Investigation on Acid-Resistant High-Silicon Iron (IV)

Corrosion Resistance to Sulphuric Acid

By

Hiroshi SAWAMURA, Osamu TAJIMA and Kyoichi AKAMATSU

Department of Metallurgy

(Received November 30, 1956)

Abstract

Corrosion tests were carried out on acid-resistant high-silicon iron in sulphuric acid with various concentrations and temperatures. The effects of the acid concentration, temperature and duration of test were discussed. The appearance of surface of specimen was also examined.

I. Introduction

In our preceding studies[1)–3)] the relations between the corrosion resistance and the following articles were investigated; the content of the constituent and alloying elements, heat treatment, and cooling rate of castings. In the present study, corrosion tests were made upon the ordinary high-silicon iron in the as-cast state in sulphuric acid in a wide range of concentration at various temperatures, because they are very important for the industrial use of this alloy.

II. Preparation of Specimen and Method of Experiment

Steel scrap and ferrosilicon containing 75 pct silicon were melted in a $\frac{1}{2}$ ton Héroult type electric furnace. After the melt was heated to about 1500°C it was poured at about 1300°C into the same shell moulds as those used in the previous study[1)] and the bars of 15 mm in diameter and 200 mm in length were prepared. These cast bars were cut and finished with a No. 80 carborundum wheel into test specimens of 14 mm diameter and 15 mm long. The analysis of the specimen is: Si 14.64 pct, C 0.63 pct, Mn 0.38 pct, P 0.076 pct and S 0.006 pct.

The apparatus used and the procedure of the test were the same as in the previous studies[1),2)] except the duration of test and the concentration of test solution. The durations of test were 2, 4, 6, 8 and 24 hr., and at each duration the specimens were taken out from the test solution and weighed to obtain corrosion loss. The test solution was used throughout the experiments without renewal. As the test solutiou, sulphuric acid of the following concentration was employed:

concentration (wt-pct)	specific gravity (at 15°C)
1	1.005
5	1.033
10	1.069
15	1.105
20	1.143
30	1.221
50	1.399
70	1.615
·98	1.841

The testing temperatures were 30, 80°C and boiling temperature of each of the test solutions.

III. Experimental Results and Consideration

The experimental results are given in Tables 1-3 and shown in Figs. 1-7. From the time-corrosion curves it can be seen that the corrosion is greatest during the first period of immersion and it gradually decreases with time until it becomes very small after 24 hr. This fact supports the evidence that the corrosion resistance exhibited by high-silicon irons depends upon the formation of a protective corrosion product film. High-silicon iron immersed in sulphuric acid solution builds up a protective oxide film on its surface and thus gains passivity. Yamaguchi[4] confirmed by an electron diffraction method the fact that the surface of high-silicon iron treated with 10-30N sulphuric acid is covered with a thin film of α-cristobalite (SiO_2) which is not accompanied by iron oxide.

To secure a good resistance to corrosion against sulphuric acid, the high-silicon iron should contain approximately 14.5—15 pct of silicon as shown by the authors[1] as well as many other investigators. This is considered to be the concentration limit of silicon at which a compact protective film of SiO_2 can be formed on the surface of the alloy.

It is to be seen in Fig. 7 that the attack of the acid, as is expected, is stronger when temperature is higher. Fig. 7 also shows the effects of the acid concentration. In the tests at 30 and 80°C the corrosion loss increases as the concentration of the acid increases from 1 pct until it reaches the maximum value at 15 pct, then it decreases with acid concentration; and in the acid over 70 pct, the corrosion loss is extremely diminished. In the boiling acid tests an approximately similar relation is seen between the corrosion loss and the concentration of

Table 1. Corrosion Tests at 30°C.

