
Crucible SC-1	0.025	26.0	2.5	3.0	—	—	0.30	0.3	—	—	Bal	0.50	—	—	0.025	—
NYBY MONIT	0.019	24.50	3.95	3.94	0.33	—	0.26	0.22	0.006	0.025	Bal	0.57	—	—	0.009	—
Uddeholm 44LN	0.023	24.1	6.3	1.65	—	—	1.67	0.65	—	—	Bal	—	—	—	0.18	—
Schomac 30-2	0.002	30.6	0.216	1.99	—	—	0.033	0.15	0.015	0.014	Bal	—	—	—	0.006	O_2-0.002
AL 29-4	0.003	29.01	0.09	3.95	—	—	0.03	0.04	0.011	—	Bal	—	—	—	0.011	—
AL 29-4-2	0.002	29.50	2.20	3.95	—	—	0.03	0.04	0.010	—	Bal	—	—	—	0.013	O_2-0.25
Titanium Grade 12	0.08	—	0.08	0.3	—	—	—	—	—	—	0.03	Bal	—	—	0.03	O_2-0.15
Titanium Grade 2	0.02	—	—	—	—	—	—	—	—	—	0.03	Bal	—	—	0.016	H_2-0.0056

Table 2 — Filler Metal Compositions as Reported by Producers

Material	Filler Metal	C	Cr	Ni	Mo	Mn	Si	S	P	Fe	Ti	Cb	N	Cu
316L	E-316L-16													
317L	E-317L-16													
317LM	Chromenar 625													
317X	T-317X													
N 50$_1$	NITRONIC-50W	0.046	21.14	10.49	1.82	6.16	0.33	0.008	0.015			0.02	0.21	
N 50$_2$	IN 112													
700	IN 112													
904L	Jungo 4500	0.016	20.9	25.1	4.6	1.26	0.84	0.007	0.012	BAL.				1.61
254SLX	254SLX	0.03	20	25	4.5	2.5	0.3	0.020	0.025					1.5
254SMO	E Ni Cr Mo 3	0.10	21	BAL.	9.0	0.3	0.5					3.5		
AL-6X	—		Autogenous											
S-28	SANICRO 28	0.016	26.86	31.08	3.54	1.74	0.08	0.003	0.017					0.96
20 Mo6	E Ni Cr Mo 3													
825	Incoloy 65													
G	—		Same as base plate											
G3	—		Same as base plate											
625	Inconel 625													
C-276	—		Same as base plate											
E-Brite	—		Autogenous											
SC-1	SC-1													
Monit	Monit	0.022	25.4	4.2	3.9		0.44	0.009			0.30	0.11	0.02	
44LN	Arosta 4462	0.015	22.6	8.9	3.0	0.95	0.96	0.011	0.022					0.06
30-2	Schomac 30-2	0.001	29.4	0.22	1.91	0.049	0.19		0.011					0.006
AL 29-4	—		Autogenous											
Al-20-4-2	—		Autogenous											
Ti 12	ASTM B348 Gr 12													
Ti 2	ASTM B348 Gr 2													
G-30	ANSI/AWS A5.14 ERNiCrMo-11													

Table 4 — Range of Temperature, pH, Chloride and Oxidizers (as chlorine)

Bleach Plant Stage	C and D/C	D	H
Number of Test Installations	8	8	3
Temp °F (°C)	103–138 (41–49)	128–176 (53–79)	88–132 (31–55)
pH	1.4–2.1	3.5 and 6[a]	7.5–9.5
Chloride ppm	1100–5500	Low–5600	Low–2453
Residual, max. (ppm)	15–320	8–181	58–1023

(a) In four of the D-stage environments, the normal pH of 3.5 was carried through to the vat where the specimens were exposed. In the other four D-stage environments, NaOH was added to partially neutralize the acidic D-stage liquor before it reached the vats.

