RP359

SOIL-CORROSION STUDIES

NONFERROUS METALS AND ALLOYS, METALLIC COATINGS AND SPECIALLY PREPARED FERROUS PIPES REMOVED IN 1930

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ABSTRACT

This paper presents the results of the examination of specimens of nonferrous materials and metallic protective coatings removed from 45 soils after exposure of from four to six years. Included in the test were specimens of copper and brass pipe, cast and forged brass fittings, galvanized pipe and sheet steel, lead sheet, lead-coated pipe, and lead-coated and galvanized bolts. Data on the rates of corrosion of steel pipe are also presented as a basis for comparison. The nonferrous metals tested were found to resist corrosion somewhat better than steel but they were not unaffected by soil action.

CONTENTS

I. INTRODUCTION

When the National Bureau of Standards soil corrosion investigation started in 1922 attention was called to soils as possible causes of corrosion, and questions were raised as to the best methods of preventing the deterioration of pipe lines. Recognizing the close relation between this problem and the investigation already started, the bureau undertook to determine the corrosion-resisting properties of a considerable variety of materials when buried in the soil. In most cases these materials were supplied by their makers or users. Some of the difficulties involved in the work were recognized, while others were underestimated.

The principle governing the acceptance or rejection of specimens was to test such offered materials as could be tested without materially increasing the cost of the investigation, with the understanding that such data would be secured as circumstances permitted.

A list of the materials tested will be found on page 453 of Technologic Paper No. 368.[1] That paper also gives a description of the soils to which the materials were exposed, a list of organizations cooperating in the tests, and the results of the tests after periods of exposure of from two to four years; that is, for the specimens removed in 1924 and 1926. Almost no nonferrous specimens were removed in 1928, but sets of all kinds of specimens, with the exception of one metallic and four bituminous coatings, were removed in 1930. The results of the examinations of the ferrous materials removed in 1930 will be found in Research Paper No. 329 entitled "Soil Corrosion Studies 1930, Rates of Corrosion and Pitting of Bare Ferrous Specimens." That report[2] is the third report on ferrous materials. The present report deals mainly with the nonferrous materials used to reduce corrosion losses, but includes a few data on rates of corrosion of ferrous materials for purposes of comparison.

As some of the tables require considerable space, it has been found advisable to refer to the test locations by number only. Table 1 gives the numbers of the soils and their approximate locations. The numbers are the same as those used in the other National Bureau of Standards reports on soil corrosion. Table 1 also gives the weighted average rates of corrosion and pitting for all the 6-year-old ferrous specimens. The weighting is based on the total exposed areas of the several kinds of specimens.

In using this table for comparing the rates of corrosion of ferrous and nonferrous materials, it should be remembered that the rate of corrosion is influenced by the time of exposure, and that on account of irregularities in soils and in commercial materials the performance of a single specimen may be either better or worse than the average performance of a group of specimens of the same material. In the case of pitting it can be shown that for relatively small specimens with only a few pits the chances are that other things being equal, the largest specimen will have the deepest pit. The effects of irregularities in soils and the difficulties arising from comparing specimens of different sizes and ages are discussed in the 1930 report on ferrous materials. On account of the nature of the tests no positive conclusions as to relative merits of materials should be drawn from the performance of individual specimens, but the average performance of the material may be taken as indicative of the usefulness of that material under the conditions of the test. Obviously, the material best suited for some soil conditions may not be the best material under radically different conditions.

[1] Bureau of Standards Soil Corrosion Studies. I. Soils, Materials, and Results of Early Observations. B. S. Tech. Paper No. 368. For sale by Superintendent of Documents, Washington, D. C., 50¢ per copy.

[2] B. S. Jour. Research, 7 (PP329), p. 1.

TABLE 1.—*Soils, locations of tests, and rates of corrosion of ferrous materials for the first six years after burial*

No.	Name	Location	6-year weighted rates of corrosion	
			Loss of weight in ounces per square foot per year	Penetration in mils per year
1	Allis silt loam	Cleveland, Ohio	0.939	10.7
2	Bell clay	Dallas, Tex	.689	7.4
3	Cecil clay loam	Atlanta, Ga	.592	11.5
4	Chester loam	Jenkintown, Pa	.743	8.7
5	Dublin clay adobe	Oakland, Calif	.849	8.0
6	Everett gravelly sandy loam	Seattle, Wash	.126	2.1
7	Fairmount silt loam	Cincinnati, Ohio	(1)	(1)
8	Fargo clay loam	Fargo, N. Dak	.621	10.7
9	Genesee silt loam	Sidney, Ohio	.496	5.3
10	Gloucester sandy loam	Middleboro, Mass	.532	6.7
11	Hagerstown loam	Baltimore, Md	.192	9.3
12	Hanford fine sandy loam	Los Angeles, Calif	.440	8.3
13	Hanford very fine sandy loam	Bakersfield, Calif	1.377	14.2
14	Hempstead silt loam	St. Paul, Minn	.563	13.0
15	Houston black clay	San Antonio, Tex	1.028	10.4
16	Kalmia fine sandy loam	Mobile, Ala	.836	14.8
17	Keyport loam	Alexandria, Va	.981	6.0
18	Knox silt loam	Omaha, Nebr	.526	12.4
19	Lindley silt loam	Des Moines, Iowa	.381	10.0
20	Mahoning silt loam	Cleveland, Ohio	.515	5.6
21	Marshall silt loam	Kansas City, Mo	.799	9.9
22	Memphis silt loam	Memphis, Tenn	.786	13.1
23	Merced silt loam	Buttonwillow, Calif	3,144	22.0
24	Merrimac gravelly sandy loam	Norwood, Mass	.160	2.2
25	Miami clay loam	Milwaukee, Wis	.292	7.9
26	Miami silt loam	Springfield, Ohio	.302	11.1
27	Miller clay	Bunkie, La	.637	7.4
28	Montezuma clay adobe	San Diego, Calif	1.569	12.2
29	Muck	New Orleans, La	1.599	13.5
30	Muscatine silt loam	Davenport, Iowa	.455	3.9
31	Norfolk sand	Jacksonville, Fla	.355	6.6
32	Ontario loam	Rochester, N. Y	.409	6.2
33	Peat	Milwaukee, Wis	.673	6.7
34	Penn silt loam	Norristown, Pa	.469	5.2
35	Ramona loam	Los Angeles, Calif	.185	2.6
36	Ruston sandy loam	Meridian, Miss	.245	8.8
37	St. Johns fine sand	Jacksonville, Fla	.758	7.4
38	Sassafras gravelly sandy loam	Camden, N. J	.175	3.6
39	Sassafras silt loam	Wilmington, Del	.568	6.9
40	Sharkey clay	New Orleans, La	1.102	12.2
41	Summit silt loam	Kansas City, Mo	.575	7.9
42	Susquehanna clay	Meridian, Miss	1.322	16.6
43	Tidal marsh	Elizabeth, N. J	1.132	12.0
44	Wabash silt loam	Omaha, Nebr	.320	10.3
45	Unidentified alkali soil	Casper, Wyo	.493	6.9
46	Unidentified sandy loam	Denver, Col	.458	9.8
47	Unidentified silt loam	Salt Lake City, Utah	.342	1.7
	Average for all soils		.690	8.9

[1] No 6-year-old specimens.

II. TESTS OF NONFERROUS METALS AND ALLOYS

1. COPPER ALLOY CASTINGS

At the time the soil corrosion tests were started, the American Water Works Association and certain manufacturers were considering the proper specification for the composition of the cocks to be used in connection with water-service lines. On this account the bureau was asked to determine the corrosion-resisting properties of four brasses, and the effect of connecting these to steel, brass, and lead service pipes. The compositions of the brasses are given in Table 16 of Technologic Paper 368, previously referred to. Roughly, the copper content of the castings ranged between 94 and 75 per cent, the tin content between 6 and 0 per cent, and the zinc content between 20 and 5 per cent. All of the castings contained small amounts of lead. Short lengths of three materials—brass, lead, and galvanized iron—were connected to castings of each composition for the purpose of studying possible galvanic corrosion caused by connecting together two two different metals. Figure 1 shows the appearance of these specimens.

Table 2 gives the rates of loss of weight of the castings and of the nipples attached to the castings. While there are some apparent differences between the rates of corrosion of the castings of different compositions, the corrosion was in nearly all cases slight and the differences in the losses may well be attributed to variations in the castings or to variations in the soil conditions to which they were exposed. On this account it does not seem worth while to report the rates of loss of weight of each compositon separately. In so far as inspection can be depended upon, castings of any of the compositions under test appear to be satisfactory from a corrosion standpoint.

