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1939 Exposure Test of Porcelain Enamels on Steel 30-Year Inspection

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1939 Exposure Test of Porcelain Enamels on Steel 30-Year Inspection

Margaret A. Baker

Building Research Division
Institute for Applied Technology
National Bureau of Standards
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1939 Exposure Test of Porcelain Enamels on Steel

30-Year Inspection

Margaret A. Baker*

The weather resistance of 192 porcelain enameled panels representing 14 enamel types was evaluated after being exposed for 30 years at Washington, D.C. A direct correlation was found between the acid resistance and weather resistance of the enamels tested. The porcelain enamel protected the base metal from corrosion if the initial coverage was complete.

Similar evaluations and findings were made on 58 panels representing 13 enamel types that were added to this test in 1947.

Key words: Acid resistance; color; gloss; porcelain enamel; weather resistance.

1. Introduction

Porcelain enamels have long been used as an exterior finish for office buildings, store fronts, and gasoline filling stations. Porcelain enamel's popularity has depended largely on the wide variety of colors available, ease of installation, and the prospect of a long maintenance-free service life. When this exposure test was initiated in 1939, there had been reports of porcelain enameled street signs that had been exposed for as long as 25 years with no apparent degradation. However, there had also been reports of porcelain enameled installations where both the gloss and color had changed markedly after only ten years' exposure. The goals of this test were to determine an enamel's durability, as measured by changes in gloss and color, and to develop accelerated tests to predict an enamel's weatherability.

A total of 864 one-foot (30.48-cm) square and an equal number of 4 × 6-in (10.16 × 15.24-cm) laboratory specimens were prepared by twelve cooperating manufacturers. Of the 864 large panels, 768 were exposed and 96 were placed in storage for use as reference standards. Duplicate panels of each of the 96 different enamels were exposed at four exposure sites: Washington, D.C.; St. Louis, Missouri; Lakeland, Florida; and Atlantic City, New Jersey. These enamels have been inspected and measured for changes in gloss and color after 1 [1][1], 7 [2], and 15 [3] years' exposure. Exposure testing was discontinued at all sites except Washington after the 15-year inspection. The enamels at Washington were returned to the exposure racks after their 15-year inspection for an additional 15 years' exposure.

This paper is primarily a summary of the results of the 30-Year Inspection of the original 96 enamels exposed at Washington, D.C. It also includes a summary of the 23-Year Inspection of 29 enamels added to this test in 1947. A description of the original enamels and earlier exposure data [1,2,3] will be repeated in this report since the earlier reports are out of print.

2. Materials

2.1. Types and Sources of Enamels

The enameled panels were supplied by 12 cooperating companies who were active in the field of architectural enamels in 1939. The frits[2] and various mill additions[3] for preparing the enamels were supplied by 4 frit companies. Each of these 4 companies furnished the materials for each of the 14 enamel types to the 12 fabricators who applied the enamel to the metal panels. By this arrangement, it was possible to introduce the two variables of frit source and fabricator. The frits were all proprietary products for which no chemical analyses were available. It is probable that there were at least minor variations in composition of the four enamels of any one type as supplied by the different frit companies. Likewise, the 12 fabricators probably produced enamels of slightly different properties from the same frit because of minor variations in the mill batch, the milling procedure, and firing conditions. Thus, although the investigation included nominally only 14 enamel types, there were, in effect, 96 somewhat different enamels under study. These enamels are listed in table 1.

*Research Associate from the Porcelain Enamel Institute at the National Bureau of Standards, Washington, D.C., 1964 to present.

[1] Figures in brackets indicate the literature references at the end of this paper.

[2] Frit is the principal ingredient used in preparing porcelain enamels. It is formed by melting suitable raw materials and then quenching the molten mass.

[3] In the preparation of an enamel for application to sheet iron, the enamel frit is ball-milled together with such ingredients as clay, opacifier, color oxide, electrolyte, and water. The materials added at the mill constitute mill additions.