Table 3 — Differing Severity of Exposure Environments

Environment	1	2	3
Base Metal	Resistant	Resistant	Pitted
WM	Resistant	Pitted	Pitted
HAZ	Resistant	Pitted	Pitted

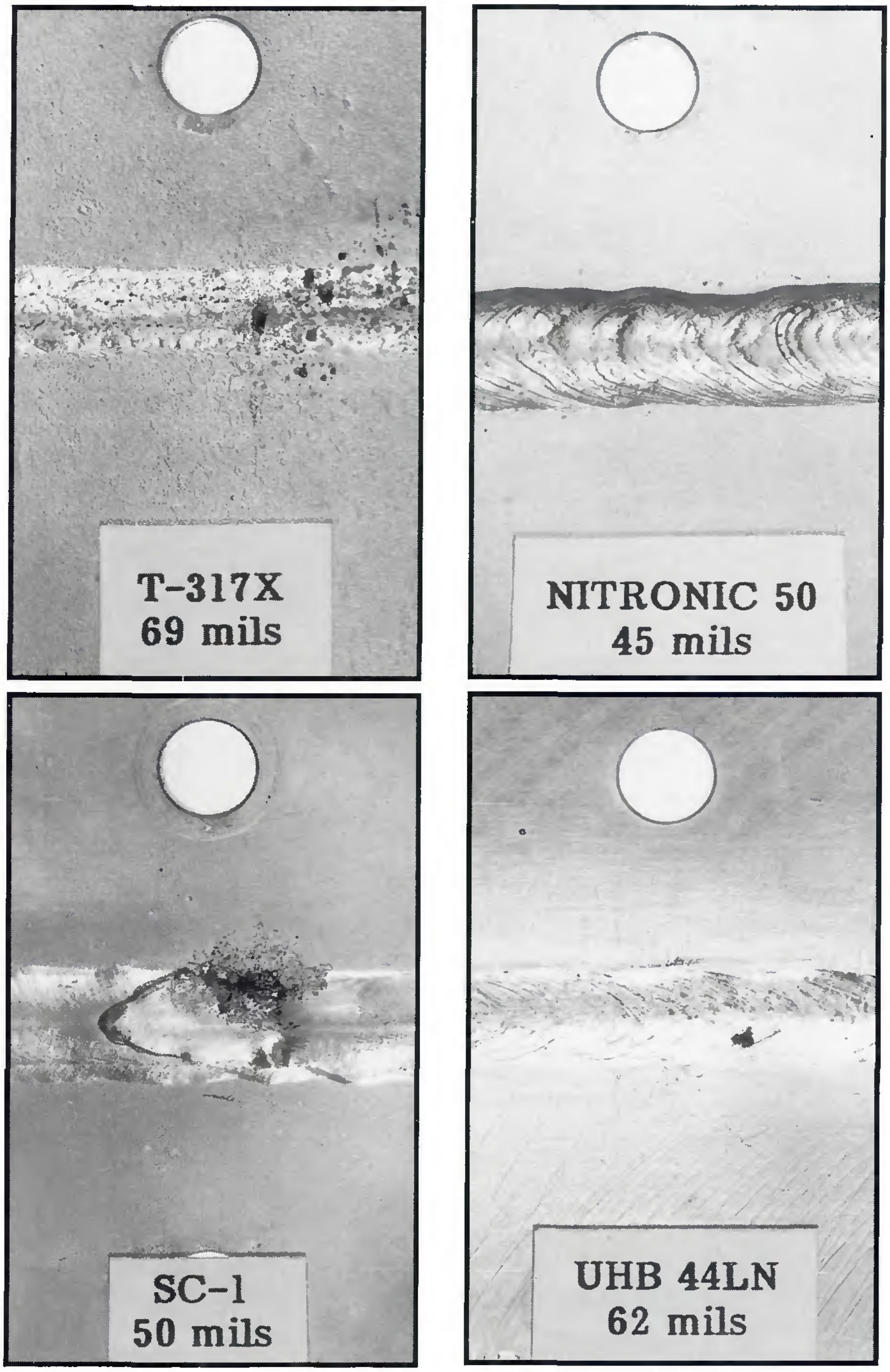

Fig. 2 — Weld metal corrosion in matching composition welds.