TABLE 2.—*Rates of loss of weight of cast brass caps, and of brass, lead, and galvanized steel nipples attached to the caps*

[In ounces per square foot per year]

Soil No.[1]	Average of 12 cast brass caps	Average of 4 brass nipples	Average of 4 lead nipples	Average of 4 galvanized steel nipples	Soil No.[1]	Average of 12 cast brass caps	Average of 4 brass nipples	Average of 4 lead nipples	Average of 4 galvanized steel nipples
1	0.0581	0.198	0.883	1.971	26	0.0190	0.123	0.447	0.330
2	.0074	.084	.415	.177	27	.0070	.124	.620	.243
3	.0228	.085	.740	.434	28	.0097	([2])	([2])	2.072
4	.0230	.239	.704	.933	29	.0354	.567	1.937	1.384
5	.0097	.199	1.020	1.118	30	.0123	.079	.323	.442
6	.0142	.024	.168	.219	31	.0124	.084	.691	.301
7	.0127	.189	.717	.420	32	.0155	.086	.332	.165
8	.0176	.130	.273	.556	33	.0355	.284	.384	.723
9	.0228	.156	.570	.357	34	.0239	.123	.341	.238
10	.0131	.127	.722	.375	35	.0112	.008	.074	.076
11	.0158	.075	.546	.295	36	.0133	.039	.408	.133
12	.0953	.111	.833	.168	37	.0806	.407	1.008	1.510
13	.0149	.172	.301	1.876	38	.0072	.033	.241	.082
14	.0103	.047	1.129	.519	39	.0198	.336	.397	.416
15	.0085	.073	.376	.369	40	.0146	.206	.666	.420
16	.0185	.151	.951	.594	41	.0129	.063	.462	.253
17	.0218	.181	.666	.880	42	.0181	.129	.908	.734
18	.0135	.120	.601	.282	43	.3318	.037	.083	1.687
19	.0211	.140	.620	.320	44	.0095	.036	.177	.282
20	.0226	.153	.691	.620	45	.0314	.623	.102	4.201
21	([2])	([2])	([2])	([2])	46	.0113	.052	.646	.884
22	.0209	.178	.697	.649	47	.0088	.020	.104	.240
23	.1910	1.678	.161	([3])					
24	.0138	.027	.156	.048					
25	.0106	.112	.546	.191	Average	.0309	.180	.552	.671

[1] See Table 1 for names and locations of soils. [2] No specimens. [3] Specimens destroyed by corrosion.

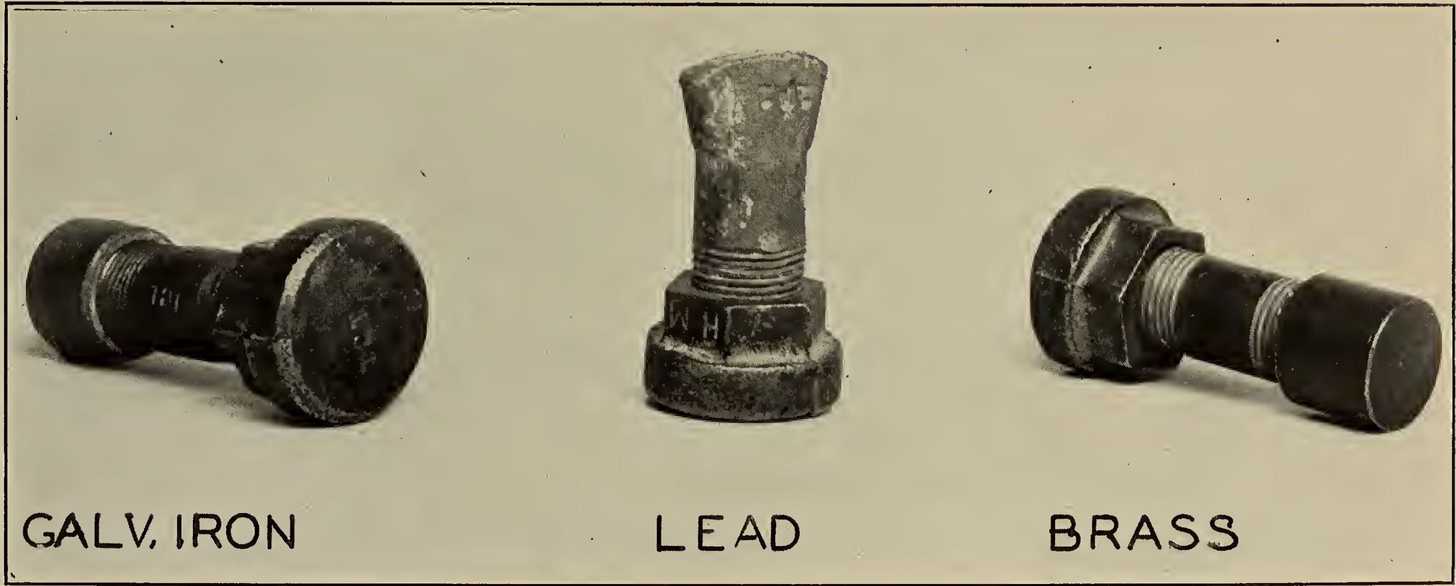

FIGURE 1.—*Brass caps attached to brass, lead, and galvanized steel nipples*

2. EFFECT OF CONNECTING BRASS TO OTHER METALS

Table 2 shows also the rates of corrosion of the nipples attached to the brass caps. In every soil the rates of corrosion of the galvanized nipples were greater than those for the brass nipples. In many soils the coating of zinc was almost or entirely destroyed. Unfortunately, the weight of the zinc coating was not determined. There is evidence of some pitting of the lead nipples which may be attributed to galvanic action. That the corrosion of the lead nipples was caused in part by galvanic action is indicated by the fact that in all soils the rates of corrosion of the lead nipples were greater than the rates of loss of weight of the commercial lead cable sheath shown in Table 6. It is probable, however, that the compositions of the two leads are not identical, since they were obtained from different sources.

Dezincification was observable in some of the brass nipples; but as this occurs also in brass pipe of approximately the same composition not connected with another metal the dezincification should not be attributed to galvanic action. There was no roughening of the brass nipples, but in one soil dezincification so weakened one of them that it crushed when an attempt was made to unscrew it from the casting.

It is somewhat doubtful whether the experiment simulates working conditions closely enough to warrant definite conclusions as to the effect of connecting together different metals. In the experiment the anodic and cathodic metals had approximately the same areas, while in service the anodic area is usually very large when compared with the cathodic area. Polarization which tends to limit galvanic corrosion is in most soils largely a cathodic phenomenon and increases as the current density at the cathode increases. Galvanic action would, therefore, be less affected by polarization when the cathodic area is relatively large, as in the test, than in actual service. This may account for the fact that there are few reported cases of corrosion of iron and steel pipes adjacent to the brass cocks which are screwed into them.

To study further the question of corrosion of iron adjacent to brass, several pairs of cast-iron strips about 2 inches wide and 8 inches long were joined by brazing and buried in a corrosive soil. After about six years the strips were removed. The specimens were irregularly pitted, but the corrosion with one exception did not appear greater at the joint than elsewhere. Thus the results of the test indicate that a small amount of brass in an iron pipe line does not increase its rate of corrosion. On the other hand, a case has recently been called to the bureau's attention in which a steel coupling in a brass water-service pipe failed within a comparatively short time. In this case, however, there was the unusual condition of a large cathodic area and a small anode. Corrosion caused by galvanic action has been reported in a number of cases where ferrous and nonferrous materials have been joined. No positive demonstration has been made showing the conditions under which such corrosion does or does not occur. Apparently galvanic corrosion may be expected if a film of corrosion products or if polarization at the cathodic surface does not interfere. Moving water tends to remove corrosion products and a relatively small cathodic area tends to increase the amount of polarization.

3. COPPER AND COPPER ALLOY PIPES AND RODS

The question as to the resistance of copper and brass pipe to soil action resulted in the burial in 1926 of three varieties of copper pipe, two kinds of brass pipe, a forged leaded brass ell, and two kinds of copper alloy rods. Analyses of these materials are given in Table 3. The rates of loss of weight of most of these materials are shown in Table 4. The figures represent the average for two specimens in each soil except where a specimen was lost. This table also indicates whether or not the specimens were pitted. In most cases the pits were too shallow to permit their accurate measurement. In addition to the pits on the Muntz metal pipe, there were, in most cases, numerous reddish spots where dezincification occurred, leaving the metal week and spongy. The bottoms of the larger pits also contained some of this dezincified metal. Of the materials for which data are shown in Table 4, the alloy (A) appears to be the poorest in most soils. Table 5 shows similar data for two materials which were buried in six soils only.

