

Inherent Corrosion Resistance and Response to Cathodic Protection in Seawater of Recently Developed Stainless Steel Alloys

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corroding electrochemical potentials over an extended period.

Cathodic protection with either mild steel (Fe) or zinc (Zn) anodes prevented crevice corrosion, but the 26Cr-1Mo and 22Cr-13Ni-5Mn stainless steels showed some edge corrosion and corrosion under the mild steel anode, respectively, when polarized to the potential of mild steel.

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INHERENT CORROSION RESISTANCE AND RESPONSE TO CATHODIC PROTECTION IN SEAWATER OF RECENTLY DEVELOPED STAINLESS STEEL ALLOYS

INTRODUCTION

Manufacturers and suppliers of stainless steel have tried continually to produce an alloy resistant to both crevice corrosion and pitting in quiescent seawater. A stainless steel resistant to these and other types of corrosion would be useful for instrument packages placed in the ocean and for other critical stainless steel components that must be electrically isolated from more active structural metals such as aluminum or steel. Generally, stainless steels are successfully used for long-term service in seawater only when cathodically protected. Protection from corrosion can be accomplished by either electrically coupling them to more active metals or providing an intentional cathodic protection system.

Many of the newer stainless steels are claimed to be more resistant than the common grades of stainless steel to localized corrosion in chloride-containing media. Unfortunately, many such claims are based on relatively short-term laboratory experiments with small specimens. Furthermore, the experiments generally are not conducted in natural seawater. In some instances, potentiostatic polarization techniques are used to assess the relative corrosion resistance of alloys in specific media, and attempts are made to extrapolate these data to indicate corrosion resistance in other media. Also, seemingly aggressive solutions such as FeCl_3 and 3.5 percent NaCl are used as test media. Such studies are not likely to provide corrosion data useful for designing structures that are corrosion resistant in natural seawater.

Use of stainless steel in critical marine applications must be based on total confidence that crevice corrosion, pitting, and other forms of corrosion will not occur in quiescent seawater, i.e., at water velocities below which stainless steels are rendered immune to corrosion by repassivation due to continual replenishment of oxygen from flowing seawater.

Earlier studies [1-6] provided data on the corrosion characteristics and response to cathodic protection of the 300 series, 400 series, and precipitation-hardened (PH) stainless steel alloys. The detrimental effects on 17-4 PH stainless steel of some levels of cathodic polarization also have been reported [2,4,6].

In the present experiments, data were developed on the corrosion characteristics of several newer stainless steel alloys in seawater and their response to cathodic protection. Table 1 shows the name/grade, structure, nominal chemical composition, specimen condition, and original thickness for the alloys studied.

EXPERIMENTAL CONDITIONS

The experiments were conducted in seawater at NRL's Marine Corrosion Research Laboratory in Key West, Fla. Water temperature ranged from 16° to 31.1°C (60.8° to 88.0°F), and the mean temperature was 25.1°C (77.2°F). Resistivity of the seawater

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Table 1 — Stainless Steel Alloys

Alloy		Nominal Composition (%)							Original Thickness		Condition
Name/Grade	Structure	Cr	Ni	Mo	Mn	Si	C	Fe	(μm)	(mils)	
24Ni-20Cr-6.5Mo	Austenitic	20	24	6.5	1.5	0.5	0.035 max	Rem.*	1676	(66)	Annealed and passivated (30T scale - 66)
26Cr-1Mo	Ferritic	26	Ni + Cu 0.5 max	1.0	0.4 max	0.4 max	0.01 max	Rem.*	1524	(60)	Cold rolled and annealed (Rb 81)
22Cr-13Ni-5Mn	Austenitic	22	13	2.0	5	0.4	0.06 max	Rem.*	1575	(62)	Rc 23
Type 216	Austenitic	20	6	2.5	8.3	0.4 max	0.08 max	Rem.*	1575	(62)	Rb 94

*Trace amounts of N, Cb, V, Cu, P, and S may be present.

ranged from 15.9 to 21.8 ohm-cm, with a mean of 18 ohm-cm. The seawater pH ranged from 8.0 to 8.3, with a mean value of 8.1. Oxygen content ranged from 5.7 to 11.1mg/1, with a mean of 8.0 mg/1. Seawater temperature, resistivity, pH, and oxygen content as a function of time are plotted in Fig. 1.

Two exposure conditions were used for these experiments. Stainless steel specimens with and without cathodic protection were exposed both under a pier, where the only water velocity was due to tides, and in acrylic cells in the laboratory, where seawater was pumped through once at a rate of 3 ml/s. This rate was just sufficient to change the seawater in the cell every 1800 s (30 min).

The experiments were conducted over two time periods, i.e., approximately 6 months (actual times varied from 176 to 218 days) and 18 months (actual times varied from 531 to 552 days). Exposure times were the same for all specimens of any one alloy.

PROCEDURES

A total of 48 specimens (12 specimens of each of four alloys) was used in this study. One specimen of each alloy was exposed in seawater unprotected, and with two levels of cathodic protection, in each of two exposure conditions, and for two time periods.

Each stainless steel specimen was shear cut to 152 × 305 mm (6 × 12 in.). The original thicknesses are listed in Table 1. Holes were punched in each specimen for mounting on the racks, for attaching the electrical leads to measure the potentials, and for attaching galvanic anodes, where used. The specimens were mounted on, but electrically isolated from, coated aluminum racks. The 25.4 × 152 × 3.2 mm (1 × 6 × 1/8 in.) polyethylene strips used to isolate the specimens from the racks also produced an intentional crevice, as did the nylon washers used with the nylon bolts and nuts to attach the specimens to the rack.

The anodes used for cathodic protection measured 32 × 152 × 13 mm (1-1/4 × 6 × 1/2 in.), with an anode-to-cathode area ratio of 1:9. Zinc anodes (Zn) conforming to specification MIL-A-18001H and mild steel (Fe) anodes provided two levels of cathodic protection. Each anode was drilled and tapped and bolted directly to the stainless steel

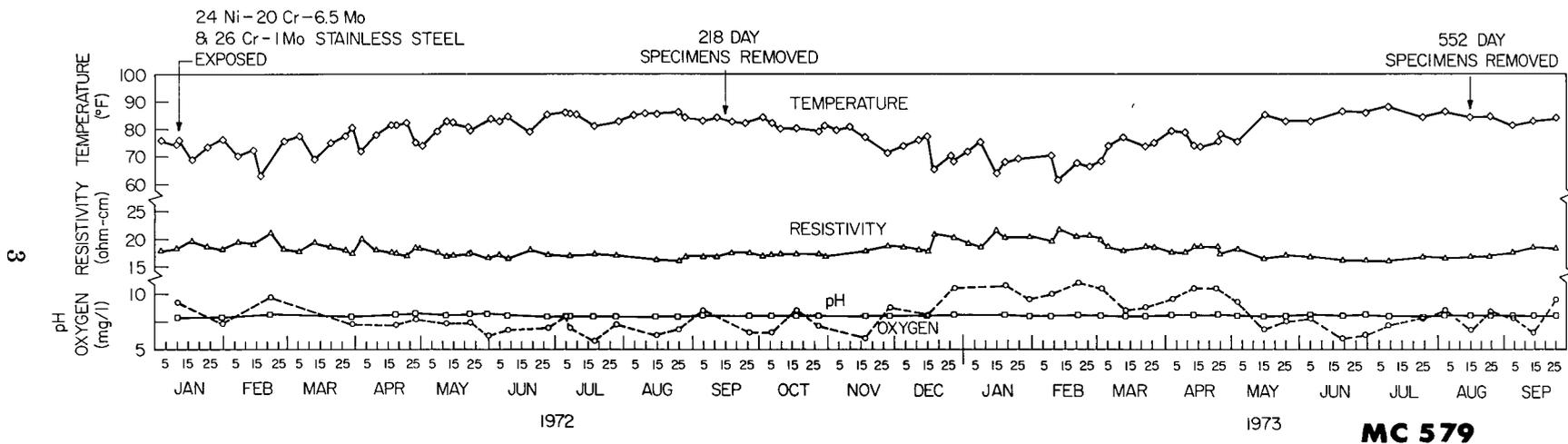


Fig. 1 — Temperature, resistivity, pH, and oxygen content of the seawater at Key West, Fla. (as a function of time)

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specimens with stainless steel bolts. Exposed parts of the bolts were coated with epoxy to seal the connections from seawater. Test wires for the potential measurements were attached to each specimen with a bolt and nut. All electrical connections were isolated from the seawater with epoxy. As in past experiments, the epoxy sealant created a severe crevice condition on the specimens.