Specimen Number	Concentration of H_2SO_4 (%)	0-2 hr.		0-4 hr.		0-6 hr.		0-8 hr.		0-24 hr.	
		A	B	A	B	A	B	A	B	A	B
1	1	0.54	0.27	0.59	0.15	0.65	0.11	0.68	0.09	0.71	0.03
2		0.57	0.29	0.63	0.16	0.63	0.11	0.63	0.08	0.63	0.03
3		0.49	0.25	0.56	0.14	0.53	0.09	0.55	0.07	0.55	0.02
		0.53	**0.27**	**0.59**	**0.15**	**0.60**	**0.10**	**0.62**	**0.08**	**0.63**	**0.03**
4	5	0.76	0.38	0.91	0.23	1.01	0.17	1.10	0.14	1.18	0.04
5		0.84	0.42	0.91	0.23	0.93	0.16	0.92	0.12	0.92	0.05
6		0.88	0.44	1.03	0.26	1.07	0.18	1.11	0.14	1.13	0.05
		0.83	**0.41**	**0.95**	**0.24**	**1.00**	**0.17**	**1.04**	**0.13**	**1.08**	**0.05**
7	10	0.53	0.27	0.64	0.16	0.69	0.13	0.72	0.09	0.78	0.03
8		0.73	0.37	0.91	0.23	0.94	0.16	0.98	0.12	1.10	0.05
9		0.73	0.37	0.89	0.22	0.94	0.16	0.96	0.12	1.09	0.05
		0.66	**0.34**	**0.81**	**0.20**	**0.86**	**0.15**	**0.89**	**0.11**	**0.99**	**0.04**
10	15	1.99	1.00	2.75	0.69	3.01	0.50	3.15	0.39	3.40	0.14
11		1.79	0.90	2.68	0.67	2.95	0.49	3.12	0.39	3.43	0.14
12		1.73	0.87	2.51	0.63	2.75	0.46	2.86	0.36	3.03	0.13
		1.84	**0.92**	**2.65**	**0.66**	**2.90**	**0.48**	**3.04**	**0.38**	**3.29**	**0.14**
13	20	0.38	0.19	0.49	0.12	0.53	0.09	0.54	0.07	0.67	0.03
14		0.34	0.17	0.42	0.11	0.42	0.07	0.43	0.05	0.48	0.02
15		0.39	0.20	0.44	0.11	0.50	0.08	0.57	0.07	0.83	0.04
		0.37	**0.19**	**0.45**	**0.11**	**0.48**	**0.08**	**0.51**	**0.06**	**0.66**	**0.03**
16	30	0.21	0.11	0.32	0.08	0.29	0.05	0.34	0.04	0.37	0.02
17		0.13	0.07	0.26	0.07	0.26	0.04	0.26	0.03	0.39	0.02
18		0.12	0.06	0.23	0.06	0.23	0.04	0.25	0.03	0.32	0.01
		0.15	**0.08**	**0.27**	**0.07**	**0.26**	**0.04**	**0.28**	**0.03**	**0.36**	**0.02**
19	50	0.01	0.01	0.02	0.01	0.02	0.00	0.04	0.01	0.05	0.00
20		0.02	0.01	0.08	0.02	0.08	0.01	0.08	0.01	0.09	0.00
21		0.06	0.03	0.10	0.03	0.10	0.02	0.10	0.01	0.14	0.01
		0.03	**0.02**	**0.07**	**0.02**	**0.07**	**0.01**	**0.07**	**0.01**	**0.09**	**0.00**
22	70	0.02	0.01	0.02	0.01	0.00	0.00	0.01	0.00	0.01	0.00
23		0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.03	0.00
24		−0.03	−0.02	−0.02	0.01	−0.04	−0.01	−0.04	−0.01	−0.03	−0.00
		−0.00	**−0.00**	**0.01**	**0.01**	**−0.01**	**−0.00**	**−0.01**	**−0.00**	**0.00**	**0.00**
25	98	−0.00	−0.00	−0.00	−0.00	−0.00	−0.00	−0.00	−0.00	−0.00	−0.00
26		−0.00	−0.00	−0.00	−0.00	−0.00	−0.00	−0.00	−0.00	−0.00	−0.00
27		−0.00	−0.00	−0.00	−0.00	−0.00	−0.00	−0.00	−0.00	−0.00	−0.00
		−0.00	**−0.00**	**−0.00**	**−0.00**	**−0.00**	**−0.00**	**−0.00**	**−0.00**	**−0.00**	**−0.00**

A : Corrosion Loss in Weight (mg/cm^2)

B : Mean Corrosion Rate ($mg/cm^2/hr.$)

The figures in Gothic type indicate the average values.