TABLE 1. *Initial data on the manufacture, gloss, thickness and acid resistance of porcelain enameled panels; the percentage of initial gloss retained and color change data after exposure at Washington, D.C.*

Enamel	Specimen fabricator	Frit supplier	Average enamel thickness (mils)	Average initial specular gloss	Acid resistance (PEI test)	Visual weathering[1] rating	Percentage gloss retained after:				Color change after:	
							30 yr	15 yr	7 yr	1 yr	30 yr	15 yr
											(NBS units)	
White, glossy, acid-resistant enamel												
A-1,2	a	1	16	57.0	AA	A	71.8	83.1	81.4	90.8	0.8	0.7
A-11,12	b	1	13	57.4	AA	A	71.1	86.9	83.2	95.4	0.9	1.0
A-21,22	a	2	17	60.4	AA	B	70.3	84.2	79.8	89.7	0.8	0.6
A-31,32	b	2	14	60.1	AA	B	67.1	76.6	74.8	90.0	0.8	0.5
A-41,42	a	3	13	58.5	AA	B	72.5	85.0	84.1	92.1	1.8	3.0
A-51,52	b	3	13	58.1	AA	B	69.3	85.4	77.5	90.2	1.5	1.2
A-61,62	a	4	13	62.0	AA	C	46.2	83.3	74.6	96.8	3.8	1.1
A-71,72	b	4	16	60.1	AA	C	52.0	73.4	70.5	91.0	3.1	1.7
White, glossy, nonacid-resistant enamel												
B-1,2	b	1	13	52.6	C	C	12.4	18.0	28.9	69.8	2.1	2.9
B-21,22	b	2	13	54.1	C	C	11.5	15.0	34.8	69.2	--	4.8
B-41,42	b	3	15	51.6	D	D	12.5	15.0	26.5	71.8	1.0	2.7
B-61,62	b	4	15	53.2	C	C	11.3	16.4	34.8	71.1	0.9	3.1
White, semimatte, acid-resistant enamel												
C-11,12	c	1	19	40.6	C	C	18.7	30.3	51.8	84.0	0.9	1.5
C-31,32	c	2	13	52.4	A	C	25.4	42.1	61.5	85.8	1.9	2.3
C-51,52	c	3	25	51.6	A	B	58.8	76.7	76.8	91.5	2.4	2.2
C-71,72	c	4	17	53.2	A	C	42.0	54.8	73.1	95.7	1.9	1.3
White, semimatte, nonacid-resistant enamel												
D-1,2	c	1	12	--	--	D	--	--	--	--	3.0	1.0
D-21,22	c	2	12	56.9	D	C	10.9	15.0	43.2	70.5	3.2	3.3
D-41,42	c	3	14	55.1	D	D	10.9	15.0	38.0	74.0	2.4	3.3
D-61,62	c	4	14	--	--	D	--	--	--	--	5.2	3.6
Buff, glossy, acid-resistant enamel												
E-11,12	d	1	13	50.9	B	B—	52.0	60.2	68.2	83.8	1.9	1.4
E-31,32	d	2	15	54.3	AA	B—	38.5	54.8	64.2	90.8	1.5	1.8
E-51,52	d	3	14	54.4	AA	A	72.8	90.0	74.0	91.6	1.0	0.4
E-71,72	d	4	16	53.5	AA	A	63.2	76.0	77.7	96.1	1.5	1.6
Buff, glossy, nonacid-resistant enamel												
F-1,2	d	1	15	51.5	D	D	18.7	24.3	43.0	72.1	13.0	7.8
F-11,12	e	1	18	48.7	D	D	23.9	35.6	61.2	90.2	2.8	4.4
F-21,22	d	2	17	50.2	C	D	24.5	33.2	52.9	72.1	5.7	3.8
F-31,32	e	2	11	55.6	D	D	32.8	44.3	48.8	69.0	5.3	2.9
F-41,42	d	3	12	43.1	D	D	20.0	26.2	37.3	71.3	21.0	13.4
F-51,52	e	3	11	56.6	D	D	16.3	27.6	33.7	74.1	8.3	5.3
F-61,62	d	4	12	46.4	D	D	13.7	24.4	22.5	61.2	15.6	12.0
F-71,72	e	4	12	52.6	D	D	13.2	23.7	28.0	62.6	16.0	12.1
Buff, semimatte, acid-resistant enamel												
H-1,2	e	1	25	39.6	A	B	59.2	64.3	60.7	81.7	3.0	2.0
H-11,12	f	1	11	48.1	A	C	51.6	52.1	57.6	71.3	1.9	0.9
H-21,22	e	2	12	56.5	A	B	62.1	77.0	70.7	88.8	0.7	0.8
H-31,32	f	2	13	54.5	A	B	62.7	74.3	71.2	87.8	0.6	0.5
H-41,42	e	3	13	47.4	AA	A	68.6	87.5	75.7	93.0	0.8	0.6
H-51,52	f	3	17	48.5	AA	A	63.2	76.8	72.5	95.8	1.3	1.2
H-61,62	e	4	18	55.1	AA	A	60.3	83.9	74.4	93.2	1.8	4.3
H-71,72	f	4	15	55.4	AA	A	63.2	83.5	76.4	92.2	4.2	2.0
Buff, semimatte, nonacid-resistant enamel												
K-1,2	f	1	16	--	--	D	--	--	--	--	9.2	7.4
K-11,12	g	1	12	--	--	D	--	--	--	--	11.5	7.2
K-21,22	f	2	12	54.1	D	C	14.7	21.3	49.0	70.7	5.7	4.1
K-31,32	g	2	11	53.7	D	C	13.7	18.8	36.4	65.9	9.5	7.2
K-41,42	f	3	17	52.0	D	C	47.2	63.8	63.5	79.6	2.8	1.7
K-51,52	g	3	11	53.5	D	D	11.0	16.2	36.5	69.9	15.2	9.2
K-61,62	f	4	11	--	--	D	--	--	--	--	19.7	6.9
K-71,72	g	4	11	--	--	C	--	--	--	--	7.4	14.4