Before assembly, the anodes and specimens were degreased with acetone and weighed to the nearest 0.1 g. Immediately before exposure, the specimens on the assembled racks were wiped with solvent to remove fingerprints and accumulated soil.

After exposure, gross marine biological fouling was removed from the specimens with a high-pressure freshwater jet. The specimens were then chemically cleaned in 10 wt-% nitric acid at 60°C (140°F) until all fouling and corrosion products had been removed.

After cleaning, the specimens were reweighed to the nearest 0.1 g, and the depth of crevice corrosion (the predominant form of corrosion observed) was measured with a needle probe (number 10 sharps) attached to a dial micrometer. These measurements were made under a stereo microscope at 22.5X magnification to ensure both through inspection and measurement of the deepest crevice corrosion. Depth measurements were made to the nearest 25 μm (1 mil or 0.001 in.).

EXPERIMENTAL RESULTS AND DISCUSSION

Depth of Corrosion, Weight Loss, Corrosion Characteristic, and Cathodic Protection

Maximum depth of crevice corrosion, weight loss, and exposure time for each stainless steel in the two exposure conditions, with and without cathodic protection, are summarized in Table 2.

Table 2 — Maximum Depth of Crevice Corrosion and Weight Loss for Stainless Steels in Seawater, With and Without Cathodic Protection

Stainless Steel Alloy	Exposure Time (Days)	Maximum Depth of Crevice Corrosion — μm (mils)*						Weight Loss — g					
		Pier Exposure			Cell Exposure			Pier Exposure			Cell Exposure		
		No CP†	CP-Fe†	CP-Zn†	No CP†	CP-Fe†	CP-Zn†	No CP†	CP-Fe†	CP-Zn†	No CP†	CP-Fe†	CP-Zn†
24Ni-20Cr-6.5Mo	218	279(11)	<25(<1)	0	1676(66)‡	<25(<1)	0	0.2	0.0	<0.1	3.4	<0.1	0.1
	552	0	0	0	0	0	0	0.1	0.0	0.0	<0.1	<0.1	0.0
26Cr-1Mo	218	1270(50)	0	0	1422(56)	0	0	3.8	0.0	0.0	5.8	0.0	0.0
	552	1524(60)‡	0	0	1524(60)‡	0	0	6.4	0.0	0.1	8.8	0.0	0.1
22Cr-13Ni-5Mn	176	483(19)	0	0	1575(62)‡	0	0	0.2	0.1	0.2	4.2	0.0	0.0
	531	838(33)	<25(<1)¶	0	1168(46)	0	0	1.0	0.0	0.0	8.0	0.0	0.0
Type 216	182	305(12)	0	0	889(35)	0	0	0.9	0.7	0.1	2.0	0.0	0.0
	546	559(22)	0	0	1524(60)	0	0	1.0	0.5	0.9	1.9	0.1	0.0

*1 mil (0.001 in.) = 25.4 μm

†CP = Cathodic Protection

‡Penetrated by corrosion

||Some edge corrosion

¶Corrosion under mild steel (Fe) anode

Maximum crevice corrosion depth and weight loss for 24Ni-20Cr-6.5Mo stainless steel are plotted as bar graphs in Fig. 2. This alloy has been reported to be essentially immune to crevice corrosion and pitting in seawater, but Fig. 2 shows that unprotected specimens crevice corroded in 218 days in both exposures. The crevice corrosion on the unprotected specimens of this alloy is shown in Fig. 3. The most severe exposure condition was the laboratory cell, where the 1676- μ m-thick (66 mil) specimen was penetrated.

Stainless steel specimens with little weight loss often exhibit severe localized corrosion. This was true of the 24Ni-20Cr-6.5Mo alloy in the pier exposure. However, in the cell exposure, where the specimen was penetrated, weight loss was measurable (Table 2).

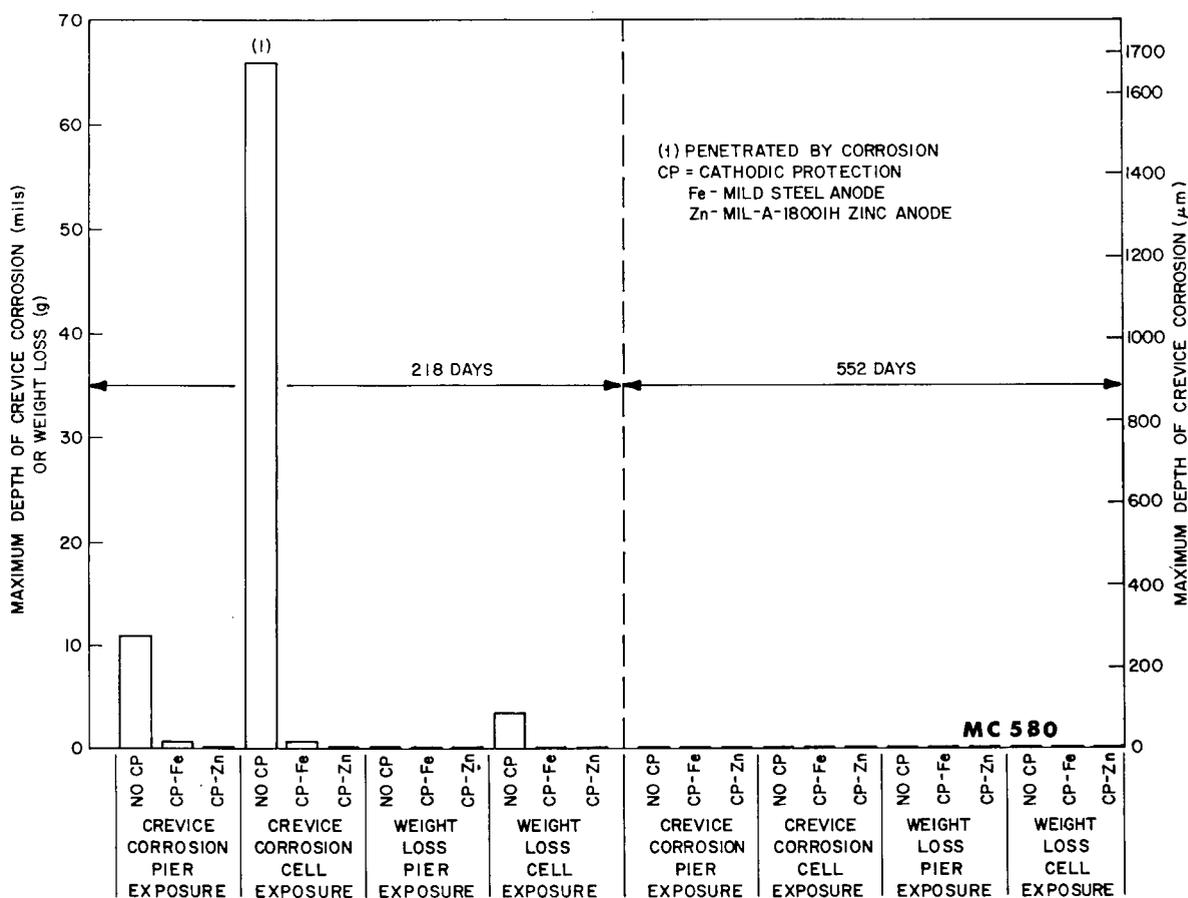


Fig. 2 — Maximum depth of crevice corrosion and weight loss for 24Ni-20Cr-6.5Mo stainless steel in seawater, with and without cathodic protection