Table 2. Corrosion Tests at 80°C.

Specimen Number	Concentration of H_2SO_4 (%)	0-2 hr.		0-4 hr.		0-6 hr.		0-8 hr.		0-24 hr.	
		A	B	A	B	A	B	A	B	A	B
28		0.36	0.18	0.37	0.09	0.36	0.06	0.34	0.04	0.38	0.02
29	1	0.75	0.38	0.83	0.21	0.83	0.14	0.86	0.11	0.88	0.04
30		0.56	0.28	0.64	0.16	0.75	0.13	0.67	0.08	0.68	0.03
		0.56	**0.28**	**0.61**	**0.15**	**0.65**	**0.11**	**0.62**	**0.08**	**0.65**	**0.03**
31		0.98	0.49	1.13	0.28	1.33	0.22	1.35	0.17	1.45	0.06
32	5	1.13	0.57	1.27	0.32	1.32	0.22	1.34	0.17	1.48	0.06
33		0.99	0.50	1.15	0.29	1.29	0.22	1.24	0.16	1.36	0.06
		1.03	**0.52**	**1.18**	**0.30**	**1.31**	**0.22**	**1.31**	**0.17**	**1.43**	**0.06**
34		1.46	0.73	1.67	0.42	1.83	0.31	2.02	0.25	2.39	0.10
35	10	1.10	0.55	1.26	0.32	1.42	0.27	1.66	0.21	2.06	0.09
36		1.07	0.54	1.18	0.30	1.35	0.23	1.38	0.17	1.66	0.07
		1.21	**0.61**	**1.37**	**0.35**	**1.53**	**0.27**	**1.69**	**0.21**	**2.04**	**0.09**
37		2.93	1.47	2.99	0.75	3.08	0.51	3.34	0.42	3.79	0.16
38	15	2.37	1.19	2.45	0.61	2.56	0.43	3.07	0.38	3.19	0.13
39		3.08	1.54	3.17	0.79	3.37	0.56	3.55	0.44	3.71	0.16
		2.79	**1.40**	**2.87**	**0.72**	**3.00**	**0.50**	**3.32**	**0.41**	**3.56**	**0.15**
40		0.72	0.36	0.85	0.21	0.96	0.16	1.12	0.14	1.44	0.06
41	20	0.83	0.42	0.96	0.24	1.05	0.18	1.36	0.17	1.66	0.07
42		0.67	0.34	0.94	0.24	1.12	0.19	1.24	0.16	1.59	0.07
		0.74	**0.37**	**0.92**	**0.23**	**1.04**	**0.18**	**1.24**	**0.16**	**1.56**	**0.07**
43		0.73	0.37	0.88	0.22	0.99	0.17	1.11	0.14	1.23	0.05
44	30	0.55	0.28	0.66	0.17	0.77	0.13	0.78	0.10	0.94	0.04
45		0.56	0.28	0.67	0.17	0.83	0.14	0.87	0.11	1.12	0.05
		0.61	**0.31**	**0.74**	**0.19**	**0.86**	**0.15**	**0.92**	**0.12**	**1.10**	**0.05**
46		0.19	0.10	0.26	0.07	0.26	0.04	0.30	0.04	0.35	0.01
47	50	0.13	0.07	0.17	0.04	0.17	0.03	0.17	0.02	0.22	0.01
48		0.07	0.04	0.09	0.02	0.17	0.03	0.13	0.02	0.19	0.01
		0.13	**0.07**	**0.17**	**0.04**	**0.20**	**0.03**	**0.20**	**0.03**	**0.25**	**0.01**
49		0.08	0.04	0.10	0.03	0.07	0.01	0.08	0.01	0.08	0.00
50	70	0.03	0.02	0.03	0.01	0.10	0.02	0.03	0.00	0.05	0.00
51		−0.02	−0.01	−0.01	−0.00	0.04	0.01	0.01	0.00	0.02	0.00
		0.03	**0.02**	**0.04**	**0.01**	**0.07**	**0.01**	**0.04**	**0.00**	**0.05**	**0.00**
52		0.03	0.02	0.03	0.01	0.01	0.00	0.01	0.00	0.01	0.00
53	98	−0.05	−0.03	−0.08	−0.02	−0.06	−0.01	−0.09	−0.01	−0.08	−0.00
54		0.01	0.01	−0.01	−0.00	0.02	0.00	−0.01	−0.00	0.00	0.00
		−0.00	**−0.00**	**−0.02**	**−0.00**	**−0.01**	**−0.00**	**−0.03**	**−0.00**	**−0.02**	**0.00**

