TECHNICAL REPORT

Naval Facilities Engineering Service Center, Port Hueneme, CA 93043-4328

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December 1993

CORROSION BEHAVIOR OF HY-80 STEEL TYPE 304 STAINLESS STEEL, AND INCONEL[R] ALLOY 600 AT 218-E-12B BURIAL GROUND, HANFORD, WA

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by

James F. Jenkins, P.E.

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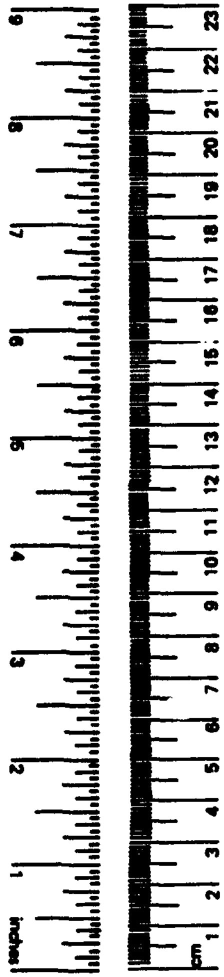
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

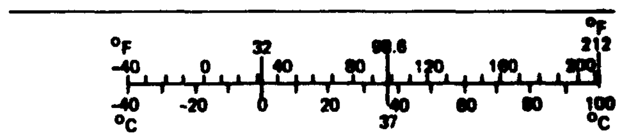
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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In order to predict the release rate of nickel into the environment from the corrosion of three alloys in soils at Hanford, Washington, the corrosion of these alloys and other similar materials at other burial sites and in other environments was evaluated. Reasonable upper limits for corrosion of the materials were established.

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PURPOSE

The intent of this evaluation is to provide a prediction of the rate of release of nickel into the environment from the corrosion of HY-80 steel, Type 304 stainless steel and Inconel Alloy 600 in soils at Trench 94 at Hanford, Washington.

BACKGROUND

Site specific data on the corrosion behavior of HY-80, Type 304 stainless steel and Inconel Alloy 600 at Trench 94 is not available. For steels similar to HY-80 and for Type 304 stainless steel there is a considerable amount of data available from burial testing. This data can be applied to Trench 94 through consideration of the corrosion related soil characteristics of the test sites compared to Trench 94.

Similar data on the behavior of Inconel Alloy 600 in soils has not been determined through test or actual exposure as Inconel Alloy 600 is not typically used in contact with soils. In order to predict the behavior of Inconel Alloy 600 at Trench 94, its behavior relative to Type 304 stainless steel in other natural environments was made and this behavior was related to the predicted behavior of Type 304 stainless steel during burial in Trench 94. The use of this method is appropriate since both these alloys are subject to the same corrosion mechanism, namely the breakdown of naturally formed passive films in natural environments.

For purposes of determining the amount of material entering the environment in the form of corrosion products, average weight loss values, expressed as mg/sq dm/yr are appropriate. In order to be conservative, reasonable upper limits for this rate should be used for this determination. For HY-80, the reasonable upper limit is 70 mg/sq dm/yr. For Type 304 stainless, the reasonable upper limit is 0.02 mg/dm sq-yr. For Inconel 600, the reasonable upper limit is 0.01 mg/sq dm/yr.

DISCUSSION

Methods for Prediction of Corrosion Behavior of HY-80 Steel, Type 304 Stainless Steel and Inconel Alloy 600 in Trench 94

In a previous study of the corrosion of steel in Trench 94 (Ref 1), the corrosion performance parameter of interest was the maximum penetration of steel due to corrosion. In that study, a very conservative approach to the evaluation of the available corrosion data was necessary in order to ensure that the maximum credible penetration rate of steel at any point was established. However, in the current study the overall rate of release of corrosion products into the environment is the value of interest. In the prediction of these release rates, there are two very important differences in the appropriate methods of the evaluation of the available corrosion data as compared to the determination of maximum steel penetration.

First, corrosion rates are based upon overall loss of weight from the surfaces of the exposed material rather than local penetration rates due to pitting which were appropriate for determination of maximum steel penetration. In this evaluation, the rate of material loss that will be experienced in Trench 94 will be based upon the weight loss that has occurred on samples exposed to other soils. This is appropriate as the value of interest is the general rate at which corrosion products will enter the environment rather than the mechanical integrity of components.

Second, the rate of weight loss of materials changes with time. In the case of materials such as HY-80 steel, the corrosion rates decrease with time. A "steady state" long term weight loss can be determined by projecting a tangent to the weight loss versus time curve. This remains a conservative approach as the tangent projection still overestimates the long term weight loss rate. Prediction of maximum penetration rates in the previous study required the use of the more conservative secant projection.

In the case of passive materials such as Type 304 stainless steel and Inconel Alloy 600, the initial rates are low due to the incubation period required for initiation of attack on the material. If corrosion initiates at some sites, it will progress at these sites. Initiation of corrosion at other sites may independently occur. Thus, in tests where corrosion does initiate at one or more sites, the long term weight loss can best be predicted by using the time of initiation of attack as "time zero" and projecting the rates using a tangent projection.