For all but the most resistant alloys, there was always one or more of the 19 environments where the matching composition filler metal was attacked, but the base metal was not (see column 2 in Table 3). This was the case for 316 with 2.5% Mo, as well as the higher Mo content austenitic stainless steels with up to 6% Mo. Of those alloys in the first column welded with the higher Mo content filler metal, Alloy 625, there were no instances where the weld metal corroded and the base metal did not. In fact, the Alloy 625 weld metal closely approached the performance of Alloy 625 base plate in all exposures.

It has been speculated that ferrite in the weld metal might account for the lower corrosion resistance of the weld metal. However, Garner's investigation of austenitic alloys of similar compositions showed that both ferrite-free and ferrite-containing stainless steel welds, up to 7.5 FN (ferrite number) were more susceptible to pitting in acidic chloride environments than the same composition base metal (Ref. 2). Ferrite content was not responsible for the lower corrosion resistance in these moderately oxidizing environments.

A second difference between cast and wrought structures is microsegregation or coring that occurs when the metal solidifies. Depending upon the solidification mode, areas lean in chromium and molybdenum may be at a dendrite center or in the interdendritic region. Garner's microprobe analysis of Type 316L base metal and weld metal (Table 6) shows the minimum local molybdenum content to be about one third the rich molybdenum area (Ref. 2). Chromium also exhibits similar microsegregation. It is believed that pitting originates in the lean areas, which are much less resistant than the base plate.

To better quantify the difference in weld metal and base metal corrosion resistance, Garner used Brigham and Tozer's critical pitting temperature test (CPT) (Ref. 3). A similar test has now become an ASTM standard, ASTM G48. Figure 4 shows the CPT of several austenitic alloys in the unwelded con-

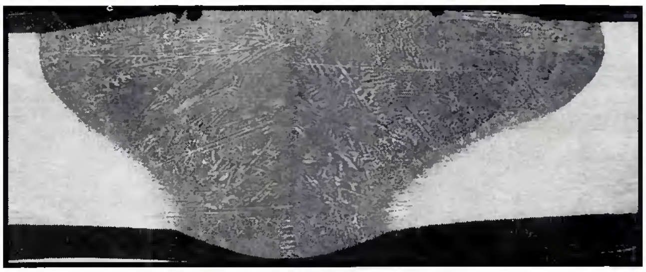

Fig. 3 — Type 317X matching-composition weld metal. Weld attacked but not the base metal.

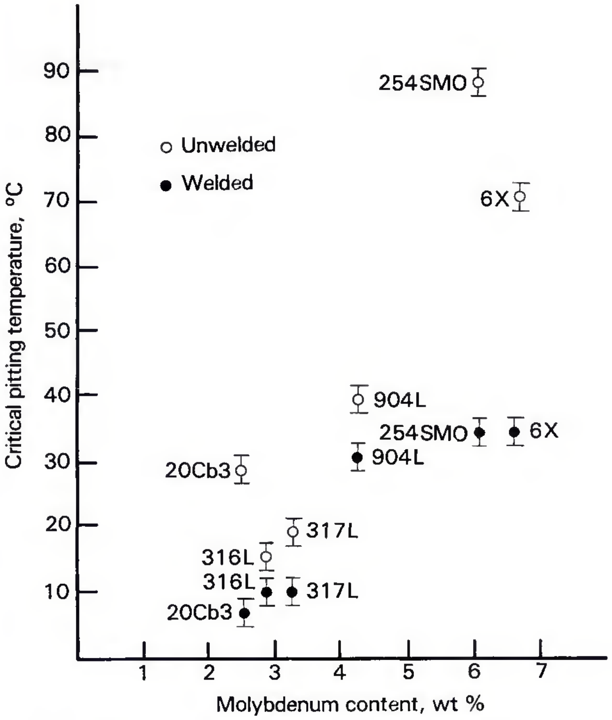

Fig. 4 — Critical pitting temperature vs. Mo content of some 2- to 6%-Mo stainless steels in the unwelded and welded condition. (reprinted with permission of Nickel Development Institute)

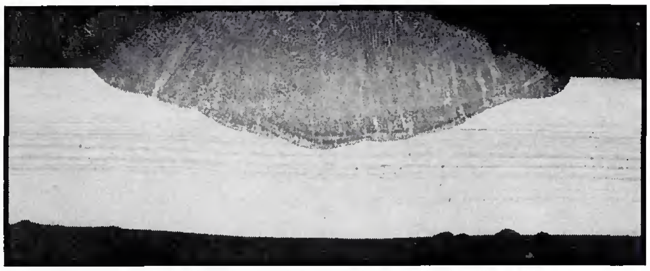

Fig. 5 — Type 317L. Pitting in the HAZ on the side opposite the weld bead.