A : Corrosion Loss in Weight (mg/cm^2)

B : Mean Corrosion Rate ($mg/cm^2/hr.$)

The figures in Gothic type indicate the average values.

Table 3. Corrosion Tests at Boiling Temperature.

Specimen	Concentration	0-2 hr.		0-4 hr.		0-6 hr.		0-8 hr.		0-24 hr.	
Number	of H_2SO_4 (%)	A	B	A	B	A	B	A	B	A	B
55		3.44	1.72	3.58	0.90	3.56	0.59	3.60	0.45	3.90	0.16
56	1	3.43	1.72	3.53	0.88	3.56	0.59	3.62	0.45	3.95	0.16
57		3.24	1.62	3.25	0.81	3.31	0.55	3.34	0.42	3.55	0.15
		3.37	**1.69**	**3.45**	**0.86**	**3.48**	**0.58**	**3.52**	**0.44**	**3.75**	**0.16**
58		1.48	0.74	2.32	0.58	3.56	0.59	3.66	0.46	3.98	0.17
59	5	1.66	0.83	2.31	0.58	3.76	0.63	3.93	0.49	4.53	0.19
60		1.26	0.63	2.93	0.73	3.50	0.58	3.63	0.45	3.97	0.17
		1.47	0.74	**2.52**	**0.63**	**3.61**	**0.60**	**3.74**	**0.47**	**4.16**	**0.17**
61		1.71	0.86	2.57	0.64	2.92	0.49	3.38	0.42	3.88	0.16
62	10	1.68	0.84	2.99	0.75	3.30	0.55	3.69	0.46	4.15	0.17
63		1.64	0.82	3.05	0.76	3.40	0.57	3.74	0.47	4.14	0.17
		1.68	**0.84**	**2.87**	**0.72**	**3.31**	**0.53**	**3.60**	0.45	4.06	**0.17**
64		3.77	1.89	4.80	1.20	4.88	0.81	4.98	0.62	5.15	0.21
65	15	3.19	1.60	4.18	1.05	4.29	0.72	4.32	0.54	4.55	0.19
66		3.42	1.71	4.62	1.16	4.77	0.80	4.84	0.61	5.14	0.21
		3.46	**1.73**	**4.53**	**1.14**	**4.65**	**0.78**	**4.71**	**0.59**	**4.95**	**0.20**
67		2.57	1.29	3.95	0.99	4.63	0.77	4.82	0.60	5.23	0.22
68	20	2.73	1.37	3.90	0.98	4.70	0.78	4.84	0.61	5.23	0.22
69		2.93	1.47	4.14	1.04	4.90	0.82	5.11	0.84	5.46	0.23
		2.74	**1.38**	**4.00**	**1.00**	**4.74**	**0.79**	**4.92**	**0.68**	**5.31**	**0.22**
70		1.90	0.95	2.33	0.58	2.55	0.43	2.66	0.33	2.86	0.12
71	30	2.34	1.17	2.98	0.75	3.27	0.55	3.40	0.43	3.73	0.16
72		2.10	1.05	2.65	0.66	2.91	0.49	3.03	0.38	3.30	0.14
		2.11	**1.06**	**2.65**	**0.66**	**2.91**	**0.49**	**3.03**	**0.38**	**3.30**	**0.14**
73		0.31	0.16	0.31	0.08	0.31	0.05	0.28	0.04	0.39	0.02
74	50	0.48	0.24	0.48	0.12	0.49	0.08	0.46	0.06	0.52	0.02
75		0.39	0.20	0.40	0.10	0.48	0.08	0.45	0.06	0.42	0.02
		0.39	**0.20**	**0.40**	**0.10**	**0.43**	**0.07**	**0.40**	**0.05**	**0.44**	**0.02**
76		0.29	0.15	0.30	0.08	0.41	0.07	0.42	0.05	0.42	0.02
77	70	0.21	0.11	0.22	0.06	0.31	0.05	0.40	0.05	0.41	0.02
78		0.26	0.13	0.29	0.07	0.40	0.07	0.42	0.05	0.43	0.02
		0.25	**0.13**	**0.27**	**0.07**	**0.37**	**0.06**	**0.41**	**0.05**	**0.42**	**0.02**
79		0.07	0.04	0.18	0.05	0.21	0.04	0.21	0.03	0.21	0.01
80	98	0.07	0.04	0.15	0.04	0.23	0.04	0.23	0.03	0.23	0.01
81		0.00	0.00	0.10	0.03	0.17	0.03	0.17	0.02	0.17	0.01
		0.05	**0.03**	**0.14**	**0.04**	**0.20**	**0.04**	**0.20**	**0.03**	**0.20**	**0.01**