In the determination of corrosion behavior presented here, it will be assumed that the environment to which the metals are exposed will be equivalent to direct burial in soil which has characteristics equivalent to those determined by EBASCO for Trench 94 (Ref 2). A value of 31,000 ohm-cm will be used as a conservative (low) estimate of the resistivity of the soil that will contact the materials of interest. This value is conservative in that it is based upon samples of material with coarse (high resistivity) material removed and contained added water to give a 6 percent by weight moisture content. The actual average in-situ resistivity of 72,500 ohm-cm measured by EBASCO was over twice the value of 31,000 ohm-cm used in this evaluation. The values for in-situ resistivities measured by EBASCO using the Wenner 4 pin method are presented in Table 1. The values of resistivity of the representative material taken from Trench 94 and measured using a soil box are presented in Table 2.

Table 1
In-situ Soil Resistivities - Trench 94

Pin Spacing (ft)	Resistivity (ohm-cm)	
	Site 1	Site 2
10	76,000	90,000
20	88,000	99,000
30	86,000	95,000
40	72,000	84,000
50	72,000	73,000

Table 2
Soil Box Resistivities - Fine Material from Trench 94

Resistivity (ohm-cm)	
Without Added Water	Water Added to Give 6% Moisture by Weight
265,000	20,000
>1,100,000	33,000
>1,100,000	40,600
>1,100,000	31,500
768,000	21,300
>1,100,000	17,800
>1,100,000	23,500
>1,100,000	23,800
>1,000,000	33,500
>1,100,000	34,000
>1,100,000	60,000
Average	30,820

The value of 31,000 ohm-cm used, which is based on 6 percent moisture by weight, results in a conservative determination of corrosion rates for both current and wet climate conditions. The burial site soil moisture is minimal under current conditions, and is not predicted to approach 6 percent by weight for even the wetter climate conditions (Ref 3).

Type and Mechanism of Corrosion on HY-80 in Trench 94

Most carbon and low alloy steels will undergo general corrosion in soil environments similar to those encountered in Trench 94. In this type of corrosion, the exposed surface of the steel is corroded. Several corrosion test programs have included carbon and low alloy steels exposed to soils similar to, but more aggressive than those at Trench 94. Where the test results have included measurement of corrosion rate based upon weight loss, the weight loss data can be used to establish the rate of material released into the environment.

Type and Mechanism of Corrosion on Stainless Steel Type 304 and Inconel Alloy 600 in Trench 94

The principal type of corrosion that can affect both stainless steel and Inconel Alloy 600 is pitting (Refs 4 and 5). This is a non-uniform type of attack and is caused by local breakdown of the passive film responsible for the corrosion resistance of these materials. On Type 304 stainless steel, this film is predominately Cr_2O_3 (Ref 6). On high nickel alloys such as Inconel Alloy 600, this film is enriched in nickel as NiO (Ref 7).

In pitting, the majority of the surface is unaffected by corrosion. Initially, the entire surface is passive and the initiation of attack depends upon the stability of the passive film in the specific exposure environment. In some environments, the localized breakdown of this passive film will allow attack by pitting where the passive film breaks down with no attack at locations where the passive film remains intact. In other environments, the film remains stable, and where damaged mechanically, naturally reforms to provide complete resistance to attack. Oxygen promotes the stability of this passive film whereas some ionic species, particularly chloride, reduce the stability of the film.

The locations on the surface where breakdown of the passive film first occurs may be determined by random defects in the passive film or may be caused by localized chemical differences on the surface of the material. The most important localized chemical difference which will permit the breakdown of the passive films on Type 304 stainless steel and Inconel Alloy 600 is insufficient access of oxygen to the surface. Oxygen is required for the stability of the passive films on Type 304 stainless steel and Inconel Alloy 600, particularly in the presence of chlorides. The local reduction in oxygen access may be caused by a mechanically formed crevice such as would be present at a flange or threaded joint or direct contact with nonporous material such as rock in soil exposure. When the site of passive film breakdown is such an area of oxygen starvation, the form of pitting is called crevice corrosion. Both pitting and crevice corrosion can reduce the corrosion on adjacent material by acting as a protective anode.

The term immunity of a passive alloy means that the passive film remains intact in a given environment for a given period of exposure.

Effect of Soil Characteristics on the Corrosion of HY-80 Steel in Trench 94

The soil characteristics that have the most significant impact on the corrosion of carbon and low alloy steels in soils are the moisture content, aeration, electrical resistivity, pH and dissolved ionic species such as chloride and sulfate. The characteristics of the soil at Trench 94 have been analyzed (Ref 2). The soil at Trench 94 is well aerated. Other salient soil characteristics at Trench 94 are given in Table 3.

Table 3
Soil Characteristics at Trench 94

Moisture Content* (wt %)	Resistivity (ohm-cm)	Chloride (mg-eq/100 g)	Sulfate (mg-eq/100 g)	pH
6	31,000	0.08	0.21	8.2

*Water added to achieve moisture content (Ref 2). Not expected to approach 6 percent by weight for wetter climate conditions (Ref 3).

In order to compare the performance of steel in Trench 94 with corrosion behavior of steels at other sites, sites with the following combination of characteristics were chosen: Alkaline (>7.0) pH, good aeration, low chloride content (<0.1 mg-eq/100 g), and low sulfate content (<0.5 mg-eq/100 g).