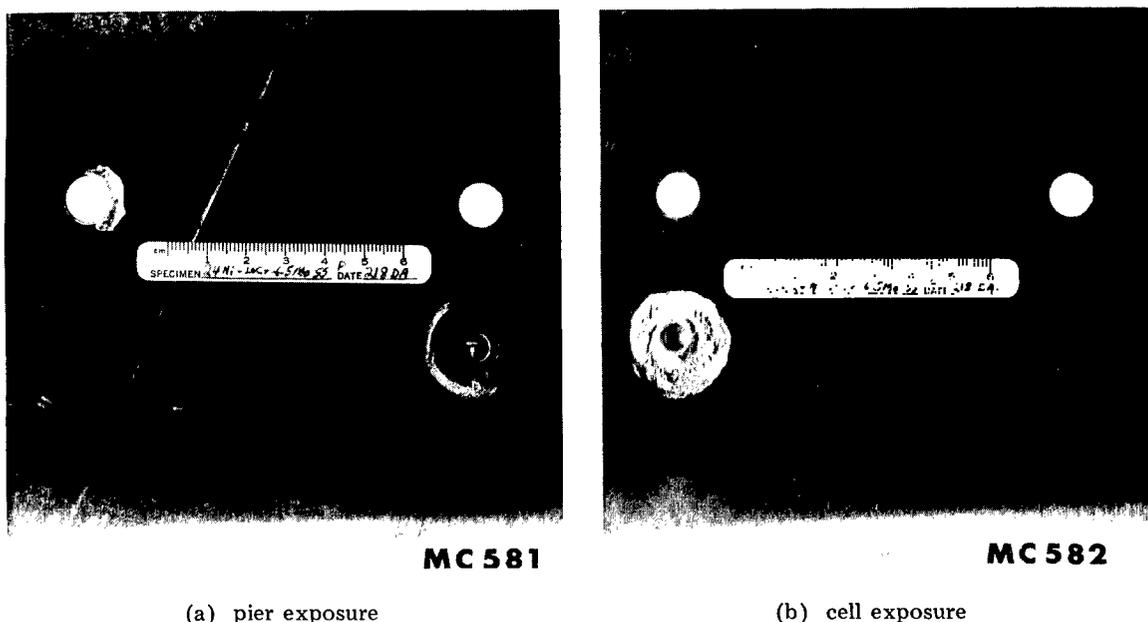


Fig. 3 — Crevice corrosion of 24Ni-20Cr-6.5Mo stainless steel; 218 days in seawater

In contrast to the severe crevice corrosion in the 218-day tests of unprotected specimens of 24Ni-20Cr-6.5Mo, neither of the two specimens of this alloy exposed for 552 days exhibited any crevice corrosion. This is only an apparent anomaly, however, because it is characteristic of stainless steels that crevice corrosion does not occur in all specimens. For the more resistant alloys, crevice corrosion may affect a relatively small percentage of the specimens.

Figure 2 also shows that cathodic protection from either Fe or Zn anodes reduced localized corrosion on 24Ni-20Cr-6.5Mo to acceptable levels.

Unprotected 26Cr-1Mo stainless steel was very susceptible to crevice corrosion in both pier and cell exposures. Figure 4 shows that this alloy suffered crevice corrosion to a depth of approximately 1270 μm (50 mils) in 218 days and was penetrated in 552 days. Corrosion was also indicated by the weight loss (Table 2) of the unprotected specimens. Figure 5 shows the severity of the crevice corrosion in both exposures after 522 days.

Cathodic protection with Fe and Zn anodes reduced crevice corrosion on 26Cr-1Mo, but some edge corrosion was still evident on the specimens protected with the Fe anode (Fig. 4).

Severe crevice corrosion occurred on unprotected 22Cr-13Ni-5Mn stainless steel in 176- and 531-day exposures, in both pier and cell conditions. Figure 6 shows that the specimen exposed in the cell for 176 days was penetrated by crevice corrosion. The other unprotected specimens crevice-corroded to depths of 483-1168 μm (19-46 mils) in periods

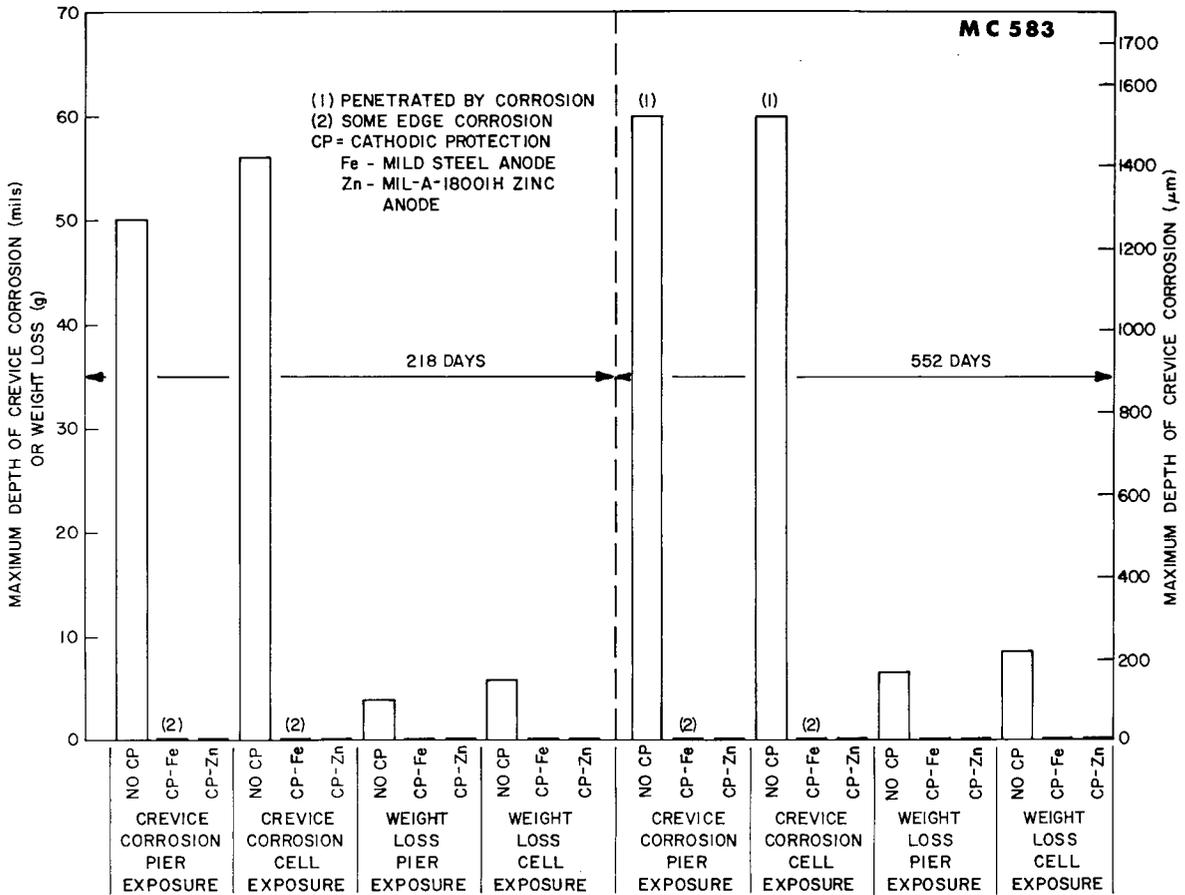
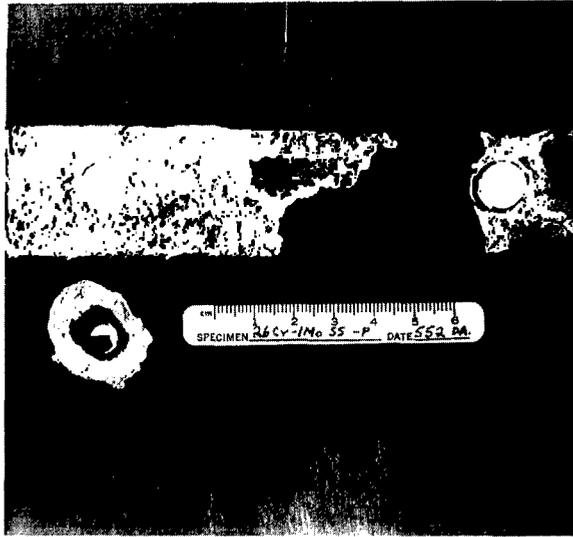
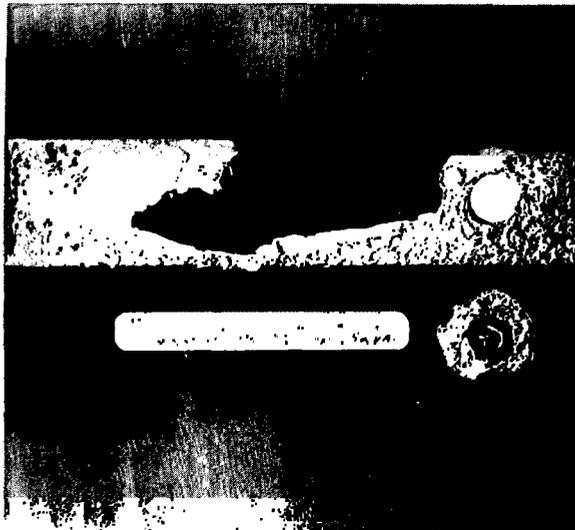