Red, glossy, acid-resistant enamel											
L–1,2	g	1	9	55.8	AA	A	65.1	85.5	76.4	85.6	6.4	3.8
L–11,12	h	1	11	56.1	AA	A	69.2	80.4	74.7	83.7	1.2	0.8
L–21,22	g	2	11	54.2	B	A	66.4	82.1	78.1	85.4	3.9	2.2
L–31,32	h	2	13	56.4	A	A	68.7	82.0	79.7	86.4	2.6	3.1
L–41,42	g	3	11	55.8	AA	B	63.3	77.0	75.7	85.1	1.6	3.0
L–51,52	h	3	12	52.3	A	B—	59.8	68.5	67.6	86.9	8.7	0.9
L–61,62	g	4	11	53.0	A	B	66.4	80.8	73.2	88.0	3.4	2.3
L–71,72	h	4	11	41.8	AA	A	77.4	91.9	74.0	87.8	0.7	1.3
Red, glossy, nonacid-resistant enamel											
N–1,2	h	1	13	51.7	C	C	55.0	65.8	70.0	76.3	3.9	2.5
N–11,12	k	1	13	50.5	C	C	71.1	86.9	83.2	95.4	2.0	2.1
N–21,22	h	2	11	51.2	D	D	70.3	84.2	79.8	89.7	4.7	1.9
N–31,32	k	2	12	45.5	D	C	67.1	76.6	74.8	90.0	2.1	2.7
N–41,42	h	3	11	51.7	C	C	72.5	85.0	84.1	82.1	4.6	3.3
N–51,52	k	3	15	46.8	C	D	69.3	85.4	77.5	90.2	3.7	2.7
N–61,62	h	4	9	47.1	D	D	46.2	83.3	74.6	96.8	15.4	4.3
N–71,72	k	4	13	54.4	D	D	52.0	73.4	70.5	91.0	23.8	22.0
Red, semimatte, acid-resistant enamel											
P–1,2	k	1	11	55.4	AA	B	66.3	86.3	70.3	86.6	4.4	3.8
P–11,12	l	1	15	--	--	D	--	--	--	--	22.2	24.7
P–21,22	k	2	--	--	--	--	--	--	--	--	--	38.0
P–31,32	l	2	14	39.9	C	D	40.7	48.6	64.4	88.5	5.0	6.2
P–41,42	k	3	14	49.5	A	A	62.5	70.6	69.2	93.5	1.6	2.6
P–51,52	l	3	12	33.4	A	D	91.3	84.2	73.8	92.5	8.8	5.9
P–61,62	k	4	11	49.7	AA	A	63.2	83.5	76.2	90.6	2.2	2.7
P–71,72	l	4	14	55.4	AA	A	66.3	89.7	81.0	92.0	3.0	5.3
Red, semimatte, nonacid-resistant enamel											
S–1,2	l	1	13	--	--	--	--	--	--	--	31.8	24.3
S–11,12	m	1	20	--	--	D	--	--	--	--	29.4	15.6
S–21,22	l	2	12	45.1	B	C	63.2	76.9	65.8	78.2	16.6	2.9
S–31,32	m	2	16	45.1	C	B	59.0	63.8	57.6	70.2	7.2	6.7
S–41,42	l	3	12	35.0	A	B—	55.8	61.9	58.0	80.4	3.2	2.6
S–51,52	m	3	11	39.5	A	A	84.8	89.4	84.1	93.9	1.5	1.0
S–61,62	l	4	13	45.0	C	D	26.4	38.8	35.2	64.7	18.7	14.3
S–71,72	m	4	15	35.7	C	D	41.2	50.0	70.3	93.4	24.9	18.6
Black, glossy, acid-resistant enamel											
T–1,2	m	1	11	73.0	AA	B	39.4	57.9	56.1	72.6	1.1	0.8
T–11,12	n	1	13	66.0	AA	A	56.8	73.4	64.2	93.7	1.1	0.4
T–21,22	m	2	13	53.8	AA	A	66.7	87.8	80.6	92.0	0.6	1.4
T–31,32	n	2	8	55.5	AA	B—	66.1	79.1	70.0	93.0	1.0	0.8
T–41,42	m	3	11	60.9	AA	B	52.3	64.2	70.7	91.0	2.0	0.0
T–51,52	n	3	8	59.0	A	B	64.9	85.4	68.9	92.3	1.5	1.5
T–61,62	m	4	9	65.5	AA	B	45.9	66.7	59.8	86.8	1.6	1.1
T–71,72	n	4	6	65.6	AA	B	48.7	57.6	54.9	78.5	1.5	0.8
Black, glossy, nonacid-resistant enamel											
V–1,2	n	1	8	55.2	C	D	58.9	61.5	63.6	76.0	26.4	19.9
V–11,12	a	1	11	56.2	C	D	35.0	34.5	57.0	74.0	49.1	41.3
V–21,22	n	2	7	57.6	C	D	56.2	64.0	58.8	68.8	2.1	1.4
V–31,32	a	2	10	56.0	C	C	36.3	41.1	40.1	65.8	5.1	4.0
V–41,42	n	3	8	53.0	C	D	56.5	66.3	59.7	75.5	8.2	4.6
V–51,52	a	3	12	54.9	C	D	53.5	58.2	58.0	71.9	12.0	12.3
V–61,62	n	4	7	46.7	C	D	44.4	41.1	75.9	83.2	18.1	13.4
V–71,72	a	4	11	54.5	C	D	61.6	61.7	73.9	78.6	10.2	6.4