It is doubtful whether there is a significant difference between the performances of similar materials included in the two tables. Comparison of the data in Tables 4 and 5 with the average rates of corrosion of ferrous materials shown in Table 1 indicates that, in most soils, copper and its alloys corroded much more solwly than did the ferrous pipe materials. It is probable, however, that the reduction in the strength of the Muntz metal pipe, material B, is considerably greater than would be indicated by the loss of weight.

Table 3.—*Compositions of copper and copper alloy pipes and rods*

Class	Form	Length	Cu	Zn	Pb	Al	Fe	Ni	P
		Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
A	7/16-inch rod	12	47	[1] 40.5	2.5			10	
B	1/2-inch I. P. S. pipe	12	60	40					
E	1-inch pipe	17	99.97						
H	do	17	84.99	14.97	.01		0.03		
M	3/4-inch pipe	12	99.93						
Me	1/2-inch S.A.E. forged ell	2	59	[1] 38.5	2.5				
N	7/16-inch rod	12	87			[1] 9.5	3.5		
P	3/4-inch pipe	12	99.94						0.015

[1] By difference.

Note.—These analyses were furnished by the manufacturers of the materials.

Table 4.—*Corrosion of copper and copper alloy pipes and rods*

[Two specimens of each material in each soil except as noted]

Soil No.[1]	Age (years)	Rates of loss of weight in ounces per square foot per year						Pitting					
		A[2]	N	M	P	Me	B	A	N	M	P	Me	B
1	4.11	0.0155	0.0085	0.0179	0.0113	0.0453	0.0165	[3] P					
2													
3	3.90	.2237	.0666	.0538	.0530	.1557	.0917	P		P	P		P
4	3.93	.0479	.0290	.0218	.0205	[4] .3114	.0146	P					
5	3.93	.1895	.0441	.0402	.0323	.4323	.0260	P					
6	3.92	.0539	.0031	.0207	.0185	.0351	.0250	P					
7													
8	3.94	.1983	[4] .0401	.0413	.0413	[4] .2122	.0686	P		P	P		P
9	4.19	.2053	.0141	.0576	.0742	.2100	.3070	P	P	P	P		P
10	3.92	.2171	.0628	.0841	.0731	.1466	.1155	P		P	P		P

[1] See Table 1 for names and locations of soils.
[2] See Table 3 for significance of the letters at the tops of each column.
[3] P signifies pitted.
[4] One specimen only.

TABLE 4.—*Corrosion of copper and copper alloy pipes and rods*—Continued

Soil No.	Age (years)	Rates of loss of weight in ounces per square foot per year						Pitting					
		A	N	M	P	Me	B	A	N	M	P	Me	B
11	3.88	0.1528	0.0255	0.0395	0.0422	0.0952	0.0810	P	----	P	P	----	P
12	3.92	[4] .0659	[4] .0302	.3576	.3421	[4] .3077	[4] .0721	P	----	P	P	----	P
13	3.84	.0570	.0515	.0320	.0340	.4119	.2727	----	----	P	P	----	P
14	3.92	.1368	.0290	.0200	.0225	.2559	.0505	P	----	----	----	----	----
15	3.90	.0845	.0374	.0264	.0262	.0669	.0533	P	----	----	----	----	----
16	3.90	.2782	.1032	.0885	.1015	.1509	.1818	P	----	P	P	----	P
17	3.89	.2704	.0953	.0665	.0678	[4] .2761	.1419	P	----	P	P	----	P
18	3.92	.0287	.0166	.0103	.0132	.1090	.0245	P	----	P	----	----	----
19	3.92	.2842	.0752	.0792	.0855	[4] .1444	[4] .2211	P	----	P	P	----	P
20	4.12	.1391	.0476	.0358	.0445	.2559	.0329	P	----	P	P	----	----
21	--------	--------	--------	--------	--------	--------	--------	----	----	----	----	----	----
22	3.91	.2884	.0739	.0939	.0957	[4] .1452	.1795	P	----	P	P	----	P
23	3.89	.2606	.1973	.0540	.0332	1.3259	.5801	----	----	P	P	----	P
24	3.92	.0570	.0201	.0249	.0223	.0485	.0362	P	----	P	P	----	----
25	3.91	.1741	.0400	.0193	.0173	.1586	.0564	P	----	----	----	----	P
26	4.18	.1261	.0251	.0274	.0241	.1089	.0780	P	----	----	----	----	----
27	3.85	.1457	.0513	.0369	.0471	--------	.0856	P	----	----	----	----	----
28	3.92	.1628	.1202	.0534	.0671	1.1783	.0684	P	----	P	P	----	----
29	3.90	.2213	.1021	.1645	.1585	.5563	.1590	P	P	P	P	----	P
30	4.52	.0104	.0054	.0078	.0079	--------	.0053	----	----	----	P	----	----
31	3.91	.0898	.0377	.0293	.0287	.0953	.0646	P	----	----	----	----	----
32	3.92	.2070	.0449	.0129	.0166	.3481	.1167	P	----	----	----	----	P
33	3.92	.1167	.0329	.0646	.0731	.2456	.0593	P	----	P	P	----	P
34	3.93	.1446	.0305	.0259	.0306	.0416	.0648	P	----	----	----	----	P
35	3.92	.0205	.0140	.0175	.0173	.0754	.0103	P	----	----	----	----	----
36	3.94	.1686	.0254	.0379	.0376	.0900	.0801	P	----	P	P	----	P
37	3.91	.2663	.0796	.2441	[4] .2199	[4] .4906	.1994	P	----	P	P	----	P
38	3.93	.0560	.0278	.0323	.0296	.0826	.0302	P	----	P	P	----	P
39	--------	--------	--------	--------	--------	--------	--------	----	----	----	----	----	----
40	3.90	.4252	.0698	.1009	[4] .0948	[4] .3531	.3030	P	P	P	P	----	P
41	3.92	.2326	.0100	.0405	.0453	.1432	.0926	P	----	----	P	----	P
42	3.94	.3128	.1273	.0948	.0866	.2334	.2249	P	----	P	P	----	P
43	3.92	.0054	.0969	.5189	.6305	.0221	.0550	----	P	P	P	----	----
44	3.92	.1593	.0438	.0417	.0390	.3575	.0735	P	----	P	P	P	P
45	3.91	.0960	.0579	.0207	.0308	.3070	.0488	P	----	P	P	----	----
46	--------	--------	--------	--------	--------	--------	--------	----	----	----	----	----	----
47	3.91	.0105	.0066	[4] .0065	[4] .2830	[4] .0240	.0060	----	----	----	----	----	----

[4] One specimen only.

TABLE 5.—*Corrosion of 1-inch copper and red brass pipe in six soils*

[Two specimens of each kind in each soil except soil 42]

Soil No.[1]	Age (years)	Rates of loss of weight in ounces per square foot per year		Pitting		Soil No.[1]	Age (years)	Rates of loss of weight in ounces per square foot per year		Pitting	
		E[2]	H	E	H			E[2]	H	E	H
13	3.84	0.0346	0.0275	[3] P		42	3.94	[4] 0.0826	[4] 0.1373	P	P
24	3.92	.0264	.0267	P		43	3.92	.4088	.0913	P	P
29	3.90	.1563	.1717	P	P	45	3.91	.0418	.0614	P	P

[1] See Table 1 for names and locations of soils.
[2] See Table 3 for significance of letters at the top of each column.
[3] P signifies pitted.
[4] One specimen only.

4. LEAD CABLE SHEATHS

Samples of two kinds of lead cable sheaths were buried in 1922 and 1924. The sheaths were split and flattened to form sheets. One set of samples contained approximately 1 per cent of antimony; the other sheath was made from commercial lead. The standard size of the alloy sheets was 22 by 8½ inches and that of the commercial lead samples was 22 by 3½ inches. The thicknesses of the specimens were 0.12 and 0.11 inch, respectively. In comparing the performances of the two materials it should be kept in mind that the larger sheets afford a greater opportunity for unusually deep pits. Table 6 shows the rates of corrosion of the two materials. Both the rates of loss of weight and the rates of pitting indicate that the samples containing 1 per cent of antimony corroded more rapidly than those without it.