Fig. 4 — Maximum depth of crevice corrosion and weight loss for 26Cr-1Mo stainless steel in seawater, with and without cathodic protection



MC 584

(a) pier exposure



MC 585

(b) cell exposure

Fig. 5 — Severe crevice corrosion of 26Cr-1Mo stainless steel; 552 days in seawater

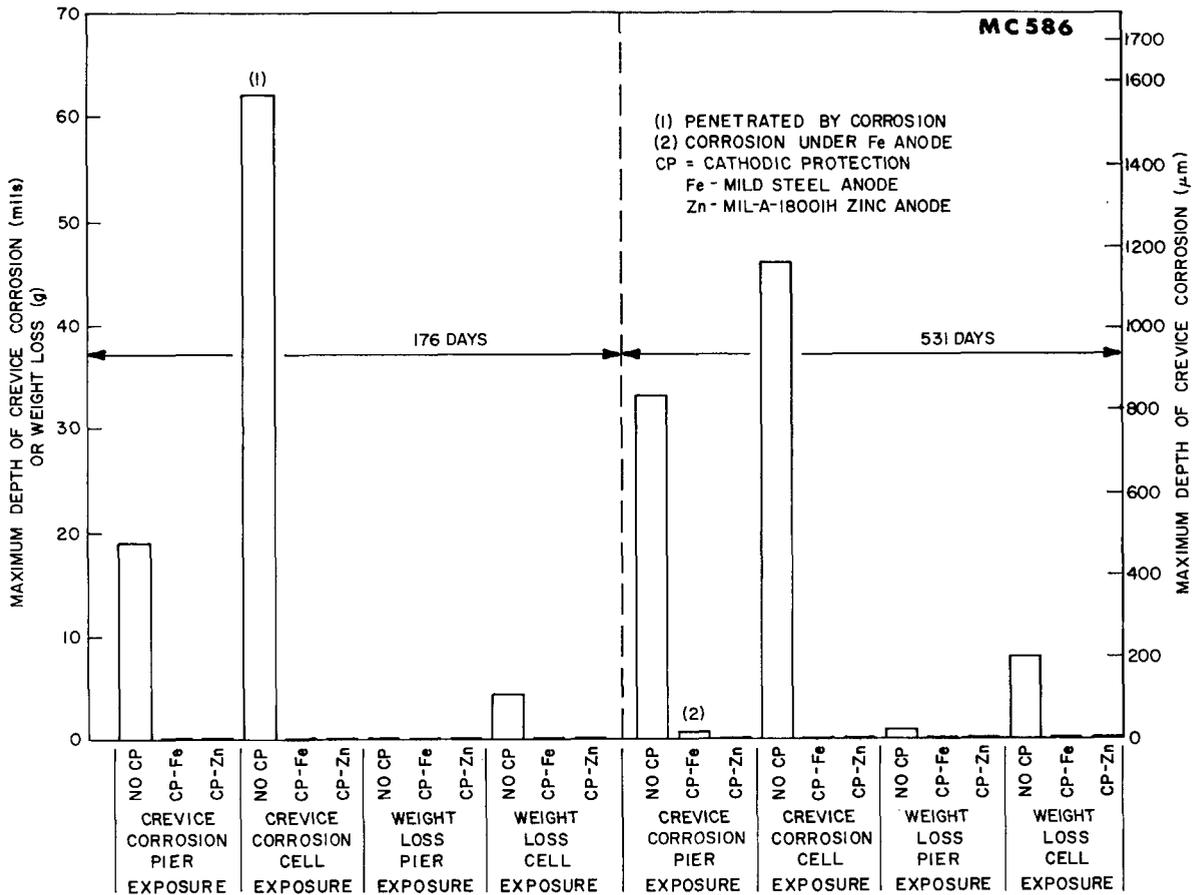
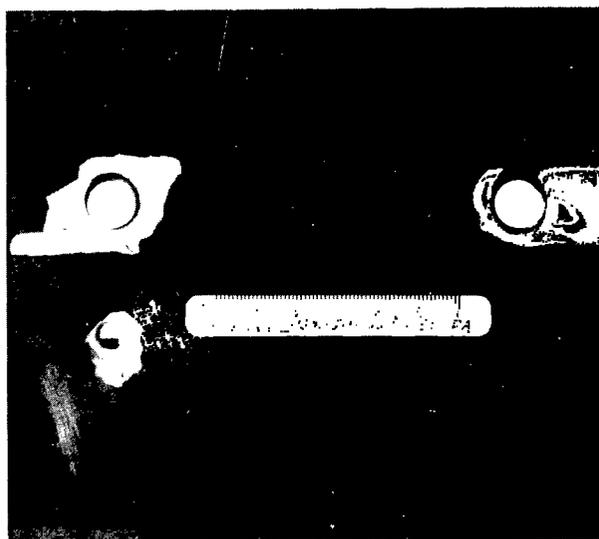


Fig. 6 — Maximum depth of crevice corrosion and weight loss for 22Cr-13Ni-5Mn stainless steel in seawater, with and without cathodic protection

up to 531 days. Weight loss of the unprotected specimens in the cell condition also indicated the seriousness of the corrosion (Table 2). The extent of crevice corrosion on the unprotected specimens of 22Cr-13Ni-5Mn in both exposures after 531 days is shown in Fig. 7. Cathodic protection with Fe and Zn anodes reduced the crevice corrosion of this alloy to acceptable levels (Fig. 6), although in longer exposures a small amount of corrosion was observed directly under the Fe anode.