[1] A visual rating of A means no apparent change in the enamel's surface, B means the enamel surface is just beginning to change, C means that moderate changes have taken place in the enamel's surface, and D means severe changes have taken place in the enamel's surface.

In 1947, 13 additional enamel types were added to this test program. The 4 frit companies and the Enameled-Metals Section at the National Bureau of Standards supplied and fabricated these additional panels. Again differences in the enamels made by the different producers probably resulted in 29 somewhat different enamels as indicated in table 2. The weathering results of the enamels added to this test in 1947 are also included in this report. This is the first published report on these 29 enamels.

2.2. Description and Methods of Mounting Enameled Panels

The panels, which were 1-ft. (30.48-cm) square, were fabricated of 16-gage (nominally 0.057-in. or 0.15-cm) enameling grade steel and had 1-in (2.54-cm) box-flanged edges. The flange of the lower side had a ½-in (1.27-cm) downward extension parallel to the face of the panel. Two clips made of 1-in (2.54-cm) strap steel were welded to the top flange so as to extend downward. The clips and the lower flange extension fitted into 18-gage (nominally 0.048-in or 0.12-cm) galvanized-iron channels, that were firmly attached to the supporting racks. The crevices between the specimens were not caulked but were left open to facilitate removal of the panels during periods of inspection.

The supporting racks were constructed of 3/16-in (0.48-cm) thick angle iron, and after priming, were painted periodically with aluminum paint. Each rack was constructed to support 28 of the 1-ft (30.48-cm) square panels. The racks were placed on the roof of the Industrial Building at the National Bureau of Standards in Washington, D.C., and were held in place by weights placed on the bottoms of the racks. The racks faced south and the panels were exposed at 45° to the horizontal.