A : Corrosion Loss in Weight (mg/cm^2)

B : Mean Corrosion Rate ($mg/cm^2/hr.$)

The figures in Gothic type indicate the average values.

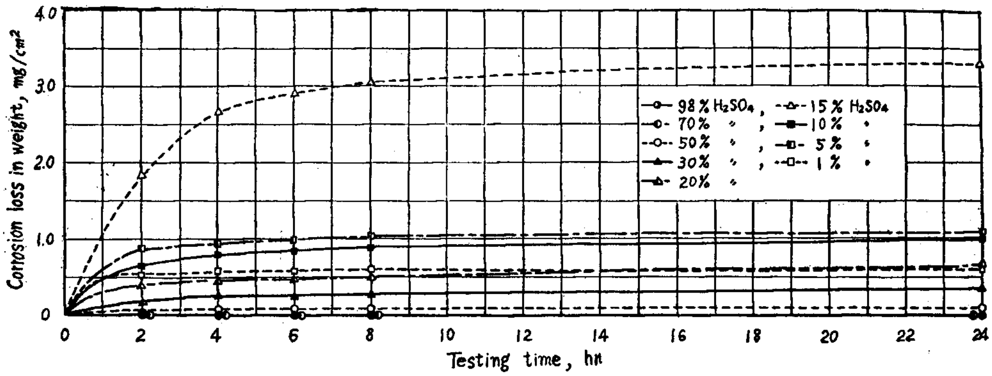

Fig. 1 Time-corrosion curves, at 30°C.

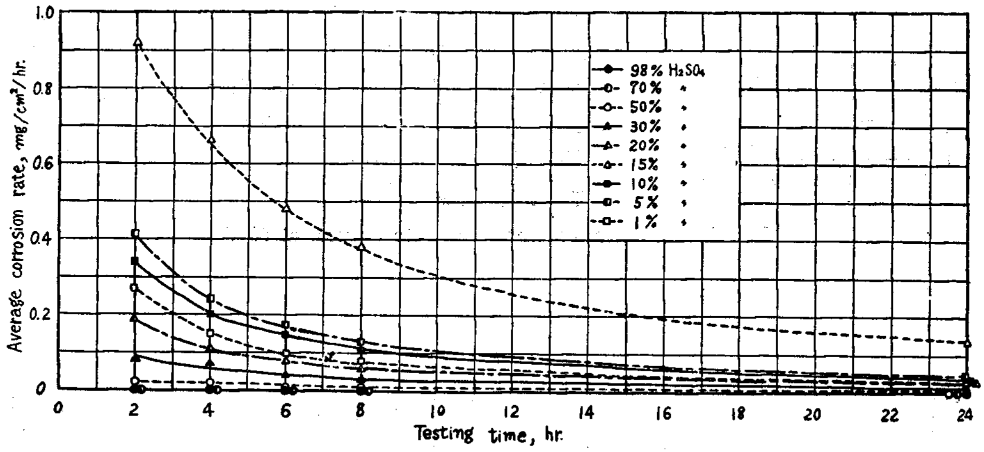

Fig. 2 Time-average corrosion rate curves, at 30°C.