There appears to be no close relation between the corrosive actions exerted by the soils upon lead and steel. The shaley subsoil of Allis loam causes bad pitting of both steel and lead. Merced silt loam (soil 23), an alkali soil which is the most corrosive soil under investigation with respect to ferrous materials, is relatively noncorrosive with respect to lead.

Table 6.—*Corrosion of lead cable sheath*

[One specimen of each material in each soil]

Soil No.[1]	Age (years)	Rates of loss of weight in ounces per square foot per year		Rates of penetration in mils per year	
		A[2]	H[3]	A	H
1	7.68	0.45	0.30	14.8	12.1
2	5.84	.11	.09	3.1	2.4
3	5.97	.07	.06	(5)	(5)
4	7.96	.24	.26	4.4	3.1
5	6.13	.25	.15	5.9	2.9
6	6.13	.04	.04	(5)	(5)
7	7.68	.17	.12	4.2	2.3
8	7.74	.09	.04	6.8	1.8
9	7.67	.11	.11	(5)	4.2
10	7.93	.08	.04	(5)	(5)
11	7.84	.05	.03	3.8	(5)
12	6.12	.23	.15	2.3	4.7
13	--------	--------	--------	(5)	(5)
14	7.72	.13	.06	3.6	(5)
15	5.99	.08	.08	3.7	2.8
16	5.98	.09	.11	(5)	3.2
17	--------	--------	--------	(5)	(5)
18	7.67	.06	.02	2.2	(5)
19	7.58	.12	.07	3.8	1.5
20	7.68	.23	.17	5.6	3.6
21	--------	--------	--------	(5)	(5)
22	--------	--------	--------	(5)	(5)
23	7.95	.03	.02	(5)	(5)
24	7.93	.04	.02	(5)	(5)
25	7.62	.04	.04	4.2	(5)

Soil No.[1]	Age (years)	Rates of loss of weight in ounces per square foot per year		Rates of penetration[4] in mils per year	
		A[2]	H[3]	A	H
26	7.67	0.06	0.03	3.4	2.0
27	6.01	.12	.07	3.5	4.0
28	5.56	.19	.14	4.9	3.6
29	7.96	.24	.29	(5)	1.4
30	8.17	.15	.11	4.4	3.8
31	5.98	.05	.04	2.2	(5)
32	7.65	.05	.03	(5)	(5)
33	7.63	.12	.14	2.5	2.0
34	7.96	.22	.19	5.2	3.1
35	6.12	.02	.03	(5)	(5)
36	6.02	.06	.05	(5)	(5)
37	5.98	.30	.31	7.0	3.3
38	7.97	.04	.03	(5)	(5)
39	7.95	.13	.11	5.5	2.6
40	6.01	.26	.17	3.7	3.2
41	7.94	.04	.04	(5)	(5)
42	6.02	.11	.10	(5)	3.0
43	7.98	.06	.03	2.5	2.0
44	7.58	.08	.05	(5)	(5)
45	7.68	.04	.03	6.0	(5)
46	--------	--------	--------	(5)	(5)
47	7.99	.27	.06	6.8	3.3

1 See Table 1 for names and locations of soils.
2 Lead + 1 per cent of antimony.
3 Commercial lead.
4 Average of the 2 deepest pits; one on each side of a single specimen.
5 No measurable pits.

By comparing Tables 1 and 6 it will be seen that the rates of loss of weight of the lead sheaths are about one-tenth of those of ferrous materials in the same soils, and the rates of pitting of the lead about half those of iron and steel. However, in most soils the ratio of the maximum to the average penetration by corrosion is much greater for lead than for steel. If the rates of loss of weight of lead are compared with the corresponding rates for copper and brass pipe, as shown in Tables 4 and 6, it will be seen that the latter materials corrode somewhat more slowly in most soils, but not in all. As the specimens of the different materials are of different sizes and have been buried for different lengths of time, and as the duration of the test is short when compared to the life of any of the materials, too much weight should not be given to the results of comparison made at this time.

5. MISCELLANEOUS ALLOYS

At the request of the Bureau of Mines there were included with the specimens buried in five soils in 1924 specimens of a number of alloys. These were 6 inches long and 2 inches wide and of different thicknesses. Such data as are available concerning these specimens are given in Table 7. This table also includes descriptions of some materials that will be discussed in later parts of this paper. Table 8 gives the rates of losses of weight of the specimens and indicates the maximum pit depths in mils per year. The corrosion of some of the aluminum and aluminum alloy specimens occurred beneath their surfaces and produced ridges or blisters. The corrosion products were not completely removed from these blisters before the specimens were weighed. It has been suggested that the aluminum specimens represented poor material, but at this time no evidence as to this is available.

TABLE 7.—*Character and dimensions of miscellaneous specimens*

Symbol	Description
A	Pure open-hearth iron, 2 by 6 by 0.125 inches.
S	Copper-bearing steel, 2 by 6 by 0.0625 inches.
Z1	Zinc sheet, 99.5 per cent pure, 2 by 6 by 0.0625 inches.
Z2	Zinc plate, 99.5 per cent pure, 2.5 by 6.5 by 0.25 inches.
Z3	Corrugated zinc sheet, 12 by 12 by 0.027 inches.
P	"Standard" zinc sheet, 2 by 6 by 0.0625 inches.
L	Bronze 90-10 Cu-Sn, 2 by 6 by 0.25 inches.
B	Brass 70-30 Cu-Zn, 2 by 6 by 0.050 inches.
H	Copper sheet, 2 by 6 by 0.050 inches.
N	Chemical lead (0.05–0.08 per cent Cu, about 0.005 per cent Ag), 2 by 6 by 0.25 inches.
NN	Hearth refined lead (less than 0.001 per cent each of Cu and Ag), 2 by 6 by 0.25 inches.
C1	Commercial aluminum, 2 by 6 by 0.0625 inches.
C2	Aluminum with 1.5 per cent Mn, 2 by 6 by 0.0625 inches.
C3	Duralumin, 2 by 6 by 0.0625 inches.
D	Wrought-iron nuts and bolts, 2 by 0.75 inches.
F	Lead-coated nuts and bolts, 2 by 0.75 inches.
G	Sherardized nuts and bolts, 2 by 0.75 inches.

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TABLE 8.—*Corrosion of miscellaneous specimens*

[Average of 2 specimens]

Material	Soil number									
	13		29		42		43		45	
	Age (years)									
	6.13		6.01		6.02		6.70		6.50	
	Loss [1]	Pits [2]	Loss	Pits	Loss	Pits	Loss	Pits	Loss	Pits
A	0.7632	6.85	0.5938	11.65	0.5628	H	1.4166	H	1.4470	H
B	.0537	(3)	.1654	(3)	.0247	(3)	.0101	(3)	.0773	(3)
C1	.0071	3.59	.0635	H	.0191	5.81	.0535	[4] 1.94	[5] .0410	4.0
C2	.0351	H	.1705	H	.0024	.92	.0007	(3)	.0363	2.54
C3	------	------	[5] .5755	H	.1816	H	.0018	(3)	.0529	H
H	.0042	(3)	.1369	1.33	.0267	(3)	[5] .4818	(3)	.0341	(3)
L	.0090	(3)	.0883	1.75	.0389	.83	.5308	(3)	.0640	2.00
N	.0475	(3)	.3781	2.49	.1880	3.24	.0502	1.19	.0750	4.08
NN	.0063	(3)	.2386	2.00	.1066	(3)	.0568	2.31	.0287	3.0
P	------	------	------	------	------	------	------	------	[5] .2037	(3)
S	.8023	H	.8058	H	.6604	H	[5] 1.7365	H	1.1243	H
Z1	.1140	2.69	.2447	1.75	.0424	.83	.1752	4.63	.1187	3.23
Z2	.1542	4.98	.2683	3.58	.0367	1.66	.1842	11.42	.1319	7.00

[1] Loss in ounces per square foot per year.
[2] Maximum pits in mils per year.
[3] No measurable pits.
[4] Pitting under asphalt only.
[5] One specimen only.
H=Hole in at least one specimen.

6. PARKWAY CABLE

Specimens of parkway cable were buried in most of the test locations in 1924. This material consists of a rubber-covered copper wire surrounded by a lead sheath. The sheath is wrapped with jute partially impregnated with a bituminous material. This is protected by two spirally wound ribbons of galvanized steel which in turn are covered by an asphalt-coated jute wrapper. The cable is intended to be buried directly in the earth. It is not practicable to determine the deterioration of the cable by measurements of loss of weight or depth of pits. Table 9 is an attempt to indicate the condition of each part of each specimen. It will be noted that while the outer steel sheath is rusted in a large percentage of the soils in which the cable was buried, the sheath was pitted in but two soils. In most cases the lead sheath was coated with a thin layer of white material, possibly lead carbonate.