All other factors being equal, corrosion rates are roughly proportional to soil conductivity which is inversely proportional to the soil resistivity. The potential of the anodic and cathodic areas will be constant where all factors other than the environmental resistivity are equivalent. In such cases, the total electrical current flow, which is proportional to the weight loss, is given by the relationship (Ref 8):

$$I = \frac{EC - EA}{R}$$

where I =Corrosion current
EC =Potential of the cathode
EA =Potential of the anode
R =Total resistance between the anode and the cathode

In a fixed geometry, particularly where the resistance through the environment is high with respect to other resistances in the circuit, the total resistance is roughly proportional to the resistivity of the environment.

The National Institute of Science and Technology (NIST) has performed extensive evaluations of the corrosion of steels in a wide variety of soils (Ref 9). Considering those NIST test sites with soils having alkaline pH, and low amounts of chloride and sulfate, the sites most similar to (but substantially more corrosive than) Trench 94 were located in Salt Lake City, Utah; Springfield, Ohio; and Los Angeles, California. The salient environmental characteristics at these sites, compared to Trench 94, are given in Table 4.

The corrosion behavior of Bessemer steel at the NIST test sites is shown in Figure 1.

Table 4
Soil Characteristics and Corrosion Rates of Bessemer Steel at
NIST Test Sites with Soils Similar to Trench 94

Location	Moisture Content (wt %)	Resistivity (ohm-cm)	Chloride (mg-eq/ 100 g)	Sulfate (mg-eq/ 100 g)	pH	Corrosion Rate (mg/sq dm/yr)
Salt Lake City, UT	25.7	1,700	0.06	0.48	7.6	1094
Springfield, OH	16.4	2,980	0.03	0.12	7.3	707
Los Angeles, CA	18.0	2,060	0.06	0.35	7.3	263
Trench 94	6.0	31,000	0.08	0.21	8.2	—

Prediction of Corrosion Rate of HY-80 Steel in Trench 94

There has been no corrosion testing of steel at the Trench 94 site, nor has there been any testing of HY-80 steel in soils. Therefore the behavior of HY-80 steel in Trench 94 must be inferred from the corrosion behavior of other steels at other sites. In the prediction of a