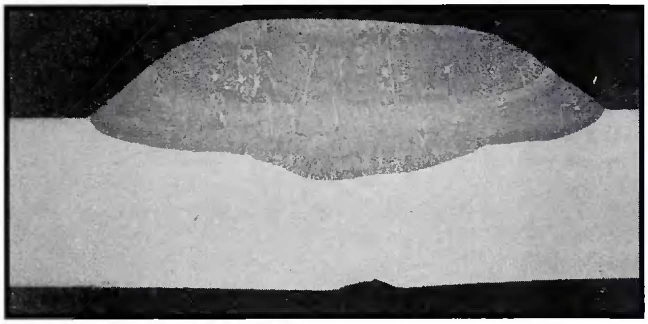

Fig. 6 — 254SLX. Pitting in the HAZ on the side opposite the weld bead.

Fig. 7 — E-Brite. Knife line attack adjacent to the weld.

Table 5 — Number of Austenitic Alloys Specimens Where Weld Metal Corroded but Base Metal Did Not

Welded with High Mo, Alloy 625 Filler Metal		Welded with Matching Composition Filler Metal	
	Stainless Steels		
Alloy	No. Samples	Alloy	No. Samples
		316L	3
NITRONIC 50	0	NITRONIC 50	5
		317L	5
		SANICRO 28	6
		Alloy 825	4
317LM	0	904L	1
JS/700	0	254SLX	3
		317X	14
254SMO	0	AL-6X	2
	Nickel-Based Alloys		
20 MO-6	0	Alloy G	1
		Alloy G-3	1

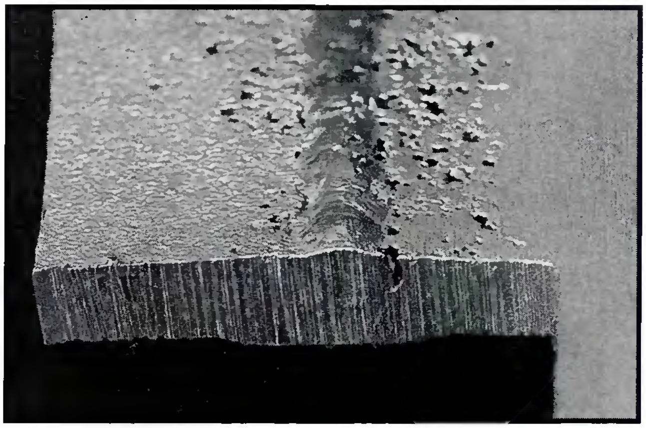

Fig. 8 — Cleaned and sectioned circumferential weld in AL-6XN. A — Deep pitting occured where there was insufficient mixing in the molten weld pool; B — metallographic view showing dark-etched areas, which are susceptible to pitting. Base metal and light etching undiluted Alloy 625 filler metal resisted pitting in aggressive bleach plant environment.

dition and with an autogenous weld. The weld metal is shown to be substantially less resistant than the base metal due to coring and microsegregation.

Based on these results it has become standard practice to weld 4- to 6%-Mo austenitic stainless steels with a higher Mo content filler metal such as Alloys 625, C-276 or C-22. Over 75 6%-Mo bleach plant washers have been fabricated with these higher Mo content filler metals and placed in service since 1982 with no reports of weld metal corrosion.

Ferritic Alloys

The behavior of the six ferritic alloys welded with matching composition filler metal in the same 19 environments is shown in Table 7.