It seems probable that the use of a wrapper which would not separate on being bent and one more thoroughly impregnated with bituminous material would offer more protection to the steel ribbons, but the condition of the lead sheath indicates that the present construction results in quite effective protection of the copper conductor, which is really the objective sought.

TABLE 9.—*Condition of Parkway cable*

(All steel is galvanized)

Soil No.[1]	Years buried	Outer fabric	Inner fabric	Outer steel wrapper	Inner steel wrapper	Lead sheath	Soil No.[1]	Years buried	Outer fabric	Inner fabric	Outer steel wrapper	Inner steel wrapper	Lead sheath
1	7.68	G[2]	G	G	G	G	24	7.93	E	G	G	G	TW
2	5.84	F	G	G	G	W	25	7.62	B	G	G	G	W
3	5.97	F	G	R	SR	TW	26	7.67	B	G	SR	B	TW
4	7.96	F	G	SR	SR	TW	27	6.01	VB	G	SR	SR	TW
5	6.13	F	G	SR	SR	TW	28	5.56	VB	G	BR	R	TW
6	6.13	F	G	R	G	TW	29	7.96	B	G	BR	R	TW
7	7.68	F	G	SR	SR	TW	30	8.17	F	G	G	G	W
8	7.74	F	G	G	G	TW	33	7.63	F	G	G	G	TW
9	7.67	F	F	VSR	G	TW	34	7.96	F	G	SR	G	W
11	7.84	F	G	SR	G	G	35	6.12	G	G	G	G	TW
12	6.12	F	G	SR	VSR	G	36	6.02	F	G	BR	R	TW
13	8.06	VB	VB	P	BR	P	42	6.02	B	G	R	G	G
16	5.98	B	G	R	SR	TW	43	7.98	G	G	G	G	G
18	7.67	F	G	R	G	TW	44	7.58	B	G	BR	G	W
19	7.58	F	G	SR	G	TW	45	7.68	F	G	G	G	G
22	7.59	B	F	BR	R	P	47	7.99	F	G	SR	G	TW

[1] See Table 1 for names and locations of soils.

[2] Ratings:
G, good.
F, fair.
B, bad.
R, rusted.
SR, slightly rusted.
BR, badly rusted.
TW, thin white corrosion product on lead sheath.
W, white corrosion product on lead sheath.
V, very.
P, pitted.

(Ratings by E. R. Shepard and I. A. Denison.)

III. TESTS OF METALLIC COATINGS

1. LEAD COATED PIPE

Since under many conditions lead corrodes less rapidly than iron or steel, lead coating has been suggested as a means of preventing corrosion of steel pipe under ground. In order to secure some data on the effectiveness of lead as a protective coating, specimens of steel pipe 1½ inches in nominal diameter and 6 inches long, and covered by a coating of lead approximately 0.002 inch thick, were buried in 1924. Two specimens of this material were removed from most of the test locations in 1930. Table 10 shows the average rates of loss of weight and penetration of the deepest pits for each pair of specimens removed. All the specimens were exposed to the soils about six years. The times of exposure were the same as those for the galvanized specimens in the same soils and can be found in Table 11. Table 10 shows also similar data for lead-coated steel pipe exposed to the same soils for two years and uncoated steel pipes of the same size exposed to the same soils for approximately six years. The data on specimens removed prior to 1930 are included to facilitate studies of the changes in rates of corrosion with time and the effectiveness of the protective coating.

Comparison of the two and the six year lead-coated specimens with respect to loss of weight and pitting indicates that for most locations the relative performances of the specimens for the two periods were similar; that is, if the soil appeared corrosive with respect to the lead coating at the close of two years, it also appeared corrosive at the close of the 6-year period. This indicates that the rates of loss of weight and pitting are not accidental, but are functions of the character of the test site.

TABLE 10.—*Corrosion of lead-coated steel pipe*

Soil No.[1]	Rates of loss of weight in ounces per square foot per year			Rates of maximum penetration in mils per year		
	Lead coated specimens		Bare steel specimens	Lead coated specimens		Bare steel specimens
	6 years old [2]	2 years old	6 years old	6 years old	2 years old	6 years old
1	0.5475	0.51	1.010	9.7	21	7.0
3	.0515	.08	.620	3.8	(3)	11.5
4	.2109	.16	.725	10.3	15	7.3
5	.3263	.15	.735	6.0	12	8.3
6	.0009	.05	.135	(3)	(3)	(3)
7	.1654	(4)	(4)	9.5	(4)	(4)
8	.0416	.14	.500	13.2	20	8.8
9	.0721	(4)	.445	6.1	(4)	5.2
10	.0699	.06	.570	5.6	12	6.4
11	.0641	.08	.235	2.9	(3)	10.1
13	.0077	.05	1.130	2.7	(3)	11.4
14	.0170	.05	.420	3.4	8	14.3
15	.0461	.07	.950	4.1	10	9.0
16	.0813	(6)	.735	6.7	(3)	15.8
17	.3364	.32	.955	5.3	(3)	4.5
18	.0179	.07	.560	5.5	9	12.5
20	.2009	(4)	.445	7.2	(4)	3.9
22	.1471	.44	.830	7.6	15	10.4
25	.0355	.08	.325	7.0	19	6.8
26	.0699	.26	.305	8.0	16	12.2
27	0.1574	0.11	0.690	7.6	13	5.3
28	.4891	.34	1.711	12.8	26	10.7
29	.3824	.88	1.580	8.1	18	15.3
30	.1245	.05	.455	10.6	19	4.1
31	.1912	.07	.305	(3)	(3)	4.9
32	.0154	.11	.395	4.7	22	5.1
33	.7494	.24	.805	12.7	15	(3)
34	.1459	.19	.450	8.1	16	[5] 2.6
35	.0119	.04	.255	(3)	(3)	[5] 6.6
36	.0190	.11	.290	(3)	(3)	6.2
37	.5441	(6)	.600	9.0	15	6.4
38	.0342	.09	.195	[5] 2.0	(3)	3.3
39	.0439	.19	.430	[5] 3.2	13	6.1
41	.0640	(6)	.750	7.7	19	8.0
42	.1182	.14	1.290	10.1	15	14.0
43	.4723	.41	1.570	21.8	(7)	10.9
44	.0651	.04	.395	5.1	16	9.0
45	.1446	.09	.560	14.6	12	6.8
46	.0405	.09	.510	4.6	9	10.8
47	.2688	(6)	.255	7.8	13	(3)

[1] See Table 1 for names and locations of soils.
[2] See Table 2 for exact ages of 6-year old lead coated specimens. They are the same as the galvanized specimens in the same soils.
[3] No measurable pits.
[4] Specimen missing.
[5] Depth of pits on one specimen assumed to be 10 mils for purpose of computation.
[6] Specimens cleaned in ammonium citrate. Some of the lead was probably taken off.
[7] Holes.

It will be noticed that in most soils the rate of penetration of the lead-coated specimens for the 6-year period is roughly half, or less than half, the corresponding rate for the 2-year period. Although the rates of penetration of the unprotected steel specimens decreased with time it is somewhat surprising to find that the rate of penetration of the lead-coated specimens also decreases with time. As the thickness of the lead coating is approximately 2 mils, corrosion of the lead in many soils must have exposed the steel beneath the lead, and one might suppose that this exposure of the steel would result in accelerated corrosion, since most tables of electrode potentials [3] indicate that iron is anodic with respect to lead. Although there are six soils in which the rate of penetration appears to increase with time, and although specimens have been found which showed serious corrosion of the steel when the lead coating showed only a pinhole, specimens in 25 soils show no accelerated corrosion. The data in Table 10 suggest the possibility that the potential which exists between lead and iron depends on the soil in which specimens composed of the metals are buried.

The pitted appearance of many of the lead-coated specimens frequently leads the casual observer to conclude that lead coating is

[3] H. S. Rawdon, Protective Metallic Coatings, Chemical Catalog Co., Table 1, p. 18.

ineffective. Although it is evident that the coating fails to furnish complete protection, comparison of the rates of corrosion of the 6-year old lead-coated specimens with those for the uncoated steel specimens exposed to the same soils for the same lengths of time indicates that in half of the soils the lead coating added considerably to the life of the pipe.

In so far as the significance of the data can be determined at this time it appears that the value of lead as a protective coating depends upon the soil to which it is to be exposed. At present not enough is known about the relations of soils to the corrosion of lead to justify a statement as to the soil conditions under which lead will provide satisfactory protection.