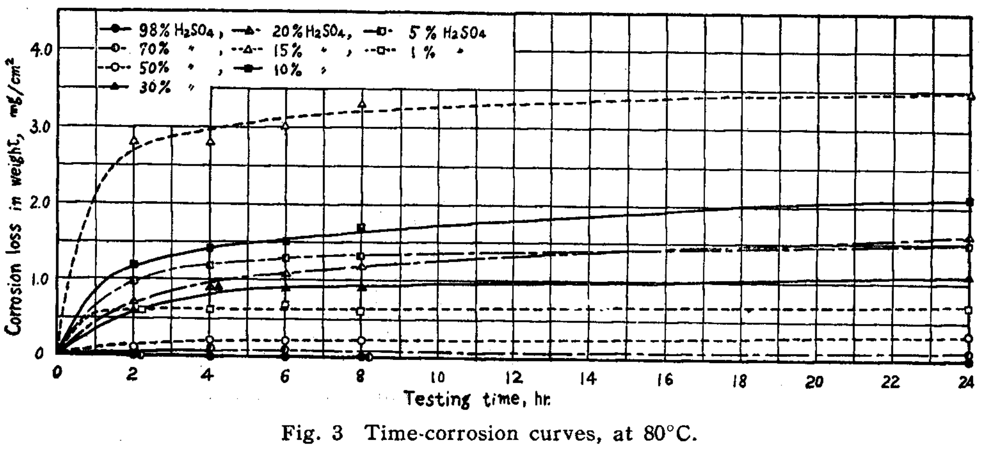

Fig. 3 Time-corrosion curves, at 80°C.

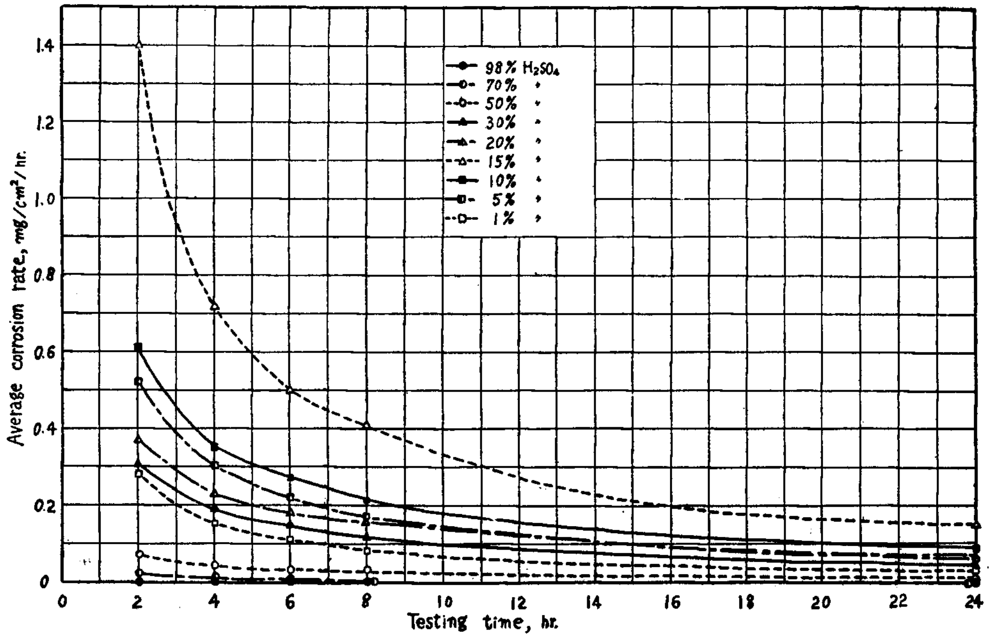

Fig. 4 Time-average corrosion rate curves, at 80°C.