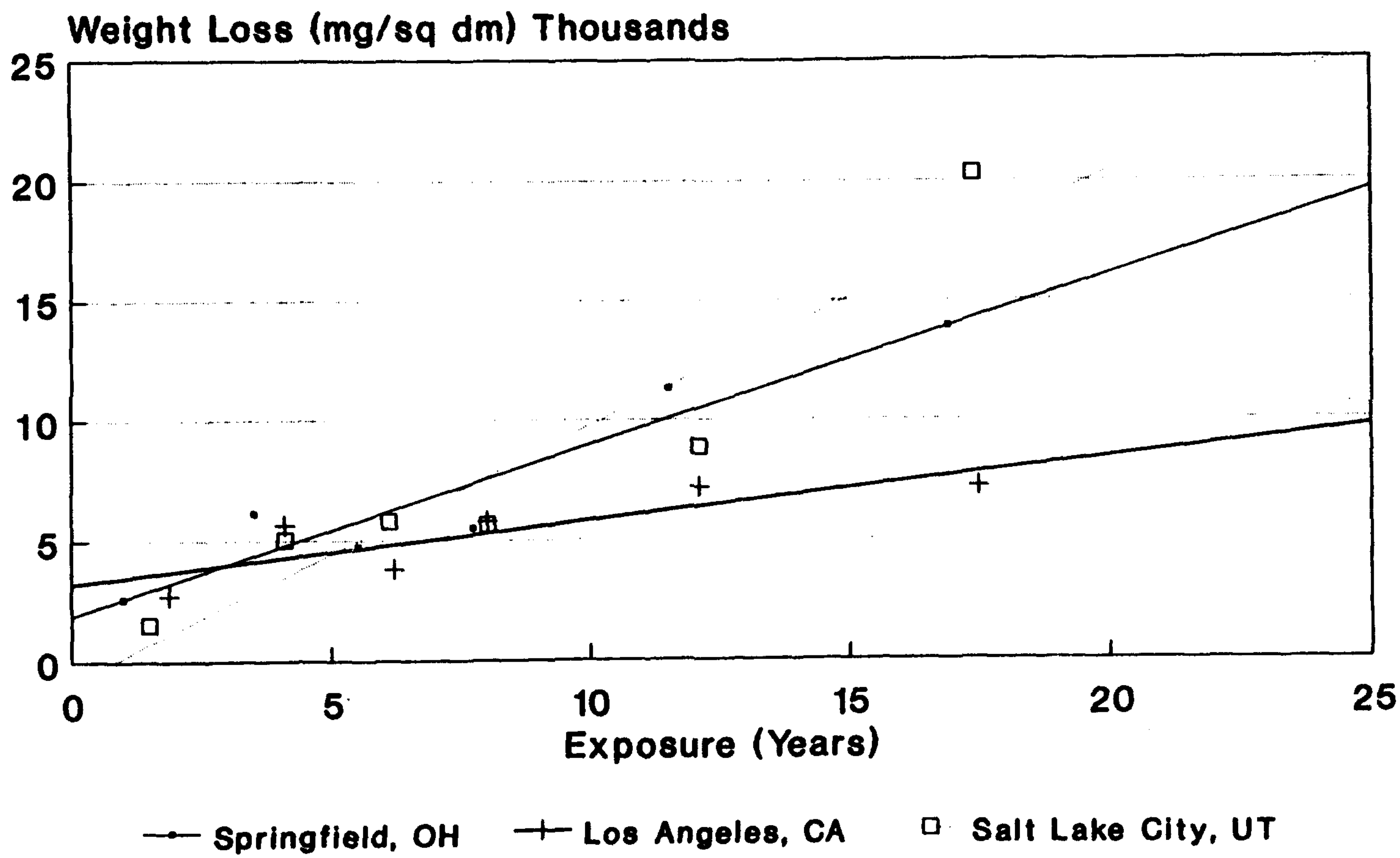


Figure 1.
Weight Loss Versus Time - Bessemer Steel

corrosion rate for HY-80 steel under conditions of burial in Trench 94, the following method will be used: values of weight loss of steel for NIST sites with similar or lower pH, similar chloride content and similar sulfate content and good aeration will be evaluated. As all of these NIST sites have a much higher moisture content and much lower resistivity than for Trench 94, the upper limit and typical values from the NIST tests will be normalized to the resistivity of Trench 94.

It is assumed for this evaluation that HY-80 steel will have a similar corrosion behavior to the Bessemer steel tested at the NIST sites. The corrosion rate of HY-80 steel in seawater has been compared with other plain carbon steel similar in composition to the Bessemer steel tested at the NIST sites. A comparison of the composition of these alloys is given in Table 5 and their corrosion behavior is compared in Table 6.

Table 5
Comparison of Composition of Selected Steels (%)

Steel	C	Mn	P	S	Si	Cr	Ni	Cu	Mo
AISI 1010	0.11	0.50	0.004	0.023	0.06	–	–	–	–
AISI 1010	0.12	0.34	0.01	0.020	0.02	0.02	0.02	0.03	–
ASTM A36	0.20	0.55	0.01	0.020	0.064	–	–	–	–
HSLA 12 (HY-80)	0.14	0.26	0.011	0.009	0.27	1.55	2.60	–	0.46
Bessemer Steel	0.08	0.40	0.098	0.038	–	–	–	–	–

Table 6
Corrosion Rates of Selected Steel in Seawater
After 1 Year of Exposure

Steel	Corrosion Rate (mpy)*
AISI 1010	8.2
AISI 1010	8.0
ASTM A36	6.2
HSLA 12 (HY-80)	4.2
Bessemer Steel	---

*Note: mpy = mils (0.001-inch) per year
average corrosion rate based on weight loss.

Although the corrosion rate of HY-80 is lower in the harsh environment of seawater than the carbon steels representative of Bessemer steel, for this evaluation a conservative approach is taken and the corrosion rate of Bessemer steel is considered to form an upper bound of the corrosion rate of HY-80.

In order to establish a realistic upper limit for the rate of weight loss from HY-80 steel, it is appropriate to normalize the weight loss data to the resistivity in Trench 94. Figure 2 shows the normalized weight loss versus time for Bessemer steel at the three test sites selected as being similar to Trench 94 except for resistivity and moisture content. The corrosion rate, in milligrams per square decimeter per year is given by the slopes of the weight loss versus time curves. It should be noted that, in general, weight losses of specimens in the NIST tests was measured to the nearest 1 mg. For the Bessemer steel samples which had a surface area of 7.29 sq dm, this gives an accuracy in the measurement of corrosion rate of 0.14 mg/sq dm/yr.