Unprotected Type 216 stainless steel also crevice-corroded in both pier and cell exposures of 182 and 546 days (Fig. 8). Depth of crevice corrosion seemed to increase with time for this alloy, but the severity of the corrosion renders such a trend an academic question. Figure 9 shows the extent of crevice corrosion in this stainless steel after 546 days in both pier and cell exposures.

For engineering purposes, cathodic protection with Fe or Zn anodes of Type 216 stainless steel is effective in preventing crevice corrosion, though some weight loss was



MC 587

(a) pier exposure



MC 588

(b) cell exposure

Fig. 7 — Crevice corrosion of 22Cr-13Ni-5Mn stainless steel; 531 days in seawater

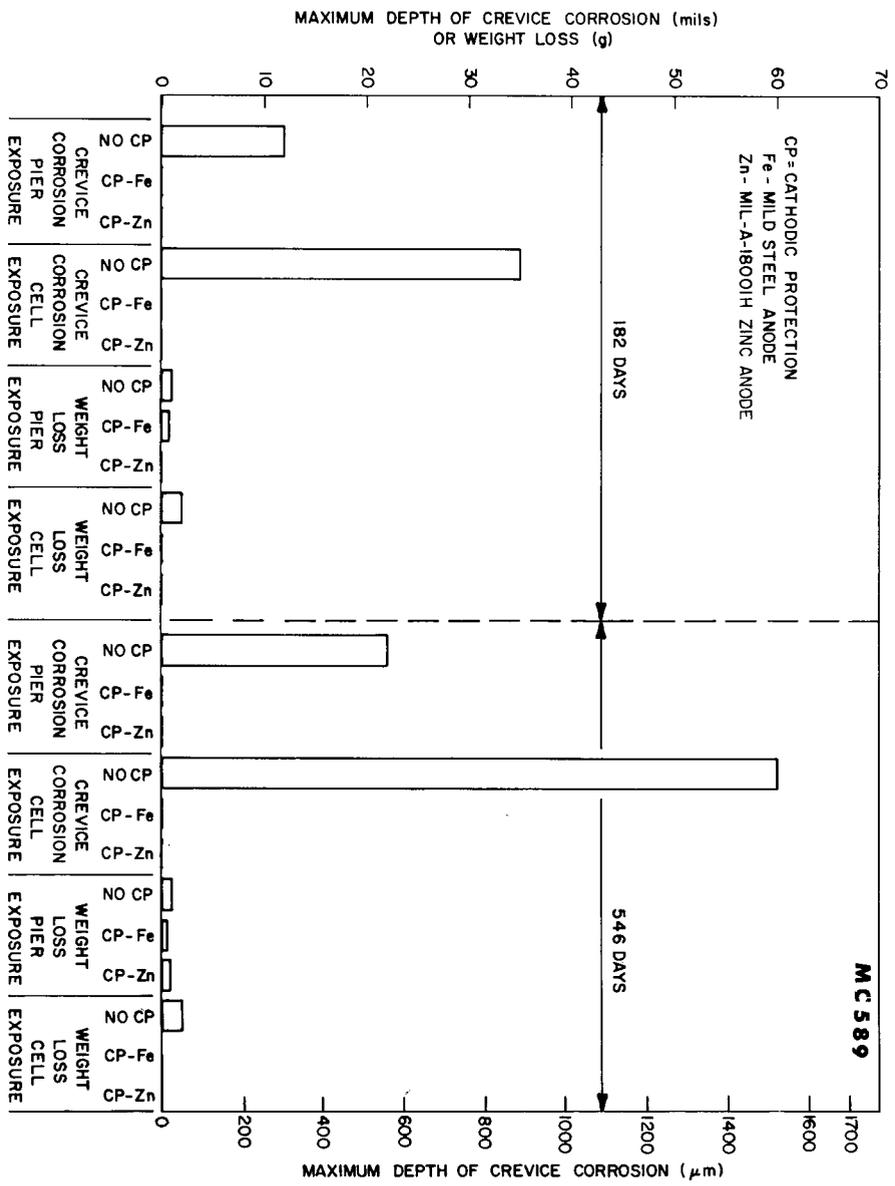
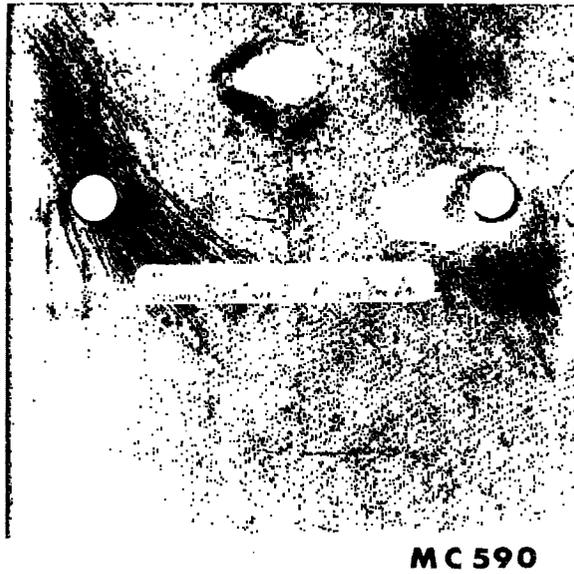
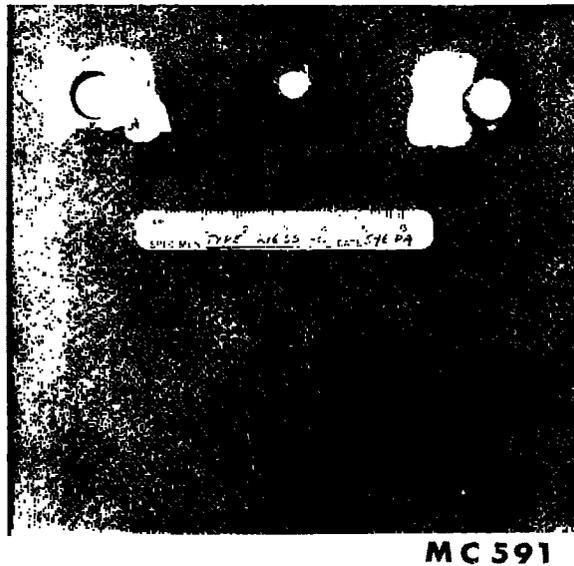


Fig 8 — Maximum depth of crevice corrosion and weight loss for Type 216 stainless steel in seawater, with and without cathodic protection



(a) pier exposure



(b) cell exposure

Fig. 9 — Crevice corrosion of Type 216 stainless steel;
546 days in seawater

measurable for the pier specimens protected by an Fe anode for both exposure periods and for the pier specimen protected by a zinc anode for the longer exposure period. This shows that some generalized corrosion occurred.

Electrochemical Potentials

The mean and the range of the electrochemical potentials for each specimen in the two exposure conditions, and with and without the two levels of cathodic protection, are shown in Table 3. The potentials were all measured relative to the Ag/AgCl/seawater reference electrode. The potentials of each stainless steel alloy in the freely corroding (unprotected) condition and polarized with either an Fe or a Zn anode are plotted as a function of time in Figs. 10-16.