2.3. Acid Resistance of Enamels

In 1937, the Porcelain Enamel Institute promulgated a citric acid spot test [4] to determine the acid resistance of porcelain enamels. The 4 × 6-in (10.16 × 15.24-cm) laboratory specimens of the enamels included in this test were evaluated for acid resistance by this procedure. The acid resistance ratings for these enamels are

TABLE 2. *Summary of initial data and gloss and color-difference after 23 years' exposure*

Enamel	Specimen fabricator	Frit supplier	Average enamel thickness (mils)	Average initial specular gloss	Acid resistance (PEI test)	Visual weathering rating[1]	Percentage gloss retained	Color change (NBS units)
Titanium white								
FA	2	2	16	42.9	B	B	91.8	0.52
CA	1	1	9	63.5	AA	A	64.1	0.88
RA	3	3	8	59.9	A	B	64.2	1.11
PA	4	4	10	62.1	A	A	64.0	0.47
Acid-resistant ground coat, one coat								
FB	2	2	6	50.9	AA	B	59.9	2.71
CB	1	1	6	53.9	AA	B	58.0	1.94
RB	3	3	4	54.6	AA	B	59.9	1.26
PB	4	4	5	54.2	AA	C	69.4	4.23
Acid-resistant ground coat, two coat								
FC	2	2	8	44.3	A	B	64.2	3.20
CC	1	1	8	52.6	A	B	51.8	2.52
RC	3	3	5	52.8	AA	B	49.9	3.46
PC	4	4	9	55.6	AA	B	59.7	6.37
Regular ground coat, one coat								
FD	2	2	6	49.6	A	C	67.4	8.81
CD	1	1	5	49.4	C	D	31.9	29.16
RD	3	3	3	51.6	C	D	36.1	30.40
PD	4	4	5	51.8	A	C	88.6	11.19
Regular ground coat, two coat								
FE	2	2	7	51.1	A	C	66.2	10.46
CE	1	1	7	52.4	C	D	63.4	41.45
RE	3	3	5	50.7	C	D	41.0	32.33
PE	4	4	6	51.4	B	C	62.9	19.64
Antimony matte								
FF	2	2	16	17.7	A	D	68.8	2.26
Titanium matte								
CG	1	1	11	54.9	B	B	63.5	1.14
Low fired, 1300 °F								
CH	1	1	10	42.9	D	D	41.9	13.31
PH	4	4	9	65.2	D	D	28.4	9.50
Antimony matte								
FK	2	2	16	14.1	A	C	67.6	10.91
Ground coat with silica added								
LN	5	5	4	49.1	AA	B	67.8	2.18
Red, semi-gloss								
PM	4	4	16	53.8	A	B	60.9	4.22
A-31								
NR	5	5	3	--	--	D	--	4.57
LH	--	--	9	52.5	AA	B	53.7	1.18

[1] A visual rating of A means no apparent change in the enamel's surface, B means the enamel surface is just beginning to change, C means that moderate changes have taken place in the enamel's surface, and D means severe changes have taken place in the enamel's surface.

presented in tables 1 and 2. Enamels with AA and A acid-resistance ratings are considered to be acid-resistant, while the enamels with B, C, or D ratings are considered nonacid-resistant.

2.4. Enamel Thickness

The enamel thickness was measured with a magnetic thickness gage at two locations on the stored panels. The average of these two readings is given to the nearest mil (0.001 in or 0.025 mm) in tables 1 and 2.

3. Results

3.1. Cleaning of Panels

At the beginning of this test, it was planned to clean the panels before each inspection with a one percent solution of trisodium phosphate on a soft cellulose sponge, followed by successive rinsing with distilled water, tap water, and alcohol. This cleaning procedure cleaned the panels after 1 and 7 years' exposure but it did not clean them at three of the 4 exposure sites after 15 years' exposure. Therefore all the panels were scoured with a commercial scouring agent at the beginning of the 15-year inspection.

The procedure adopted to clean the panels prior to the 30-year inspection was a combination and modification of the two techniques outlined above. The panels were scoured with calcium carbonate (a mild abrasive) on a sponge that had been moistened with a one percent solution of trisodium phosphate. The panels were then rinsed successively with tap water, distilled water, and alcohol. This procedure removed the visible dirt from almost all of the panels. A few of the matte panels retained some dirt, but the amount of dirt retained did not appear to affect the gloss or color measurements.

3.2. Visual Observations

a. Comparison with Stored Panels

Following cleaning, the exposed panels were compared with the stored panels for changes in gloss and color. The exposed panels that did not appear to have changed were given a visual rating of A, those that showed only a slight change were given a visual rating of B, those that showed readily noticeable changes were given a visual rating of C, and those that showed extreme changes were given a visual rating of D. These ratings for all enamels in the test are presented in tables 1 and 2. The enamels with visual ratings of either A or B should be acceptable to the user while enamels with visual ratings of C or D would probably prompt complaints since the changes in these enamels were readily apparent.