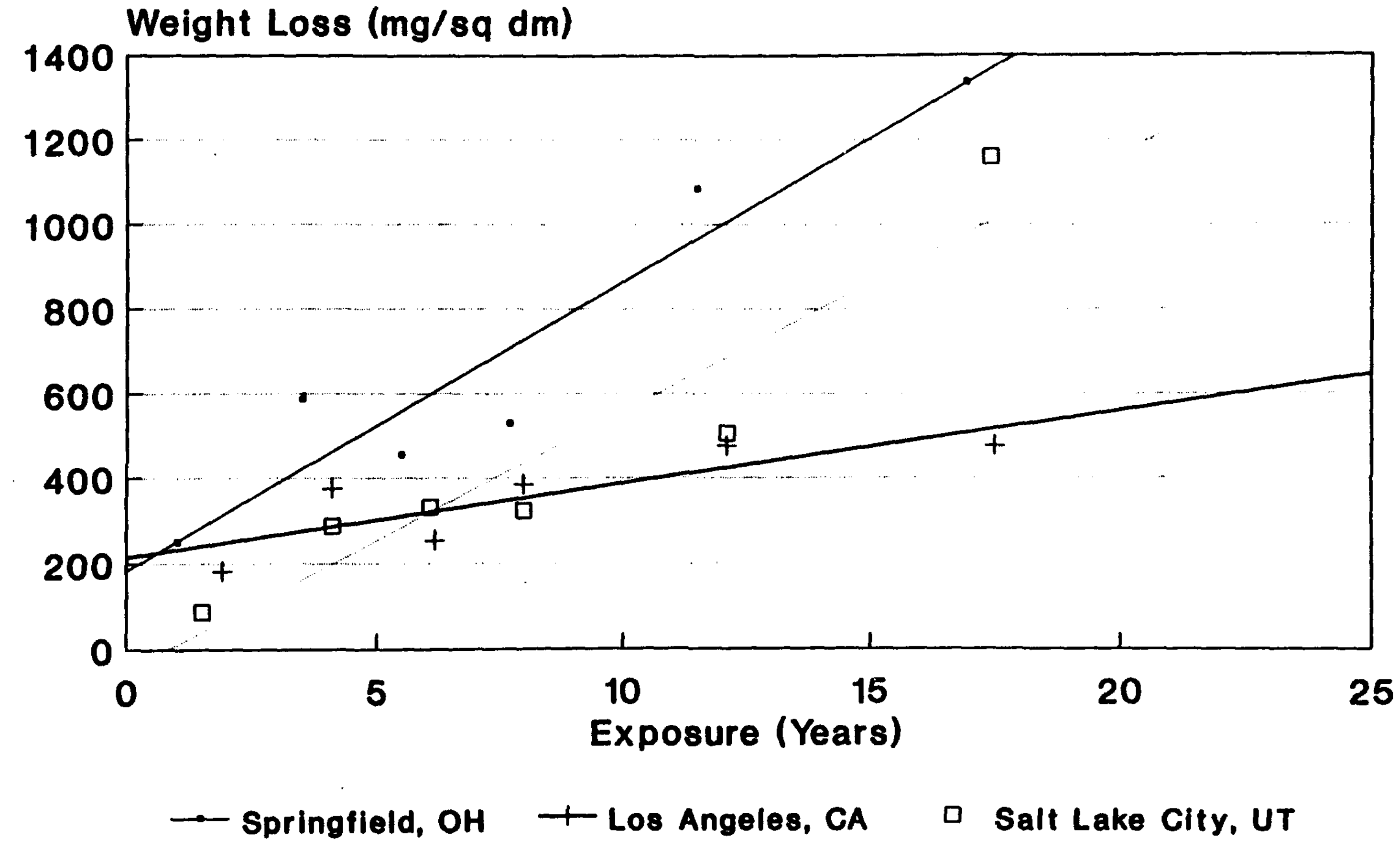
The highest normalized corrosion rate is selected as the upper bound rate for conservatism. This rate (68 mg/sq dm/yr) is from the Springfield, Ohio site. The normalized rate for Salt Lake City is 60 mg/sq dm/yr which is comparable to the value for Springfield. The normalized value for Los Angeles is 17.5 mg/sq dm/yr which is significantly lower than for the other sites and indicates the conservative nature of the method used for predicting corrosion rates. The average rate from all three test sites (49 mg/sq dm/yr) is a likely rate for Trench 94. It is recommended that the value of 70 mg/sq dm/yr (68 rounded to the next higher one digit significant figure) be used as a conservative value for the corrosion rate of HY-80 in Trench 94 for purposes of calculating the amounts of material entering the environment in the form of corrosion products.

Effect of Soil Characteristics on the Corrosion of Stainless Steel Type 304 and Inconel Alloy 600

The soil characteristics that are the most significant with regards to the corrosion of Type 304 stainless steel and Inconel Alloy 600 are the resistivity, moisture content, aeration, pH and chloride content. Chloride ion, in the presence of moisture, causes the breakdown of the passive film responsible for the corrosion resistance of both Type 304 stainless steel and Inconel Alloy 600. The breakdown of the passive film on both the Type 304 stainless steel and Inconel Alloy 600 is inhibited by oxygen and alkalinity. Thus, the good aeration and high pH at Trench 94 are beneficial with regards to the stability of the passive film on Type 304 stainless steel and Inconel Alloy 600.

Corrosion Performance of Type 304 Stainless Steel in Soil Environments

Initiation of Attack. Several evaluations of the corrosion performance of Type 304 stainless steel in soils have been performed. In the NIST study (Ref 10), pitting of Type 304 stainless steel occurred at some aggressive test sites. In the more extensive Japan Stainless Steel Association (JSSA) study (Ref 11), there was no pitting attack of Type 304 stainless steel in up to five years of exposure. Some of the JSSA test sites are comparable to Trench 94 as shown in Table 7. In this table, a value of 31,000 ohm-cm is used for the soil resistivity at Trench 94 since this represents the most corrosive localized conditions that might occur rather than the higher average resistivity of 72,000 ohm-cm determined by the Wenner four-pin testing.



<u>Figure 2.</u>
Weight Loss Versus Time - Bessemer Steel
Normalized to 31,000 ohm-cm

Table 7
Soil Characteristics at JSSA Test Sites with Soils Similar to Trench 94

Site ID	Resistivity (ohm-cm)	Chloride (mg-eg/100 g)	Sulfate (mg-eg/100 g)	pH
G	22,333	0.02	--	8.4
Q	18,722	0.04	0.38	8.2
R	45,000	0.27	0.05	8.1
T	14,993	0.02	0.02	8.2
V	32,666	0.01	0.01	8.1
Trench 94	31,000	0.08	0.21	8.2

The soil characteristics at all of the sites given in Table 7 from the JSSA test program are similar to that at Trench 94 in that they are all well aerated, and have an alkaline pH and low chloride and sulfate content.