Table 3 — Mean Potentials and Range of Potentials for Stainless Steels in Seawater, With and Without Cathodic Protection

Stainless Steel Alloy	Exposure		Potential (V) to Ag/AgCl Reference Electrode			
			Pier		Cell	
	Time (Days)	Condition	Mean	Range	Mean	Range
24Ni-20Cr-6.5Mo	218	No CP	+0.023	+0.217 to -0.187	+0.038	+0.296 to -0.415
		CP-Fe	-0.662	-0.607 to -0.702	-0.689	-0.562 to -0.739
		CP-Zn	-1.024	-1.002 to -1.043	-1.045	-1.020 to -1.065
	552	No CP	+0.152	+0.269 to -0.057	+0.256	+0.320 to -0.148
		CP-Fe	-0.646	-0.600 to -0.700	-0.653	-0.577 to -0.737
		CP-Zn	-1.021	-0.984 to -1.052	-1.038	-0.998 to -1.065
26Cr-1Mo	218	No CP	-0.154	-0.006 to -0.235	-0.047	+0.075 to -0.228
		CP-Fe	-0.651	-0.608 to -0.692	-0.670	-0.567 to -0.724
		CP-Zn	-1.021	-1.002 to -1.037	-1.043	-1.017 to -1.058
	552	No CP	-0.098	+0.017 to -0.222	-0.035	+0.173 to -0.193
		CP-Fe	-0.628	-0.589 to -0.693	-0.676	-0.577 to -0.724
		CP-Zn	-1.016	-0.995 to -1.036	-1.026	-0.894 to -1.052
22Cr-13Ni-5Mn	176	No CP	-0.094	-0.023 to -0.180	-0.004	+0.053 to -0.117
		CP-Fe	-0.676	-0.649 to -0.697	-0.683	-0.665 to -0.708
		CP-Zn	-1.015	-1.003 to -1.033	-1.021	-1.004 to -1.037
	531	No CP	-0.065	+0.079 to -0.230	-0.085	+0.031 to -0.117
		CP-Fe	-0.637	-0.599 to -0.699	-0.666	-0.631 to -0.709
		CP-Zn	-1.008	-0.989 to -1.031	-0.987	-0.930 to -1.037
Type 216	546	No CP	-0.136	-0.007 to -0.440	-0.047	+0.155 to -0.297
		CP-Fe	-0.656	-0.500 to -0.720	-0.671	-0.562 to -0.721
		CP-Zn	-1.014	-0.995 to -1.029	-1.015	-0.948 to -1.053

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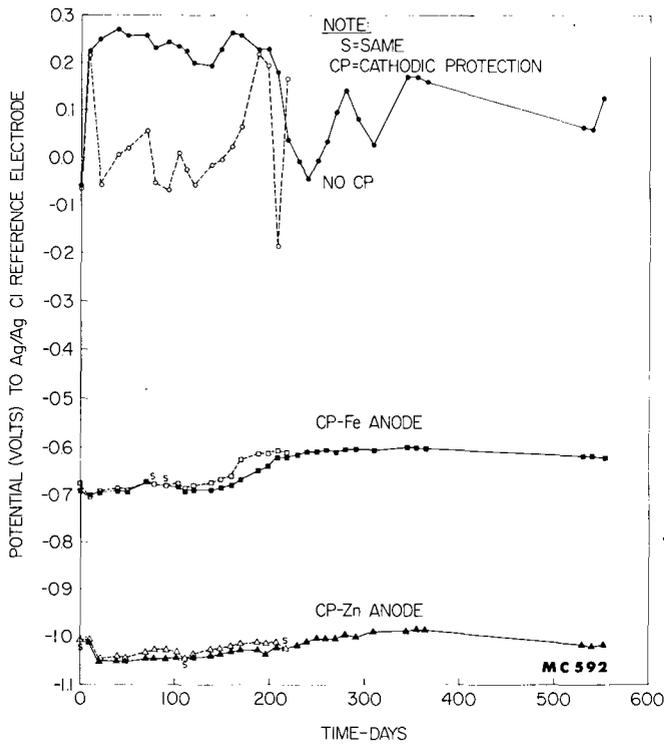


Fig. 10 — Electrochemical potentials of 24Ni-20Cr-6.5Mo stainless steel as a function of time in seawater; pier exposure, with and with cathodic protection

Fig. 11 — Electrochemical potentials of 24Ni-20Cr-6.5Mo stainless steel as a function of time in seawater; cell exposure, with and without cathodic protection

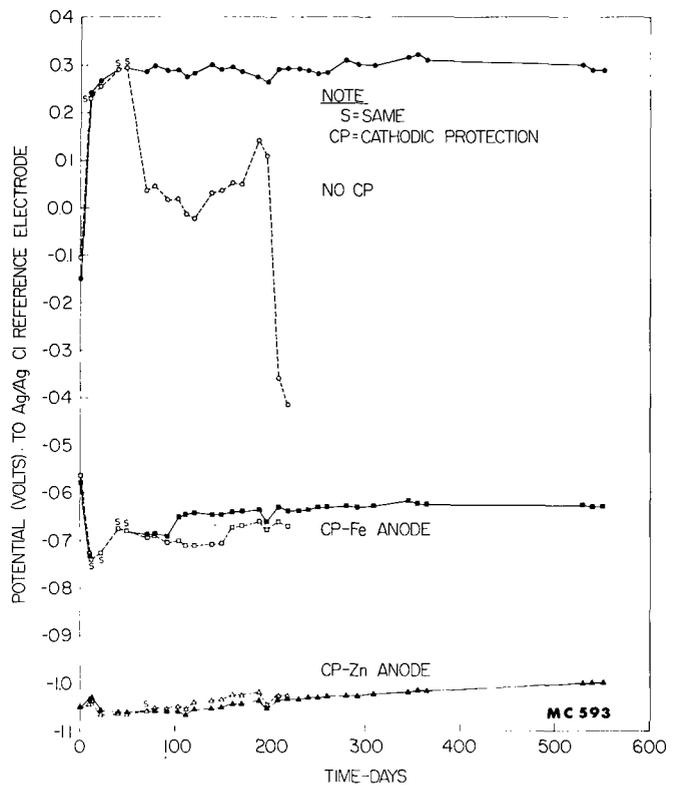


Fig. 12 — Electrochemical potentials of 26Cr-1Mo stainless steel as a function of time in seawater; pier exposure, with and without cathodic protection