Tables 3 and 4 summarize the visual ratings of the enamels with different acid-resistance ratings.

TABLE 3. *Comparison of visual weathering rating with the enamel's acid resistance rating for enamels exposed 30 years*

Visual rating	Acid resistance				
	AA	A	B	C	D
A	15	3	1	0	0
B	10	10	1	1	0
C	2	3	1	8	4
D	0	1	0	12	13

TABLE 4. *Comparison of visual weathering rating with the enamel's acid resistance rating for enamels exposed only 23 years*

Visual rating	Acid resistance				
	AA	A	B	C	D
A	1	1	0	1	0
B	7	4	1	0	0
C	1	3	1	0	0
D	0	1	1	4	2

Although there are some exceptions, the trend is for enamels with good acid resistance to have good weather resistance as indicated by the visual ratings.

b. Corrosion Protection

Following the visual rating, the panels were inspected for evidence of corrosion on the face of the panel. Corrosion of the base metal was noted on the face of only one enamel (panels A–71 and A–72) that had been exposed for 30 years. This corrosion occurred in what appeared to be large fishscale-type spalls. When the panel was turned over, it was noted that the enamel coverage on the back was poor and the back of the panel was severely corroded. The fishscale-type fractures on the front of the panels occurred over severely corroded sections on the back of the panels. Corrosion and spalling similar to this was observed at Atlantic City after 7 years' exposure and at Lakeland and St. Louis after 15 years' exposure. In the 15-year report [3] it was hypothesized that hydrogen originating from the action of condensed moisture on the unprotected metal was the probable cause of this spalling. The hydrogen diffused through the metal and generated enough pressure to rupture the enamel on the face side of the panel. If this is indeed true, then it is important to have good coverage on the back of the panels as well as on the front if there is any possibility of moisture, either from occasional rain leaks or from the humidity inside the building, contacting the back of poorly coated panels.

Five of the enamels exposed in 1947 (23 years' exposure) showed rust on the face of the panels. Three of these enamels (CD, RD, and CH) were enamels with poor acid resistance and would not normally be considered for outdoor applications. However, the remaining two enamels RA and FF showed rust around pinhole-type defects and indicated a definite need for continuous coatings to be applied when the enamels are to be used in

outdoor exposures. This finding is particularly significant when it is realized that only one of 96 of the original enamels exposed in 1939 rusted while 5 of only 29 of the enamels exposed in 1947 rusted. This indicates that the thicker enamels (average thickness 13 mils) originally included in this test did a much better job of protecting the base metal from corrosion than did the newer enamels that had an average thickness of only 8 mils.

3.3. Gloss Retention

The 45° specular gloss was measured at four orientations at 90° to each other near the center of each panel. This procedure varied slightly from that used previously when the gloss was measured at two locations on the panel. The gloss data are expressed as the percentage of the initial gloss retained after exposure and they are presented in tables 1 and 2. The initial gloss values are also reported in tables 1 and 2.

It is of interest to observe how acid-resistant and nonacid-resistant enamels weather with time. These results are illustrated in figure 1 for the enamels exposed in 1939. The data in figure 1

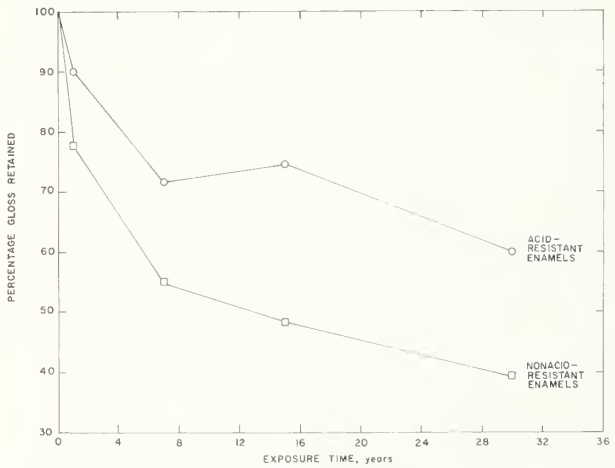

FIGURE 1. *Effect of exposure time on the gloss retention of porcelain enamels on steel.*

indicate that the rate of gloss loss is greatest during the first 7 years' exposure for both acid and nonacid-resistant enamels. However, the nonacid-resistant enamels lose more gloss during the first seven years' exposure than the acid-resistant enamels. The apparent increase in gloss of the acid-resistant enamels at 15 years is probably caused by the scouring treatment given these enamels at that time. There are two possible ways in which the scouring could increase the enamel's gloss: (a) a thin film that reduced the gloss might have been removed by scouring, or (b) the scouring may have polished the surface.