There were also several (four) NIST test sites where no pitting attack on Type 304 stainless steel was reported even after 14 years of exposure.

The soil characteristics at all of the NIST test sites where pitting of Type 304 stainless steel initiated are compared to Trench 94 in Table 8. The weight loss rates indicate the average weight loss for all samples exposed at each test site. As previously discussed, the use of average corrosion rates is appropriate for this evaluation as average rates reflect the amount of material entering the environment as corrosion products. Averaging the weight loss of multiple specimens effectively increases the amount of surface area being evaluated which, for materials that pit, makes the rates statistically more accurate as more potential pitting sites are exposed.

All of the NIST test sites where pitting of Type 304 stainless steel initiated are considered to be significantly different and more aggressive than at Trench 94. Sites 63, 56, 67, C, E, 51 and 61 have poor or very poor aeration. Sites 64, 65, 66 and A have very low soil resistivities and high chloride levels. Site D had an acidic pH.

Thus, as pitting did not initiate on Type 304 in any of the JSSA sites and in several of the NIST sites, and where pitting did initiate on Type 304 stainless steel, the environment was significantly more aggressive than at Trench 94, it is probable that pitting corrosion will not initiate on Type 304 stainless steel in Trench 94. However, in order to take the most conservative approach, it will be assumed that corrosion of Type 304 stainless steel does initiate under conditions of burial at Trench 94 in order to establish an upper bound of the rate of conversion of metal into corrosion products.

Propagation of Attack. In the unlikely event that pitting corrosion of Type 304 stainless steel initiates due to some local aggressive conditions, the release rate of corrosion products will be low. NIST Test sites A, 65, and 66 are test sites where corrosion of Type 304 stainless steel did initiate that had alkaline pH and at least fair aeration. The soil conditions of resistivity and moisture content are significantly different from Trench 94, but this can be accounted for by normalizing for resistivity as discussed earlier. The chloride level at these sites is higher than at Trench 94. However, as chloride primarily affects the initiation of attack rather than the propagation of the attack (except for its effect on resistivity) the chloride level will be at least partially addressed in normalizing the rates for resistivity and will result in a conservative value for the corrosion rate in any case. The weight loss of Type 304 stainless steel at these test sites is given in Table 9.

Table 8
Soil Characteristics and Weight Loss Rates at NIST Test Sites
Where Type 304 Stainless Steel Did Pit

Site ID	Aeration	Resistivity (ohm-Cm)	pH	Chloride (mg-eq/ 100 g)	Sulfate (mg-eq/ 100 g)	Weight Loss Rate (mg/sq dm/yr)
63	Very poor	84	6.9	12.7	36.6	13.1
56	Very poor	406	7.1	1.59	3.04	43.6
67	Very poor	455	7.6	0.08	2.8	0.17
C	Poor	400	4.3	9.94	14.0	23.9
E	Poor	2,500	7.1	9.16	0.06	22.6
51	Poor	190	6.2	5.75	22.0	6.5
61	Poor	943	6.8	0.10	0.91	0.09
64	Fair	62	7.5	28.8	0.26	0.65
66	Fair	232	8.0	2.77	2.97	0.19
65	Good	148	8.0	6.05	16.90	2.18
A	Good	400	8.8	0.93	0.45	0.99
D	Good	13,800	5.7	Low	Low	2.13
Trench 94	Good	31,000	8.2	0.08	0.21	---

Table 9
Weight Loss of Type 304 Stainless Steel at Selected NIST Test Sites

Site ID	Exposure Years	Weight Loss (mg/sq dm)	Weight Loss Rate (mg/sq dm/yr)
A	8.1	8.0	0.99
65	14	30.5	2.18
66	14	2.7	0.19

Weight loss versus time behavior of Type 304 stainless steels at the test sites could not be determined as the samples were only evaluated after one exposure time. However, dividing the total weight loss by the years of exposure provides conservative values of the long term corrosion rates. This calculation is equivalent to the secant projection method. It should be noted that, in general, weight losses of specimens in the NIST tests was measured to the nearest

1 mg. For the Type 304 stainless steel samples which had a surface area of 3.09 sq dm, this gives an accuracy in the measurement of corrosion rate of 0.32 mg/sq dm/yr.

Prediction of Corrosion Rate of Type 304 Stainless Steel in Trench 94

As in the case of the propagation of corrosion on HY-80 steel, the propagation of corrosion on Type 304 stainless steel is dependent upon the resistivity of the environment. The potential difference between the active pit (anode) and surrounding passive area (cathode) drives the corrosion of the anodic pit. This can be shown to be the case for Type 304 stainless steel by comparing the weight loss rates for site A with those for site 65 where the environmental conditions other than resistivity are most similar.