Ferritic alloys are normally produced in thin-wall welded tubing, not in thicknesses generally used in welded fabrications. Nevertheless, it is interesting to note that matching composition welds in the higher chromium alloys with 29 to 30% Cr-2 to 4% Mo were as resistant as the base metal, whereas matching composition welds in the three 24.5 to 26% Cr -1 to 3% Mo alloys were not as resistant as the base metal.

Duplex Alloys

There were four specimens of duplex alloy 44LN where the base metal was resistant but the weld metal corroded. The filler metal was higher in nickel, as has become standard for welding most duplex stainless steels. Nevertheless, the weld metal had lower corrosion resistance than the base metal. We are reluctant to speculate further on the corrosion behavior of welded duplex materials other than to note further investigation of the corrosion resistance of duplex alloy weldments seems very much in order.

Nickel-Based Alloys and Titanium

One weld each of Alloy G and Alloy G-3 did corrode (pit), while the base metal did not (Table 3 column 2 and Table 5). It may be that Alloys G and G-3 were so resistant that there were few if any of the 19 environments corrosive enough to attack the weld metal even if its resistance was not quite as good as the base metal. Or it could be that molybdenum segregation in these more highly alloyed materials may not result in as great a reduction in weld metal resistance as in the less highly alloyed stainless steels. In either case, the data indicate that the corrosion resistance of

Table 6 — Microprobe Analysis of Weld Metal

	Composition, %			
	316L		317L	
	Cr	Mo	Cr	Mo
Base metal	16.3	2.8	18.4	3.2
Weld metal min. local composition	14.3	1.8	14.2	2.0
max. local composition	20.1	5.7	24	6.6

Alloys G and G-3 filler metals closely approached that of their respective base metals in these environments.

Matching composition filler metal for Alloys 625 and C-276 and the two titanium alloys were as resistant to corrosion as the base metal in the 19 bleach plant environments. Whether this would hold true for more corrosive environments is a question that will have to be answered by other test programs.

Heat-Affected Zone

There are several instances where there was pitting in the heat-affected zone but not in the base metal or weld metal. Figures 5 and 6 show pitting of the HAZ on the side opposite the bead of a plate weld on 317L and 254 SLX specimens. In Fig. 7 there is knife-line-like pitting of the HAZ just adjacent to the weld on an E-Brite specimen. No special studies of this type of HAZ corrosion were undertaken in this program.

Pipe Weld Test Program

Following publication of the results of the welded coupon tests, a new program was undertaken to determine the behavior of pipe welds in the more resistant stainless steels and nickel-based alloys. It was felt that piping in the more highly alloyed materials would be produced and fabricated in the same general manner as Types 304L and 316L pipe. Accordingly, 2-ft (0.61-m) long sheets of 3/16-in. (4.8-mm) thick AL-6XN, Alloys G-30, 625, C-22 and 1/4-in. (6.4-mm) thick C-276 clad were roll formed and welded into pipe on a conventional boom welding machine. The AL-6XN 6%-Mo alloy was solution annealed at 2150°F (1175°C) and all except the clad pipe were pickled. Each 2-ft section was then cut circumferentially in half. The two sections were rotated 180 deg then welded in the flat position using a positioner and the GTAW process with hand-fed Alloy 625 filler metal.

Careful examination revealed no corrosion of any longitudinal weld and no corrosion of the nickel-based alloy groove welds, including the C-276 clad pipe. Figure 8A and B shows a type of pitting that occurred in the root bead of a groove weld on an AL-6XN 10-in. (254-mm) diameter pipe (Ref. 4). The environment corresponded closely to the 3.5 pH of the D stage environment shown in Table 4. The filler metal was Alloy 625. Microanalysis across the weld revealed large swirls of weld metal interlaced with large swirls of melted but unmixed base metal. These areas can also be identified by their different response to the etchant in the photomicrograph. The pitting at some distance from the weld is believed to be secondary pitting underneath ferric corrosion deposits from the original corrosion sites in the HAZ of the weld. Secondary pitting of this type is common in chlorine dioxide bleaching environments.