Since this is the first inspection of the enamels exposed in 1947, the average percentage gloss retained for the acid-resistant and the nonacid-resistant enamels is given below:

Acid-resistant enamels	63.5
Nonacid-resistant enamels	51.2

Again it can be seen that the acid-resistant enamels have better gloss retention than the nonacid-resistant enamels.

3.4. Color Change

The color-change data[4] in tables 1 and 2 indicate the color change between the stored panels and the exposed panels. The color change was indicated in this way because color difference meters [5] were not readily available at the beginning of this test program so it was not possible to measure the initial color values on the exposed panels. The color change data are shown as a function of time and of acid resistance in figure 2.

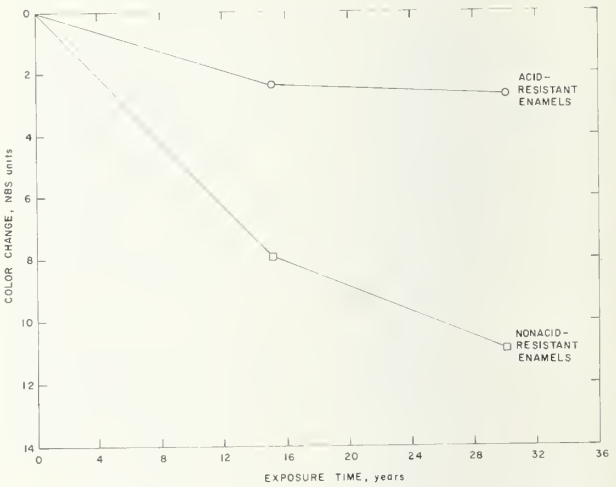

FIGURE 2. *Effect of exposure time on the color retention of porcelain enamels on steel.*

The difference between the acid- and nonacid-resistant enamels is more pronounced for color difference than it is for gloss retention of these same enamels as indicated by the greater separation of the two sets of curves. The enamels appear to have lost color gradually over the entire exposure period, but because of the lack of color-change data during the early years of exposure any more rapid color change that may have occurred during this period was not observed.

Again the only color-difference data for the enamels exposed in 1947 is after 23 years' exposure. These data are presented in table 2. The average color differences for the acid- and nonacid-resistant enamels are given below:

Acid-resistant enamels	4.2 NBS units
Nonacid-resistant enamels	19.2 NBS units

It must be remembered that these are average values and some nonacid-resistant enamels have gloss and color retentions as high or higher than some of the acid-resistant enamels. This is illus-

[4] The color difference parameters, L (lightness-darkness), a (red-green), and b (yellow-blue) were measured with a color difference meter. The color change, in NBS Units, was calculated by the following formula:

$$\text{Color Change } (\Delta E) = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$$

where L is $10\sqrt{Rd}$
and Rd is the 45°,0° luminous daylight reflectance.

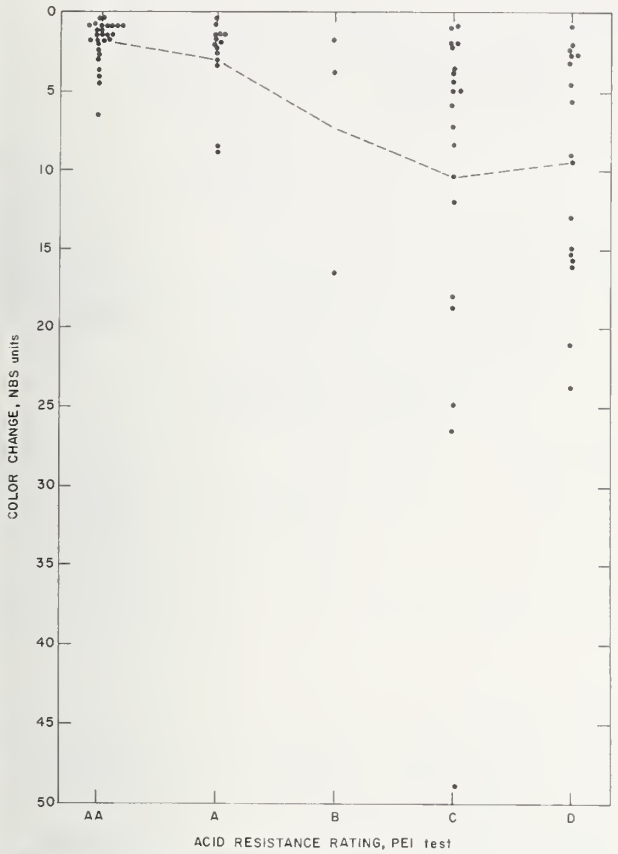

FIGURE 3. *Color change after 30 years' exposure for enamels with different acid resitance ratings.*

trated for color change of the enamels exposed in 1939 in figure 3.