Normalizing the propagation rate for a soil resistivity of 400 ohm-cm gives rates of 0.81 mg/sq dm/yr for site 65 and 0.99 mg/sq dm/yr for site A. To normalize the data for Trench 94, a value of 31,000 ohm-cm is used as this is a conservative yet realistic value for the minimum local soil resistivity. This is appropriate as the pitting propagation rate is dependent upon the local resistivity in the vicinity of the pit rather than the average resistivity over the entire structure. The normalized value for pitting rate in Trench 94, conservatively based upon the highest normalized rate at the NIST sites (site A) is 0.99 X 400/31,000 = 0.013 mg/sq dm/yr. Normalized rates for Site 66 are much lower indicating the conservative nature of the normalized rates for sites A and 65. In the unlikely event that pitting initiates on Type 304 stainless steel in Trench 94, the value of 0.013 mg/sq dm/yr is predicted. It is recommended that the value of 0.02 mg/sq dm/yr (0.013 rounded to the next higher one digit significant figure) should be used as a conservative value for the corrosion rate of Type 304 stainless steel in Trench 94 for purposes of calculating the amounts of material entering the environment in the form of corrosion products.

Corrosion Performance of Inconel Alloy 600

There is no available data on the corrosion performance of Inconel Alloy 600 in soil environments. Lacking such data, its projected performance must be inferred from a comparison of the performance of Inconel Alloy 600 with an alloy having similar corrosion characteristics. In this case, the performance of both Inconel Alloy 600 and Type 304 stainless steel in several natural environments has been determined and the performance of stainless steel Type 304 in Trench 94 has been projected from its performance during burial in other soils.

Initiation of Attack. In fresh water, Inconel Alloy 600 is essentially immune to corrosion (Ref 5) whereas Type 304 stainless steel is subject to pitting in some, more aggressive fresh waters. In seawater, Type 304 stainless steel is subject to severe pitting and crevice corrosion whereas Inconel Alloy 600 is essentially resistant to direct pitting in moving seawater but is susceptible to pitting in stagnant seawater and is also subject to crevice attack in both moving and stagnant seawater (Ref 5). As previously discussed, it is probable that pitting will not initiate on Type 304 stainless steel in Trench 94. Thus, it is very unlikely that any corrosion of Inconel Alloy 600 will initiate during burial in Trench 94.

Propagation of Attack. In the very unlikely event that pitting corrosion initiates on Inconel Alloy 600 in Trench 94, the propagation of attack can be predicted by comparison of the propagation of corrosion on Type 304 stainless steel and Inconel Alloy 600 in environments where pitting attack occurs. In seawater where pitting corrosion initiates on both Inconel Alloy 600 and Type 304 stainless steel, the weight loss versus time for both alloys in simultaneous exposure to seawater are presented in Table 10 and plotted in Figure 3 (Ref 12).

Table 10
Corrosion of Type 304 Stainless Steel and Inconel Alloy 600 in Seawater

Exposure Years	304 SS Weight Loss (mg)	Inconel Alloy 600 Weight Loss (mg)
1	96	37
2	280	148
3.5	443	285
5	530	346

It can be seen from Figure 3 that the corrosion rate of Inconel Alloy 600 is lower than that for Type 304 stainless steel. The tangent rate of 40 mg per square decimeter per year for Inconel Alloy 600 is 0.7 times the tangent rate of 57 milligrams per square decimeter per year projected for Type 304 stainless steel.

Prediction of Corrosion Rate of Inconel Alloy 600 in Trench 94

In the very unlikely event that any corrosion at all initiates on the Inconel Alloy 600, the predicted corrosion rate for Type 304 stainless steel in Trench 94 can be adjusted to give a predicted corrosion rate for Inconel Alloy 600 in Trench 94 using the relationship between the corrosion rate of Type 304 stainless steel and Inconel Alloy 600 in an environment where both corrode. The upper bound for propagation of corrosion on Type 304 stainless steel in Trench 94 is 0.013 mg/sq dm/yr. The upper bound rate for propagation of attack on Inconel Alloy 600 is thus 0.013 x 0.7 = 0.009 mg/sq dm/yr. It is recommended that the value of 0.01 mg/sq dm-yr (0.009 rounded to the next higher one digit significant figure) should be used as a conservative value for the corrosion rate of Inconel Alloy 600 in Trench 94 for purposes of calculating the amounts of material entering the environment in the form of corrosion products.

SUMMARY

Although corrosion data for HY-80, Type 304 stainless steel and Inconel Alloy 600 in Trench 94 is not available, a conservative prediction of the corrosion of these materials in Trench 94 can be established through an evaluation of the behavior of the materials in environments other than that in Trench 94. This can be accomplished by using values for sites most similar in corrosivity to Trench 94 and normalizing the data to account for the differences in corrosivity between the test sites and Trench 94. The use of the lower soil resistivity values resulting from soil box tests vice the significantly higher "in-situ" values from Wenner four-pin testing adds an extra measure of conservatism to such predictions.