This unusual root pass corrosion has received considerable attention from producers of the higher molybdenum stainless steels in the several Metals Subcommittee forums held on this problem since it was first reported. While the corrosion that occurred in the root pass of the Alloy 625 weld was originally described as corrosion of the unmixed zone, the authors now believe the corrosion is better described as occurring in an area of the root bead where there

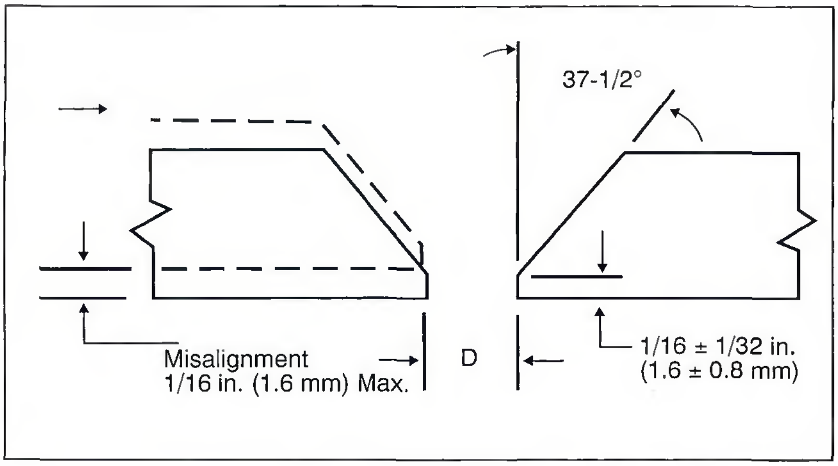

Fig. 9 — Typical joint design for pipe welded without a consumable insert and using the GTAW process for the root pass. D < diameter of the filler metal for the keyhole method. D > diameter of filler metal for continuous feeding method.

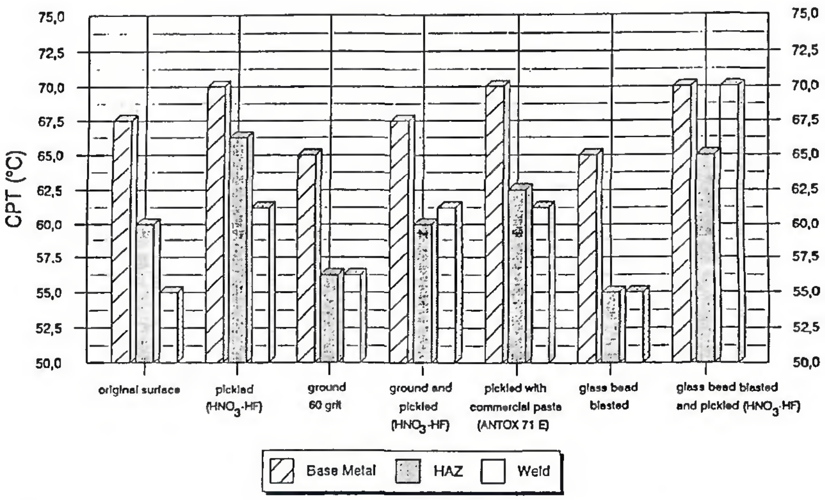

Fig. 10 — Effect of surface treatment on critical pitting temperature in 10% $FeCl_3$ X $6H_2O$ for the 6-Mo stainless steel Cronifer 1925 hMo, GTA welded with Alloy 625 filler metal. (reprinted with permission of Krupp-VDM).

Table 7 — Number of Ferritic Alloy Specimens Where Weld Metal Coroded, but Base Metal Did Not[a]

Weld Metal Resistant	Weld Metal Corroded	
Alloy	Alloy	No. Samples
Schomac 30-2	E-Brite (26-1)	2
AL 29-4	SeaCure SC-1	3
AL 29-4-2	Monit	1

(a) All specimens welded with matching composition filler metal.

Fig. 11 — Pitting corrosion associated with postweld cleaning by stainless steel wire brush on the back of a 316L coupon after exposure in chlorine dioxide-stage washer.

was insufficient mixing in the molten weld pool.