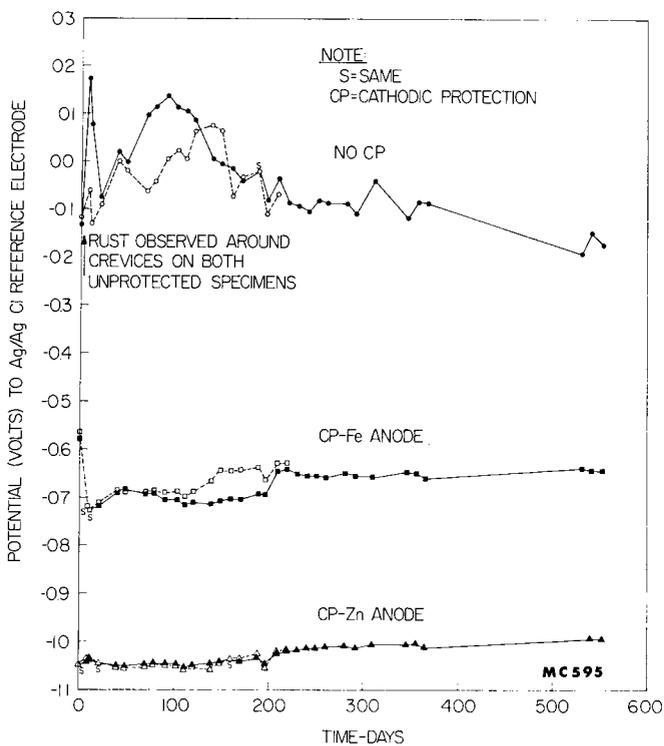
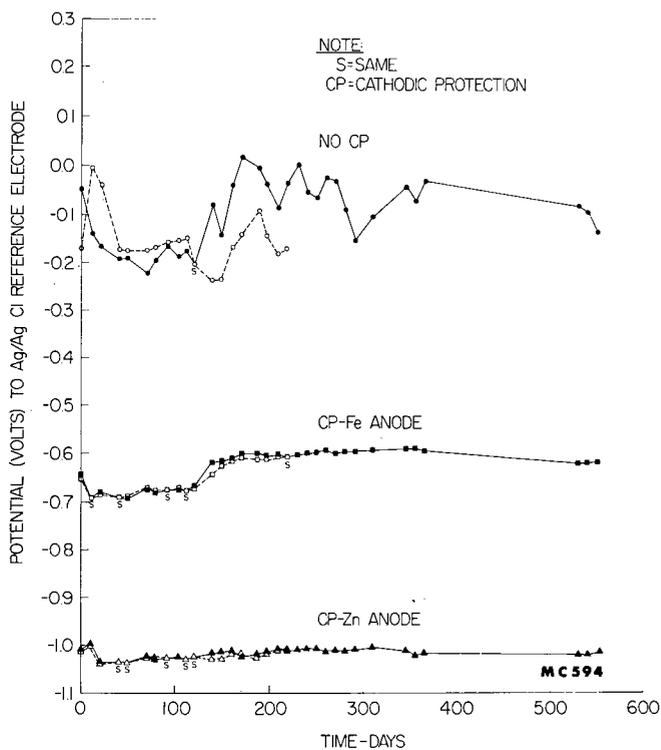


Fig. 13 — Electrochemical potentials of 26Cr-1Mo stainless steel as a function of time in seawater; cell exposure, with and without cathodic protection

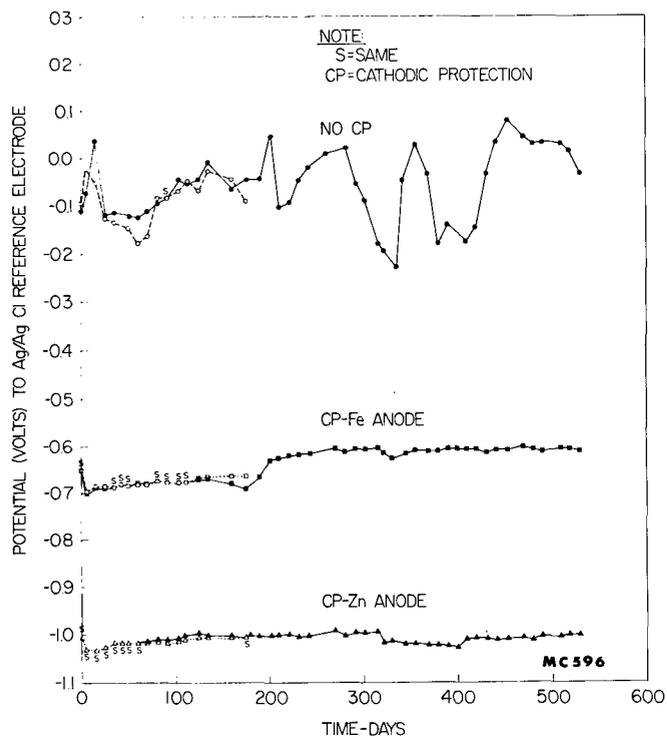
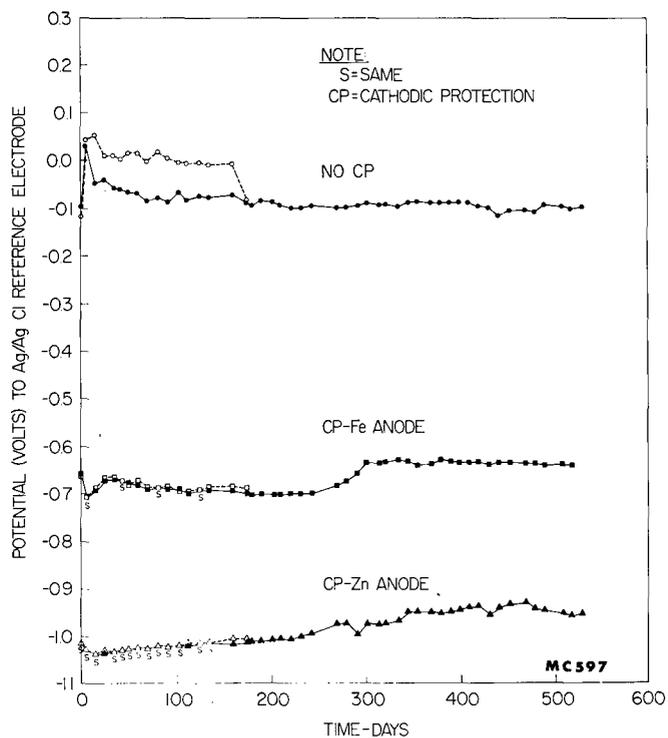


Fig. 14 — Electrochemical potentials of 22Cr-13Ni-5Mn stainless steel as a function of time in seawater; pier exposure, with and without cathodic protection

Fig. 15 — Electrochemical potentials of 22Cr-13Ni-5Mn stainless steel as a function of time in seawater; cell exposure, with and without cathodic protection



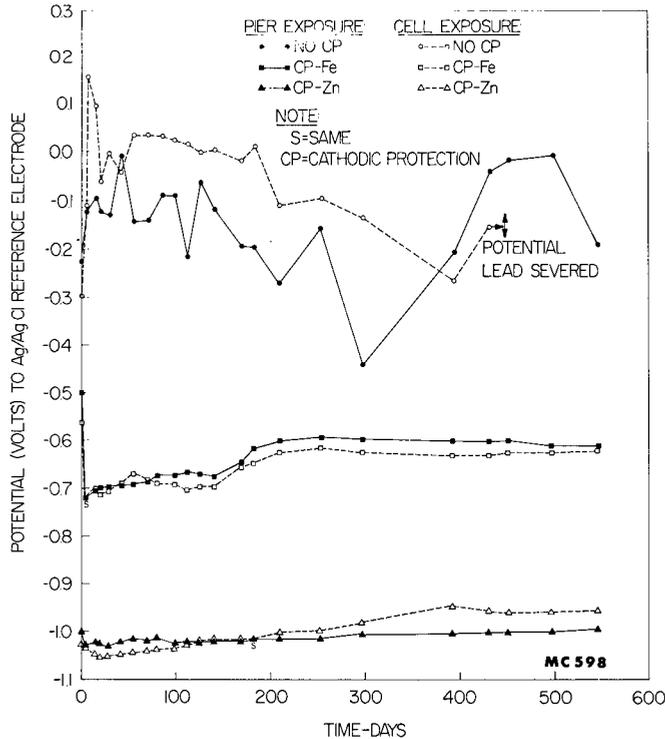


Fig. 16 — Electrochemical potentials of Type 216 stainless steel as a function of time in seawater; pier and cell exposures, with and without cathodic protection

In most cases, the potential of the freely corroding specimens varied considerable with time of exposure. However, the 24Ni-20Cr-6.5Mo alloy in the long-term cell exposure had a fairly constant potential after 40 days (Fig. 11). This specimen did not crevice corrode. In the long-term pier exposure, this alloy did not crevice corrode, and the potential was generally more noble than for either the other stainless steel alloys or the specimens of the same alloy which crevice corroded.

The mean electrochemical potentials of the stainless steels for each exposure condition and each exposure time are plotted as a function of maximum depth of crevice corrosion in Fig. 17.