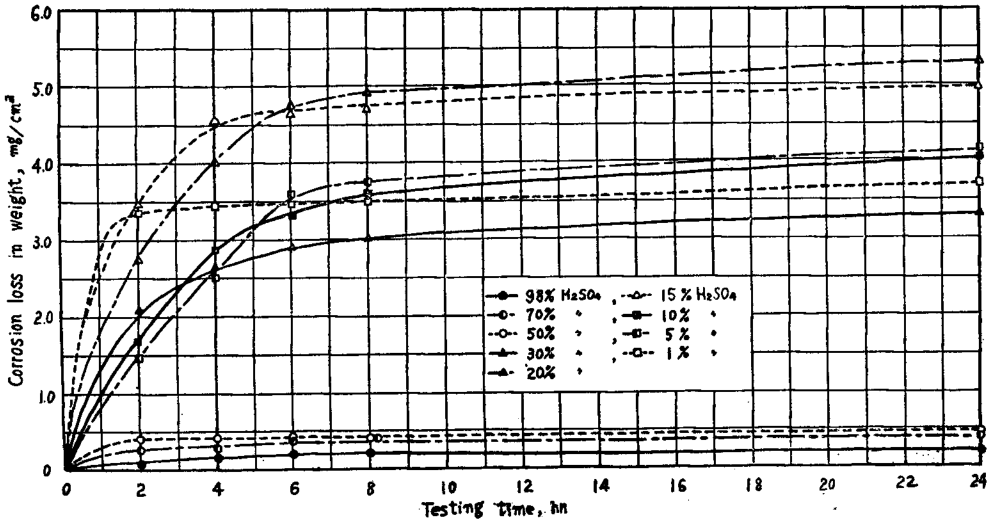

Fig. 5 Time-corrosion curves, at boiling temperature.

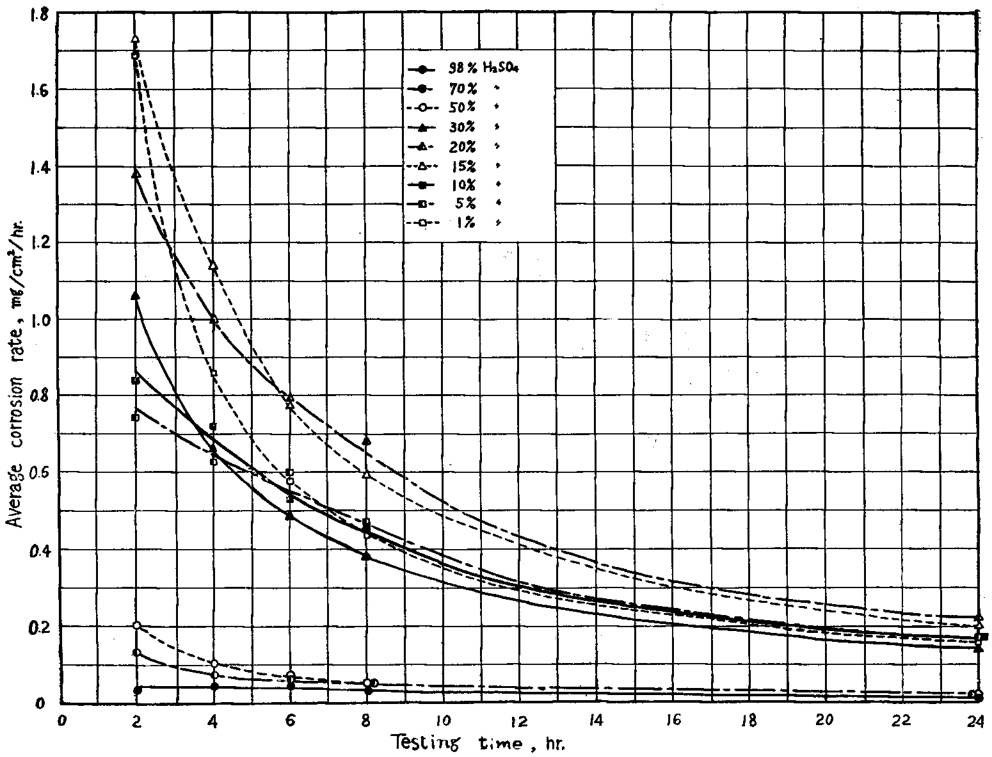

Fig. 6 Time-average corrosion rate curves, at boiling temperature.