2. GALVANIZED PIPE AND SHEET STEEL

Among the specimens buried in 1924 were galvanized pipes and galvanized iron and steel sheet. The pipes were 17 inches long and from 1½ to 3 inches in diameter, the size depending on the kind of material. The galvanized sheets were mostly 16-gage metal 6 inches wide and 12 inches long. Most of the specimens carried 2-ounce coatings of zinc applied by the hot-dip process. It was hoped that the results of the tests would show the influence of the kind of base metal to which the coating was applied and the effect of differences in weights of coating. On this account 16-gage sheet of Bessemer steel, pure open-hearth iron, and open-hearth steel containing approximately 0.2 per cent of copper were buried in 45 soils. In 7 soils there were also buried 16-gage sheets of the last two materials carrying nominally 1.5, 2.5, and 3 ounce coatings, respectively. Eighteen-gage sheets of each material carrying 2-ounce coatings and 18-gage ungalvanized sheets were also buried in 7 soils. Pure open-hearth iron pipes carrying a 2-ounce coating were buried in 46 soils, and in 7 of these soils samples of galvanized wrought iron and steel pipe were also buried. The testing of these specimens is somewhat more fully described in Technologic Paper No. 368. The determination of the conditions of the specimens after their removal in 1930 proved a difficult problem. No method has been found by which all of the corrosion products can be removed from a partially rusted specimen without removing some of the remaining zinc and zinc-iron alloy. It was finally decided to scrub the specimens with a stiff wire brush and then to weigh them. The results of the weighings and pit measurements on the sheets are shown in Table 11. On account of the fact that not all the rust was removed from some of the specimens, the rates of loss of weight are in some cases smaller than they should be.

The appearance of the specimens is indicated in the rating sheet, Table 12, which also shows the average weights of coatings as determined in 1926. The ratings of the specimens were made by R. F. Passano, of the American Rolling Mill Co., and E. S. Taylerson, of the American Sheet & Tin Plate Co., both of whom have had extensive experience in the inspection of galvanized sheet metal. Sheets galvanized by the hot-dip process are subject to some unavoidable variation in the thickness of the coating. Rawdon [4] states that a variation of 17.5 per cent is considered by many manfacturers as good commercial practice and shows a diagram of a repre-

[4] H. S. Rawdon, Protective Metallic Coatings, p. 74, Chemical Catalog Co., New York, N. Y.

sentative sheet with a nominal 2.5-ounce coating which a spot test showed to vary from 1.79 to 2.98 ounces per square foot. When the variations in soil conditions within a few inches are also considered, the agreement in the rates of corrosion of the three specimens in any one soil is in most test locations quite good and too close to indicate that one type of material is superior to the others either on account of the characteristics of the base material or the process of galvanizing.

Table 11.—*Corrosion of 16-gage galvanized sheet steel with 2-ounce coatings*

Soil No.[1]	Age (years)	Rates of loss of weight in ounces per square foot per year				Rates of penetration[2] in mils per year			
		A[3] (pipe)	A3	B	Y3	A	A3	B	Y3
1	6.70	(4)	7.993	6.627	6.769	(4)	10.45	9.70	5.60
2	5.84	(4)	.0246	.0256	.0264	(4)	(5)	(5)	(5)
3	5.97	0.0383	.0275	.0292	.0278	(5)	(5)	(5)	(5)
4	6.58	.1733	.2092	.2344	.1841	2.13	2.81	1.98	2.89
5	6.13	.1475	.1704	.1717	.1551	(5)	(5)	(5)	(5)
6	6.13	.0102	.0055	.0078	.0060	(5)	(5)	(5)	(5)
7	6.64	.2379	.1388	.1151	.1296	(5)	[6].83	(5)	(5)
8	6.60	.0733	.0412	.0385	.0449	(5)	(5)	(5)	(5)
9	6.64	.0985	.0555	.0397	.0498	(5)	1.58	1.58	.75
10	6.60	.0344	.0268	.0196	.0247	(5)	(5)	(5)	(5)
11	6.48	.0599	.0373	.0487	.0570	3.70	1.23	4.86	3.16
12	6.12	(4)	(4)	[7].0498	[7].0395	(4)	(4)	(5)	(5)
13	6.13	.1303	.0571	.0532	.1052	(5)	(5)	(5)	(5)
14	6.59	.0350	.0236	.0218	.0243	(5)	(5)	(5)	(5)
15	5.99	.0509	.0242	.0235	.0304	(5)	(5)	(5)	(5)
16	5.98	.0896	.0736	.0839	.0616	1.67	2.26	2.59	1.51
17	6.50	.1390	.2096	.1950	.1609	(5)	(5)	(5)	(5)
18	6.48	.0334	.0168	.0150	.0167	(5)	(5)	(5)	(5)
19	6.46	.0888	.0574	.0678	.0606	(5)	.77	1.86	.54
20	6.71	.1776	.1209	.1208	.1391	(5)	2.76	1.12	2.01
21	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)
22	5.87	.0842	.0837	.1052	.0780	(5)	3.32	2.81	2.39
23	6.12	(4)	2.3947	1.6679	2.6084	(4)	11.44	10.62	12.35
24	6.62	.0160	.0013	.0019	.0011	(5)	(5)	(5)	(5)
25	6.60	.0640	.0451	.0381	.0437	(5)	(5)	(5)	(5)
26	6.63	.0620	.0479	.0417	.0448	(5)	(5)	(5)	(5)
27	6.01	.0718	.0737	.0705	.0654	(5)	1.33	(5)	(5)
28	5.56	.1964	.2297	.2728	.4481	(5)	4.41	4.23	6.56
29	6.01	.2612	.3204	.3309	.3137	1.91	3.83	2.58	2.33
30	7.05	.0912	.1392	.1712	.7469	(5)	(5)	(5)	(5)
31	5.98	.0139	.0087	.0059	.0076	(5)	(5)	(5)	(5)
32	6.71	(4)	.0250	.0298	.0223	(4)	(5)	(5)	(5)
33	6.60	(4)	.1826	.2235	.2198	(4)	[6].83	[6].68	[6].83
34	6.58	.0910	.0876	.0738	.0657	(5)	2.51	1.44	.68
35	6.12	.0632	.0438	.0375	.0387	(5)	(5)	(5)	(5)
36	6.02	.0248	.0126	.0167	.0180	(5)	(5)	(5)	(5)
37	5.98	.2100	.1546	.1633	.1409	(5)	3.18	2.34	.50
38	6.57	.0202	.0037	.0050	.0092	(5)	(5)	(5)	(5)
39	6.56	.0605	.0451	.0398	.0496	(5)	1.14	.23	.84
40	6.01	(4)	.0890	.1101	.0840	(4)	3.24	4.41	3.00
41	6.47	.0533	.0247	.0292	.0280	(5)	(5)	(5)	(5)
42	6.02	.0803	.1455	.0533	.0560	(5)	5.32	2.08	1.00
43	6.70	.1472	.2124	.5604	.0707	(5)	8.36	8.21	(5)
44	6.48	.0532	.0193	.0108	.0206	(5)	(5)	(5)	(5)
45	6.50	.1437	.0614	.1439	.0809	(5)	(5)	3.08	(5)
46	6.50	.0133	.0082	.0085	.0062	(5)	(5)	(5)	(5)
47	6.51	(4)	.0482	.0403	.0492	(4)	(5)	(5)	(5)

[1] See Table 1 for names of soils.
[2] Average of 2 deepest pits, one pit from each side of plate.
[3] See Table 12 for identification of materials.
[4] No specimen.
[5] No pits of measurable depth.
[6] Measurements less than 6 mils assumed to be 3 for calculating purposes.
[7] Average of two specimens.

TABLE 12.—*Condition of galvanized pipe and 16-gage sheet*

Soil No.[1]	A	A3	Y3	B	Soil No.[1]	A	A3	Y3	B
1	--------	H	P	H	25	G	F	F	F
2	--------	G	G	G	26	E	E	E	R
3	E	G	G	G	27	G	P	R	R
4	P	R	P+	P	28	G	P	P	P
5	G	R	R	R	29	P	P	P	P
6	E	E	E	G	30	--------	R	R	R
7	F	P	R	R	31	E	E	E	E
8	G	G	G	G	32	--------	E	E	G
9	G	P	P+	P	33	R	P	P	P
10	E	G	G	G	34	E	P	P	P
11	P+	P	P	P	35	E	G	G	G
12	--------	--------	FG	RG	36	E	E	E	E
13	E	R	R	F	37	F	P	P	P
14	E	G	G	G	38	E	E	E	E
15	G	G	G	G	39	R	P	P	P
16	P	P	P	P	40	--------	P	P	P
17	R	P	P	P	41	E	E	E	E
18	E	E	E	E	42	G	P	P+	P
19	E	P	P	P	43	G	P	R	H
20	R	P	P	P	44	E	E	E	G
21	--------	--------	--------	--------	45	G	R	R	P
22	E	P	P	P	46	E	E	E	E
23	--------	H	H	H	47	G	G	G	G
24	E	E	E	E					

[1] See Table 1 for names and locations of soils.