These data indicated that unprotected stainless steels that exhibited a relatively noble and steady potential over a long period in seawater, were not susceptible to crevice corrosion. The limited data of this study also indicated that the exposure time required to substantiate this trend would be 100 to 200 days, depending on exposure conditions. Meaningful exposure times required to establish such a trend would have to be confirmed by extensive field-service experiments comparing freely corroding electrochemical potential with susceptibility to crevice corrosion under the conditions of interest. Short-term potential data would be useless in a study of this type, as indicated by Figs. 10 and 11.

In addition, mean potential data alone cannot be relied on to establish trends, because mean potential is influenced by not only the variation of potential with time but also the

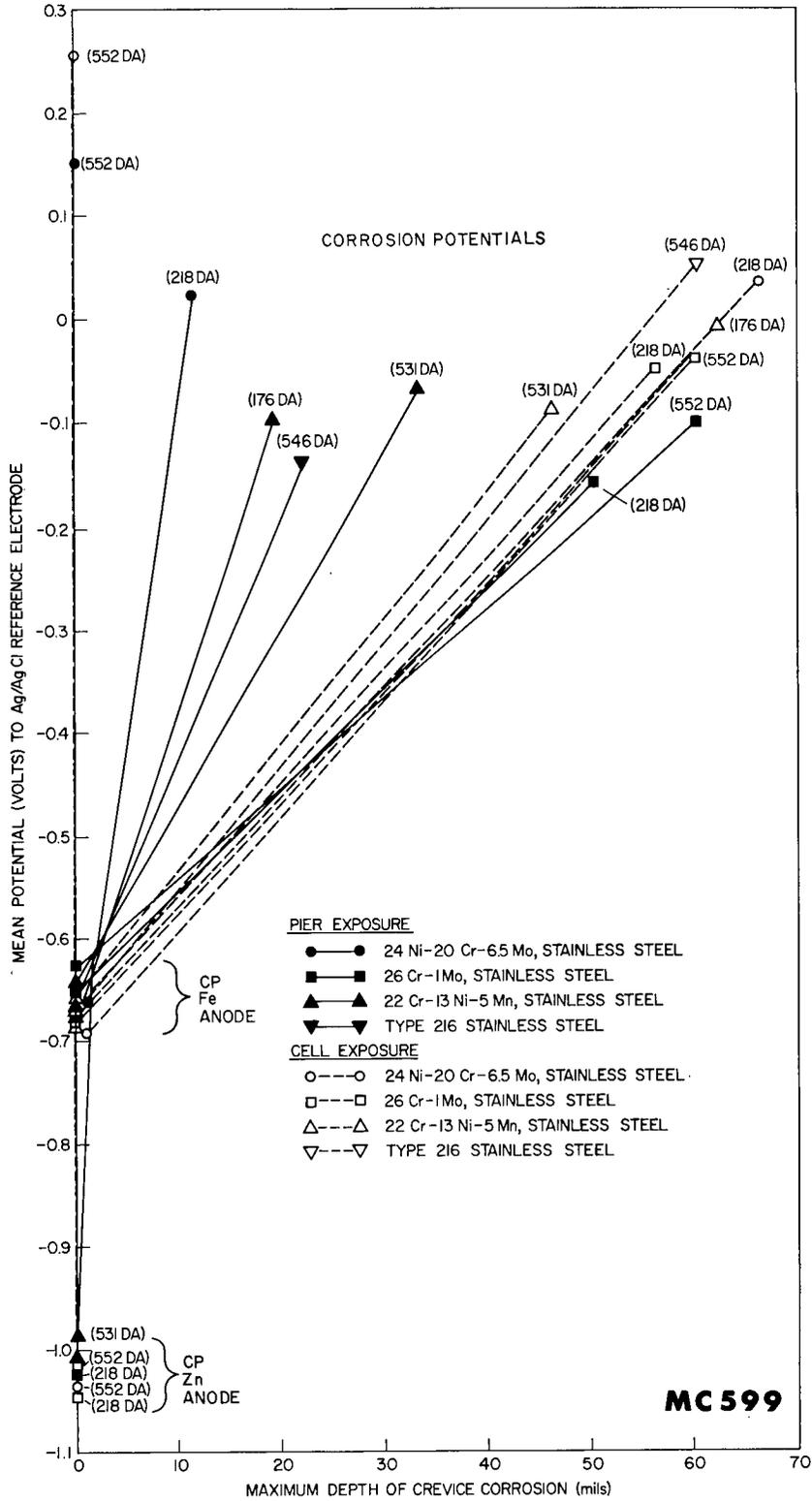


Fig. 17 — Mean potential as a function of maximum depth of crevice corrosion of unprotected stainless steels in seawater; pier and cell exposures

frequency of obtaining data and the length of time over which the potentials are observed. One must also consider actual long-term potential changes in such a study.

CONCLUSIONS

1. None of the stainless steel alloys studied (24Ni-20Cr-6.5Mo, 26Cr-1Mo, 22Cr-13Ni-5Mn, and Type 216) were inherently resistant to crevice corrosion in quiescent seawater. Specimens exposed in the cells generally showed more severe crevice corrosion than those exposed under the pier.
2. Two specimens of the 24Ni-20Cr-6.5Mo stainless steel did not show crevice corrosion in either cell or pier exposures, indicating that some specimens of this alloy were inherently resistant to crevice corrosion even under varied exposure conditions.
3. The uncorroded specimens of the 24Ni-20Cr-6.5Mo stainless steel showed relatively noble and steady potentials over long periods in quiescent seawater, compared to specimens that exhibited crevice corrosion. The freely corroding electrochemical potentials of stainless steel alloys over extended periods in seawater offer a possible criteria for determining the inherent corrosion resistance of alloys, but extensive field-service experiments would be required to validate this technique.
4. Cathodic protection from either mild steel (Fe) or zinc (Zn) anodes in most cases effectively protected the stainless steels against crevice corrosion, although corrosion was not completely eliminated in some alloys.

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REFERENCES

1. M.H. Peterson and T.J. Lennox, Jr., "The Corrosion Behavior of Stainless Steels in Sea Water," NRL Memorandum Report 1795, June 1967.
2. T.J. Lennox, Jr., M.H. Peterson, and R.E. Groover, "The Corrosion Characteristics and Response to Cathodic Protection of Several Stainless Steel Alloys in Quiescent Sea Water; with a Partially Annotated Bibliography," NRL Memorandum Report 1948, Nov. 1968.
3. M.H. Peterson, T.J. Lennox, Jr., and R.E. Groover, "A Study of Crevice Corrosion in Type 304 Stainless Steel," Proc. 25th Conf. National Association of Corrosion Engineers, Mar. 1969, pp 314-317; Mater. Protect. 9, No. 1, 23-26 (Jan. 1970).
4. T.J. Lennox, Jr., R.E. Groover, and M.H. Peterson, "How Effective is Cathodic Protection of Stainless Steels in Quiescent Sea Water?" Mater. Protect. 8, No. 5, 41-48 (May 1969).

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5. M.H. Peterson, T.J. Lennox, Jr., and R.E. Groover, "Special Applications of Cathodic Protection — Stainless Steel, Aluminum Alloys and Unusual Geometries," Proc. 3d Annu. Offshore Technol. Conf. (OTC 1462), Houston, Texas, April 19-21, 1971, Vol. 2, pp 433-440.
6. R.E. Groover, T.J. Lennox, Jr., and M.H. Peterson, "Stainless Steels in Quiescent and Flowing Seawater: Effectiveness and Pitfalls of Cathodic Protection." Proc. 4th Annu. Offshore Technol. Conf. (OTC 1580), Houston, Texas, May 1-3, 1972, Vol. I, pp 659-670.