4. Discussion

The goals of this test are to determine the durability of porcelain enamels on exposure to outdoor weathering, and to develop or evaluate laboratory tests to predict this durability. The results of this inspection indicate that, in general, the enamels with good acid resistance had good weather resistance after 30 years' exposure at Washington, D.C. The weather resistance was evaluated either visually by comparison of exposed panels with stored panels or by measured changes in gloss and color of the exposed panels. Subsequent weathering studies [6,7] have indicated that enamels exposed at different locations often weather at different rates. Therefore, the weather resistance of porcelain enamels exposed at sites other than Washington may vary from the results given in this report.

One significant finding of this inspection was the increased percentage of enamels that failed to protect the substrate from corrosion when the enamels were applied in one or two coats (average total thickness 8 mils) instead of three or more coats (average total thickness 13 mils). This indicates that extreme care must be given to the application of porcelain enamel to assure complete coverage of the base metal. This will be more and more important as the porcelain enamel is applied in thinner coatings.

5. Future Exposure Testing of These Enamels

In the past [1,2, and 3] these enameled panels have been inspected and returned to the exposure racks on the Industrial Building in Washington, D.C. for additional exposure. Since the primary interest in this program is to determine the durability of porcelain enamels, it has been decided to re-expose only those enamels which received a visual rating of either A or B, (very little change in the porcelain enamel surface after exposure). These enamels will be placed on new exposure racks at the current location of the National Bureau of Standards, Gaithersburg, Maryland. The next inspection of these enamels is tentatively scheduled for 1986 after a cumulative exposure period of 45 years.

6. Summary

After 30-years' exposure at Washington, D.C., it can be said that:

(1) All the glossy and semimatte porcelain enamels in this test were easy to clean.
(2) The porcelain enamel protected the base metal from corrosion if the initial coverage on both the front and back of the panel was complete.
(3) Both the visual appearance, and the average color and gloss retention correlated quite well with the enamel's acid resistance.
(4) The majority of enamels with good acid resistance showed only barely perceptable changes in gloss and color.

Similar statements can be made for the 29 enamels that were added to this test program in 1947 and have been exposed for 23 years in Washington, D.C.

7. References

[1] Harrison, W. N., and Moore, D. G., Weather Resistance of Porcelain Enameled Iron Structural Units, J. Research, NBS 28, 735 (1942) RP1476.
[2] Harrison, W. N., and Moore, D. G., Weather Resistance of Porcelain Enamels Exposed for Seven Years, J. Research, NBS 42, 43 (1949) RP 1949.
[3] Moore, D. G., and Harrison, W. N., Fifteen-Year Exposure Test of Porcelain Enamels, NBS Building Materials and Structures Report 148 (1957).
[4] Test for Acid Resistance of Porcelain Enamels, PEI Bulletin T-21, Porcelain Enamel Institute, 1900 L St., N.W., Washington, D.C. 20036, 1962.
[5] Hunter, R. S., Photoelectric Color-Difference Meter, J. Opt. Soc. Am. 38, 661 (1948).
[6] Rushmer, M. A., and Burdick, M. D., Weather Resistance of Porcelain Enamels: Effect of Exposure Site and Other Variables After Seven Years, Nat. Bur. Stand. (U.S.), Bldg. Sci. Ser. 4, 16 pages (May 1966).
[7] Baker, M. A., 1964 Exposure Test of Porcelain Enamels on Aluminum, Three Year Inspection, Nat. Bur. Stand. (U.S.), Bldg. Sci. Ser. 29, 13 pages (April 1970).

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The weather resistance of 192 porcelain enameled panels representing 14 enamel types was evaluated after being exposed for 30 years at Washington, D.C. A direct correlation was found between the acid resistance and weather resistance of the enamels tested. The porcelain enamel protected the base metal from corrosion if the initial coverage was complete.

Similar evaluations and findings were made on 58 panels representing 13 enamel types that were added to this test in 1947.

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