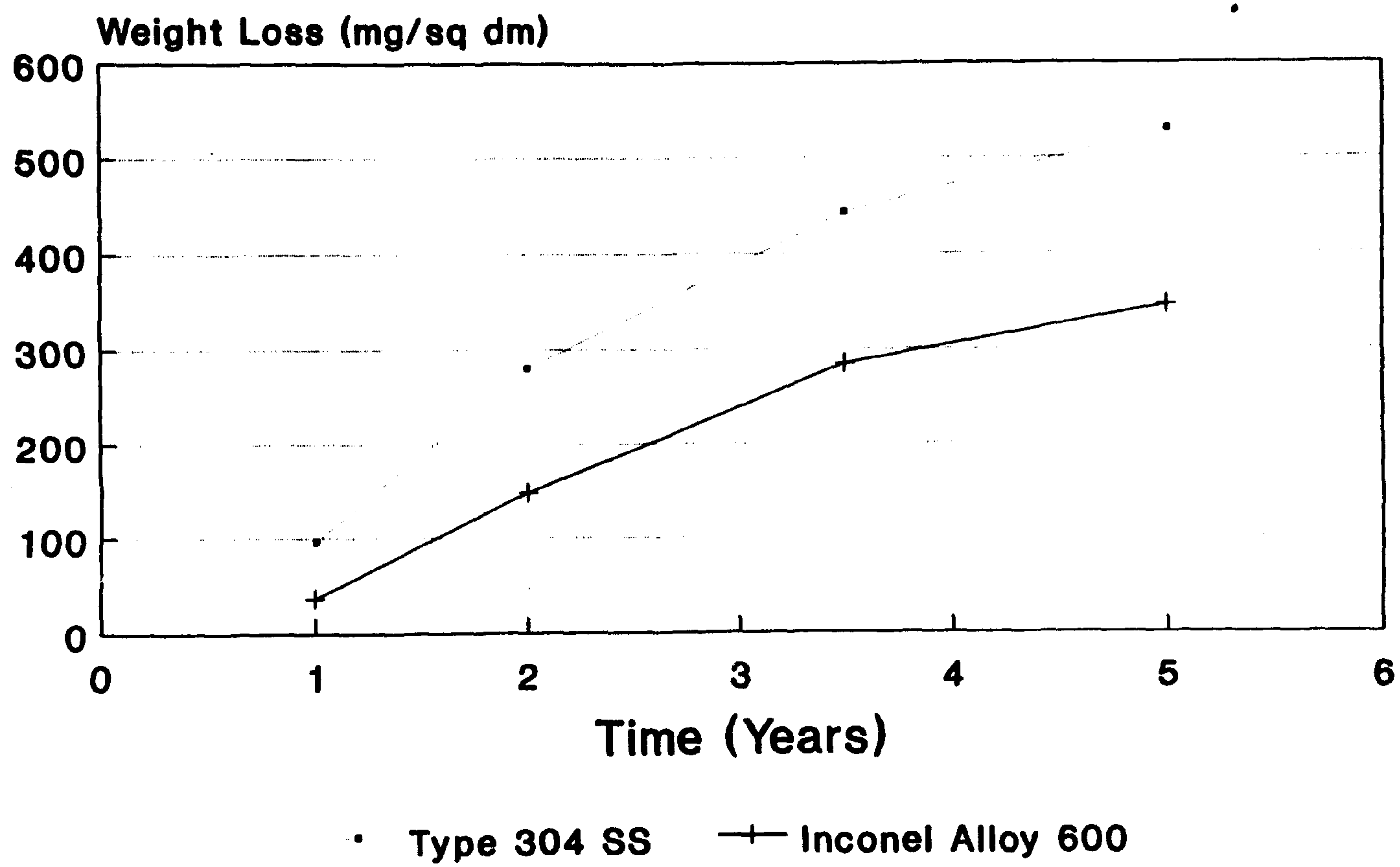


Figure 3.
Inconel Alloy 600 and Type 304 Stainless Steel in Seawater

Prediction of the corrosion rate for HY-80 steel in Trench 94 has been made by a direct evaluation of the corrosion of steel in environments similar, but more corrosive than Trench 94. These values were normalized to correct for the differences in soil resistance between the sites where corrosion data were available and Trench 94. An upper bound value of 68 mg/sq dm/yr with a more likely value of 49 mg/sq dm/yr was obtained using this method. A value of 70 mg/sq dm/yr is recommended for use in the calculation of the amounts of material entering the environment from HY-80 in the form of corrosion products.

The corrosion of Type 304 stainless steel under conditions of burial at Trench 94 have been inferred from its performance in more aggressive soils. In most soils where corrosion tests have been performed and in all soils similar to those at Trench 94 where corrosion tests have been performed, pitting attack did not initiate on Type 304 stainless steel. Thus pitting attack is unlikely to initiate on Type 304 stainless steel in Trench 94. In the unlikely event that pitting does initiate on Type 304 stainless steel in Trench 94, the rate of propagation was predicted by normalization of rates of propagation of pitting attack at other, more corrosive test sites. For Type 304 stainless steel, a value of 0.02 mg/sq dm/yr should be used as a conservative value for the corrosion rate of Type 304 stainless steel in Trench 94 for purposes of calculating the amounts of material entering the environment in the form of corrosion products.

Inconel Alloy 600 is even more resistant to corrosion than Type 304 stainless steel and will probably not exhibit any attack during burial in Trench 94. However, in more aggressive natural environments where both Inconel Alloy 600 and Type 304 stainless steel do corrode, the rate of weight loss of Inconel Alloy 600 is 0.7 times as great as the weight loss experienced by Type 304 stainless steel. Thus, in the very unlikely event that corrosion initiates on Inconel Alloy 600 in Trench 94, a value of 0.01 mg/sq dm/yr should be used as a conservative value for the corrosion rate of Inconel Alloy 600 in Trench 94 for purposes of calculating the amounts of material entering the environment in the form of corrosion products.

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