Section 12, "Dissimilar Metals," Vol. 4 of the 7th Edition of the *Welding Handbook*, p. 515, states in part: "Significant agitation occurs in the molten weld pool with most fusion welding processes. This agitation tends to produce weld metal with a substantially uniform composition, except for narrow bands next to each, unmelted base metal."

The authors believe that there was insufficient mixing in the molten weld pool and that it is these insufficiently mixed areas, rather than the narrow unmixed zones where the corrosion shown in Fig. 8A and B occurred.

Remedial measures that have been suggested for improving the area of insufficient mixing but not yet proven include: 1) increasing the root opening normally used in making groove welds in stainless steel pipe, 2) using consumable inserts and 3) orbital welding. These are discussed in more detail below.

Three pipe welding procedures that should provide greater agitation and mixing of the root pass are presented below.

1) *Manual welding with modified weld joint* — Standard grades of thin-wall stainless steel pipe used in mild environments are often welded as a tightly fit butt joint (no root opening) with little or no filler metal added. Welders get used to this practice and when filler metal must be added, for example in welding a 4- to 6%-Mo stainless steel with a high molybdenum filler metal, they often add too little filler metal or do not add it uniformly. The result is a root pass with insufficient or unblended weld metal. A joint design such as shown in Fig. 9 better assures adequate filler metal addition and a homogeneous weld bead. After qualifying the procedure, welders should be properly trained and careful follow-up inspection made during welding.

2) *Consumable inserts* — Consumable inserts are available in a number of different shapes (AWS A5.30-79) and a variety of filler metals. The inserts can be used in either manual or automatic welding. By using weld parameters to assure complete fusion of the insert, good weld metal mixing is accomplished.

3) *Orbital or automatic welding with filler metal addition* — While this type of weld was not evaluated in the TAPPI program, the process offers the potential of making reproducible, high quality welds with good weld metal mixing.

Postweld Cleaning of Stainless Steel

It has long been known that postweld cleaning of stainless steel weldments is necessary for the best performance of any grade of stainless steel, but there is very little good data in the literature to substantiate "what everyone knows." Differences of opinion have arisen on the cost and usefulness of pickling and other postweld cleaning. Some recent work by Krupp-VDM provides definitive information on postweld cleaning (Ref. 5). Figure 10 shows that nitric hydrofluoric acid pickling improves the corrosion resistance of surfaces that have been light ground or glass bead blasted. The data in Fig. 10 provide a good yardstick for those who need to know how much improvement in corrosion resistance nitric-hydrofluoric pickling provides.

Heat tint is frequently removed mechanically. The authors' experience indicates that light grinding with clean aluminum oxide abrasive disks or flapper wheels and glass bead blasting are effective methods of removing heat tint. Even properly mechanically cleaned surfaces are improved by nitric-HF pickling.

Wire brushing with stainless steel wire brushes is also a common method of cleanup after welding. Garner reported corrosion initiated on several stainless steel specimens in the area where the specimen had been power wire brushed with a clean stainless wire brush (Ref. 6) — Fig. 11. He suggested that the attack may be due to inadequate heat-tint removal, the use of low-alloy stainless steel brushes such as Types 410 or 304, or due to redeposition of abraded metal and oxides. Pickling would be expected to remove any such metal transferred by stainless steel wire brushing or remove other foreign surface deposits.

The authors have found that heavy grinding with grinding wheels degrades the corrosion resistance to a greater depth than can be restored by pickling. Blasting with steel grit and steel shot also degrades the corrosion resistance beyond the ability of pickling to fully restore. Grinding is best limited to pencil grinding for removal of small defects or where required for other reasons for removal of weld reinforcement.

Postweld Cleaning Nickel-Based Alloys

The question of whether heat tint is as detrimental to the corrosion resistance of the inherently more corrosion resistant nickel-based alloys was investigated by Silence and Flashe (Ref. 7). While not conclusive, this work indicated heat tint removal did not appear to give the same incremental increase in corrosion resistance that heat tint removal does for stainless steels. This may be due to the greater inherent corrosion resistance of the base metal or to other factors yet to be identified.

Conclusions

1) Welds made autogenously or with matching-composition filler metals on 2- to 6%-Mo austenitic stainless steels have inherently lower corrosion resistance than the base metal in these low-pH oxidizing environments with chlorides.