E, excellent. G, good. F, fair. R, rusted. P, pitted. H, holes. +, better.
A, pure open-hearth iron pipe. Coating=2.82 ounces per square foot.
A3, pure open-hearth iron sheet. Coating=1.98 ounces per square foot.
B, Bessemer steel sheet. Coating=1.62 ounces per square foot.
Y3, open-hearth steel 0.2 per cent copper. Coating=2.15 ounces per square foot.
(Rating by R. F. Passano and E. S. Taylerson.)

It is, of course, possible that when more of the zinc has been removed from the specimens the effects of the base metals will be more apparent. In view of the small number of samples in any one location, the variation in soil condition which may occur within a few inches, and the variation in weight of coating, it is not considered possible from these data to determine such differences in materials as may exist.

Comparison of Tables 1 and 11 indicates that while galvanizing does not permanently protect steel, it adds very considerably to its life in most soils. Because of changes in rates of corrosion of both galvanized and ungalvanized steel with time, it is not possible to determine from the tables the extension of the life of pipes to be expected as the result of galvanizing them. While some soils that are destructive to ferrous materials are not so destructive to galvanized materials, many soils appear to attack both iron and zinc. When a better understanding of soil action has been obtained it may be possible to designate the kinds of soil in which the use of galvanized pipes is advantageous.

If the protection afforded by a zinc coating is the result of the corrosion resisting properties of zinc, it should follow that the thicker the coating the more slowly will the pipe deteriorate. An attempt to determine the influence of the thickness of the zinc coating was made by burying sheets of two materials protected by several weights of coating in seven soils. All of these soils with the exception of soil No. 24 are corrosive with respect to iron and steel.

Table 13 shows the rates of loss of weight and rates of pitting of the materials. The weights of coating are given at the top of the columns. A description of the conditions of these specimens is presented in Table 14. The data on the pipes give no indication that one base material is superior to the others in the soils shown in the table. This is perhaps because all of the pipes with one exception remained in good condition in all of the soils. On the whole, the data on the 16-gage galvanized sheets indicate that the rate of loss of weight is less for the sheets with the thicker coatings of zinc. The data on rates of pitting are less consistent than those for rates of loss of weight. It is probable that the effect of the thickness of the coating will become more evident when specimens buried for a longer period of time are examined. The data on the 18-gage specimens do not differ materially from those of the thicker specimens having approximately the same weights of coating. The data on the ungalvanized specimens show quite clearly that the galvanizing of the sheets afforded them a very considerable amount of protection. The size of the holes in some of the ungalvanized sheets indicates that they failed long before their removal.

TABLE 13.—*Effect of weight of zinc coating on rates of corrosion*

RATES OF LOSS OF WEIGHT IN OUNCES PER SQUARE FOOT PER YEAR

Soil No.	Age (years)	Galvanized pipe				Galvanized sheet										Black sheet		
		A	D	Y	Y	A2	A3	A4	Y2	Y3	Y4	Y5	CA	CB	CY	CA-B	CB-B	CY-B
		[1] 2.82	3.48	3.47	3.47	1.79	1.98	2.65	1.57	2.15	2.76	2.92	1.87	1.66	2.16	--------	--------	--------
13	6.13	0.1303	0.2719	0.1351	0.1645	0.0606	0.0571	0.0778	--------	0.1052	0.0973	0.0841	0.0500	0.0571	0.0553	0.9304	0.8600	0.9232
24	6.62	.0160	.0147	.0137	.0139	.0017	.0013	(2)	0.0011	.0011	.0031	.0012	.0024	.0034	.0025	.1876	.1811	.1615
28	5.56	.1964	.1522	.1724	.1492	.3135	.2297	.1791	.7424	.4481	.2288	.2961	.2039	.4619	.2142	1.7424	1.5618	1.7420
29	6.01	.2612	.3145	.2740	.2490	.3120	.3204	.2480	.4227	.3137	.2808	.2863	3073	.3084	.2521	1.4136	1.3302	1.3874
42	6.02	.0803	.0965	.0899	.0498	.1498	.1455	.0894	.1560	.0560	.0782	.0990	.0593	.0591	.0667	1.1025	1.3343	1.0821
43	6.70	.1472	.2165	.1871	.1631	.0628	.2124	.1013	.0722	.0707	.0831	.0678	.4505	.3906	.1047	1.3532	1.5266	1.0831
45	6.50	.1437	.3044	.1946	.1395	.0525	.0614	.0743	.4631	.0809	.0719	.0757	.5700	.2830	.1499	1.6540	1.4187	.9396

RATES OF MAXIMUM PENETRATION IN MILS PER YEAR [3]

Soil No.	Age (years)	A	D	Y	Y	A2	A3	A4	Y2	Y3	Y4	Y5	CA	CB	CY	CA-B	CB-B	CY-B
13	6.13	(4)	(4)	(4)	(4)	3.02	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)
24	6.62	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	3.55	2.49	2.64
28	5.56	(4)	(4)	(4)	(4)	4.68	4.41	4.14	10.70	6.56	5.94	3.78	2.43	3.24	1.89	9.89	9.89	9.89
29	6.01	1.91	(4)	1.67	1.83	3.58	3.83	2.83	3.00	2.33	2.50	2.83	4.16	1.66	1.83	9.15	9.15	9.15
42	6.02	(4)	(4)	(4)	(4)	6.98	5.32	3.99	7.81	1.00	1.83	3.07	3.99	2.91	(4)	9.14	9.14	9.14
43	6.70	(4)	(4)	(4)	(4)	(4)	8.36	(4)	(4)	(4)	(4)	(4)	4.85	7.46	(4)	8.21	8.21	8.21
45	6.50	(4)	(4)	(4)	(4)	(4)	(4)	(4)	5.15	(4)	(4)	(4)	7.92	4.08	2.92	8.46	8.46	8.46

1 Weight of coating in ounces per square foot.
2 Weight not available.
3 In case of sheet, average of two deepest pits, one from each side of specimen.
4 No pits of measurable depth.

A, pure open-hearth iron.
B, bessemer steel (when separated from another letter by a dash denotes sheets were not galvanized).
C, denotes 18-gage material.
D, wrought-iron pipe.
Y, open-hearth steel containing about 0.2 per cent copper.

Pit measurements by E. R. Shepard and R. B. McDowell.

TABLE 14.—*Condition of specimens with different weights of coatings*

Soil No.	Galvanized pipe			Galvanized 16-gage sheet								Galvanized 18-gage sheet			18-gage black sheet		
	A	D	Y	A2	A3	A4	Y2	Y3	Y4	Y5	B	CA	CB	CY	CA-B	C-B	CY-B
	[1] 2.82	3.48	3.47	1.79	1.98	2.65	1.57	2.15	2.76	2.92	1.62	1.87	1.66	2.16	------	------	------
13	E, F	E	E, E	P	R	F	F	R	R	R	F	R	R	F	H	H	H
24	E, E	E	E, E	E	E	E	E	E	E	E	E	E	E	E	P	P	P
28	G, G	G	G, G	P	P	P	P	P	P	P	P	P	P	P	H	H	H
29	P, P	F	P, P	P	P	P	P	P	P	P	P	P	P	P	H	H	H
42	G, G	R	R, E	P	P	P	P	P	P	P	P	P	P	F	H	H	H
43	G, G	G	G, G	R	P	G	R	R	R	R	H	P	P	P	H	H	H
45	G, F	F	F, G	R	R	F	P	R	R	R	P	H	P	P	H	H	H

[1] Weight of coating in ounces per square foot.

Rating symbols:
- E, excellent.
- G, good.
- F, fair.
- R, rusted.
- P, pitted (see Table 13).
- H, holes.

Materials:
- A, open-hearth iron.
- B, Bessemer steel (after a letter signifies no zinc).
- Y, open-hearth steel with 0.2 per cent copper.
- C, 18-gage sheet.
- D, wrought iron.