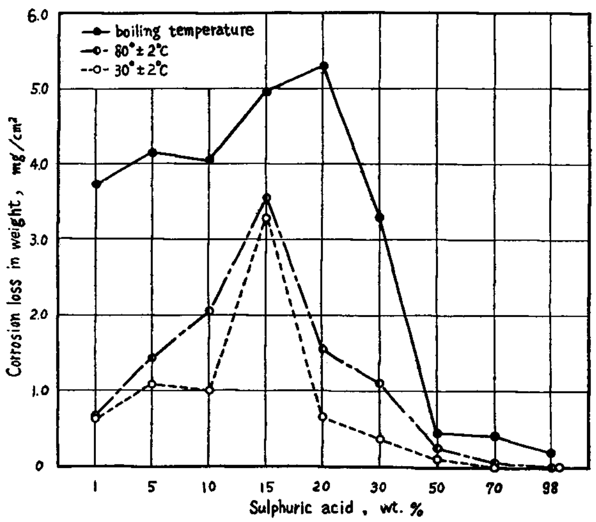

Fig. 7 Relation between the corrosion of high-silicon irons and the concentration of sulphuric acid.

the acid except the fact that the maximum corrosion occurs in the 20 pct acid.

The surface condition of the specimens after the immersion test of 24 hr. is shown in Photo. 1. When Photo. 1 is compared with Fig. 7, it is seen that the

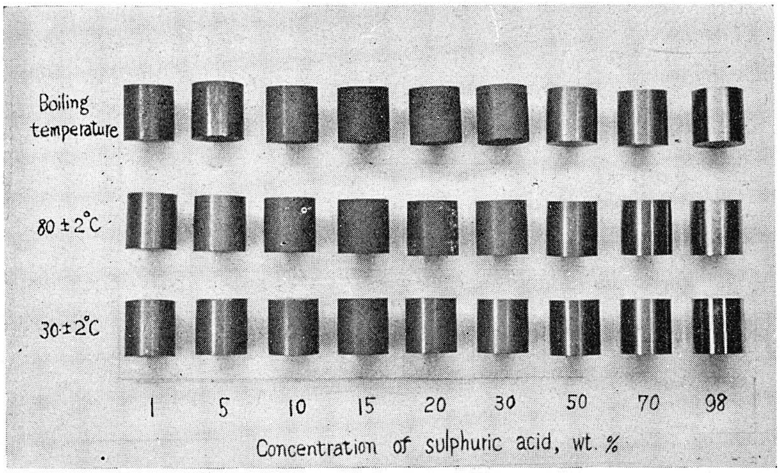

Photo. 1 Appearance of surface of specimens after immersion of 24 hr.

surface condition of the specimens after the test has a close relation with their corrosion loss. The surface of the specimens, of which the corrosion loss was very small or nil in concentrated sulphuric acid, is maintained as brilliant as before the test; while the surface of the specimens, which were corroded fairly in 15-20 pct sulphuric acid, is a little rough and dark gray coloured. Under all conditions of the test, the specimens did not exhibit any localized corrosion such as pitting.

IV. Summary

The corrosion tests were made on a typical high-silicon iron in sulphuric acid varying its concentration from 1 to 98 pct and temperature from 30°C to the boiling points of each concentration. The results are summarized as follows:

(1) Sulphuric acid attacks high-silicon iron more strongly when temperature is higher.

(2) Sulphuric acid of 15-20 pct corrodes high-silicon iron most strongly. Concentrated acid over about 70 pct hardly corrodes high-silicon iron at even its boiling temperature.

(3) The corrosion of high-silicon iron in sulphuric acid is the greatest during the first period of immersion and it decreases remarkably after a certain period.

(4) The corrosion resistance of high-silicon iron against sulphuric acid depends upon formation of a protective film.

(5) The corrosion rate after the completion of the protective film is very small under all conditions of the acid concentration and temperature.

(6) The appearance of the surface of specimens after the immersion tests indicates the degree of corrosion loss.

Reference

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3) H. Sawamura, O. Tajima and K. Akamatsu: unpublished.
4) S. Yamaguchi: Bull. Chem. Soc. Japan, 18 (1943), 53.