2) The lower corrosion resistance is not due to the higher ferrite content of the weld metal.

3) The lower corrosion resistance is

due to coring and segregation of molybdenum and to a lesser extent similar segregation of chromium.

4) The use of high-Mo filler metals, such as Alloys 625, C-276 or C-22, overcomes the loss of weld metal corrosion resistance and has become standard for welded fabrication of 4- to 6%-Mo stainless steels.

5) Nickel-based alloys, including clad C-276 and titanium, did not exhibit the marked reduction in corrosion resistance when welded with a matching composition filler metal in these environments.

6) High-alloy clad materials can be produced as welded pipe in much the same manner as welded stainless steel pipe and are good candidates for high-corrosion-resistant pipe.

7) The root pass of groove welds in 6%-Mo pipe may be subject to lower corrosion resistance due to insufficient mixing in the molten weld pool. Remedial measures are being investigated.

8) Pickling is very effective in restoring the corrosion resistance of stainless steels after the surface has been degraded by welding, light grinding, stainless steel wire brushing or glass bead blasting.

9) Matching composition welds in ferritic alloys with 29 to 30% Cr were as corrosion resistant as the base metal, whereas they were not in ferritic alloys with lower (24.5-26%) Cr.

Acknowledgments

The authors are grateful to Andrew Garner, Pulp and Paper Research Institute of Canada; Richard B. Hitchcock, Consultant; and Thomas Ladwein, Thyssen Edelstahlwerke Research, for their review and comments. We also thank the Nickel Development Institute for its support.

References

1. Hill, J. B., and Tuthill, A. H. 1983. TAPPI phase II corrosion test program — Part II: Weld metal and heat affected zone corrosion in bleach plant environments. *Proceedings Fourth International Symposium on Corrosion in the Pulp and Paper Industry*, Stockholm, Sweden.

2. Garner, A. 1979. The effect of autogenous welding on chloride pitting of austenitic stainless steels. *Corrosion* 35(3): 108–14.

3. Brigham, R. J., and Tozer, E. W. 1973. *Corrosion*, 29:33.

4. Tuthill, A. H., and Garner, A. 1989. Evaluation of bleach plant piping materials. *Proceedings TAPPI Engineering Conference*, Atlanta, Ga.

5. Rockel, VDM-NT AG. Private communication.

6. Garner, A. 1986. Corrosion of weldments in pulp bleach plants. *Welding Journal* 65(9): 39–44.

7. Silence, W. L., and Flashe, L. H. 1986. The affect of heat-tint on corrosion resistance of alloys used in FGD systems. *Corrosion 86*, Paper No. 358, Houston, Tex.

Appendix

The producers of proprietary alloys used in this work are listed below.

Trademark	Product of
AL-6X	Allegheny Ludlum Steel Corp.
AL-29-4	Allegheny Ludlum Steel Corp.
AL-29-4-2	Allegheny Ludlum Steel Corp.
Avesta 254 SLX	Avesta Jernverks AB
Avesta 254 SMO	Avesta Jernverks AB
Carpenter 20 Mo-6	Carpenter Technology
Crucible T-317X	Colt Industries
Crucible SC-1	Colt Industries
E-Brite	Allegheny Ludlum Steel Corp.
Hastelloy G	Haynes International
Hastelloy G-3	Haynes International
Hastelloy G-30	Haynes International
Hastelloy C-276	Haynes International
Hastelloy C-22	Haynes International
Incoloy 825	Inco Family of Companies
Incoloy 65	Inco Family of Companies
Inconel 112	Inco Family of Companies
Inconel 625	Inco Family of Companies
Jessop 700	Jessop Steel Company
NITRONIC 50	Armco, Inc.
NYBY Monit	Uddeholm Corporation
Sanicro 28	Sandvik, Inc.
Schomac 30-2	Showa Denko KK
Uddeholm 904L	Uddeholm Corporation
Uddeholm 44N	Uddeholm Corporation
Chromenar 625	Arcos
Jungo 4500	Smitweld bv
Arosta 4462	Smitweld bv