(Ratings by R. F. Passano and E. S. Taylerson.)

3. LEAD AND ZINC COATED BOLTS

At the request of an advisory committee, specimens of lead coated bolts, sherardized bolts and wrought iron bolts were buried in six soils in 1924. All the bolts were ¾ inch in diameter and 3½ inches long and were provided with nuts of the same materials. Four bolts of each kind were removed in 1930. Table 15 shows the loss of weight of these specimens. Both lead and zinc appear to prolong the life of the bolts in the soils in which they were buried. The maximum corrosion was usually at the threaded end of the bolts.

4. CALORIZED PIPE

Samples of pipe calorized by the wet and by the dry process were buried in six soils in 1924. The data shown in Table 16 indicate that calorizing adds very considerably to the life of pipe in the soils in which the specimens were buried. It is too soon to determine the usefulness of this method of protecting pipes.

IV. TESTS OF COPPER STEEL AND GROUND SPECIMENS

At the suggestion of Dr. F. N. Speller, of the National Tube Co., there were buried in six soils in 1926 two classes of materials, the performances of which are reported here, although they are neither nonferrous materials nor protective coatings. However, they represent suggestions for reduction of corrosion. The first material is steel containing 1.5 per cent of copper. The second group of specimens were intended to indicate whether the type of the pipe surface affected the rate of corrosion. One specimen of steel pipe 2 inches in diameter and 17 inches long and sealed at the ends was ground to a semipolished surface. This was accompanied by a pipe of similar material with the original mill surface. Similar specimens of wrought iron were furnished by the Reading Iron Co. The surfaces of the ground wrought-iron specimens were, however, much rougher than those of the ground-steel specimens. The data obtained from these specimens are shown in Table 17. There have also been included in this table data on some lead-coated pipe buried with the steel specimensand having the same dimensions.

TABLE 15.—*Rates of loss of weight of nuts and bolts*

[Average of 4 specimens in ounces per square foot per year]

Soil No.	Bolts			Nuts		
	G	D	F	G	D	F
13	0.084	1.344	0.135	0.178	2.206	0.144
24	.022	.100	.056	.025	.086	.083
28	[1] .693	[1] 1.813	----------	[1] .536	[1] 1.855	----------
29	.525	1.222	.740	.242	.822	.559
42	.806	1.236	.294	.782	1.188	.225
43	.987	1.542	.621	.687	1.406	.437
45	.231	1.595	1.021	.345	1.734	.669

[1] One specimen only; D, wrought iron; F, lead-coated; G, sherardized.

TABLE 16.—*Corrosion of calorized specimens*

Soil No.	Age (years)	Rates of loss of weight in ounces per square foot per year		Rates of maximum penetration in mils per year		Soil No.	Age (years)	Rates of loss of weight in ounces per square foot per year		Rates of maximum penetration in mils per year	
		Dry cal.	Wet cal.	Dry cal.	Wet cal.			Dry cal.	Wet cal.	Dry cal.	Wet cal.
13	6.13	0.163	0.021	5.38	5.87	42	6.02	3.19	0.122	6.81	8.64
24	6.62	.023	.010	[1] 2.42	4.38	43	6.70	1.163	.739	6.57	7.76
28	5.56	.311	----------	6.47	----------	45	6.50	.338	.403	4.92	5.23
29	6.01	.251	.296	6.32	7.65						

[1] Depth of pit on one specimen assumed to be 10 mils for purpose of calculation.

The data do not indicate that the addition of copper to steel improved its resistance to the action of the soils in which the specimens were buried. In four of the six soils the ground wrought iron lost slightly more weight than the unground specimens of the same material, and all of the ground specimens showed deeper pits than the corresponding unground specimens. On the other hand, in four soils out of six the polished steel lost less weight than the unpolished steel. Half of the polished steel specimens were pitted more deeply than the unpolished specimens. The data are not sufficiently consistent to show definitely whether grinding the surface of a pipe improves its resistance to soil action; but if grinding does improve its resistance the improvement is probably not great.

TABLE 17.—*Corrosion of copper steel, ground and unground wrought iron and steel, and of lead-coated pipes*

RATES OF LOSS OF WEIGHT IN OUNCES PER SQUARE FOOT PER YEAR

Soil No.	Age (years)	C	D	K	M	P	L (2 specimens)
13	3.84	1.6158	1.2389	1.7887	1.0417	0.9550	.4833
24	3.92	.3851	.3984	.3560	.3483	.2232	.0615
28	3.92						.9812
29	3.90	4.0924	1.2021	1.5130	1.3762	1.6392	.8527
42	3.94	1.5902	1.7041	1.7787	1.6915	1.4431	.8139
43	3.92	1.2000	.8837	.7096	.8855	.3367	.6911
45	3.91	1.2730	2.4840	3.0243	2.3812	2.7770	.5782

RATES OF MAXIMUM PENETRATION IN MILS PER YEAR

Soil No.	Age (years)	C	D	K	M	P	L (2 specimens)
13	3.84	19.27	14.06	19.79	7.81	9.38	[1] 6.50
24	3.92	7.14	5.10	9.18	4.59	8.16	
28	3.92						11.60
29	3.90	29.49	14.87	18.21	14.87	17.18	8.71
42	3.94	20.56	20.56	26.40	23.35	21.07	13.96
43	3.92	15.82	11.99	21.68	27.30	17.86	24.23
45	3.91	16.88	18.41	24.30	27.37	24.55	12.78

[1] Depth of pit on one specimen assumed to be 10 mils for purpose of calculation: C, Steel+1.5 per cent copper; D, wrought iron; K, ground wrought iron; M, bessemer steel; P, ground and semipolished Bessemer steel, L, lead coated pipe.

The lead-coated specimens in this group behaved similarly to the other lead-coated specimens in that they showed less loss of weight than the unprotected specimens although the pits were deeper in one soil.

V. SUMMARY

The information concerning soils which has been obtained as the result of the bureau's soil-corrosion investigations makes it clear that that the rate of corrosion of any metal exposed to soil can not be accurately expressed by a single figure or group of figures. On account of the variations found in all soils the influence of the character of the soil, differences in contact between the soil and the metal, changes in the supply of oxygen and moisture, and the effects of the corrosion products, the best that can be hoped for is an expression representing the average rate of loss of weight or pitting accompanied by a figure for the standard deviation, probable error, or some other expression indicating how much the behavior of any single specimen may be expected to differ from the behavior of the average of a representative group of specimens.

Average values sufficiently accurate to show small differences in the performance of competing materials can only be secured through the testing of a very large number of specimens. Since in any one case any material may prove considerably better or worse than the average, it is doubtful whether the drawing of fine distinctions between materials would be of practical value except for the consumers of very large quantities of materials. Attention should, therefore, be directed chiefly to the unmistakable differences between different kinds of materials rather than to possible small differences between nearly similar materials.

The most general conclusion to be drawn from the data is that for best results the material must be chosen to fit the soil in which it is to serve, since no one material is best for all soil conditions. Another general conclusion is that small differences in the data should not be considered significant, since it is improbable that a repetition of the test would yield identical results.

In nearly all soils copper and alloys high in copper resist corrosion well. Muntz metal shows at least slight dezincification after six years burial in half of the soils investigated and serious dezincification in a few of them.

In nearly all of the soils considered, lead corroded much less rapidly than iron or steel. The rates of pitting of commercial lead specimens were 3 mils per year or greater in 25 per cent of the soils. The lead containing antimony showed rates of pitting greater than 3 mils per year in nearly 50 per cent of the test locations.

The outer metallic ribbon of the parkway cable showed corrosion in most test locations. The inner ribbon was somewhat less corroded. Serious pitting of the lead sheath occurred only in the soil containing alkali carbonates.

All of the metallic coatings tested appeared to increase the life of the material to which they were applied. Comparison of the effectiveness of the metallic coatings is difficult because they differed in thickness. All coatings showed evidences of deterioration in several soils. In most of the soils, there was no evidence that the rate of penetration by pitting increased after the lead coating had been punctured. The possibility is suggested that the relative positions of lead and iron in the electrochemical series depends upon the soil in which specimens composed of lead and iron are placed. The precision of the data is insufficient to show at this time whether one base material is better than another for galvanized sheets to be used underground, but it appears that any difference which may exist is not great.

In conclusion, the author wishes to recognize and express his appreciation for the work of V. A. Grodsky, R. H. Taylor, E. S. Hammond, and R. B. McDowell, who determined the rates of losses of weight and penetration and prepared the tables for this report.

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